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Introduction

- 1 Traditionally, climate research has been considered the domain of the natural sciences, such as meteorology, palaeo-climatology and geology. Climate change was considered to be restricted to particular geological periods. For instance, the alternation of cold glacials and warm interglacials was considered to be characteristic for mainly the Pleistocene, while the present Holocene period was looked at as a short and mainly warm period. Although weather variability and the impact of weather conditions on human events were well recognised, the historical period (AD) was generally considered to have a stable climate similar to that of the 1950s and 1960s.
- 2 During the recent five decades continuing research has changed this view profoundly. Thanks to systematic palaeo-climatological research in Northwestern-Europe in general and large scale soil mapping in the Belgian and Dutch coastal areas in particular there now is a better understanding of how climate developed since the end of the last glacial period. We also know now much more details about the connection between general sea level rise and the formation of particular soil types in coastal regions and its hinterland. Moreover research on tree rings, ice cores, sediments, solar radiation and volcanic eruptions, has also resulted in a more accurate signal of climate variability during the recent millennia.
- 3 Yet historical climatology has also contributed to a better understanding of climate variability during the last millennium. Because it has its origin in the social sciences, this article will show how historical climatology has evolved from history, historical geography and historical ecology into a field of research of its own. First will be shown how important historical climatology has become by giving an overview of how it has

spread amongst European universities and climate research centres. Although historical records are the main source of information used by historical climatologists, only specific information about weather conditions is useful. Therefore the major categories of climate related written sources will be discussed. Because most of the information is prior to the mid-18th century instrumental observations and therefore of a qualitative nature, it needs to be transferred into quantitative data. Historical climatologists have therefore developed a special methodology that enables them to reconstruct temperature, air pressure, rainfall and wind force of the past. This methodology will be discussed briefly and then mention will be made of the main results achieved by historical climatologists so far by focusing on various examples of climate reconstruction, weather extremes and their impact on society. Finally, it will be shown how historical climatology in the Low Countries can contribute to a higher spatial and temporal resolution climate reconstruction and therefore a better understanding of climatic change, climate extremes and their prediction for the near future.

Background: terminology and evolution of historical climatology

Terminology

- 4 The history of climate can be studied by using data from the natural environment, such as ice cores, tree rings, varves and lake sediments. This data provides information related to periods of variable duration. Information of a more recent history of climate is provided by instrumental measurements and by data that is provided by historical documents. Consequently, the term “historical evidence” was introduced by the meteorologist Lamb (1977) suggesting the use of only written documents. However, looking at the present methods used by historical climatologists, it seems better to define historical climatology in terms of reconstructing climate and weather extremes and their impact by primarily using written documents in combination with instrumental weather data. Results must also be compared to all additional information on climate variability during a particular period provided by proxy data obtained by research of tree rings, sediments, ice cores, etc. (Jones and Mann, 2004).
- 5 This in fact primarily puts historical climatology in the field of history and historical geography in close co-operation with other disciplines of climate research. At the same time it places historical climatology within a European context, because of its long tradition of keeping records.
- 6 Historical climatologists use specific terms relating to certain periods. Within the Late Holocene period (2,000 years), several warmer and colder periods have been distinguished. The Medieval Warm Epoch (MWE) is an example of the former while the Little Ice Age (LIA) is perhaps the best known example of the latter. The Late Maunder Minimum (LMM) is also distinguished as a specific period within the LIA. There is also a temporal distinction based on the kind of data used. The instrumental period is divided into an Early Instrumental Period (EIP, mid-18th – mid-19th century) and a Recent Instrumental Period (RIP, mid 19th century until the present day).

Historical evolution

- 7 Interest for climate started well before the Second World War. Although some very old and systematically kept weather observations are known from 14th century England (Mortimer, 1981; Buisman, 1995), on the European continent some scientists started recording daily weather conditions as early as the 16th century. In the German Lands perhaps, Tycho Brahe (Lenke, 1968) Kilian Leib and Wolfgang Haller (Schwarz-Zanetti *et al.*, 1992; Pfister, 1999b) have left the most famous weather diaries of their time. In the Netherlands Johan Fabricius and Isaac Beeckman are of interest (Lenke, 1968; 1939-1953; Buisman, 1995). Fabricius who lived in Frisia, kept a weather diary from 1590 to 1612; Beeckman, who lived partly in Zierikzee, Utrecht, Dordrecht and Rotterdam, kept a diary of which only the period November 1612 to March 1615 has survived. Beeckman was not content with just recording meteorological phenomena, he also wanted to understand the mechanisms behind them. He argued that the only method to understand the natural mechanisms of the environment was by measuring all aspects of daily weather, such as rain, wind, temperature and pressure. Because no useful thermometers existed at the time, he used a kind of wording system (see below) to assess temperature. Unfortunately, Beeckman never succeeded in studying his weather data the way he meant them to be used.
- 8 During the 17th and following centuries systematic recording of weather conditions evolved from a mainly descriptive method into measurements of temperature, wind direction and wind force and pressure (Geurts *et al.*, 1983, 1985 and 1992; Kington, 1997; Brázdil *et al.*, 2002). Although at that time none of the early instrumental data was analysed in any detail, it did not result in the founding of national meteorological institutes (e.g. De Bilt and Ukkel).
- 9 It was not until the 20th century that scientists became interested in the climate of the recent past. Although Easton's (1928) book on historic winters was already published in the Netherlands, a wider interest in climate history began to sprout in England (Britton, 1937), Germany and France as well. The most important centres that have contributed to the development of historical climatology are mentioned in the following paragraph.

The Netherlands and Belgium

- 10 As far as The Netherlands and Belgium are concerned, the geological and soil mapping of the coastal region that started just after the end of the Second World War and the 1953 storm surge, stimulated climate research which focused on the Holocene. From this the concept of transgressions and regressions (Tavenier, 1948; Ervynck *et al.*, 1999) was initiated and an inventory on historic storm surges (Gottschalk, 1971-1977) was published. Having a wider time scope, palaeoclimate research carried out by Verbruggen (Verbruggen *et al.*, 1991) needs to be mentioned that helped to lay a foundation for similar further research. Next to this storm surge research, reconstruction of winters started in the 1970s (De Vries, 1977) and 1980s (Buisman, 1984). This resulted in a very detailed inventory of historical weather data compiled by Buisman and Van Engelen (Buisman *et al.*, 1995-2006). While the storm surge research concentrated at the universities of Amsterdam and Ghent during the 1960s and 1970s, the broader reconstruction of weather of the past concentrated mainly at the Koninklijk Nederlands Meteorologisch Instituut (K.N.M.I., De Bilt) during the 1990s. The Koninklijk Meteorologisch Instituut (K.M.I.) in

Ukkel is also doing similar research on the history of climate (Demarée, 1990, 1993, 1999; Demarée *et al.*, 2000, 2001).

Great Britain

- 11 In Great Britain the development of historical climatology owes a great deal to the pioneering work of Hubert Lamb. He used to work at the British Meteorological Office, but in 1979 he started the Climate Research Unit of the University of East Anglia in Norwich. Besides the simple methodologies developed by him, he also initiated the interdisciplinary and multidisciplinary research into recent climate variability (Lamb, 1961, 1965) by including history. Next to Lamb, Gordon Manley focused on the reconstruction and variability of rainfall and temperatures of the past (Manley, 1952, 1974). While a lot of the early historical climatologists stuck to the study of written sources, such as Wigley, Kington (1975a, 1975b, 1980, 1997) Ogilvie (Bell *et al.*, 1978; Jones *et al.*, 2001) soon the Climate Research Unit would be dominated by specialists in the reconstruction of natural climate forcing (tree rings, solar activity) early instrumental measurements and by climate modelers. On the other hand the new generation of researchers of climate history focused on many more fields of climate history and developed a global perspective, which proved to be very valuable during the 1990s.

France

- 12 During the 1950s and 1960s the French Annales historians were eagerly seeking all kinds of processes (trends) that were determining the economic and social development of past and present societies. In order to assess the impact of these underlying processes, everyone who wanted to be taken serious as a social scientist started to compile long series of prices and wages. In particular Braudel (1958) set the tone by distinguishing three trends: the “longue durée”, shorter trends and the events, which he considered to be mere passing inconveniences of a political and military nature. His paper did not only add to the search for and compilation of long time series, it also stimulated the “histoire de mentalité” and it focused the attention of some historians on climate again.
- 13 In France historical climatology became closely connected to mainly one pioneer: the historian Emmanuel Le Roy Ladurie. Except for his contribution to methodology (Le Roy Ladurie, 1959; Le Roy Ladurie *et al.*, 1980) he also published one of the first books on the reconstruction of climate of the past millennium (Le Roy Ladurie, 1967). Although a second major contribution to the reconstruction of climate during the Middle Ages was made by Alexandre (1987) and a third by De Vries (1977), it was not the “Institut des Sciences Humaines” in Paris that would develop into a kind of climate research unit.

Germany

- 14 In Germany the meteorologist Hermann Flohn, the third pioneer of historical climatology, published a paper about 16th century weather conditions in Zürich in 1949. In following papers he also noted the variability of climate, in particular during the Middle Ages (Flohn, 1949, 1950, 1958, 1967). It would be until the 1990s before another major step forward could be made. In several papers and related publications Glaser (1991, 1996; Glaser *et al.*, 1990, 1991, 1999) set out to study the period prior to

instrumental measurements by using records on harvesting, as well as some climate impact studies carrying out (Glaser, 1998; Glaser *et al.*, 1990; Jacubowski-Tiessen, 1992).

Switzerland

- 15 During the 1970s the centre of historical climatology on the European continent slowly shifted from France to Switzerland, in particular to the Bern University, where the climate department was directed by Christian Pfister. As early as 1975 this outstanding researcher published a major work on the relationship between agriculture and weather, which was followed by a number of papers (Pfister, 1975, 1977, 1981, 1986) and finally his extended study on the Swiss climate from c. 1525 onwards (Pfister, 1988). Swiss historical climatology focuses on the research of documentary evidence from the pre-instrumental period that provides data on plant growth, agricultural production and alike. Apart from a special method that has been developed to quantify these data, also a database (CLIMHIST) (Pfister, 1985) has been set up for collecting weather data from all over Europe. Thus a European network of historical climatologists was created.

Czech Republic and Eastern Europe

- 16 In the Czech Republic the most outstanding research is directed by Brázdil. Similar to other countries, Czech historical climatology aims at publishing relevant weather diaries and investigating data on weather extremes, such as extreme rainfall and its impact and historic storms and their impact (Brázdil, 1992, 1996; Brázdil *et al.*, 1999, 2000, 2001). Meanwhile, in co-operation with Pfister a methodology has been developed to process qualitative data into quantitative data (see below).
- 17 In Poland and Hungary historical climatology concentrates around a few universities, such as the Jagiellonian University of Cracow (Glaser *et al.*, 1999; Bokwa *et al.*, 2001) and the Hungarian Academy of Sciences (Glaser *et al.*, 1999). Of course, much additional research on the recent history of climate is carried out in various countries, but many results are published in national journals and in the native language and thus hard to obtain and read for foreign researchers.

Scandinavia

- 18 In Sweden research was carried out on an individual basis. The astronomer Maunder, for instance, showed that the second half of the seventeenth century was characterised by a decreasing solar activity. This period (1645-1715) has become known as the Maunder Minimum. His fellow country man Utterström (1955) noted a series of very mild winters between 1721 and 1735. Recent research focuses the oldest instrumental data (Barring, 2000).
- 19 In Norway historical climatology focuses on the changes in land use in mountainous regions and the relation with climatic change (Nordli, 2001; Nordli *et al.*, 2003).

Italy and Spain

- 20 In Italy the research carried out by Camuffo warrants a mention. Focusing on Northern Italy he studied climate extremes, such as storm surges and winter severity around Venice (Camuffo, 1987, 1993). He also tried to reconstruct climate during historic periods

(Camuffo *et al.*, 1992; Glaser *et al.*, 1999). In Spain much of the research has focused on annual rainfall (Rodrigo *et al.*, 1994) and flooding events (Barriendos *et al.*, 1998).

Historical climatology and its weather data

Introduction

- 21 In order to reconstruct temperatures, rainfall, air pressure, wind direction and wind force during the pre-instrumental period, weather extremes and their impact, historical climatology is looking for information about weather conditions of the past obtained from the study of written sources. Fortunately historical climatologists are able to extract direct and indirect information from special kinds of written sources, so that they can reconstruct rainfall, air pressure, wind force and temperature. The specific climate information provided by these written sources is also very important for comparison with similar climate signals obtained from the climate research on tree rings, ice cores and varves. Although the written sources can hardly be discussed separately from the method that is used to process them, first the written sources that have a high potential for climate research will be discussed.

Kinds of written (climate) sources

Wind

- 22 Wind force plays a vital role in pre-industrial times, providing energy for ships to sail and wind mills to grind grain, press oil and saw wood. When the recording of wind, its force and direction has begun remains unknown, but as soon as this became of a high economic interest, records began to provide some information. First it was only information on extreme events, such as devastating storms causing mills to collapse and ships to sink. During the 16th century ships logs were kept on ships that went to overseas areas (Oliver *et al.*, 1970; Wheeler, 1988; De Kraker, 2000a; Wheeler, 2005). The motivation to keep these logs was manifold. Logs were kept for eventually recording the safest and fastest route to the overseas European colonies. Logs were also kept for military reasons, while in the Dutch Republic ships sailing to the East Indies were even ordered to keep ships logs.
- 23 Logs are the most important source for wind force and wind direction. These characteristics were observed on a daily basis, sometimes to four times a day. Wind direction was recorded by using a compass of 32 wind directions (fig. 1). Wind force was characterised in a standard vocabulary. This wording system consisted of hundreds of words and expressions to characterise what kind of wind was blowing and at what speed. Although sailors from different European countries each had their own language, the kind of words and expressions used were rather similar. This wording system slowly evolved into the Beaufort scale. Sailors used to record all kinds of other weather conditions in their logs as well, such as cloud cover and rainfall. There can be no doubt about the high quality of ships logs for the reconstruction of weather conditions. It should be noted that because most of the time ships are on the move, weather conditions cannot be so easily reconstructed for a particular area over a longer period. However, some logs even have recorded weather conditions while ships were anchored for a long time.

Figure 1. Part of a ships log kept by Philips Grimmaert on the ship Zeelandia, June 1599.

Jaer	Daeg	U	V	W	W	W	W
1599	11	Donersdag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt
	12	Freudag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt
	13	Freudag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt
	14	Freudag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt
	15	Freudag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt
	16	Freudag	U	6	Roet wylt	Roet wylt	Roet wylt
			V	12	moes roet wylt	moes roet wylt	moes roet wylt
			n	6	Donner met wylt	Donner met wylt	Donner met wylt
			n	12	Donner met wylt	Donner met wylt	Donner met wylt

NATIONAL ARCHIVES, THE HAGUE, EAST INDIA COMPANY, NO. 54

- 24 Records and accounts kept of wind mills also provide some information on wind direction and wind force in particular. The oldest records date from the 14th and 15th centuries and deal with the letting out to lease and maintenance of wind mills. Repairs to wind mills were mostly carried out after severe storms or thunder storms. In such cases only weather extremes have been observed. In general millers had thorough knowledge of wind, storms and how thunder storms could arise on the horizon and how these could affect a windmill. So in Holland some millers kept records of daily winds as early as the 17th century. The way they characterized winds is somewhat similar to that of the ships logs. Mills were also situated on canals and lakes in order to drain recently reclaimed polder areas, and therefore sluice masters began to record wind directions on a daily basis, for instance at Bilderdam, Amsterdam and places in the vicinity (fig. 2).

Figure 2. Wind observation at Bilderdam, 1-10 September 1707.

Day	Wind Direction	Force (duijn)	Other Notes
1	Z. (Zuid)	15	Land water 15 duijn beno de poel uit d' land
2	Z. (Zuid)	15	Land water 15 duijn beno de poel uit d' land
3	Z. (Zuid)	15	Land water 15 duijn beno de poel uit d' land
4	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
5	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
6	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
7	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
8	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
9	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land
10	N. (Noord)	14	Land water 14 duijn beno de poel uit d' land

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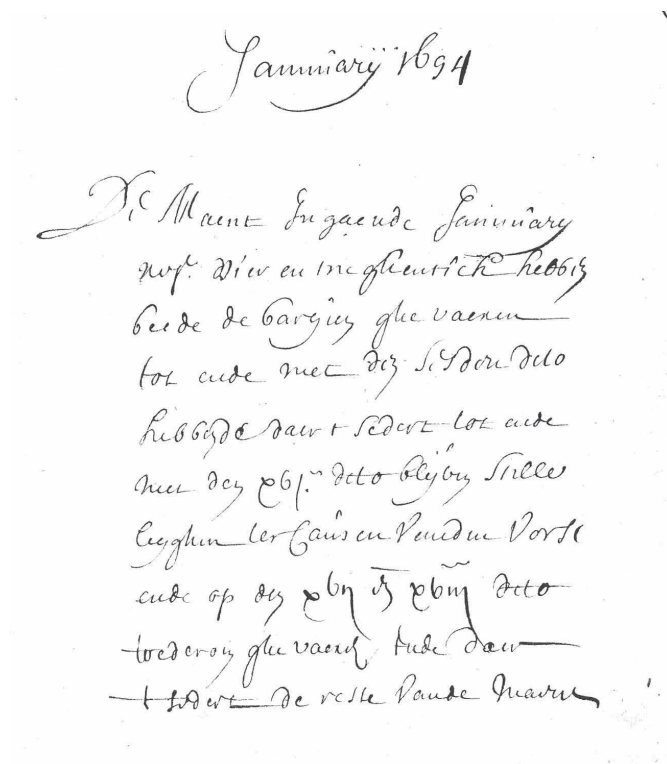
- 25 Accounts of dike maintenance and upkeep of dunes also provide information on wind, although mostly extreme storm events were recorded because they caused damage requiring repairs (De Kraker, 1997). Similar information can be provided by accounts of maintenance of high towers of city halls, churches and castles. Even accounts of large domains, such as forests, may provide information of storminess. Each severe storm causes extra work for labourers to clean up the forest and restart planting young trees after major thunderstorms.

Temperature

- 26 It was not until the 17th century that thermometers were introduced. In the Dutch Republic these instruments were first seen during the 1620s. Some scientists began to use thermometers. Because different instruments were used in different places, most of these recorded temperatures, if even preserved, are inaccurate. Although temperature observations began to improve during the 18th and 19th centuries, most of these early instrumental (EIP) measurements remain to be homogenized.
- 27 So for the pre-instrumental period other written sources need to be used to reconstruct temperature. If a distinction is made between winter, spring, summer and autumn temperatures, one can look at all kinds of mainly economic activity characteristic for one of the four seasons or strongly affected by changing in temperature. This knowledge provides two major categories of written evidence.
- 28 The first category contains accounts on shipping, ranging from toll accounts to accounts of leasing out of barges, passing and repairs of locks and bridges. Because canals and rivers formed the most important transportation routes during the pre-industrial period, any kind of interruption was harmful to the economy, resulting in a loss of income on tolls, on leasing out of barges and on dues paid at bridges and locks. Long-lasting interruption could even lead to social unrest in large cities, due to the lack of supplies of food and fuel. Consequently all revenues were administered very accurately, often on a daily basis and also all events that meant a loss of income. Among these events, warfare

was one thing, repairs on canals were another. The most important cause of shipping to be interrupted, however, was ice coverage of canals or rivers. So most accounts record the beginning and ending of these periods and often provide additional information on the severity of the frosty period as well (fig. 3). Similarly accounts of water mills may also provide such information.

Figure 3. Interruption of shipping caused by frosty weather, January 1694.



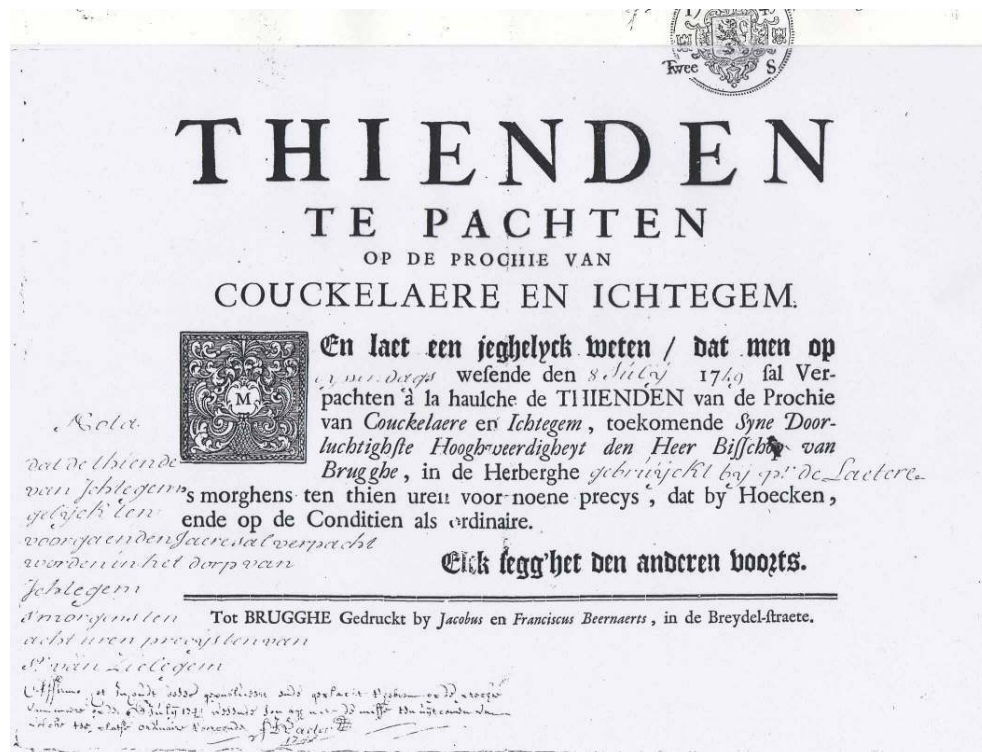
Januarij 1694
 De Maent Ingaende Januarij
 wof. Wier en in gheentekene hebbij
 beide de Gargen ghevaeren
 tot ende met den Scheldt
 hebbij de Rijn tot ende
 met den Rijn tot ende
 legghen ter Gansen Pande Vort
 ende op den Rijn tot
 wederom ghevaeren tude den
 tude de resten Pande Maent

MUNICIPAL ARCHIVES FURNES, NG, NO. 528

- 29 The second major category of written sources has an agricultural background. Most domain accounts register crop production and how arable land and pastures were let out to lease. Specific information for climate reconstruction is provided by the time of harvest or other events related to harvesting and the production of crops.
- 30 Some of these accounts also record weather that completely destroyed crops. For instance long lasting frosty weather destroyed the *Brassica napus* crop, while a long rainy period could destroy the grain harvest. Generally cold and dry weather conditions have a negative impact, while warmer weather with variable periods of rain may have a positive impact on crop production. Milder weather may stimulate an early harvest. After a long hot summer grape harvest may begin in the middle of September. Colder weather generally causes a later harvesting, consequently grape harvesting sometimes started during the second week of October.
- 31 In fact milder weather conditions in winter and in spring may stimulate an early blossoming of trees, such as the cherry tree. Sometimes time series of such phenological data may go back more than a thousand years.
- 32 A particular kind of account records the letting out to lease of tithes. Tithes are a 10% taxation on every tenth sheaf or newly born farm animals. Usually putting out to lease

occurred on a fixed date prior to the harvesting. If harvesting occurred early, then putting out to lease the tithes also occurred early, if harvesting occurred late, then this also occurred late (fig. 4). In fact the annual date of putting out to lease the tithes correlates very well with the annual date of the beginning of the harvest and is therefore an excellent proxy. Moreover tithes occurred in every part of Christian Europe and were abolished as late as the French Revolution while in some countries tithes occurred even as late as the middle of the 19th century, resulting in a long overlap with the instrumental records.

Figure 4. Tithe leasing at Koekelare-Ichtegem, 8th July 1749.



NATIONAL ARCHIVES BRUGES, "BISDOM", NIEUW KERKARCHIEF, NO. 316

Precipitation and general weather information

- 33 Finally old chronicles, diaries and travel journals should be mentioned as important sources of weather information. Most of these written sources often have a negative perception of weather events. So weather extremes such as severe storm surges that caused large scale flooding were recorded and "explained". Long severe droughts or long frosty periods, that often led to scarcity and therefore famine and consequently an increase in mortality, were noticed by chroniclers. Extreme rainfall causing river flooding and thunder storms with large hailstones destroying crops were also mentioned. In fact the larger part of the information on weather events is an inventory of extreme weather events. It should be noted that as soon as chroniclers started to record weather events from far away areas or from much earlier periods, their information starts to become unreliable.
- 34 There are few specific written sources on rainfall which usually occurs very locally. Generally weather diaries contain information on rain fall (Manley, 1952; Manley, 1974).

Also accounts of crop production and accounts related to the transportation on rivers may provide information on rainfall. Most written sources providing information on rainfall, mention extreme rainfall events and periods of extreme droughts. In cases where river flooding caused by extreme rainfall has a negative affect on cities, city accounts may also provide important rainfall information (Barriendos *et al.*, 1998; Brázdil *et al.*, 1999).

- 35 Most of the written records discussed so far are continuous until the end of the 18th century. Putting out to lease tithes and barges on canals even continued well into the 19th century. At the same time the early instrumental weather records began to appear (EIP). These are mostly not counted among the traditional written records, because they contain rows of figures which are the result of daily measuring temperature, wind (force and directions) rain fall and air pressure. During the 18th and the larger part of the 19th century these results have never been used to gain a thorough knowledge of the weather system or climate. Moreover most of the instruments used at that time were not very accurate for one thing and for another, very different kinds of instruments were being used. Still, these instrumental series of temperatures, rainfall and air pressure are the only ones that co-existed with the proxy data obtained for the written sources for more than a century. Therefore these early instrument series play a crucial part in, for instance, processing the proxies into series of temperatures.

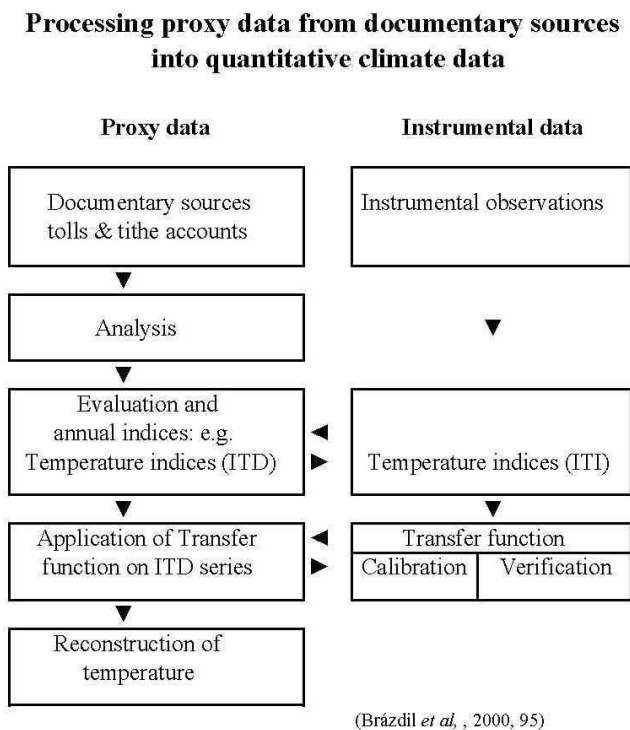
Methodology

- 36 Research of written records prior to the instrumental measurements provides mainly indirect weather observations, in fact mostly with the consequences of particular weather conditions. In order to transfer this qualitative information or proxy data into quantitative data, historical climatology has developed a methodology of its own. This method aims at extending the times series of, for instance temperatures provided by the instrumental measurements, as far back into time as the earliest time series of proxy data start. This can only be successful if both the instrumental measurements and the proxy data have a long overlapping period, if the qualitative data can be directly transferred into hard quantitative data or if the proxies can calibrated with similar climate signals provided by other disciplines of climate research.
- 37 Research of high potential climate related written sources begins with a critical analysis of the written sources. Looking at the beginning years of historical climatology, most of the research was carried out by meteorologists who were only interest in historical data. Unfortunately most of their studies seriously lacked the critical analysis of the written sources used (Easton, 1928; Weikinn, 1958; Vanderlinden, 1924). This had consequences for the reliability of their compiled time series and the way these were used. On the other hand most historians and historical geographers, using the critical historical analysis of the written sources did not know how to compile their time series into quantitative data (Gottschalk, 1971-1977; Alexandre, 1987). This remained a problem until far into the 1990s and was one of the major causes why natural scientists had little faith in the outcome of reconstructions made by historical climatologists. Despite the fact that historical climatology started to develop its own methods, scepticism from natural scientists continued throughout the 1990s (Pfister *et al.*, 1999a).

Historical analysis

- 38 Le Roy Ladurie (1959) showed that high quality written sources had to comply with three criteria. The first criterion was that written records need to be annual, providing a similar climate signal for every year of the period under consideration. The second criterion was that written series of records need to be long and continuous, showing no serious gaps. At least time series need to be continuous for several decades in order to calculate a five to eleven years average. The third criterion was that written sources need to be homogenous and uniform. This implies that climate signals recorded in the documents need to have been observed in the same area and under the same conditions. It also implies that for instance crop production needs to be administered in the same way, yields are about the same species and agriculture techniques need to remain somehow unchanged.
- 39 If these three criteria are applied to written sources, this results in a selection of only specific records providing very special types of proxy data. This critical and very selective part of the methodology used by historical climatologists is rather similar to that used by tree ring specialists (fig. 5). Only trees of the same species, grown under roughly the same environmental conditions, including soil and climate conditions, the same latitude and altitude qualify for reconstructing long time series of proxies.

Figure 5. Diagram of methodology used to process proxy data into hard climate data.



Indices and verification (data control)

- 40 High quality written sources provide a climate signal or proxy data, which can be expressed as, for instance annual indices; temperature indices (TI) and precipitation

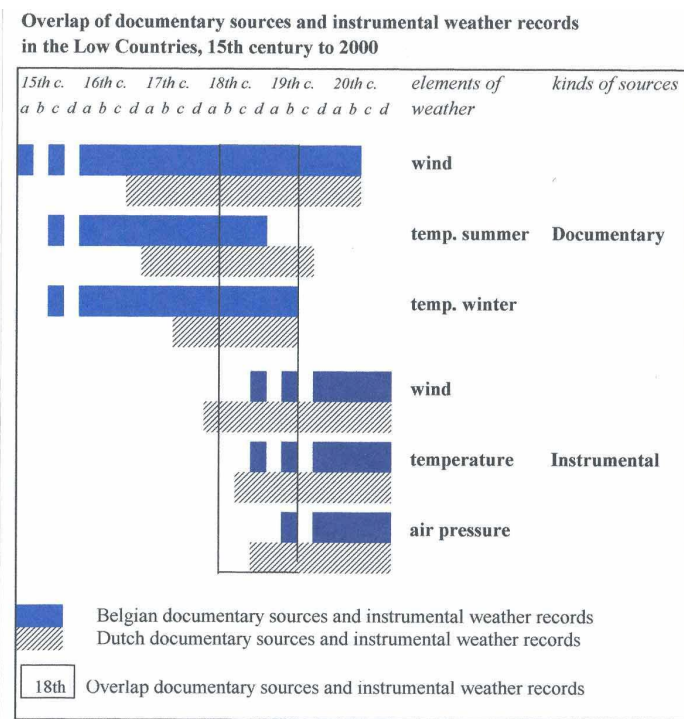
indices (PI). If such a proxy data is provided by written records on the length of frosty weather, this is the number of frosty days per winter season. However, if winter seasons have been very mild, there is no record of frosty days. Temperature during such winter seasons may range from slightly above Celsius to 3 or more degrees minus Celsius. In such cases additional weather information is required.

- 41 If proxy data is provided by written records on the time of harvesting (phenological data), the date of harvesting provides the annual indices. So if grape harvesting began on 15th September 1651, this results in an indices of 15. If proxy data is provided by records on the time of leasing out the tithes, which always occurred at a fixed time prior to the time of harvesting, the tithe data similarly provides a proxy data. So leasing out the tithes at for instance the 31st, 15th or the 5th of July is providing an indices of respectively 1, 17 or 27.
- 42 In order to have the necessary data control and to check errors and all kinds of anomalies in the long series of indices, it is important to have at least three or more parallel time series of indices from the same region. In this way Le Roy Ladurie combined many long parallel time series of dates of grape harvesting in France (Le Roy Ladurie *et al.*, 1980). This resulted in a kind of standardized time series of dates of grape harvesting, which starts in 1484. Because each particular crop has its own specific growing conditions and consequently its own time of harvesting, proxy data of the time of the grain harvesting (rye, wheat, oats, etc.) and of the harvesting of *Brassica napus* as a winter crop, also provide valuable annual indices (De Kraker, 2004).
- 43 Another way to obtain (temperature) indices (TI) consists of assessing (evaluating) temperatures every ten days into seven categories or levels (seven level index). For instance if the first ten days of January have been very mild the assessment is +2 or +3, if weather during the second ten days has changed into frost, the assessment will be 0 and if during the last ten days of January frost is continuous, the assessment will be -1 or -2 (Lamb, 1963, 1965; Pfister, 1988, 1992, 1999b; Brázdil *et al.*, 1996; Glaser *et al.*, 1999). Of course it is hard to make an accurate assessment of each short period, but much of this also depends on additional information on weather conditions provided by other written sources and comparison to weather conditions during other winter seasons. The same method of assessment can be applied to the temperatures of the other three seasons. In fact assessing temperatures this way is rather similar to assessing wind force by the wording system, discussed earlier on.
- 44 The seven level index can also be used for assessing precipitation. So dry months are assessed -1; average months 0 and wet months +1 (Glaser *et al.*, 1999). Because assessment as such is mostly considered to be rather subjective, the results acquired so far have to undergo additional processing.

Comparison: correlation coefficients and transfer

- 45 Depending on the kind of data used to compile time series of indices, series also need to be continuous right throughout the 18th century when early instrumental time series are available (fig. 6). The overlap in time is required in order to correlate the indices with for instance the temperature series (De Vries, 1977; Van den Dool *et al.*, 1978; Shabalova *et al.*, 2003).

Figure 6. Overlap of instrumental climate data and proxy climate data in the Low Countries.



- 46 So the time series of indices of grape harvesting may provide a combined spring and strong summer temperature signal. The time series of indices of the putting out to lease of tithes may provide a strong spring temperature signal. Likewise the time series of indices of the number of frosty days may provide a strong winter temperatures signal. Of course, part of the indices also shows a precipitation signal or some other kind of noise, as is the case with time series of tree rings. In general, expected pseudo temperature signals are renounced from the data sets by smoothing or filtering.
- 47 If a satisfying high correlation coefficient (0.90) is found between the time series of indices and the instrumental data, then the indices may be used to transfer these into temperatures. The reconstructed time series of temperatures thus represent an average winter, spring or summer temperature.
- 48 It should be noted that only the Dutch, British and partly the Belgian proxy data is so unique that they are continuous throughout the 18th century and therefore overlap instrumental data by several decades. In neighbouring countries, such as Germany, Switzerland and the Czech Republic, instrumental data from the 18th century is very rare. However, some time series of proxies in Switzerland, such as plant phenological data, is continuous throughout the 19th and 20th centuries (Rutishauser *et al.*, 2004).

Additional methods

- A special method has been developed by Lamb (1961; 1963; 1972) in order to classify storms. He distinguishes eight directional types of storms, which are characterised by an overall atmospheric circulation. He also added three types to these eight categories that are non-directional: anti-cyclonic (A) cyclonic (C) and unclassifiable (U). So a CW-type or

cyclonic westerly circulation “corresponds to a situation where the steering of synoptic features is from west to east” with depressions passing over the northern part of the North Sea (Kelly *et al.*, 1997). The use of this classification is that weather types can be roughly linked to pressure field patterns and precipitation.

- 50 Finally a method has been developed to assess wind force and its variability on a longer time scale (De Kraker, 1997, 1999) by studying long continuous time series of dike accounts. This method distinguishes eight categories by taking into account the following criteria. One criterion is the way how a particular storm is described in the document: high tide, storm, storm surge or disastrous storm surge, etc. Additional information on the duration of a storm, the wind direction and the height of the flood is also taken into account. Next the consequences of storm are assessed, for instance some only caused damage to dikes others flooded many thousands of acres of arable land, while many cattle and people drowned (De Kraker, 2000).

Climate reconstruction: temperature

General

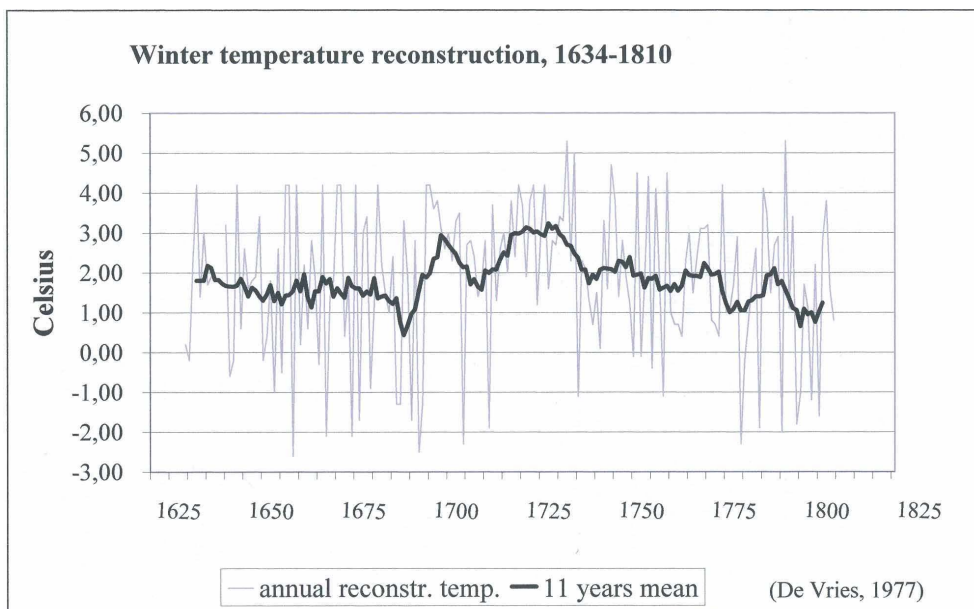
- 51 About 1950 historical climatology was still non-existent. For several countries and European regions traditional compilations were available on climate extremes, some of them providing an overview of extremely cold winters (Easton, 1928) others of flooding events. In fact most of these compilations were unreliable, but still these were used by meteorologists interested in the past. On the other hand historians and geographers began to critically analyse the older weather observations, but still were not able to find a method to reconstruct parts of past climates. Within half a century this changed. Especially from the fields of history and geography ideas about the use of unexplored historical weather data emerged and new methods were applied from both the social and natural sciences. From meteorologists much effort was put into getting their older instrumental measurements right. At the same time a closer co-operation between the two fields resulted in interdisciplinary approach of historical climatology. A brief overview of the results obtained so far follows.

Temperature reconstructions

- 52 During the 1950s the historical climatological debate was dominated by Lamb, Flohn and Le Roy Ladurie.
- 53 Lamb thought that climate of the recent 2,000 years was variable, which he concluded on the basis of evidence coming from human activities in the Northern Atlantic, the changing tree lines in mountainous regions and the related glacier movements, grape cultivation and the then existing compilations of severe winters (Lamb, 1965). Although most of his historic evidence was of a qualitative nature, he consequently distinguished a Medieval Warm Epoch (MWE) and a Little Ice Age (LIA). Lamb did not invent the name Little Ice Age; this seems to have been initiated by Matthes (1942). Lamb believed the LIA started about 1550 (Lamb, 1977). He also developed a method of roughly measuring temperature that has been discussed above (Lamb, 1963). Following from here several studies were made of very recent climatic periods by looking at the consequences of temperature change, such as the advance and retreat of glaciers.

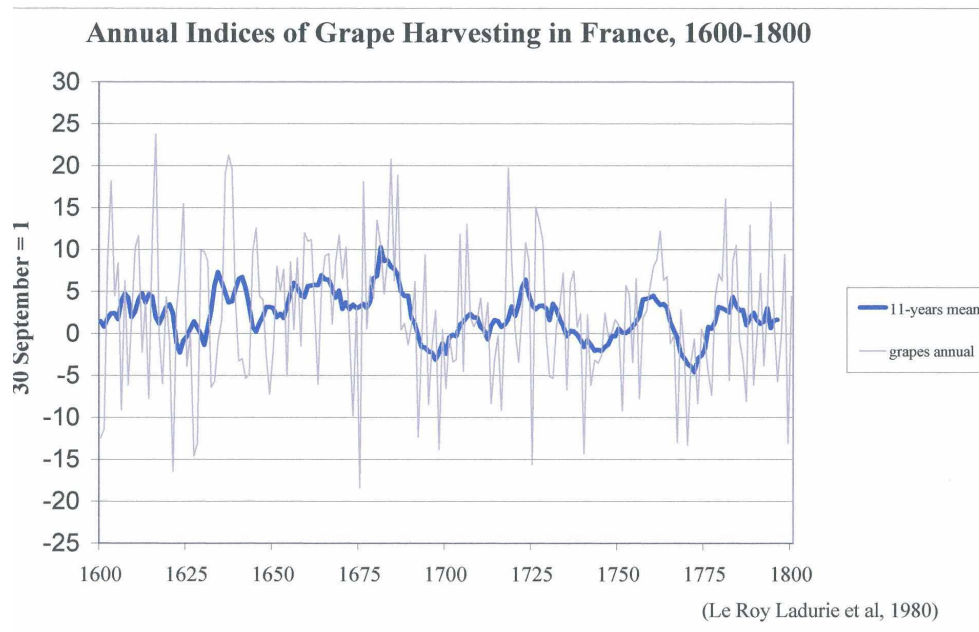
- 54 One of the first historians to look into this problem was Le Roy Ladurie (1967). Using glacier data, he distinguished five periods of glacier advancing during the last 3,500 years (Le Roy Ladurie, 1983). The interval or warmer periods are referred to as optima, the periods of glacier advancing are referred to as maximums. Particularly the long period of advancing glacier between 1550 and 1850, Le Roy Ladurie's fifth period, was the Little Ice Age. This hot item has also been thoroughly analysed by Jean M. Grove (1988, 2001; Grove *et al.* 1995) who finally admitted the LIA started about 1250-1300, agreeing with Porter (1986) and O'Brien (O'Brien *et al.*, 1995) who considered the LIA to be complex. The complexity of the LIA was shown by a sequence of alternating cold and warmer periods. One of the colder periods started during the last quarter of the 16th century (Pfister *et al.*, 1996). But perhaps the coldest period of the LIA was the Maunder Period (1675-1730) which received much attention during the nineties (Frenzel *et al.*, 1994). By now it has been firmly established that the Maunder Period is also much more complex and consequently shows two extremely cold decades 1676 to 1695, that are explained by solar variability, an increase in volcanic activity and the internal oscillation in the North Atlantic region (Luterbacher, 2001).
- 55 At the same time discussion on the beginning and nature of the LIA was well underway, also the MWE, prior to the LIA received much attention. While Lamb argued mainly on biological and phenological data, that the period about 1200 was relatively warm, although settlement of Iceland began in the 9th century A.D. and written evidence stops about 1430, Ogilvie could not find the perfect connection with climatic conditions (Ogilvie *et al.*, 1997). During the MWE Icelandic climate seems to have been more variable than in other parts of Europe. On the other hand research carried out by Alexandre (1987) clearly established a relatively warm period that seems to have lasted well into the 15th century. Recent research tends to an earlier ending of the MWE (Ogilvie *et al.*, 1997; Gunnarson *et al.*, 2002)
- 56 A more accurate climate variability of the recent millennium was obtained by the availability of an increasing number of publications on historical weather observations and proxy data, combined with the use of better statistical methods of reconstruction. Research on the freezing of waterbodies by De Vries (1977, 1980) not only showed the variability of winter severity on a long time scale by analysing the number of days shipping was interrupted on the Haarlem canals, but he also initiated a method to translate the length of the frosty winter period into temperatures (fig. 7). Although his method was corrected immediately (Van den Dool *et al.*, 1978; Van Engelen *et al.*, 2001) it proved to be a valid one and it showed that the winters of 1634 to 1838 indicated that the Little Ice Age was more complex than had been assumed. In fact, it showed that in particular the late 17th century was a period of extremely cold winters. It was also realised that more than just proxies for winter temperature were needed to assess the variability of temperature throughout the last five or six centuries.

Figure 7. Reconstruction of winter temperature in the Netherlands, 1634-1810.



DE VRIES, 1977

- 57 Studying proxy data provided by growth of plants also proved to be a very promising path to obtain a more accurate annual mean temperature. The most outstanding early example of such a study was carried out by Le Roy Ladurie, who already in 1959 addressed the potential of the dates of the grape harvest. Grape harvesting usually occurs in September, but the exact date and its annual fluctuation on longer time scale were closely connected to the April-July temperature. Shortly after De Vries' (1977) innovative paper on reconstructed winter temperatures, Le Roy Ladurie (Le Roy Ladurie *et al.*, 1980) compiled a long time series of dates of grape harvesting, which was soon to be used to estimate mean temperatures for April-June (Burkhardt *et al.*, 1985; Lauscher, 1985) (fig. 8). There was more evidence to come from other phenological data. First dates of the grain harvest were studied in Germany (Glaser, 1991, 1995, 1997) and elsewhere (Tarand *et al.*, 1994) and first dates of the blossoming of fruit trees, such as the cherry tree (Pfister, 1988, 1999c). All results showed a similar variability of reconstructed temperatures throughout the periods under study.

Figure 8. Annual dates of grape harvesting, 1600-1800.

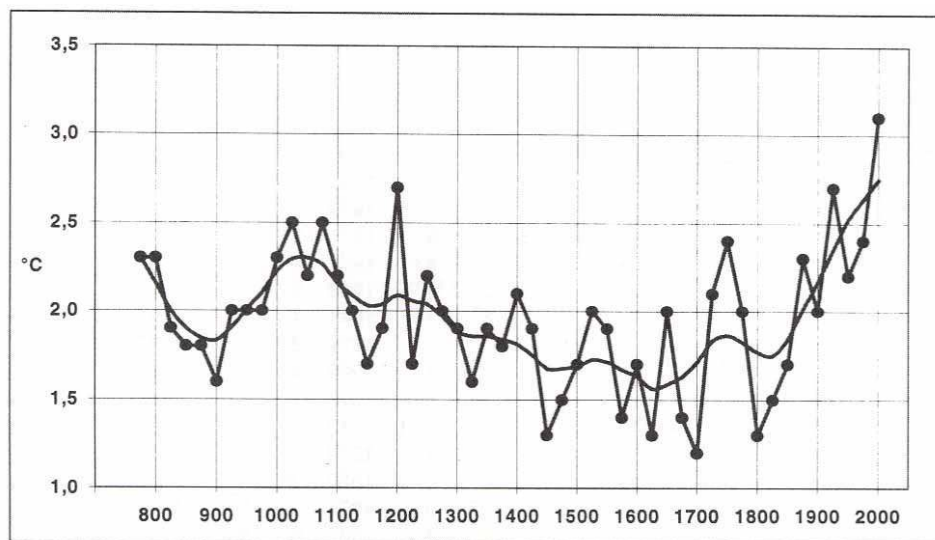
After Le Roy Ladurie *et al.*, 1980

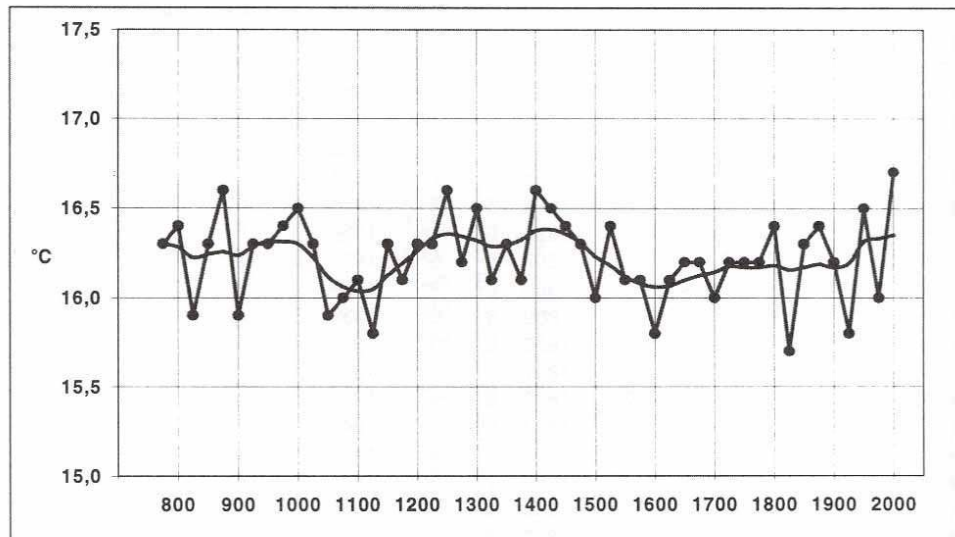
- 58 Although the backbone of climate reconstruction publications focusing on mean annual temperature came from other disciplines, such as research on tree-rings (e.g. Briffa *et al.*, 1992, 2002a, 2002b) and on ice cores (see below) they also established the same climate variability.
- 59 Another line of investigations explored by historical climatologists during these decades is what can be termed “historical meteorology”. Meteorologists became more interested in the oldest time series of instrumental observations and their history. Especially the search for the earliest observations was intensified, ranging from the Czech Republic (Brázdil *et al.*, 1996, 1999a) Switzerland, Germany, Denmark to Holland and Belgium (Demarée *et al.*, 2000, 2002). The early work of Gordon Manley (1952, 1974) deserves some special attention in this respect. He managed to extend the record of reconstructed mean monthly temperatures in central England as far back as 1698, and in 1974 adding another 40 years to extend it to 1659. At the same time he warned to use this kind of old instrumental material carefully because of the inaccuracy of the oldest instruments. This resulted in a critical analysis of the oldest instrumental time series. Although the majority of research into recent climate history already were involved dealing with direct historical weather observations, this finally and fortunately resulted in a closer co-operation of meteorologists and climate historians, ultimately resulting in the methodology discussed above.
- 60 The results obtained from reconstruction of temperatures of the recent five to six centuries resulted in a focus on the particular cold period, the Maunder Minimum (MM) of 1675 to 1715 (Frenzel *et al.*, 1994). The outcome of a special issue devoted to the Maunder Minimum accelerated the systematically collection of weather observations and proxy data, in particular by the recently established CLIMHIST Data Bank (Pfister, 1985; Schüle, 1994; Schüle *et al.*, 1994). The causes of the large number of cold extremes in the winter half of the years of the Maunder Minimum (1676-1695) have already been

discussed (Luterbacher, 2001). It also showed that the Maunder Minimum effect was stronger in Central and Northern-Europe than in the Mediterranean.

- 61 During the last decade studies on temperature reconstruction have made a remarkable progress. One of the most outstanding publications is without any doubt the result of a huge collection of detailed weather observations and proxy data by Van Engelen and Buisman. It is not their published data base of weather observations with all kinds of irrelevant anecdotal stories (Buisman, 1995-2006) but the processing of these proxy data into long series of reconstructed winter and summer temperatures, that is of interest (Van Engelen *et al.*, 2001; Shabalova *et al.*, 2003) (fig. 9). These time series have a long overlap with the time series of instrumental measured temperatures from the 18th century. As a result, the mean temperatures of the Netherlands could be reconstructed as far back as 843 A.D. However, looking a little bit closer to this time series, it soon appears that the increasing uncertainty renders the reconstructed time series of temperatures before 1400 far less useful. It therefore needs to be used as a means of reference with other time series, such as tree-ring series and ice cores, from that early period. On the other hand such time series always originate from far away regions. The Dutch reconstructed temperature series and the Mid-England series are in good accordance with each other.

Figure 9. Reconstruction of Winter and Summer temperatures of the Netherlands, 800-2000.





VAN ENGELEN *ET AL.*, 2001

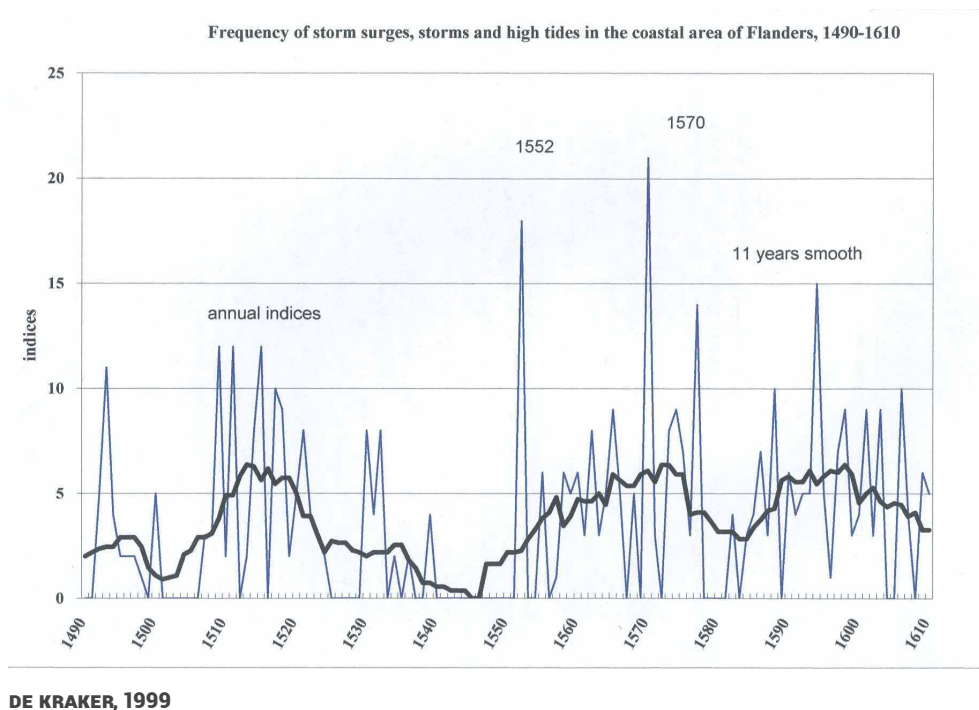
Climate reconstruction, extremes, impact and perception

High tides, storms and storm surges

- 62 One of the climate events that triggered renewed interest in historical climatology was beyond any doubt the storm surge of 1953. In order to know whether this climate extreme, that killed 1,836 people in The Netherlands alone, was an exception or the beginning of a new era, characterised by an accelerated rise of general sea level and consequently increasing danger for the coastal defence, the study of historic storms gained a huge interest. This renewed interest in fact coincided with the recently developed concept by Quaternary geologists of transgression and regression phases during the Holocene (Tavenier, 1948; Ervynck *et al.*, 1999). Some even believed the 1953 storm surge to be the signal for another transgression phase, the so called Dunkirk IV? (Ervynck *et al.*, 1999).
- 63 Already in 1970 the All Saints Flood of 1570 received so much attention, that a special congress was held to present an overview of the devastating aspects of the storm surge from several part of the Netherlands, Belgium and Northern Germany (De Vries and Winsemius, 1970). This revived interest immediately made clear that there was no inventory of historic storms, not even of historic storm surges. Moreover it showed that using old chronicles for the reconstruction of historic storms was dangerous, because most of these writings were considered unreliable. During the post-war decades there already was a large expertise in the Netherlands from the domain of historical geography on using written sources to reconstruct historic landscapes and the development of landscapes on long time scales (Gottschalk, 1955-1958). At the same time historical geography studies paid attention to the impact of e.g. historic storm surges (Gottschalk, 1955-1958; Dekker, 1980). Thus it was a relatively small step for scientists to start a study of old chronicles and their use for compiling historical storm surges and river flooding

events. However, at the same time this was a major step towards the historical climate research as well.

- 64 During the 1970s this research resulted in a three volume edition of “Storm surges and river flooding in the Low Countries, 800 AD to 1700 AD” (Gottschalk, 1971-1977). Not only did it show that many historic storm surges could be ignored, because chroniclers had made serious mistakes, it also showed the spatial and temporal variability of storm surges in the Low Countries coastal region. For instance, the disastrous storm surges of 1424 caused considerably less damage in the Northern German coastal region than in the Dutch coastal region. Unfortunately, the big effort did not result in any other research of similar impact in the Netherlands. Undoubtedly the major reason was that from the storm surges compilation it was concluded that it would be impossible to make a quantitative assessment of the storm surges for the pre-instrumental period. Moreover the study was “only” based on chronicles, not on a large amount of additional primary written sources. Similarly Augustyn’s ecological study was restricted to qualitative aspects of climate (Augustyn, 1992).
- 65 During the 1990s a first attempt was made to quantify storminess, by using primary written sources, such as accounts on dike maintenance (De Kraker, 1997, 1999, 2005). A special method was used to assess the impact of the weather event, such as the duration, wind direction, water levels reached during spring tide, the way in which the event was characterised (wording system) the duration of storm events and all possible consequences of the event, from small scale damage to large scale flooding of polders. The quantification of storm surges, storm and high tides resulted in a record of storminess variability during the 16th century (fig.10). Still, the area studied for this purpose remained limited to a polder area of approximately 400 km² to the west of Antwerp.
- 66 Finally, further study on the proxies of storms is carried out to translate the wording systems into hard numbers. One of the most important category of written sources used to reach this goal is ships logs (see below).

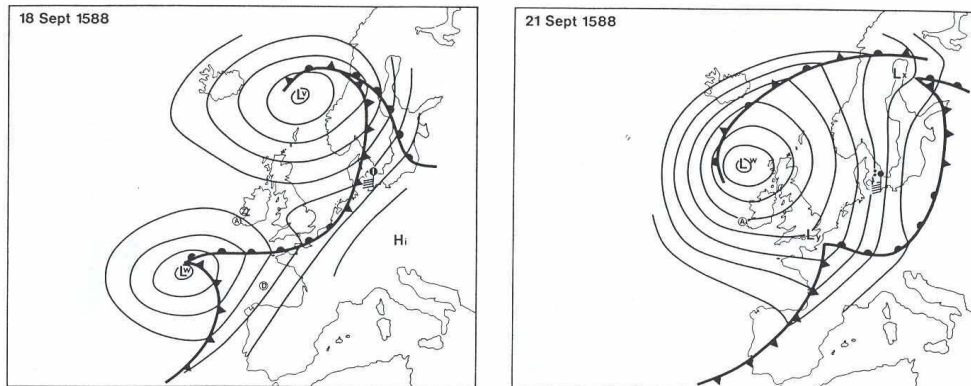
Figure 10. Frequency of storminess in the Zeeland Delta, 1488-1609.

Atmospheric density maps

- 67 Research on the variability of storms in the past in Great Britain continued to be one of the topics of Lamb. After having classified daily weather types (see above), historic storms were put into a broader temporal and geographical perspective resulting in the first attempt to reconstruct an entire historical pressure field pattern (Douglas *et al.*, 1978) (fig. 11). These synoptic maps became a starting point to continue the compilation of historic storms and soon more reconstructions of pressure field patterns of particular storm events were produced (Lamb *et al.*, 1991). In fact it resulted in combining the data of the earliest known instrumental observations of air pressure and wind direction with the written evidence on historic storms in the North Sea region on a global scale, linking them with the North Atlantic Oscillation Index and other climate phenomena such as El Niño, La Niña, solar forcing, ice core results from the Greenland area and the results of the tree ring record. The first attempt to link land and marine weather data was made by Jones (Jones *et al.*, 1982, 1986, 1999; Kelly *et al.*, 1997). By now this research has included much additional data of meteorological stations around the world, including those from oceanic stations of which the larger number only dates from the post-Second World War era. A very promising recent development of this research is the digitising of old ships logs dating as far back as the mid 18th century (Koek *et al.*, 2003; Garcia-Herrera *et al.*, 2003; Wheeler, 2004, 2005), extending the pre-instrumental data base is prolonged back into time. Already a huge amount of data is available, but only from the well known sea routes, along the South African coast to the East Indies and the North and Mid Atlantic routes. Besides the large spatial and temporal coverage of this oceanic climate data, they need to be assessed in such a way that for instance the observations of wind and storms can be easily translated into wind force as it has evolved into the Beaufort scale about

1800 (Gram Jensen, 1985). However, the outlooks of achieving this goal are very promising (Wheeler *et al.*, 2004).

Figure 11. Reconstruction of air pressure fields during the Armada attack, 1588.



LAMB ET AL., 1991

Climate extremes, impact and perception

- 68 Apart from reconstructing past climates, historical climatology also sets out to investigate extreme climate events and their impact, such as flooding events caused by extreme rainfall or storm surges. Although climate is variable within certain boundaries, these boundaries become more tightened as soon as regions become populated and man begins to change its environment. As soon as boundaries are dictated by man climate extremes tend to be considered natural catastrophes. Such catastrophes leave important traces in the written sources, because they are very harmful to society.
- 69 In fact, the earlier compilations of climate events and weather data were mere collections of extreme weather events, such as extreme cold winters, long droughts and storms. As shown above, the renewed interest for storm surges in the Netherlands after the storm surge of 1953, resulted in a detailed study of recorded storm surges from 800 AD to 1700 AD (Gottschalk, 1971-1977). Recently, storms in the Zeeland delta have been studied in more detail (De Kraker, 1997, 2000). The analysis of the 1717 Christmas storm surge in Germany (Jacubowski-Tiessen, 1992) included not only the causes and the immediate impact but also the longer term consequences. Similarly, storm surges have been studied for the Adriatic region (Camuffo, 1993).
- 70 An increase in extreme weather events caused by heavy rainfall during the last ten years has again turned the attention of climatic controls on flooding of European rivers. Of course, earlier researchers had focused on rainfall events (Wales-Smith, 1971, 1973; Craddock, 1976; Wigley *et al.*, 1977) before. In the Netherlands special attention was paid to the rivers Waal and Maas (Driessen, 1994; Stangl, 2003).
- 71 In Spain and Italy the Mediterranean climate produces torrential floods mainly during winter, which may turn into catastrophic floods, affecting city centres located on the main rivers (Barriendos *et al.*, 1998; Camuffo *et al.*, 1996; Bràdzil *et al.*, 1999b).
- 72 River flooding in Germany, Poland and the Czech Republic in 2000 and 2002 also attracted considerable scientific attention from historical climatologists (Brázdil *et al.*, 2003; Munzar, 2003; Deutsch *et al.*, 2003; Glaser, 2003; Poliwoda, 2003; Rohr, 2003; Stangl, 2003).

- 73 The impact of extreme cold periods on society is shown from scarcity during severe winters, which could result in hunger and an increased mortality rate. One of the most interesting case studies of this kind of impact on society is the severe winter of 1740 (Post, 1984, 1985). Similarly, the relation between hot and dry summers and the occurrence of malaria in former salt marsh regions of the Low Countries is an example of climate impact, which can now be shown from the increased knowledge of climate variability of the pre-industrial centuries (Devos, 2001).
- 74 Attention was again paid to the impact of extreme weather events on military campaigns and on politics in general. The weather conditions that led to the attempt of the Spanish Armada to sail around Scotland in the autumn of 1588 can be considered a classic example (Douglas *et al.*, 1978).
- 75 Finally, perception of weather extremes has become important, because the way people perceived extremes in the past may teach us vital lessons how to deal with present extremes. For instance, there is a close link between human response to storm surges causing large scale flooding and perception in which the Divine Act played an important role throughout the centuries (Kempe, 2003; Stuber, 2003). However, the concept of a gradual diminishing interest of religious beliefs in perceiving weather extremes particularly during the Age of Enlightenment, is a far too simple concept. Because hardly any attention has been paid to this aspect of historical climatology in the Low Countries (Buisman, 1995-2006; Slager, 2003), this will not be further explained.

Discussion, conclusion and outlook

- 76 This review has traced the development of historical climatology as an emerging science during the past 50 years. Having its origin in the social sciences, of which historical geography and history are most distinctive, historical climatology has contributed much to the understanding of climate variability of the recent millennium by showing what kind of climate information is provided by written sources and how this information can be used. While at the start only a few individuals, such as Lamb, Flohn and Le Roy Ladurie, showed any interest in recent climate, within a few decades historical climatology evolved into a specialised field of research. By now most of the European countries, of which England, Switzerland, Germany and the Czech Republic are by far the most important contributors, are involved in historical climatology.
- 77 During these five decades historical climatology has already contributed greatly to all aspects of climate and weather research. First, it has unlocked a wide variety of written sources mainly dating from the pre-instrumental period providing indirect information on climate conditions: proxy data. These proxy data provides a climate signal (temperature, precipitation and pressure) which has been used to compile long time series of climate related signals. Second, historical climatology has developed special methods in order to transfer the indirect climate signal into data that is directly comparable to the data provided by instrumental measurement of weather. In this way it has contributed hugely to extending the time series of instrumentally measured temperature back into the 16th century and for some parts of Europe, even earlier. Third, historical climatology is able to assess the impact of man and how this has changed during the recent millennium, which is of great interest in the present discussion on recent climate change.

- 78 Finally, historical climatology as a specialised field of research of its own has not only contributed very much to the understanding of climate variability of the recent millennium, but can continue to do so in the future.
- 79 In the Low Countries, for instance, one major contribution is the ongoing study of long series of written sources that provide temperatures, storms and precipitation signals (De Kraker, 2003, 2004; Shabalova *et al.*, 2003; Demarée *et al.*, 2002). In Belgium these series start as early as 1400 and are continuous throughout the 18th century. Among these time series of tithe leasing and of river tolls and putting out to lease of barges are by far the most important (De Kraker, 2003). For the Netherlands most of these series are continuous from the second half of the 16th century to the 18th century, while some tithe records series extend to the first quarter of the 19th century. The second benefit of the existence of such long time series of written records in the Low Countries is the long overlap these documents have with the beginning of instrumental time series. This overlap period is long enough to establish a good calibration of the historical temperature proxy data for nearly all seasons. Until now, only a single reconstructed time series of temperatures has been compiled for the Netherlands focusing on mainly the central part of Holland (Shabalova *et al.*, 2003). Furthermore, the high number of available high potential time series of historical records in the Low Countries provide an unrivalled spatial resolution for the reconstruction of weather and climate patterns, which, when combined with present-day data, may lead to better reconstructions of pressure fields and weather systems (De Kraker, 2003, 2004). A final contribution can be made by studying the climate extremes and their impact on society in their temporal and geographical context, so that it can be shown how much of weather extremes is natural and how much of it is human induced.

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ABSTRACTS

This article presents an overview of the development of historical climatology during the past 50 years and how this discipline has contributed to a better understanding of past, present and future climate change. It not only shows how historical climatology has evolved from mainly the social sciences as a special field of research and how it operates, but also how it has spread among institutes, universities and meteorological services throughout Europe.

Historical climatology studies written sources providing indirect information on weather

conditions, ranging from rainfall, temperatures and air pressure to extreme weather events. Discussing the wide range of written sources, it is explained what kind of a climate signal they provide and how historical climatology has used this indirect climate information or proxy data by developing a methodology of its own, which aims to transfer the proxy data into reconstructed temperatures, rainfall and air pressure time series. Then the contribution of historical climatology to a better understanding of climate variability and its impact of the recent millennium will be discussed by showing the results reached so far. In this respect the paper strongly focuses on temperature change which occurred during the Little Ice Age and in particular the Maunder Minimum and weather extremes such as storm surges and their impact. Finally, perspectives for further research are discussed by focusing on the Low Countries.

Cet article examine le développement de la climatologie historique au cours du dernier demi-siècle et montre comment elle a permis de mieux appréhender les changements climatiques passés, présents et futurs. Outre son fonctionnement, l'article montre comment cette discipline s'est développée à partir des sciences sociales pour devenir un domaine spécifique de recherche, et comment elle s'est propagée parmi les instituts, universités et services météorologiques à travers l'Europe.

La climatologie historique étudie les sources écrites fournissant une information indirecte sur les conditions météorologiques, depuis le niveau des précipitations, la température et la pression atmosphérique jusqu'aux événements climatiques extrêmes. L'examen des multiples sources écrites permet de savoir quel type de signal climatique est fourni et comment la climatologie historique a utilisé ces informations indirectes en développant sa propre méthodologie visant à transformer ces indications en séries temporelles de reconstruction des températures, précipitations et pression atmosphérique.

Nous verrons ensuite comment la climatologie historique a contribué à mieux appréhender la question de la variabilité du climat durant le dernier millénaire en présentant les résultats atteints jusqu'ici. A cet égard, l'article est fortement centré sur le changement de température intervenu au cours du Petit âge glaciaire, en particulier le Minimum de Maunder et les événements climatiques extrêmes comme les ondes de tempête et leur impact.

Enfin, nous aborderons les perspectives de recherche aux Pays-Bas.

INDEX

Keywords: Belgium, climatic change, climate impact, climate reconstruction, historical climatology, instrumental weather data, Little Ice Age, Medieval Warm Epoch, proxy data, storm surges, The Netherlands, weather extremes, written sources

Mots-clés: Belgique, changement climatique, impact climatique, reconstruction climatique, climatologie historique, données climatiques instrumentales, Petit âge glaciaire, Période médiévale chaude, indicateurs, ondes de tempête, Pays-Bas, événements climatiques extrêmes, sources écrites

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