

DOCUMENTARY EVIDENCE ON CLIMATE IN SIXTEENTH-CENTURY EUROPE

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Abstract. The known documentary climatic evidence from six European countries -Switzerland, Germany, the Czech Republic, ancient Hungary, Italy and Spain -is presented and classified in this article and then further analyzed in subsequent papers included in this volume. The sixteenth century witnessed an increase in the number and variety of sources in Switzerland, Germany and the Czech Republic as well as in the western and northern parts of ancient Hungary (present Slovakia). In northern Italy, the relevant sources are more abundant and widespread than in central Europe, but they have hardly been explored. Town chronicles written by members of the literate elite comprise the basic type of evidence in central Europe (including northern Italy and Hungary). This kind of source reports exceptional climatic events (e.g. anomalies and natural disasters) along with their impact on the environment and on society .Documentary data are the only evidence known to exist for reconstructing time series of natural disasters prior to the twentieth century. In order to document the extreme character of an event, chroniclers frequently referred to features in the cryosphere, biosphere or hydrosphere that were known to be more accurate yardsticks of temperature and precipitation patterns than subjective impressions. When records of such events are compiled with the description of some of the known effects, the results can be transformed into a severity index. Whereas chroniclers usually focused upon extreme events, long, continuous and seemingly homogeneous series of different kinds of proxy data are drawn from administrative records. Most of them are connected to the timing of certain kinds of agricultural work (hay- making, beginning of grain harvest or vintage) or to the amount and quality of agricultural production (per hectare yield of vineyards, sugar content of wine, etc.). In most cases the timing of these works was found to be directly related to temperature patterns over the preceding months and weeks.

All the Iberian peninsula towns, which had an institutionalized municipal authority, have preserved documents generated from the late Middle Ages. These records frequently contain references to floods and meteorological anomalies such as droughts and long wet spells. They also include mention of the system of rogations, those religious rites performed in a standardized way within the Spanish world with a view to putting an end to an alleged meteorological stress.

The data for Switzerland, Hungary and Spain as well as much of the data for Germany are stored in the EURO-CLIMHIST database set up at the Institute of History at the University of Bern. At present, EURO-CLIMHIST comprises some 600,000 data for the period from AD 750 to the beginning of the period of instrumental networks. About 120,000 records for Germany are currently stored in a data bank called HISKLID located at the Department of Geography of the University of Würzburg. The database for the Czech Republic includes records for the time-span AD 975-1900 and is housed with the Department of Geography of Masaryk University in Brno. Data on Italy were collected with different purposes and are stored in two data banks, the CNR-ICTIMA (climatic data and natural disasters) and the SGA (extreme events).

1. Introduction

The documentary data used in these studies contain information on a broad spectrum of time-scales extending from hourly to annual. It includes in particular detailed descriptions of natural disasters and severe anomalies far back in time. The more extreme the event, the more descriptions providing greater detail are available. In assessing the relevance of global warming, especially in view of the great public interest and sensitivity to extreme events, it becomes especially fitting to consider the fact that the frequency of natural disasters displays considerable variation within a natural climate (Barriendos and Martin-Vide, 1998; Pfister, 1999). Some of the extremes documented in the early instrumental or in the pre-instrumental past are more outstanding than those documented with instrumental measurements in the twentieth century. It seems well possible that reconstructions of extreme disasters may provide a realistic background for (re-)insurance companies to study the economic effects of worst-case scenarios.

On the other hand information on less severe events and on what contemporaries considered to be "normal" or "near normal" is not continuously available over long periods of time, and even when extant, it is generally not homogeneous nor easily converted to a quantitative form. That is the reason why the results obtained from the analysis of documentary data could thus far not be submitted to the usual statistical tests and, unfortunately, are therefore held to be somehow less credible in the opinions of a few obstinate scientists. In the present volume new ways are explored in an effort to find a solution to the problem of statistical testing and consequently improve the image of documentary data.

This article presents the basis of evidence from six European countries - Germany, Switzerland, Hungary, Italy, Spain and the Czech Republic - that is further analyzed in several subsequent papers included in this volume, particularly those by Glaser et al., Jacobeit et al., Brazdil et al., Pfister et al. as well as Pfister

and Brazdil. Instead of discussing documentary data in the introductory part of each of those papers it was decided to summarize some general considerations in a special paper and briefly survey the evidence by country within this framework. Therefore, the overall evidence presented in the aforementioned papers is interpreted according to the specific topic being handled in each individual article, and that is why the papers previously mentioned do not include a climatological conclusion, something unfamiliar to many readers.

In the second section special consideration needs to be given to the term "historical data", the meaning of which has changed in recent years. In the third section an improved classification of palaeoclimatic data is proposed, including newly discovered types of data. Furthermore, some of the general characteristics of documentary data are highlighted and the problem of calendar dating is mentioned, something of particular importance for sixteenth-century research because of the modified calendar introduced in 1582 by Pope Gregory XIII (1502-1585).

The subsequent five sections give a survey of the evidence by country. Those parts of this paper dealing with a specific country were written by different research teams, because an outsider lacks the intimate knowledge of languages, sources and places needed for the interpretation of the material considered. Moreover, the topics which are common to all countries (e.g. data terminology, classification, style of dating, guidelines of source evaluation etc.) could be summarized in two sections (see 2 and 3), thus allowing an avoidance of redundancy. For the same reason the references were divided into a general section and source-specific sections per country. The "individualistic" features of the sections could not altogether be eliminated.

2. Data Terminology, Classification and Set-up

The term "historical evidence" was introduced to climatological literature by Lamb (1977) to designate information contained in "historical" i.e. descriptive manuscripts or printed documents. Later on, the term "historical climatology" emerged to encompass an approach which at present aims at reconstructing weather and climate, natural disasters and large-scale synoptic situations on the basis of man-made data and natural data for the period prior to the creation of networks run by national weather services. This includes documentary, natural and early instrumental data. However, in recent years the terms "historical data" and "historical climatology" have been used in a more fundamental way, merely reflecting the fact that the data refers to some period in the past. "Historical data", surprisingly, has even been subsumed under recent series of instrumental measurements and the term "historical climatology" has been used as a synonym for time-series analysis (e.g. Kaas et al., 1996). Thus, the term "historical data" is

Archives	Natural		Man-made	
Information				
direct observation of weather and climate or instrumental measurement of meteorological parameters			observed • anomalies • natural hazards • weather situations • daily weather	measured • barometric pressure • temperature • precipitation • water-gauge, etc.
indirect references: (Proxy data) indication of controlled or affected processes through meteorological parameters	organic • tree rings • fossil pollen • animal and plant remains • fossil wood (trees), etc.	non-organic • ice-cores • varves • terrestrial sediments • temperature of boreholes • moraines, etc.	organic • plant phenology • yield of vine • time of grain and vine harvest • sugar content of wine, etc.	non-organic • water levels • snow fall • freezing of water bodies • snow cover, etc.
			• cultural: rogations • pictorial	• epigraphical
			material:	• archeological remains

Figure 1. A survey of evidence for reconstructing past weather and climate (Source: Pfister, 1999).

becoming ambiguous and misleading. It therefore seems practicable that it should be avoided altogether and replaced with a more appropriate one which is on the same level as the many kinds of data known to date from natural archives.

Data from natural archives are named after the medium in which the climatic signal is contained (e.g. tree rings, varves, ice cores). Le Roy Ladurie (1911) coined the corresponding term "documentary evidence" for designating man-made evidence. Indeed, documents are the means by which climate-related, textual and pictorial information is stored, and the work of an historical climatologist consists in decoding this information in such a manner that somehow a comparison is enabled, for example, with the analysis of wood samples by a dendrochronologist or the handling of ice cores by an environmental physicist. The term "documentary data" will be used in this sense throughout the present volume.

A classification of palaeoclimatic evidence yields the known dichotomy of natural and man-made archives (Figure 1). As fundamentally different processes - i.e. natural processes and human actions - are involved in the creation of these

archives, the classification process also requires different methodologies and skills, including those of both the natural and social sciences.

In the following focus on documentary data, a differentiation has been made between the classifications of descriptive documentary data and documentary proxy data. Descriptive data refer to direct observations of weather and climate preserved in written form. Chronicles include narratives of events memorable to a particular region or town, such as wars, fires, epidemics, dearth, meteorological anomalies and natural disasters. The attention of chroniclers to weather patterns and the occurrence of natural disasters depended on their own personal background and preferences which mirrored not only local traditions but also social environment. In general there is a focus on events which were considered outstanding. The more outstanding an event the more lengthy and minutely it was described. Many chroniclers included more or less systematic descriptions of weather sequences in their accounts. Such descriptions of the weather are also found in diaries together with other daily observations (see Pfister et al., this volume).

The list of examples in Figure 1 is by no means exhaustive. For instance, summary weather descriptions for each semester between 1560 and 1573 were found in the matriculation register of Wittenberg University in Germany and must be interpreted as being the product of a bureaucratic process (*Album Academiae*). Occasionally meteorological notes are even found in church records. For example, notes contained in the parish register of the little Swiss town of Stein am Rhein repeatedly mention a freezing of the lower part of Lake Constance, the so-called "Untersee" (*Kirchenbuch Stein am Rhein*, quoted by Türlér, 1925).

The term "proxy" is used to denote any material that provides an indirect measure of climate. Such data comprises both natural and man-made evidence. Often descriptions of weather patterns include observations of hydrological or biological features that are to some extent controlled by climatic factors. Many chroniclers were well aware that their observations were impressionistic. In order to compensate for this shortcoming they referred to features in the cryosphere (e.g. the persistence or melting of a snow-cover, the freezing or thawing of bodies of water), the biosphere (phenological and oenological data) or the hydrosphere (occurrences of floods or low water-levels) that were known to be more accurate yardsticks of temperature and precipitation patterns. Documentary proxy data may be calibrated with instrumental series if there is a sufficient period of overlap. The distinction between "direct" and "indirect" data is not always straightforward. For example, it is not clear how "rogations" are to be classified. The term refers not only to the fasting and litany of solemn prayers originally associated with harvest rituals but specifically to a set of highly formalized religious procedures applied by municipal communities in Spain and, apparently, in the former Spanish colonies (Garza and Barriendos, 1998) to cope with problems of meteorological stress with

crops (Martin-Vide and Barriendos, 1995). Rogations were called forth by guilds and municipal authorities when the grain harvests appeared to be endangered from drought or excessive rainfall. In fact, rogation records are very close to being phenological observations. Barriendos (personal communication) suggested referring to them as "cultural data" (see Figure 1).

According to the regularity of reporting, a distinction may be made between sporadic and continuous data. The evidence is occasional if the event described does not occur every year (e.g. the freezing of a body of water or a drought). Continuous proxy data are the product of administrative routine related to agricultural work, the dates of which are recorded. Some records refer to the timing of annually recurrent events such as the beginning of the grain (Pfister, 1995) and Vine harvests (Guerreau, 1995). Or, for example, they express the volume of tithe levied on grain and wine production, something which was proportional to the size of the harvest (Lauer and Frankenberg, 1986; Pfister, 1995; Landsteiner, this volume).

The category of pictorial sources includes paintings, prints and photographs as well as maps and charts. The earliest ones were published in the sixteenth century shortly after the invention of printing and even some of them contain information related to the history of climate (see Holzhauser and Zumbühl, this volume). The category of epigraphic sources includes inscriptions and marks engraved on stones or rocks kept in museums or found in the field, such as data chiseled on the so-called "hunger stones", flood-marks on buildings and flood monuments (see Brazdil et al., this volume) as well as house inscriptions most often painted on the front of individual traditional farm-houses (Pfister, 1999). Epigraphic sources have some properties of a document in a most general sense insofar as their creation involves a human act which attempts to transmit some message to posterity. Most archaeological remains, such as traces of extinct settlements destroyed by a flood or abandoned as a consequence of drought, do not include such a "documentary" element. They are simply classified as "material sources".

Compared to proxy data, descriptive documentary data have a number of obvious strengths. These include:

- a good dating-control and a high time-resolution
- a disentangling of meteorological parameters (temperature, precipitation, snow cover, wind)
- a focus on anomalies and natural disasters
- a sensitivity to events throughout the year (i.e. no seasonal restriction).

On the other hand, some weaknesses cannot be overlooked. These include:

- a discontinuous and heterogeneous structure
- biases by the selective perception of the observer
- restriction to simple and robust techniques of mathematical elaboration and interpretation.

In order to come to grips with these shortcomings it must be noted that these observations need to be consistent with meteorological processes in order to be valid. For this reason the amount and variety of data to be collected should be as large as possible and it should also be possible to display the evidence in a spatial context.

In the early 1990s, a database named EURO-CLIMHIST was set up at the Institute of History at the University of Bern. The fundamental objective of EURO-CLIMHIST is to provide methodological and software solutions for standardizing and mapping documentary data written in different European languages. Accordingly, a numerical coding scheme was developed that is adaptable to the many kinds of observations found in documentary sources from different parts of Europe. The data may be mapped on the basis of a procedure that allows the flexible handling of an hierarchical four-level space and time structure. It provides suitable icons (based, wherever available, on WMO symbols) and also includes principles of systematic data-reduction as seen in conjunction with a convenient display of the data (Pfister et al., 1994). At present, EURO-CLIMHIST comprises some 600,000 data from many European countries for the period from AD 750 to the beginning of the period of instrumental networks in the mid-nineteenth century. The database is organized as a complex file architecture which makes access for those attempting to gain entrance from "outside" intensive and expensive. A new relational database architecture is being created which should be accessible on an internet website by the turn of the millennium.

3. Pitfalls of Documentary Data

The researcher attempting to work with documentary data should be familiar with certain pitfalls which turn up with this type of evidence. It has become commonplace over the last two decades to emphasize the importance of dealing with contemporary observations recorded shortly after the event (e.g. Ogilvie, 1991; Ball, 1992). Chronicles were copied from predecessors, supplemented with observations made during the lifetime of the chronicler and passed on to subsequent generations. Some of the information came to be included in compilations consisting of an indiscriminate mix of contemporary and non-contemporary observations (Bell and Ogilvie, 1978). Despite these shortcomings, such compilations should not be altogether dismissed because at least a few of them contain some original, local observations to which the author had access when he wrote his manuscript and which, today, would be otherwise lost.

When dealing with sixteenth-century documentary sources it must be kept in mind that dates were recorded during most of that century according to the Julian calendar originally introduced under the authority of Julius Caesar (100-44 BC).

The change of style proposed by Pope Gregory XIII skipped the ten days between October 4th and 15th in 1582. The Gregorian calendar came to be adopted in most Catholic countries in the years that followed. The Protestants rejected the reform altogether~ even in some Catholic territories the adoption of the Gregorian style was deferred. It is therefore important to use the well-known compendium composed by Grotefend (1971) to deal with this problem. For the present study this particularly relates to the territories situated in present-day Germany, Italy and Switzerland. Unless otherwise noted, all dates in this volume appear in the converted, Gregorian style.

Finally, a word of caution must be issued regarding vine harvest dates which are included in most climate reconstructions attempted for central and southern Europe over a period of several centuries (e.g. Le Roy Ladurie, 1971). Lachiver (1988) investigated the institutional context of the vintage ban in his history of viticulture in France. He discovered that prior to the sixteenth or seventeenth century the vintage was opened on a preferential day of the week according to local tradition. This confirms the results of a statistical analysis by Legrand (1979), who demonstrated that small variations of early vine harvest data could not be interpreted in climatic terms. Moreover, Lachiver (1988) pointed out the fact that vine growing before the sixteenth or seventeenth century was dominated by motives of risk aversion. The strategy was a mixed planting of early and late varieties in order to still have a minimum yield in a bad year. The power of these local traditions gradually vanished and, at least in France, market forces became dominant. Hence cultivation was directed more and more towards obtaining a maximum yield and a high sugar content. These changes are mirrored in the statistical analysis of the series (Le Roy Ladurie and Baulant, 1980).

4. The Evidence for Switzerland

4.1. DESCRIPTIVE DOCUMENTARY DATA

Seasonal and monthly indices of temperature and precipitation for Switzerland have been compiled from a broad variety of sources (Klemm, 1974; Pfister, 1984, 1985a, 1995). Some of the material is included in specific compilations of climatic events which were published from the eighteenth century such as the "Annales" by Boive (1854-1855; Kopp, 1861) and later regional compilations for the catchment of the Reuss and the Aare rivers (Amberg, 1890), for the canton of Grisons (Brügger, 1890) and for the canton of Uri (Schaller, 1937). A total of some 7,350 records from the sixteenth century are included in the EURO-CLIMHIST database (Pfister et al., 1994), although they are not evenly distributed over time. During the first half of the century weather observations are

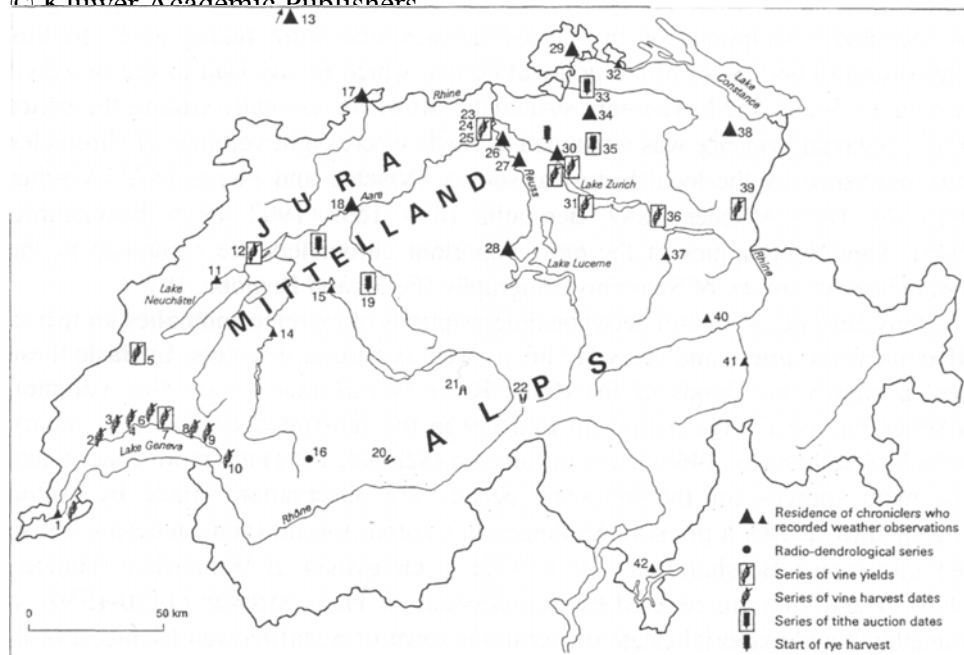


Figure 2. Spatial distribution of weather observations in sixteenth-century Switzerland.

known to exist for 228 out of 600 months (38%); in the second half of the century this percentage rises to 98%.

The vast majority of sources known to date originate from the towns of the so-called midland ("Mittelland") where the literate elite lived. Most of them were produced within a triangle extending from Basle to Lucerne and Lake Constance and even farther north into Germany. Considering the number of chronicles available for the early decades of the sixteenth century, Basle was clearly the leading cultural center of Switzerland. This might be because of the university (founded in 1460) which was the only one in Switzerland at that time. Later on, the focus of environmental record keeping moved more to the east. The imbalance between the number of historical weather records in the eastern and western parts of Switzerland is not restricted to the sixteenth century. It seems to reflect an outflow of different attitudes towards the environment rooted in regional traditions. Very few sources are available for the Alpine region (Figure 2).

The introduction of the Reformation in some of the cantons (while others retained the old faith) was the fundamental event that motivated many literate persons to write a chronicle. Most of them were clergymen or belonged to the

group of the ruling elite. They devoted much of their energy to providing lengthy and detailed descriptions of the heated debates that were taking place in this context and to both sides of the political action, which finally lead to the two civil wars in 1529 and 1531. The only systematic effort for critically editing the entire known regional evidence was attempted in Basle where eight volumes of chronicles were published by the local historical society (Vischer and Stern, 1872; Vischer and Boos, 1880; Vischer, 1887; Bemoulli, 1890, 1895, 1902, 1915; Burckhardt, 1945). Short biographies of the most important chroniclers are contained in the comprehensive survey of Swiss historiography (Feller and Bonjour, 1979). Many chronicles contain occasional descriptions of extreme anomalies known to affect harvests, prices and everyday life as well as natural disasters. In Basle these were primarily the floods of the Rhine River (see Brazdil et al., this volume). Weather reports for the period up to 1509 in the illustrated chronicle of notary Diebold Schilling (ca. 1460-1515) in Lucerne (Schmid, 1981) are more continuous. The main sources for the following decade are observations made by Anton Tegerfeld (d. 1528), a priest in Mellingen in Canton Aargau (von Liebenau, 1884) and Laurencius Bosshart (ca. 1490-1532), a clergyman in Winterthur (Hauser, 1905). The 1520s are covered by the chronicle of Hans Stockar (1490-1556), a councilman and manorial estate owner in the town of Schaffhausen (Schib, 1949). His political successor, Hans Oswald Huber (1521-1582), who became the second chancellor of Schaffhausen, is criticized by Feller and Bonjour (1979) for sticking too much to local events, mainly because weather and natural disasters were important topics in his chronicle (1537-1581) (Bächtold, 1906). Hans Ardüser (1557-1614), a teacher in Thusis (Canton Grisons) is among the few noteworthy chroniclers who lived in the Alpine area. His chronicle (1572-1614) focuses on the everyday life of peasants exposed to the risks of weather (Bott, 1877). The "Collectanea", a collection of miscellaneous pieces of information compiled by Renward Cysat (1545-1614), a naturalist and politician in Lucerne (Schmid 1969, 1972), is the most important source of climatic evidence in the Alps for the period from 1585 to 1614 (see Pfister et al., this volume). He observed a broad variety of meteorological and environmental data including snowfalls in the summer on the summits surrounding the town of Lucerne and he even presented some of his data in quantitative terms: [1613] "May [...] had 25 days of rainfall, among which 9 were very abundant and it rained more or less all day and all night" ("Maius [...] hat ghebt 25 regentag darunter 9 wol ergibig und wassers gnuog meertheils tag vnd nacht.") (Schmid, 1969).

Besides the daily observations noted in printed almanacs (see Pfister et al., this volume), ordinary diaries and some other kinds of personal records occasionally included short summaries of monthly weather. From the point of view of historical climatology, the diary kept by physician Joachim Watt (1484-1551) between 1516 and 1533 cannot be overlooked (Göttinger, 1879). Watt (Vadianus) was elected as

"Rector magnificus" of the University of Vienna (Austria) in 1517. Later he became mayor of his native town of St. Gallen (Switzerland) where he introduced the Reformation (Feller and Bonjour, 1979). The diary of Hans Stoltz (d. 1540) is the most valuable source for the history of climate during the 1530s in southern central Europe. Stoltz lived in the Upper Rhine town of Guebwiller (Alsace) not far from Basle. His diary frequently contains short although not systematic descriptions of the weather patterns from month to month (see, 1871). Heinrich Bullinger (1504-1575), the successor of reformer Huldrych Zwingli (1484-1531) in Zurich, had a genuine interest in weather. On ten occasions between 1550 and 1571, for example, he noted in his diary (1504-1574) the day on which the rye harvest was begun in the Zurich region. He likewise very carefully watched the impact of meteorological patterns on grain prices (Egli, 1904). The diary of Jean Lardy in Auvernier (Canton Neuchatel), kept from 1575 to 1587, is one of the rare narrative sources from French-speaking Switzerland which includes a number of references to weather events (Matile, 1845). In Italian-speaking Switzerland the extensive diary of Domenico Tarilli (1993), a priest from Comano (Canton Ticino), includes a few remarks on climate.

Military campaign histories occasionally refer to the weather which often influenced warfare even into modern times. There were no major wars in Switzerland in the sixteenth century except for the two short civil wars between Protestants and Catholics in 1529 and 1531 (Hughes, 1975). Towards the end of the century a conflict arose between the House of Savoy and the town of Geneva, which was an ally of the Protestant cantons. The description of this campaign in the diary of Simon Goulart (1543-1628) includes a few sporadic references to weather patterns.

4.2. DOCUMENTARY PROXY DATA

The freezing of major lakes and rivers in the Swiss midland was a significant event which was always registered by a number of chroniclers. From the cases documented with thermometric measurement it has been established that lakes in the Alpine borderland froze in a specific ranking order according to their surfaces, depths and individual characteristics. The freezing of lakes is primarily a function of the sum of below-freezing-point daily mean temperatures, plus such other factors as wind-speed. It became important to know whether the ice was thick enough to support men and cargoes as well as how long the cover of ice remained. For the freezing of Lake Zurich, which is the best documented, the sum of below-freezing-point daily mean temperatures has exceeded 350° in those cases where people could walk on the ice (Pfister, 1984).

Chroniclers often mention an extremely long duration of a blanket of snow or of a lack of snow to underline the severity or the warmth of a particular winter. For

the climatological interpretation of such data the relationship between the persistence of a covering of snow and the sequence and duration of weather situations favoring accumulation or ablation must be taken into consideration. A very small number of days with snow coverage may accompany warm winters but may also coincide with extended dry and cold anticyclonic situations. For the pre-instrumental period the hypothesis of warmth therefore needs to be supported with observed signs of vegetation activity.

Grain was by far the most important public source of revenue within agrarian societies. It was therefore necessary to prevent peasants from harvesting their crop without paying the tithe. In Switzerland the right to collect tithing paid in grain was sold by auction to one of the wealthy farmers in the village. He then collected the tithe on his own account. In autumn he threshed the grain and delivered it to the granary. The act of bidding for the tithe immediately preceded the start of the harvest. The date of the bidding procedure is frequently listed in tithing records. A total of 42 local series were set up for the Swiss midland, the area between the Jura mountain ranges and the Alps (see Figure 2). They are all normally distributed and significantly correlated among themselves. The level of the coefficient decreases because the function of the distance between the series and the average time of the auction is a function of altitude above sea level. Evaluation showed that from the early seventeenth to the early nineteenth centuries the dates of such auctions were closely related to the times of maturation of the earliest winter grain, generally rye. The times of the auctions are significantly correlated at $r = -0.8$ with temperatures in May and June in Basle (Pfister, 1984, 1992). For the sixteenth century three local series are available for the period from 1557.

Long continuous series of Vine yields are obtained from the account books of private manors as well as state and ecclesiastical institutions. Wine was a major cash-producing crop in many central European areas and therefore a key object of taxation. In central Europe Vine yield is chiefly an indicator of the duration of warm, sunny, anticyclonic weather in midsummer. The longer such conditions prevailed the more grapes could be harvested in autumn disregarding the effects of severe late frosts. Several long series of tithe revenues and yields per hectare are available for the sixteenth century from several parts of the Swiss midland (Pfister, 1981; Landsteiner, this volume).

Temperatures in August and to some extent also in September were estimated from natural proxy data because an appropriate documentary proxy indicator is lacking. The density of the late wood in tree rings from trees near the upper timberline is known to be a good proxy for the temperatures from July to September (Schweingruber, 1978, 1983). The long record of tree ring density data from Lauenen in the Bernese Oberland was used to assess the Swiss thermal indices for the months of August and September. A cross correlation with the Basle temperature series (1755 to the present) revealed that low densities are reliable

Table I
 A survey of proxy data used for estimates of monthly temperature in Switzerland

Month	Inorganic data	Organic data
Nov	snowfall; snow cover	duration of pasture
Dec	freezing of bodies of water	activity of plants and insects
Jan	freezing of bodies of water	activity of plants and insects
Feb	snowfall; snow cover	activity of plants and insects
Mar	snowfall; snow cover	grapevines in leaf
Apr	snowfall; snow cover	blossoming of cherry trees
May	snowfall; snow cover	blossoming of grapevines date of tithe auctions and begin of grape harvest
June	snowfall in the mountains	date of tithe auctions and begin of grape harvest grapevine yields
July	snowfall in the mountains	grapevine yields densitometric tree ring data
Aug	snowfall in the mountains	densitometric tree ring data
Sep	snowfall	sugar content of grape juice densitometric tree ring data
Oct	snowfall	blossoming of fruit trees

indicators for cool summers. On the other hand, some of the hottest summers in the last 450 years (1616, 1719, 1947) do not stand out in the record (Pfister, 1985b). This suggests that tree ring density data should be used cautiously as climatic indicators unless they can be cross-checked with man-made observations.

Table I shows a survey of the proxy information used as substitutes for thermometric measurements according to organic and inorganic processes. The indicators are listed in the month for which they are most conclusive. The parameters related to grapevines are given separately to underline their importance. The indicators listed for October and November allow the documentation of extreme anomalies although they cannot be used to document minor variations of temperature .

Nearly continuous rough estimates of precipitation in the second half of the century were obtained by counting the number of rainy and snowy days mentioned in the diaries kept by Wolfgang Haller (1525-1601) and Mathias Borbonius of Borbenheim (1566-1629) and the "Collectanea" compiled by Renward Cysat (1545-1614) (see also Pfister et al., this volume).

5. The Evidence for Germany

Data from natural and man-made archives are particularly abundant for the territory of present-day Germany. Many of these sources were discovered and transcribed during recent decades. The evidence has been stored in a data bank named HISKLID in the Geography Department of the University of Würzburg which is a regional branch of the EURO-CLIMHIST database (Pfister et al., 1994). In the early 1990s the data collected by Mathias Deutsch (University of Halle-Wittenberg) and Stefan Miltzer (University of Leipzig, data-bank ClimDat) were included. The HISKLID database currently comprises some 120,000 records. Weather patterns are known for every single season during the sixteenth century, thereby enabling the compilation of continuous series of temperature and precipitation from said database (Glaser et al., this volume). The spatial distribution of observations is shown in Figure 3.

5.1. DESCRIPTIVE DOCUMENTARY DATA

Sixteen German weather diaries have been found to date. They are dealt with in more detail by Pfister et al. (this volume). The data obtained from the analysis of daily observations provided the backbone for the derivation of temperature and precipitation indices for Germany (Glaser et al., this volume).

Town chronicles were written in almost every region. They generally relate to the territory owned by the town or to the area of its commercial activities. For example, the Augsburg town archives contains more than fifty such chronicles. It was customary for each chronicler to more or less faithfully copy the records of his predecessors before adding the observations which he himself made during his lifetime. This yields a great redundancy of information and a confused mixture of contemporary and non-contemporary data which must necessarily be disentangled before an analysis is attempted. A first survey of late medieval urban chronicles was presented in the renowned series "Chronicles of German Cities from the 14th to the 16th Centuries" (in German), edited by the Historical Commission of the Bavarian Academy of Sciences. This effort was supplemented by a range of more regionally oriented editions, such as the series of southwest-German urban chronicles published by the Library of the Literary Club of Stuttgart, which includes, for example, the well-known chronicles of Esslingen (Diehl, 1901) and Villingen.

There are also chronicles referring to larger territories of the German Empire. The "Mansfeldische Chronica. Der erste Theil" ("The Mansfeld Chronicle. The First Part"; Eisleben, 1572) was compiled by Cyriacus Spangenberg (1528-1604), a clergyman at the court of the Duke of Mansfeld. Spangenberg's "Chronica"

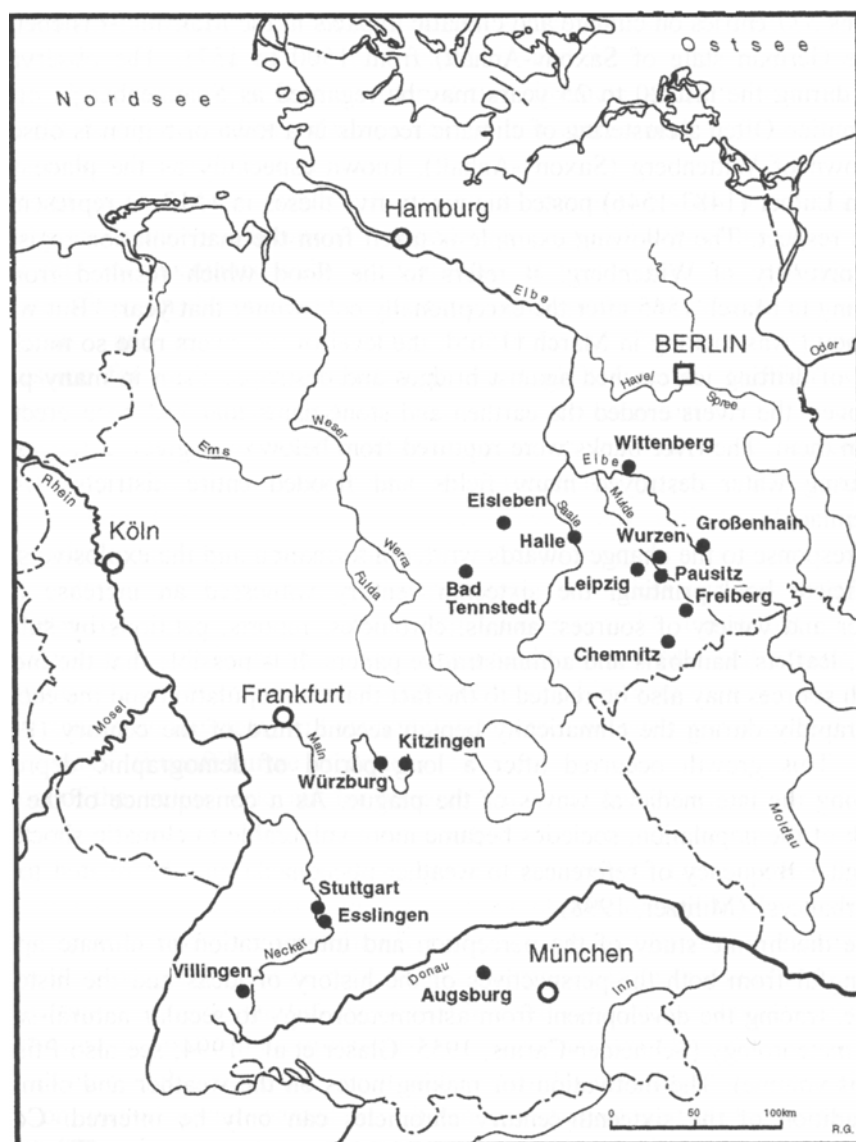


Figure 3. Spatial distribution of documentary data within sixteenth-century Germany (HISKLID and ClimDat databases).

contains 577 entries on climate and climatic impacts in the Mansfeld-Eisleben area (in the German state of Saxony-Anhalt) from 1500 to 1571. The observations noted during the last 20 to 25 years may be regarded as Spangenberg's original contribution. Often a clustering of climatic records in a town or region is observed. The town of Wittenberg (Saxony-Anhalt), known especially as the place where Martin Luther (1483-1546) posted his ninety-five theses in 1517, is representative in this respect. The following example is taken from the matriculation register of the University of Wittenberg. It refers to the flood which resulted from ice damming in March 1565 after the exceptionally cold winter that year: "But when it [the snow] was melting in March [1565], the level of the rivers rose so much that pieces of drifting ice crashed against bridges and destroyed them in many places. Moreover, the rivers eroded the earthen and stone dams that had been erected to contain them. The river banks were ruptured from below over great distances. The in-pouring water destroyed many fields and flooded entire districts" (*Album Academiae*).

In response to the change towards written information and the explosive spread of efficient book-printing, the sixteenth century witnessed an increase in the number and variety of sources: annals, chronicles, reports, petitions by subjects, letters, leaflets, handbills and administrative papers. It is possible that the increase in such sources may also be related to the fact that the population and the economy grew rapidly during the climatically benign second third of the century (Pfister, 1994). This growth occurred after a long period of demographic depression following the late medieval waves of the plague. As a consequence of the rapid growth of the population, societies became more vulnerable to climatic shocks and the higher frequency of references to weather phenomena may be related to such "disturbances" (Militzer, 1998).

The diachronic study of the perception and interpretation of climate appears meaningful from both the perspectives of the history of ideas and the history of science, tracing the development from astrometeorology to secular natural-science based meteorology (Schneider-Carius, 1955; Glaser et al., 1994; see also Pfister et al., this volume). The motivation for making notes on the weather and climate in the tradition of the sixteenth-century chronicles can only be inferred. Context analysis indicates a general effort to pass on information on unusual events in everyday life with a focus on recording impacts on the economic sector and atmospheric events interfering with the quality of life (Militzer, 1998). Emphasis is put on the linking of weather and climate observations with agricultural production, which was the dominating form of economic activity. In this context chronicles from vine-growing regions are particularly sensitive to climate. For example, a record noted in the chronicle of Kitzingen on the River Main reads as follows: "The price for wine, of which there was little, albeit of good quality, was 28 fl. [florin, or guilder, i.e. an historical monetary unit in Germany]

because the vines which were not covered last winter were killed by frost. For those who still possessed vines, a barrel yielded 50 and 52 fl. after a good and dry summer. Friedrich Bernbeck, the writer of this chronicle, sold that same wine for 60 fl. per barrel around St. Martin's day of this year, which never happened in Kitzingen before" (Bernbeck, 1543). Exceptional weather events, often seen as punishment by the Lord, were recorded and used for educational purposes as tokens of impending change or as urgent calls for repentance within the Christian community (see also Behringer, this volume). Thus, (On the occasion of "sharply rising prices, starvation and horrible rainstorms" and in accordance with the Suffragan Bishop of Bamberg, a "procession for all..." was conducted at Our Lady's Church "together with an urgent prayer to avert this God-sent and well-deserved punishment". In his first sermon the bishop remarked: "Who amongst all of you fails to see beyond and together with this heavenly punishment of unprecedented price increases and large starvation how God persecutes us so much every day with horrible weather, namely with too much and unnecessary rain, already for quite a long time and up to this very day, yeah, so much and so superfluous that unless our benevolent Lord has a heart for us and shows us His compassion it is to be feared that the grain, most of which is still in the field, part of it already cut and part still standing, will be of no use to us, but will (as has already happened in many corners and places) start sprouting on the stem, will rot and will be eaten by birds and mice and be lost in other ways" (Fuenff kurtze Predigten, 1574).

Most of the "relics" relevant for research are found in histories of everyday life. Special reports or the continuous tendering of accounts by administrators of a sovereign or a town may link negative production results in agriculture or trade as well as unpaid taxes and dues to the weather and climate during an annual or semi-annual report period. Not infrequently records were kept in such a standardized fashion that long series can be derived and interpreted from this kind of evidence. An illustration of such interlinking of weather and economic conditions is seen in the following example: In the spring of 1571, Abraham von Thumshirn, a councilor of the Elector of Saxony and a senior inspector of his manors, wrote the following report on the manorial estates of Chemnitz (Saxony) and Freiburg (Saxony-Anhalt): "The summer and winter grain stands very poorly, which can be attributed to the longlasting snow cover, the evil wetness [...]" (von Thumshirn, 1940).

In comparison to the Middle Ages many more sources are available for the sixteenth century and they are simultaneously more abundant and more differentiated. To some extent this may be due to the rapid spread of printing and to higher levels of education. On the other hand, documents of commerce originating in the offices of the early modern territories proliferated enormously, thereby shedding light on facts, especially on the economic side of society, that therefore had been in the dark. This is particularly noticeable in the practice of

systematic accounting on the level of smaller territories, cities and towns, and also possessions of local nobility. Such evidence comprises numerous volumes of accounts following more or less the same scheme over hundreds or even thousands of pages which, however, offer a broad spectrum of detailed information on tax - related features. The following entry refers to the fisheries in the Grossenhain district of Electoral Saxony and explains why this important source of income had almost dried out by the end of the sixteenth century: "[The decline of income from carp is] ... because during Lent of the year 1595, the discharging water which followed the high snows flooded this pond and the water went above the weir and destroyed it altogether so that, without doubt, the fish were carried away" (SächsHStA, Intradenrechnung Amt Großenhain 1595/1596).

Because of the known climatic vulnerability of agriculture the fact is often overlooked that most kinds of mining and manufacturing activities were also dependent on weather and climate because they were powered by wind and water. An oversupply or an undersupply of water power could disrupt the flow of energy and therefore often lead to massive unemployment. Such a case is reported in a chronicle from the town of Freiberg (Saxony) following the drought in the late summer and fall of 1575: "Around St. James' Day [July 25th] a severe drought and dearth of water took place which lasted from then on through the entire fall so that most springs dried out and the level of rivers became so low that the malt had to be ground in a horse-powered mill and not more of it than for a single brewer, also because he had to cast lots with others for the water, as nobody could ever have imagined". In particular, the mining activities suffered: "Because of the lack of water all lifting gear came to a standstill so that many mines [...] had to close down and more than nine-hundred workers had to be laid off, as nothing could be lifted to the surface, so that there was much moaning and complaining amongst the poor people" (Moller, 1963).

5.2. DOCUMENTARY PROXY DATA

Most kinds of documentary proxy data that are available for Germany were already discussed in chapter 4.2. However, a short remark on tithing data is appropriate. In contrast to other countries tithe registers have hardly been used as sources for agrarian history in Germany. This is a result of the influential criticism by Abel (1955) who rejected a simplistic use of this data for estimating the volume of harvests. Recently, Bauernfeind (1993) took a closer look at this type of data and came to the conclusion that tithing registers in Germany have indeed the same properties of those in adjacent countries. In this context, and this may be crucial for historical climatology, he discusses the mode of tithe auctions. Tithes were sold by auction immediately preceding the harvest in the same way as they were sold in Switzerland. Therefore, it is likely that the dates of auction, if preserved in the

registers, could be used as proxies to assess temperatures in May and June (see chapter 4.2.). Quite often, the tithe registers contain explanatory references to weather impacts leading to a reduction of taxes. The following example is taken from the District of Wurzen, situated on the Mulde River in Electoral-Saxony. Numerous floods of this river between January and June 1593 led to the erosion of fields in the village of Pausitz. The following commentary is made under the heading "Income from tax paid in kind [on St.] Martin's [Day, November 11th] anno 93, normal tax 38 .5 bushels [of grain] is reduced by 1 bushel for the village of Pausitz because of the fields ["Vorwerks"] which the water [of the Mulde River] has torn away, as such fields were given to the people of Pausitz and Bach [another village, situated south of Pausitz] in the year [15]49 under the condition that if water were to carry off some of those fields, for each field thus lost the annual tax should be reduced by one bushel of rye, one bushel of barley and one bushel of oats, in accordance with the inheritance document" (SächsHStA, Intradenrechnung Amt Wurzen 1593/94).

The crucial operation of source evaluation, a standard procedure to be applied to all kinds of documentary data, is also needed for the interpretation of epigraphic sources. High Water marks intended for use due to the content of their hydrological information must by all means be subjected to a formal critical analysis of the sources (Deutsch, 1997). In order to avoid misinterpretations it has to be ascertained that the position of the mark on the building did not change over time. This is not obvious. At Bad Tennstedt (Thuringia) for example, a stone with a flood mark from 1552 was removed and later placed in another part of the building. It is also necessary that the date of the event be verified by cross-checking it with written sources describing the same event. Environmental damage, especially by polluted air, may have disfigured the inscriptions so as to make them almost illegible. In many cases, unfortunately, flood marks were restored without making certain that the original dates were correct, thereby leading to involuntary falsifications (Deutsch, 1993). Another source of error that has to be taken into consideration when working with flood-marks is capillarity. Because of this physical process and depending on its intensity on the type of stone, humidity will rise in a wall even after the flood has subsided. If a flood-mark was later engraved into a wall by tracing the moisture line, it could well be that the mark was placed too high (Fuchs, 1960). Prior to the climatic interpretation it is also necessary to determine to what extent the condition of the surrounding landscape as well as the water retention potential has changed. Only after all these points have been considered is it possible to use long sequences of analogues obtained from documentary data for a number of applications, including flood frequency prediction. It is' especially the information gleaned from flood marks that impressively documents natural disasters such as the severe floods that occurred

along the Eibe River at Dresden in the years 1501, 1515, 1531, 1566 and 1573, or along the Saale River at Halle in 1585 and 1595 (Deutsch, 1993).

All kinds of proxy data are known to be affected by non-climatic noise which needs to be removed by some kind of statistical analyses in order to capture the climatic signal. Quite often these noise factors are related to the institutional surroundings in which the data came into being. Agricultural yield figures, for instance, have to be evaluated by including information on soil and land conditions; cultivation, fertilization and harvesting techniques; or changes of agrarian policy (Glaser et. al., 1988). For a pragmatic approach to historical yield data a filtering procedure was developed that allows the splitting of the yield curves into high and low frequency parts. It is thereby hoped to separate the long-term socio-cultural and other non-climatic changes from the short-range fluctuations of crop yields depending on weather and climate (e.g. Pfister, 1984). The results of such analyses are still quite often affected with residual errors which have to be taken into consideration for the interpretation. The methods employed for interpreting the climate-yield relationship on the basis of presently observable relationships cover a range from simple correlations to sophisticated procedures such as factorial analysis, the results of which tend to be very difficult to interpret (Lauer and Frankenberg, 1986). This also holds for the application of so-called response functions that permit, for instance, the climatic interpretation of tree ring data (Schweingruber, 1989). These remarks can only hint at the large variety of possible proxy data. The complexity and diversity of these data therefore has to be complemented with a broadly based methodology for the climatic interpretation of the source material. In spite of the restrictions to which brief reference has been made, a number of points speak in favor of the use of such data: their distribution is almost ubiquitous; they are relatively simple to obtain; some of them can be converted into figures, such as days of the year, meters, kilograms or Öchsle-degrees for wine quality, and therefore lend themselves to complex statistical treatment. Experience has further shown that they give climatic information for various times of the year. The tree ring sequences of spruce in central Europe, for instance, permit the drawing of conclusions concerning the amount of summer precipitation, whereas it is obvious that data on the freezing of rivers and lakes translate into winter temperatures. Another aspect that can hardly be overrated is the support given to proxy data by viewing them together with descriptive data. Several time sequences compiled independently of each other and their interpretation can be effectively used for verification and interpolation.

To summarize, there is a host of most diverse data types available in Germany that allow a detailed reconstruction of sixteenth-century climate. The spectrum of methods employed ranges from descriptive and statistical analysis to complex

numerical procedures, thereby reflecting diversity. In addition to single extreme events the results also make visible long-range changes in the course of climate.

6. The Evidence for the Czech Republic

As in Germany and Switzerland, the sixteenth century witnessed a substantial increase of written documentary evidence in the Czech lands as compared to the first half of the millennium (Brazdil and Kotyza, 1995a). The foundation of Prague University by Emperor Charles IV (1316-1378) in 1348 was relatively late with regard to Western Europe and the Hussite wars in the fifteenth century lead to economic stagnation. A revival of economy and science was initiated from the late fifteenth century (Petran, 1983). The cultural upswing during the sixteenth century lead to an intensive development of the school system and the fostering of humanistic culture. Consequentially, books and education became accessible to a larger share of the population, in particular to the burghers in the towns and to the landed aristocracy (Valka, 1996). During this period the Czech Estates and the Hapsburg crown were struggling for superiority in the early-modern Czech state. Finally the uprising Estates were defeated in the Battle of White Mountain (near Prague) on 8 November 1620. As a consequence the Hapsburg imperial family seized absolute power and the Roman Catholic Church became dominant. The sources of data hereinafter described provide the backbone of evidence from which the temperature and precipitation indices in the Czech lands were inferred (see Glaser et al., this volume).

The documentary evidence used for historical reconstructions of climate consists of three kinds of sources: literary narrative sources such as chronicles and memoirs; daily weather records; and, economic records (e.g., account books). In addition, documentary proxy data of biological and hydrological character may also be analyzed. More information about all existing documentary evidence from the Czech lands including quotations and detailed characterizations is provided by Brazdil et al. (1999).

The field of natural proxy data includes only reconstructions based on temperatures in boreholes (Bodri and Cermak, 1995, 1997) which, however, have a low temporal resolution. Further, long dendrochronological series of fir was compiled for southern Moravia (Kyncl and Kyncl, 1998) and preliminary results show some coincidence with precipitation patterns.

6.1. DESCRIPTIVE DOCUMENTARY DATA

In the following sections the evidence is discussed according to data-type.

6.1.1. *Literary narrative sources*

These sources contain a lot of non-systematic information about weather and climatic extremes including their impacts on society or nature. They can be distinguished between extensive historiographic sources and memoirs.

The first group comprises large official chronicles referring mostly to political, social or ecclesiastical events. They have a low significance for climatological research. An exception is the "Bohemian Chronicle" compiled by Catholic priest Vaclav Hajek z Libocan (d. 1553). He focused on such diverse things as natural disasters, harvests and prices up to 1527 (Hajek, 1541). Additional information for the first quarter of the sixteenth century is found among a collection of manuscripts, annals and chronicles known as the "Old Bohemian Annals" (Palacky, 1941). These records, associated mainly with Prague and Hradec Kralove, form the most important historiographical works from the late Middle Ages in the Czech lands (see Brazdil and Kotyza, 1995a).

Information from older chronicles and many contemporary sources were noted in almanacs imported from Germany and Italy during the early parts of the century (see Pfister et al., this volume). Such an almanac was published in Latin in 1584 by Prague University professor Prokop Lupac z Hlava.Cova (d. 1587) (Lupac, 1584). Another more popular almanac, written in Czech by Daniel Adam z Veleslavina (1541-1599), was originally published in 1578, followed by a second edition in 1590 (Adam z Veleslavina, 1590). Almanacs were often used by various scribes for making notes on the weather and related phenomena.

Another kind of source containing various items of news, memoirs, letters and other documents, often accompanied by recollections of the author, is known as "Collectanea " or collectibles. Marek Bydzovsky z Florentina (1540-1612), a Professor of Astronomy at Prague University, published such a volume of collectible items for the period 1526-1596 (Kolar, 1987). Throughout the century reports of remarkable catastrophes were issued in printed newspapers and posters. One such account refers to the flood of the Vltava River in Prague on 27 February 1581 (Julian style), in which some 150 people were drowned.

Weather information may even be found in such unusual works as epic-style pieces of poetry written by religious moralists. Jan Stelcar Zeletavsky (1530- 1596), a clergyman in Mnichovice (central Bohemia), described a lot of meteorological extremes in this way (Stelcar Zeletavsky, 1588). Another example is the well-known rhyme-chronicle about Usti nad Labem written and published by Johann Augustin Tichtenbaum (1586-1634). It relates to the period 1432-1609 and is considered to be the most outstanding Renaissance chronicle of northern Bohemia. Another abundant source during the time-span 1550-1609 is the "History of the Rosenberg [Rozmberk] Dynasty" (Panek, 1985) written by Vaclav Brezan (1586-after 1618), the archivist and librarian of this important southern Bohemian aristocratic family.

A large body of source material containing weather data was created for internal use. Authors were generally town scribes, burghers, clergymen, soldiers, rectors, merchants or noblemen. Reports were written as an official duty or simply for the sake of memory. They usually refer to the vicissitudes of everyday life including late frosts, downpours, thunderstorms, hailstorms, floods, etc.

Many descriptive weather reports were written in the town of Litomerice, an administrative, economic, cultural and social center situated on the Elbe River. Many of the original records have been preserved in the "Book of Remembrance" compiled by the Litomerice town scribes (e.g. Jan od Hradu for the period 1500- 1529). This body of evidence includes a wealth of information on the level of the River Elbe and observations on the vineyards, including such items as the growth phases, damage to the plants by hailstorms or frost, times of vintage, notes on the quality and quantity of vine harvested, etc. (SOkA Litomerice, Smetana, 1978). Various chronicles reporting weather observations are extant from Prague (one, for example, by an unknown burgher of New Prague Town for the time-span 1492- 1539: see Zilynskij, 1984) and from Ceske Budejovice (one among others written by baker Frantisek Machnicky [1513-1583] for the period 1450-1578: Mares, 1922). Many important sources are extant from western Bohemia. These include chronicles by lawyer Pankraz Engelhart of Haselbach (d. 1571) and by lawyer Andreas Baier (ca. 1528-1598) from Cheb for the respective periods 1134-1561 and 1179-1594 (Gradl, 1884). A short chronicle for the former mining town of Jachymov was compiled by parson Johann Mathesius (1504-1565) and his successor, clergyman Jakob Schober (before 1578-after 1617) covering the respective time-spans of 1516-1562 and 1578-1618 (Mathesius, 1562; Wolkan, 1890). Much information about the weather is included in the chronicle by Pavel Mikšovic (ca. 1575-1632), a lawyer and town official from Louny, for the period 1490-1631 (SOkA Louny); it is an important source in cross-checking with the economics records of the town (see chapter 6.2.). Very precious descriptions of the weather are included in the memoirs written by Vaclav Knezovesky (1546-1621), a town official and landowner from Slany, covering the time-span 1578-1620 (Peters, 1898). The chronicle written by painter Simon Hüttl (1530-1601), a burgher of Trutnov, for the period 1484-1601 (Schlesinger, 1881) is the most well-known in northern Bohemia. Very important notes made by the Catholic priest Valentin Frumald (1547-1624) from Dobruška are also extant for the time-span 1567-1614 (Wiechowsky, 1911).

The most important sources in Moravia are chronicles concerning the town of Jihlava. They were written by miller Franz Setzenschragen (1514-1593) and town scribe Martin Leupold von Löwenthal (ca. 1579-1623) for the respective periods 1402-1547 and 1402-1617 (Mayer, 1938; d'Elvert, 1861). A lot of weather information has been preserved in the chronicle of town councilman Jiri Bartosek (ca. 1545-1584) from Uherský Brod for the period 1518-1584 (and continued to

1594 by Daniel Dvorsky) (SOkA Uherske Hradiste). The memoirs of estate administrator Matyas Matuska z Topolcan (1560-1602) provide very detailed weather observations from Zidlochovice for the time-span 1586-1601 (Ondruj, 1977). A further important book of remembrance is written by Jan Belkovsky z Ronsova (ca. 1560-before 1637) and his successors as well as that by Pavel Zlypivo (1594-after 1622) for the town of Prostějov covering the periods 1445- 1637 and 1445-1610, respectively (SOkA Prosrejev; Kühndel, 1926). On the other hand, weather observation records are relatively poor for the largest Moravian towns, Bmo (e.g. the chronicle of town councilman and druggist Georg Ludwig [1555-1609], for the time-span 1555-1604: Chlumecky, 1859) and Olomouc (e.g. summary chronicle of Olomouc for the period 1432-1656, including the observations of physician Georg Hass for the time-span 1540-1565: Dudik, 1858).

Spatial distribution of places with a relative abundance of weather reports is shown in Figure 4. In general, evidence-producing data is more dense and coherent for Bohemia than for Moravia. Moreover, with time, a continuous increase in the density of records is noticeable. It must be emphasized that only the second half of the sixteenth century is covered sufficiently. During the first half of the century there are even some years for which no useful information at all is available (e.g. 1528, 1529).

6.1.2. *Daily weather records*

Daily weather records in the Czech lands are biased by their non-continuous temporal character and often by the changing of places where the records were made. They nevertheless contain useful information for the reconstruction of temperature and precipitation indices in years when other evidence is often missing. Furthermore they often also contain summarizing information about the weather patterns during individual months. However, such records are not sufficiently coherent to allow frequency analyses for different weather characteristics as demonstrated by Pfister et al. (this volume) except for just a few months (see Brazdil and Kotyza, 1996a). Only daily weather observations over a period of a few months are discussed here.

The oldest dally weather observations were written by nobleman Jan z Kunovic (1482-1545) in south-eastern Moravia, mainly for winter half-years during the period 1533-1545 (see Brazdil and Kotyza, 1996a, 1996b; Pfister et al., this volume).

Tadeas Hajek z Hajku (Hagecius, prob. 1525-1600) was a renowned mathematician, physicist and astronomer as well as serving as physician-in- ordinary to Emperor Rudolf II (1552-1612). He compiled notes on the weather in Prague, writing them in an ephemeris between August 1557 and February 1558 with only a few gaps (Brazdil and Kotyza, 1996a).

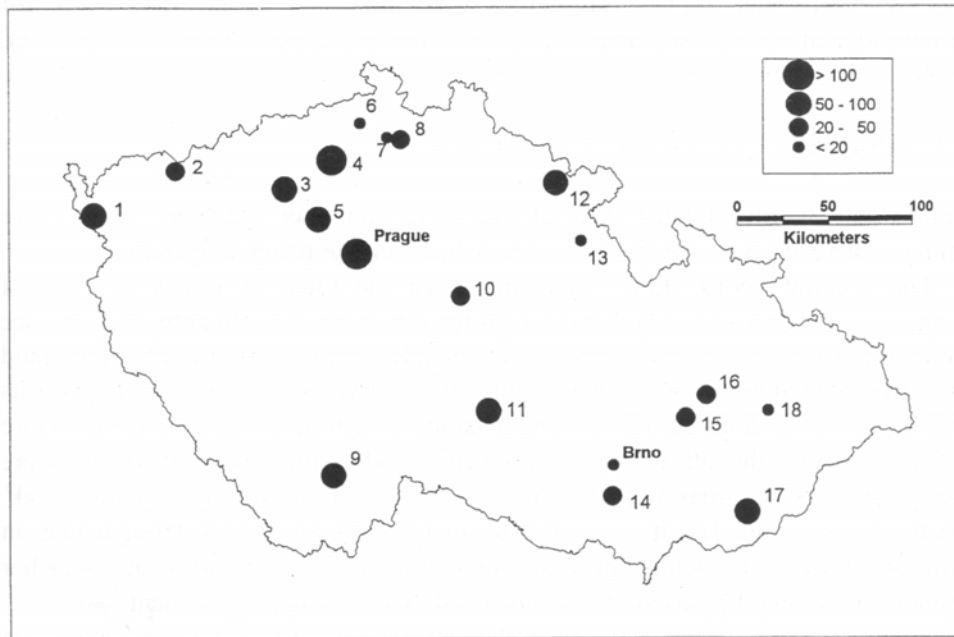


Figure 4. Main locations of documentary data for the Czech lands in the sixteenth century: 1 - Cheb, 2 - Jáchymov, 3 - Louny, 4 - Litoměřice, 5 - Slaný, 6 - Benešov nad Ploučnicí, 7 - Česká Lípa, 8 - Dobruška, 9 - České Budějovice, 10 - Kutná Hora, 11 - Jihlava, 12 - Trutnov, 13 - Dobruška, 14 - Židlochovice, 15 - Prostějov, 16 - Olomouc, 17 - Uherský Brod, 18 - Drahotuše.

Jan Strialius z Pomnouse (1535-1582) was a schoolteacher and later a town- scribe. He made his daily observations during the period 1558-1563 in Wittenberg (Saxony-Anhalt) and Meissen (Saxony) and, as of 1564, in Prague, Litomerice, Ceske Budejovice and Zatec. But his entries, included in two almanacs, rarely cover more than half of the days in a month. On the other hand, the continuity of these records during some 19 years is exceptional for this period in Bohemia (Brazdil and Kotyza, 1999).

Karel starsi ze Zerotina (1564-1636), a famous Moravian politician, made his daily weather observations at a young age following studies and travels abroad between 1588 and 1591 (see Brazdil and Kotyza, 1995b; Pfister et al., this volume).

The physician Matyas Borbonius z Borbenheimu (1566-1629) began his weather observations during a stay in Basle (March 1596 -June 1597) where he served as preceptor of young Sir Jan z Vartenberka. Upon returning to Napajedla (Moravia) he continued his observations until January 1, 1599 (Brazdil and Kotyza, 1999). In 1622 he resumed writing daily weather observations during a

stay in Prague and Teplice (his diaries were published by Dvorak, 1896; for meteorological records see also Pejml and Munzar, 1968; Brazdil and Kotyza, 1999).

6.2. SOURCES OF ECONOMIC CHARACTER

Besides the weather-related data of economic character included in narrative sources, there are two continuous sources which contain proxy information.

The account books (*Liber rationum*) from the town of Louny are almost continuous between 1450 and 1632 (for records from the fifteenth century, see Brazdil and Kotyza, 1995a). This source includes detailed records of wages paid for different field work such as haymaking, grain harvests and work in vineyards as well as for work done during the winter months, such as cutting ice on the Ohre River or between the mill wheels, clearing snow and floating wood. Payments were always made on Saturday so that the paid wages reflect the work of an entire week. On the basis of this data it is possible to infer the timing of such labor which, in turn, is related to the temperature and precipitation patterns and/or any weather phenomena during the period of time immediately preceding the payment.

Similarly, the account books from the Dobromence estate contain records on wages paid for work in the fields during the time-span 1517-1622. They refer mainly to field work such as picking hops, haymaking, grain harvest and helping with the harvests of some other crops. Records on the quality and quantity of grapes harvested on the Malic estate (near Litomerice) are known from 1554 to 1606 (see Kostal, 1958).

7. The Evidence for Ancient Hungary

7.1. DESCRIPTIVE DOCUMENTARY DATA

At the beginning of the sixteenth century the Kingdom of Hungary extended over an area of 300,000 km² from Transdanubia to Transylvania (see Figure 5). Following the defeat of the Hungarian army against the invading Turks in 1526 the kingdom broke into three parts and became the borderland between the Ottoman and Hapsburg Empires until 1686. The continuous warfare disrupted the structure of economy and society in the Carpathian Basin, but at the same time it was the golden age of Hungarian culture. During this period the Protestant churches set up elementary and high schools in the three political units of the Carpathian Basin which were still under their influence. This promoted literacy based on the Hungarian language. Consequentially, the number of manuscripts and the circle of readers increased.

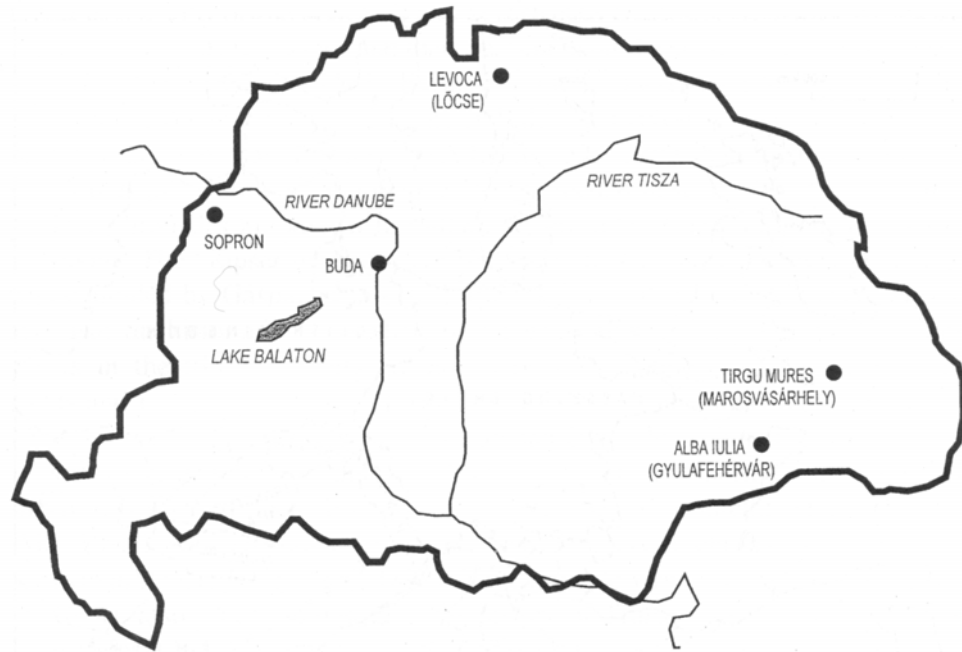


Figure 5. The Hungarian kingdom in the early sixteenth century before the Turkish invasion.

Another result of the Turkish conquest was a cultural opening of the country towards the Balkan peninsula and the Middle East. Several Protestant ministers from Transylvania traveled to the Holy Land. In addition, Turkish authors left descriptions of the conquered areas of Hungary in connection with their military campaigns. The most famous of them is the diary written by Suleiman the Magnificent (Ottoman sultan: 1520-1566) who twice (in 1529 and again in 1532) tried in vain to conquer the fort of Vienna (Suleiman, 1893).

Because the climatic conditions and the cultural patterns in the Carpathian Basin are different, the area under study is broken down into four regions: Transdanubia, Highlands (present Slovakia), Transylvania and the Hungarian Plain (Figure 6). For the last region that was under Turkish control, only sporadic information is available. All Hungarian data are stored in the EURO-CLIMHIST database (Pfister et al., 1994).

The sources discussed below are included in the compilation made by Rethly (1962). Care is needed because the collection of materials contains contemporary and non-contemporary observations. Moreover, sources in other languages, such as Latin or German, were translated into Hungarian.



Figure 6. The Hungarian kingdom after the Turkish occupation.

The chronicles are the most important group of sources used as a basis for the climatic reconstruction of the sixteenth century. Eleven chronicles are mentioned but only one, entitled "Pannonii historiarum de rebus ungaricis", encompasses the entire century (Istvanfi, 1622). The author, Miklós Istvanfi (1535-1615), was a statesman and historian. He wrote his chronicle in Latin and dealt mainly with the military history of Hungary between 1490 and 1606. Most of his weather observations were noted in conjunction with these campaigns. Three chronicles are known for Transdanubia. They were all written in the city of Sopron near the Austrian border, a place where Hungarian intellectuals met because other cities in the Transdanubian region were occupied by Turkish troops. The "Haus Chronic des Gottlieb Bruckner" (Ms. Bruckner) is the richest among them. It is a personal chronicle written in German and it describes climatic patterns on the level of months and seasons and refers to harvests, prices and epidemics. The style of the chronicle written by György Payr and Mihály Payr (Payr, 1942) is very similar. The so-called Fauth Chronicle, written by Sopron city councilor Mark

Fauth at the turn of the sixteenth and seventeenth centuries, describes the general characteristics of the seasons and their bearing upon the economy for the time-span 1579-1616. For example: 1585 "Because of the spring drought the grain could not grow and prices increased. [...] In the end, the rye harvest was good, but the yield of barley and hay was very low. " (" A tavaszi esok hanyaban a gabona elmaradt.

[...] A rozs jól sikerült, a zabjoforman nem termett, s fu sem volt".) (Ms. Fauth).

Two chronicles are known from the northern part of ancient Hungary (present Slovakia). The "Zipserische oder Leutschauerische Chronica", written in German, was compiled by Gaspar Hain (1632-1687), mayor of the city of Levoca (Locse) and also an historian. Although it is not contemporary, it refers to memorable events in the town including climatic anomalies, natural disasters, agricultural yields and prices (Ms. Hain). The diary written by Zsigmond Torda from 1558 to 1568 originates from the same area (see Pfister et al., this volume).

Five main chronicles and a collection of various shorter chronicles have survived from the Principality of Transylvania, a Turkish satellite state. The latter (Ms. Bielz) was composed from the so-called Saxon chronicles compiled by clergyman Albert Bielz (1817-1898). The chronicle written by Mate Sepsi Lackó (d. 1624), also a parson, describes the history of Transylvania between 1520 and 1624 (Sepsi, 1857). Lestár Gyulafi (1557-1605), an intellectual refugee, was born in Transdanubia. After completing his university studies he settled in Transylvania, where he became a statesman, diplomat and historian. Gyulafi wrote a chronicle about the history of Transylvania (Ephemerides) but it was lost and only his notes survived (Ms. Gyulafi). Sebastyen Borsos (1520-1584), mayor of Tîrgu Mureş (Marosvásárhely, central Transylvania) between 1565 and 1582, compiled a history of the city covering the time-span 1490-1583 (Borsos, 1855). István Szamosközy (d. 1612) was a gifted humanist and historian. He began his career in the city archives of Alba Iulia (Gyulafehérvár) which was then the capital of the Principality of Transylvania, and later became court historian to Prince Bocskai. Unfortunately, Szamosközy's work remained incomplete (Szamosközy, 1889). The relatively large number of five chronicles written in this area reflects the fact that Transylvania was a prosperous region during the second half of the sixteenth century and the first half of the seventeenth century. Because of its tolerance for twelve different religions, it provided a safe haven for many Hungarian intellectuals.

7.2. DOCUMENTARY PROXY DATA

Hungary is close to the northern border of European wine production and therefore the Hungarian vine-growing areas are very sensible to climate changes. The quantity and the quality of vintage depends on the climate of the preceding year (from fall to fall) (Le Roy Ladurie and Baulant, 1980). The relationship between

the temperature anomalies and the snow cover during the winter is very important because without snow cover the frost could kill the grapevines. Late spring frosts are the most dangerous. Hot and quite dry summers with long warm spells are needed for the best vintage. An almost continuous series from the city of Sopron (Transdanubia) for nearly the entire sixteenth century and a shorter series from the northern part of ancient Hungary and Transylvania for the last third of the sixteenth century have been reconstructed (see Landsteiner, this volume).

As winter (December, January and February) temperatures in the Carpathian Basin fluctuate between 1°C and -3°C during the period 1930-1960 (Peczely, 1981), water bodies do not freeze regularly. If a freezing of the large Lake Balaton and the great rivers (chiefly of the Danube) is reported, this yields a good clue for a severe winter.

8. The Evidence for Italy

8.1. INTRODUCTION

Politically and administratively speaking, sixteenth-century Italy was foffiled by sixteen states, amongst the most important of which, in teffilS of continuity and size, were the Kingdom of Naples, belonging to the Spanish crown, the Papal States, the Republic of Venice, the Grand Duchy of Tuscany, the Duchy of Milan and the Duchy of Ferrara (see Figure 7).

The total population of Italy is estimated to have been 11,600,000 in the middle of the sixteenth century and 13,300,000 in the early seventeenth century (Beloch, 1937-1961). Among the many towns, the most densely populated were Naples with 240,000 inhabitants, Venice with 131,000, Milan with 95,000, Rome with 80,000 and Florence with 65,000. City-states of commune origin became "signorie" by absorbing territory and small towns, which thus lost their local autonomy and became subject to a strong centralized princely power. The sixteenth century in Italy was also a time of generally increasing mobility, trade, cultural activity and long-distance exchanges.

Once the equilibrium of the fifteenth century was lost, the new Italian states clashed in wars which often saw them allied to foreign powers (France and Spain). These wars were frequent, and had disastrous social and economic effects, with crop losses and epidemics. The population nevertheless increased, as did the amount of cultivable land through the deforestation of hillsides and lower mountain slopes.

Culture was supported by economically strong powers and protected in court circles, but it was not solely the elite culture of the Renaissance, for it now also influenced the widespread learning of the urban middle classes, who had previously



Figure 7. Italy in the sixteenth century.

been excluded. That is the reason why so many of the writers responsible for sources used in the history of climate were lawyers, notaries, doctors, merchants or men of moderate literary culture, who often had an important part to play within the confines of their town. These new townsmen liked to keep family diaries, to write almost day-by-day chronicles of their town, and to record and comment on events whose horizons often went no further than the town walls or the frontiers of the seigniorie or duchy. Many of these texts are still preserved in manuscript in local libraries.

Historiography also began to flourish in the sixteenth century. Its subject matter was the history of kingdoms and "signorie", but it was no longer solely concerned to eulogize the prince's family and extol its magnificence. It now dealt with major political and civil events and inter-state relationships, and was written by important men of letters such as Pietro Bembo (1551) and Francesco Guicciardini (1561), or churchmen such as Carlo Sigonio (1580, 1591) and Cesare Baronio (1607).

This elevated historiography was much concerned with actual events, including natural disasters, and it later led to the erudite local historiography in which Italy has a very strong tradition. Writers involved in this minor historiographical genre tended to concentrate their attention on the political and civil history of their home town. Within a few generations -and partly as a result of the spread of printing - local history became a popular genre which proliferated in small towns as well as in cities with a long-standing historical tradition, and it often made use of sources which are no longer available to us. It has made a substantial contribution to our knowledge of the history of climate and natural disasters.

At a more popular level, too, there were important changes in the sixteenth century. Printing led to a gradual increase in new demands for information, involving urban classes which had previously been illiterate. Popular printed sheets -embryonic newspapers, one might say - began to appear in Italy in the second half of the sixteenth century. They are an indication of an increase in literacy and the importance of urban populations, and they satisfied a new demand for news, including reports of natural disasters. Such events were often considered to be prodigies and occupied an important place in popular printed works.

A number of academies were founded in the closing decades of the sixteenth century and their number increased strikingly in the seventeenth and eighteenth centuries. There was also an increase in the number of universities. By the end of the sixteenth century, there were 23 universities in Italy, nearly all of them in the center and north (Figure 8).

8.2. DOCUMENTARY DATA

Written documents describing climate, meteorological events or natural disasters can be found everywhere, but Italy has a unique and virtually seldom exploited

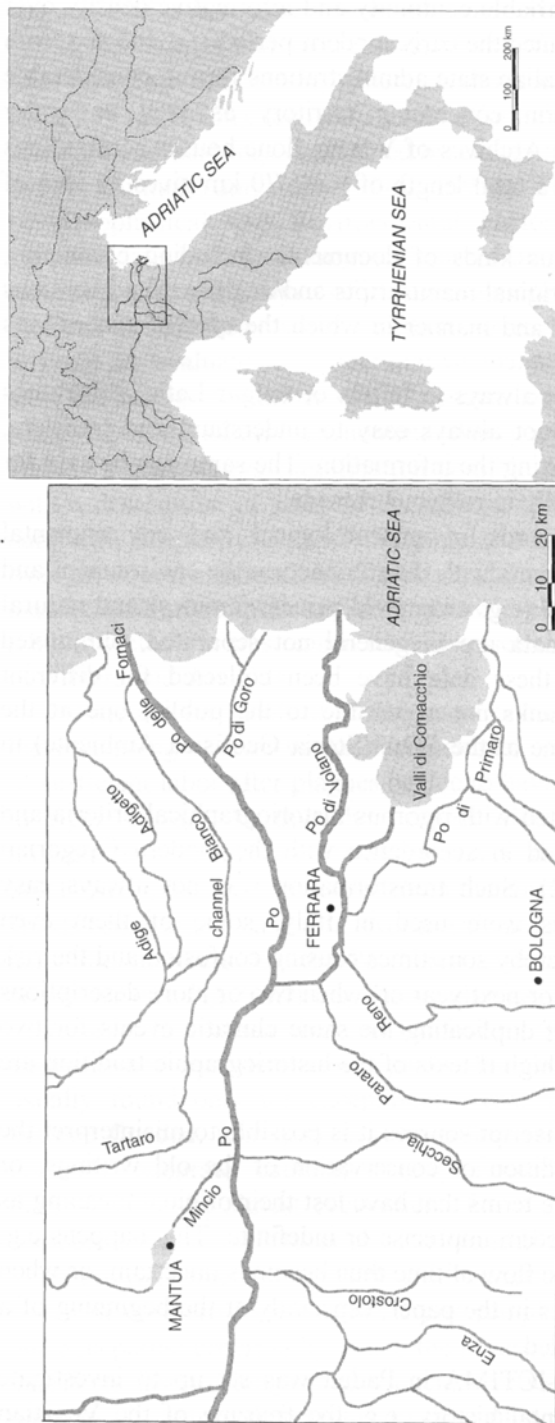


Figure 8. Situation of the lower Po plain (northern Italy) in the sixteenth century.

mine of data extending back with variable continuity and informative density over the last 2,500 years. In particular, since the early modern period (i.e. the sixteenth century) data produced by ancient Italian state administrations form a considerable part of the archival documentation concerning territory as well as water management. The fact that the State Archives of Venice alone houses scaffoldings full of ancient documents extending a total length of some 70 km gives an idea of the extent of this documentation.

Data were compiled from various kinds of documents, including chronicles, annals and archival records. Both original manuscripts and/or their edited versions were used, depending on the period and manner in which the type of record was written.

The language of the texts, almost always in Italian or vulgar Latin, sometimes in vernacular language as well, is not always easy to understand and translate, thereby creating problems in interpreting the information. The same can be said for the late, medieval Latin used especially in religious records.

These sources report daily records of meteorological and environmental observations, exceptional climatic events with their impact on the environment and the society, documentary proxy data (e.g. crop yield prices, famines) and natural hazards. These different types of data are in general not separated, but mixed together in the same source. All these data have been collected for different purposes into two research data banks not accessible to the public, one at the CNR-ICTIMA in Padua, another one at the SGA (Storia Geofisica Ambiente) in Bologna-

All the records have been validated with rigorous historiographical criteria and the original dating has been adjusted in accordance with the modern Gregorian calendar (Camuffo and Enzi, 1992). Such transformation was not always easy inasmuch as fourteen dating-styles were used in Italy, some of them even simultaneously in the same town, thereby sometimes causing confusion and the risk of attributing events to the previous or next year or, when two or more descriptions were found with different dating, of duplicating the same climatic events for two consecutive years. This risk is very high if texts of the historiographic tradition are used instead of original sources.

Furthermore, when reading manuscript sources it is possible to misinterpret the text nowadays due to the bad condition of conservation of the old writings, or because of chronological or semantic terms that have lost their original meaning as time has passed and therefore now seem imprecise or indefinite. This happens e.g. when the pages are separated and the flow of time thus becomes uncertain, or when abundant amounts of ink made holes in the paper, especially at the beginning of a line where dates were usually recorded.

The research database at CNR-ICTIMA in Padua was set up to investigate several features of past environmental history, e.g. the freezing of the Venetian

Lagoon and other large bodies of water (Camuffo, 1987; Camuffo and Enzi, 1992), sea surges and river floods (Camuffo, 1993; Camuffo and Enzi, 1995b; Enzi and Camuffo, 1995), general features of the climate in Italy (Camuffo and Enzi, 1994a, 1995a), locust invasions (Camuffo and Enzi, 1991), natural pollution, acid rain and acid fogs constituted by clouds of volcanic aerosols (Camuffo, 1992, 1993b; Camuffo and Enzi, 1994b, 1995c). The SGA (Storia Geofisica Ambiente i.e. Geophysical and Environmental History) research database in Bologna, supplies data both from original sources and from literature concerning extreme natural events and analysis of historical environmental impact.

Because of their nature, written sources may be subjective and therefore difficult to evaluate in a quantitative manner (e.g. a hot summer), even when included among a number of independent observations. However, there are also some types of natural phenomena that generate characteristic effects, thereby making a quantitative classification possible. When such events are found together with a description of some of the effects, they can be transformed into objective data with a severity index. For example, a winter may be judged from a chilling frost or from the formation of thick ice slabs over large bodies of water; a drought may be similarly appraised from the low levels of rivers and the drop of the water-table in wells. For this reason the events selected for this study include the severity of winters and droughts.

Floods are the result of various environmental and man-made factors (such as the weakening of river banks, for example, something often conditioned by a lack of sufficient labor after plagues or due to having enrolled all available healthy men to fight a war)" so that they cannot always be taken as the best index of precipitation (Guidoboni, 1998). However, there is no doubt that there is a close link between the two, especially when the episodes are not isolated but where many floods occur at the same time over a wide area. For this reason floods involving the main Italian rivers, i.e. the Po, Tanaro, Bormida, Secchia, Panaro, Adige, Arno and Tiber (see Fig. 6 and Fig. 7), are also included in this paper.

In order to evaluate the level reached by flood waters, epigraphic sources were also used and due attention was paid to their original placement. Such sources were usually found only for exceptional events when, for example, inhabited areas became flooded. It is quite easy to collect this kind of data because detailed and critically accurate catalogues (e.g. Forcella, 1879) with Latin and Italian inscriptions exist almost everywhere. For a survey of river floods in central and southern Europe see Petts et al. (1989) and Brazdil et al. (this volume). There were many particularly cold winters which had a disastrous impact on the whole of northern Italy and numerous complaints can be found. But there is only one acceptable criterion by which the severity of a winter can be verified, namely, its effects. Establishing the nature and severity of a winter is much easier and more objective in nature than trying to determine summer conditions. That is because

intense and lasting cold leads to specific effects, such as the formation and thickening of ice which does not pass unobserved due to the damage caused or simply the unusualness of seeing people walk over a frozen river .

An extreme "great winter" was defined when the cold was particularly severe and when it lasted for a relatively long time over a large area, thereby causing exceptional events to be well documented, e.g. people walking over large bodies of completely frozen water, wine frozen in butts, death of people, trees and animals.

A "severe winter" was defined when despite numerous complaints the cold was severe but lasted for shorter periods, often killing people, trees and animals, and was not sufficient to cause the complete freezing of large bodies of water (Camuffo and Enzi, 1992).

There were also various winters that were defined as being "cold" by people who lived at that time but remained without a clear description of the effects or were mentioned only by one or few chroniclers. Such cases were probably due to effects affecting Italy only marginally or, most probably, when a chronicler made a subjective evaluation about winters that were alternatively cold and less cold. For example, a limited diet could, in some cases, have increased the sense of cold; or a simultaneous scarcity of wood for heating could make the effects of the cold more and more dramatic. This definition is more uncertain than the others and winters thus classified have not been included except in a few clear cases (e.g. persistent snow, or cold persisting in the early springtime) in order to make the teleconnections with other regions easier .

"Mild winters" can be said to be those when there was a complete absence of ice (as expressly mentioned) or the premature flowering of plants was confirmed by various independent sources in different areas, in order to avoid the over-evaluation of local effects.

Summer heat is also often mentioned, but unfortunately there are no phenomena that can quantitatively indicate hot in the same way as ice can point to the coldness of a winter. Often, heat and drought were associated in the chronicles, even though drought could be more objectively documented in that it is related to a specific phenomenon, such as precipitation. However, it is necessary to be careful when discussing drought because sometimes it was not due to a climatic anomaly, but linked to particular needs of the agricultural calendar. A lack of rain at certain critical harvesting periods was often termed "drought". In fact, processions and "novenas" (i.e. periods of nine successive days of intense prayer) were used to invoke rain to save a harvest, and not to bring about the expected statistical value of the precipitation. In this sense, the most serious and reliable information usually says something specific: "There has been no rain from this date to that date." Obviously, single notes such as "it is raining today" concern the frequency and not the quantity of rain. Quantity and frequency often appeared to be strictly linked to each other and based on agricultural needs. From the data bank, it can be seen that

there were complaints almost every year about at least one drought, very often in two or even three different places, but there are also some cases where such a phenomenon was not isolated but mentioned by various independent sources. Naturally, it is better to consider only those few cases which are of an objective nature, simply because of the almost unanimous complaints about a drought, or those cases when the chroniclers also mentioned some kind of objective consequences, e.g. that the rivers were low, the levels of the wells had dropped or springs had dried up.

There were also many periods of drought, some of which lasted several months. Even when assuming that some of these periods were broken by sporadic brief periods of precipitation, drought was an anomaly absolutely exceptional to the climate of northern and central Italy. The sources used in this research are of various kind. They include archival sources, coeval memoir sources, antiquarian and local histories, and scholarly catalogues. These categories of sources are explained below in somewhat more detail. .

8.2.1. *Archival sources*

Administrative sources are made up of reports and letters written by those with official responsibility for running the territory concerned.

Diplomatic sources: Since Italy consisted of numerous small states, ambassadors played an important part in inter-governmental communications, and their dispatches and reports provide a very valuable web of information. An example of these kinds of sources used in this research are the documents coming from the archives in Mantua, Modena, Ferrara, Venice and Ravenna.

Reports of experts: Hydraulic experts, engineers and mathematicians were asked for surveys and advice by the ancient local governments.

8.2.2. *Antiquarian and local historiography*

This genre was much developed in northern Italy in the sixteenth century, on the basis of the writer's interest in the origins of his home town or the vicissitude of the prince's family.

Historians of this kind were careful collectors of ancient memoirs, many originals of which are now lost. When they recorded natural events, a fair amount of details was usually included and any disastrous effects were considered quite suitable for inclusion in civil history as "historical" facts. Some of the most significant published sources of this kind are the anonymously written "Annales Forolivienses" (Mazzatinti, 1903-1909) and the "Diario Ferrarese" (Pardi, 1928- 1937) as well as the works by Candido (Joppi, 1886), Morosini (1720) and Rizzoni (1747).

8.2.3. *Scholarly catalogues and lists of calamitous events*

This group consists of treatises and catalogue compilations which cannot be considered as providing primary basics but are often based on general information.

Works such as officially quoted sources are a valuable product of that Italian literary and historical scholarship which from the eighteenth century onwards displayed a keen interest in natural phenomena. We have used them only when substantial agreement with primary sources was found and also when they filled chronological gaps in primary sources. The principal ones are those by De Morani (1795), Zandrini (1811), Bottoni (1873), Corradi (1892), Fiandrini (Ms.), Anon. "Codex Gradenigo", Gallicciolli (1795) and Tovazzi (18th cent.).

8.2.4. *Memoirs*

These consist of diaries and chronicles written by individual citizens to record events at a personal, family or local level. The texts concerned were written by eyewitnesses of the events described, whose interest in meteorological events and related effects were almost always acquired. Zambotti's sixteenth century memoirs (Pardi, 1937) are an example of such a source and it admittedly borders on the category of local history .

8.3. SUMMARY LIST OF PRINCIPAL SOURCES OF THE SIXTEENTH CENTURY (IN CHRONOLOGICAL ORDER)

Tommaso di Silvestro (ca. 1440- after 1511)

His chronicle (Fumi, 1920-1929) deals with the town of Orvieto and the region of Umbria from 1481 to 1514. In 1471 Di Silvestro is recorded as being a canon of the church of Santa Maria in Orvieto, and later as principal canon at Orvieto cathedral. As is evident from his original records in the Orvieto Notarial Archives, he served as a notary public between 1471 and 1511. Generally, his chronicle deals with local history .He was an eyewitness of the events he reported and paid particular attention to meteorological events, which he described in some detail. Some parts of the surviving chronicle manuscript relating to a few years in the 15th century are missing. The original codex is preserved in the Archivio Storico Comunale di Modena.

Bernardino Zambotti (ca. 1450- after 1504)

His diary (Pardi, 1937) deals with the city and duchy of Ferrara from 1475 to 1504. Zambotti studied law at the University of Ferrara. He began writing his diary in 1475-1476, perhaps when he became a student. Upon completion of his studies, he worked as a civil servant in Ferrara, Reggio Emilia and Mantua. He was an eyewitness of the events he described, displaying interest in meteorological and climatic news and providing detailed reports, especially in the case of extreme phenomena and when damage occurred in Ferrarese territory .The parts of his work

which we have used refer solely to the opening years of the sixteenth century .An autograph manuscript of his work is preserved in the Biblioteca Civica Ariostea in Ferrara. Copies are held in the Vatican Library .

Tommasino de ' Bianchi, known as de ' Lancellotti (15th/16th century)

His chronicle (De' Bianchi, 1862) deals with Modena and its territory from 1506 to 1554. He was born and lived in Modena, where he carried on the work of his father, spice merchant Jacopino de' Bianchi. His chronicle is narrated in simple style and adopts a civic approach, with a vigorous attempt at impartiality .His narrative often goes beyond the city confines and draws attention to major events in an historical context of all Italy, such as changes of government and factional strikes. He provides careful reports of meteorological events, including some which were not of an extreme nature.

Marin Snudo [sic] "il Giovane" (1466-1536)

His chronicle (Stefani et al., 1903) deals with the Republic of Venice and its colonies from 1496 to 1533. A scholarly chronicler with a classical background, he devoted himself to politics from 1498 onwards, but with little success. Between 1483 and 1495, he published a number of political histories which were intended to serve as a sort of preface to his "Diarii", an enormous chronicle which records daily events throughout the forty years of his personal observations. The work's 59 volumes are a mine of information not just about political and economic affairs, but also about climatic and other natural phenomena. The documentary basis for his work consists of public reports, witnesses' letters and official documents. The "Diarii" were published by various editors between 1879 and 1903.

Francesco Guicciardini (1483-1540)

His chronicle deals with the whole of Italy from 1494 to 1540. An historian, politician and man of letters, he held important public positions in Florence and Romagna thanks to the patronage of Popes Leo X (1475-1521) and Clement VII (1478-1534). In 1529 he was threatened with arrest and his property was confiscated by the Republic of Florence. He withdrew to Romagna and returned to Florence in the Medici entourage only after the fall of the Republic in 1530. After falling out of favour, he fled to Arcetri, where he remained until his death. His surviving works consist of the 20 volumes of his "Storia d'Italia" (1537-1540) and his "Ricordi" (1527-1530). Unlike Machiavelli, he was convinced that it was impossible to formulate general laws from past events, and he saw history as the way events developed around the "particular" and the choices made by individuals who have to accept compromises in the real world. His record of natural phenomena is governed by this philosophical attitude to events, which involve "chance" problem and destruction.

Filippo Rodi (d. 1623)

Rodi's chronicle (Ms.) deals with the city and duchy of Ferrara from their beginnings to 1590. He was a lawyer, a historian and a scholar who held political

positions in the commune of Ferrara and at the court of Rome. His personal experience of the events makes him a reliable source for the history of Ferrara in the second half of the sixteenth century. His manuscript "Annali", in 3 volumes, is preserved in the Biblioteca Ariostea in Ferrara. He paid considerable attention to floods and other natural phenomena, describing them in great detail.

Giovanni Battista Spaccini (1570-1636)

His chronicle (1911) deals with Modena and its territory from 1588 to 1633. Spadini was a man of letters with a particular interest in the graphic arts. He collected information about the history of Modena and the surrounding territory throughout his life. He was a well-informed and careful narrator, who kept thorough records and set out the facts in full detail. He was particularly interested in recording the social life of Modena, but sometimes included events in other cities as well. His work is in diary form and shows a keen interest in meteorological events, especially as regarding the damage they caused.

Girolamo della Corte (16th century)

Della Corte (1594) deals with Verona and its territory from the earliest times to 1560. The only work of this historian and scholar to survive is his "Storia di Verona", which was published in 1594 in Verona in 2 volumes. It is thought to be incomplete and is, generally speaking, rather imprecise, especially with regards to chronology. However, it proved very successful and became a basic work for local Veronese historiography. He gave continued attention to natural phenomena, especially to the flooding of the River Adige.

Guglielmino Schiavina (1542-1616)

Schiavina deals with the town of Alessandria and the Piedmont region from the twelfth century to 1612 (Pongiglione, 1863). A canon, historian and scholar who collected documents about the history of Alessandria, he used sources which have since been lost. His work is the basis for modern historiography about Alessandria. He paid particular attention to natural phenomena, which he described in detail and dated with precision.

9. The Evidence for Spain

9.1. DESCRIPTIVE DOCUMENTARY DATA

The historical climatology of the Iberian Peninsula offers considerable possibilities for development. This field has traditionally been neglected although a rich documentary heritage is extant in a number of various archives. For example, all towns which had an institutionalized municipal authority in the Middle Ages have preserved the documents generated from that time (usually between the thirteenth and fifteenth centuries), assuming that the same were not destroyed by fire or

warfare. Municipal and ecclesiastical records allow an homogeneous and continuous documentation extending throughout the entire sixteenth century .

Urban annals, chronicles, brief accounts of journeys and events, etc., which provide the backbone of the evidence in central Europe and in Italy, are only available for the town of Barcelona in a significant number (Barriendos, 1994). Research mainly focusing on Andalusia (southern Spain) was directed to a combined analysis of different types of sources (Rodrigo et al., 1995). It allowed, for example, checking the rogation series of Seville (see chapter 9,2.) and exploring the spatial coverage of different recorded information.

Events of every sort were usually reported in broadsheets and pamphlets, called "relaciones", the forerunners of modern newspapers. Many of them reported weather occurrences of great impact. These reports, published immediately after the event, constitute reliable documents and when used with old records of official transactions provide important cross-references for information collected from other sources, such as chronicles and city histories. Chronicles and urban annals are miscellaneous on the subject of nature and generally report on the most extreme events which affected the local agriculture or the city water supply. Authors of such chronicles were usually priests, lawyers or merchants with similar cultural backgrounds. They were often eyewitnesses of the events, or they recorded their information from reliable oral and written sources. They all lived in Andalusian cities and were familiar with the "normal" behavior of the local climate. Such authors include, for example, Juan de Mariana (1536-1624) (1623), Jerónimo de Zurita (1512-1580) (Canellas López, 1976), Ximenez Paton (1569-1640) -who lived in Jaen (510 m above sea level) (Ortega y Sagrista, 1983), Rodrigo Caro (1573-1647) in Utrera (3 m above sea level) (Menendez Pelayo, 1883) and Bermudez de Pedraza (1585-1655) in Granada. A more detailed description of each source may be found in Barriendos (1994), Rodrigo (1994) and Rodrigo et al. (1995).

The criteria used for reliability are those of contemporaneity , propinquity , faithful transmission, cross-comparison of information from different sources and a good agreement with other proxy data, such as agricultural yields (wheat, wine), which have been compiled in various studies (e.g. Ponsot, 1986). Another reliability criterion is the accuracy of the authors when describing non- meteorological events, such as, for example, military and political events, plagues, famines, and known astronomical events (comets, eclipses). The data recorded are qualitative descriptions that for the greater part, but not always, deal with natural disasters and events that had a direct impact on the society of the period. Generally, the data correspond to extreme events relating to agricultural yields, such as the drying of rivers and springs, lack of rain, storms, dry and wet spells, floods, etc. All data are stored in the EURO-CLIMHIST data-base (Pfister et al., 1994). The main sources are listed in the appendix.



Figure 9. Main cities of the Iberian Peninsula where information was recorded.

The information recorded enables a general survey of precipitation in Andalusia and Catalonia during the sixteenth century (Figure 9). The nature of the records referring to extreme phenomena that had a direct impact on agriculture -mainly droughts, long-spell rains and floods -determines a seasonal resolution for most of them. The number of records related to rainfall by far exceeds any other type, such as those related to the thermal regime, winds and cloudiness. For this reason only a rainfall index was elaborated (see Glaser et al., this volume). This feature is explained by the link between rain and agricultural production, the main focus of attention of the sources. It also suggests that climatic change in the Iberian Peninsula may be related more to precipitation than to temperature. In fact, the rainfall regime dominates the present climatic pattern in Andalusia (Capel Molina and Andujar Castillo, 1978), and this result is consistent with modern studies which show that changes in prevailing (zonal or meridional) circulation responsible for climate changes do not have a statistical correlation with the temperature fluctuations in southern Europe (Kozuchowski, 1993).

9.2. DOCUMENTARY PROXY DATA

Besides urban annals, chronicles, brief accounts of journeys and events, etc., administrative documents were used in the analysis. This allowed a cross-checking of the events reported as well as a control, to some extent, of the subjectivity of the authors (Ingram et al., 1981). In order to obtain specific results within a limited time-span it became necessary to make a selection of documents to be consulted. Considering the length and quality of the series, the homogeneity of the recorded data and its absolute reliability, the books of resolutions of municipal authorities and cathedral chapters stood out: the daily activity of institutional officials in the towns and the nearby rural surroundings were recorded in these sources together with the deliberations of the officials involved. This included any events which altered the daily routine. These records frequently contain references to floods and meteorological anomalies such as droughts and long wet spells. By their very nature, these documents had to be signed by a public notary, who certified that everything registered in the document was factual.

Flood records often contain details on meteorological circumstances and hydrological characteristics of the disaster and list the damages caused to the infrastructure and to the populace. In the cases with more limited information, only the date of the flood and the seriousness of the damage caused was noted. The analysis of floods is based on the basic reference of the standard flood level at each observation point, i.e. the level reached by maximum swells when the water flow is contained within its banks. When the water exceeds these levels, flooding occurs. Two main categories can thus be distinguished: floods (when overflow is slight or lasts a short length of time and does not cause damage to city infrastructures) and severe floods, when the water causes serious damage to the city. In the last case, the force of water is capable of destroying buildings or any infrastructure near the water course (watermills, bridges, walls, builds, roads, etc.) (see Brazdil et al., this volume). Droughts and long wet spells were recorded with the system of rogations. These religious acts were performed in view of putting an end to a perceived meteorological stress which jeopardized the crops. The rogation system offers a follow-up to episodes of drought ("pro pluvia" rogations) and episodes of prolonged rainfall ("pro serenitate" rogations). The information in these proxy data is not very detailed, but it is highly reliable because the rogation procedures were carried out by professionals and rigorously controlled by the Catholic Church (Martin- Vide and Barriendos, 1995). Different institutions involved in the rogation mechanism provide relative reliability for the information: guild, municipal and ecclesiastical authorities participated in the generating process and definitive resolution of every episode of rogation ceremonies. Depending on the severity or

persistence of a phenomenon, different levels of rogations were performed. A detailed analysis of the system used in Barcelona shows five levels of drought intensity (Martin-Vide and Barriendos, 1995): Level I rogations consisted of simple prayers made during regular religious acts. The most frequent was a prayer during mass called "Colecta pro pluvia". Level II involved a public act, usually a display of relics or religious images in the cathedral. Level III involved the participation of most of the population in general processions which followed a specific route through the city. A level IV procedure involved an immersion of relics or religious images. Finally, a level V rogation required a mass pilgrimage to important regional sanctuaries. To gain an approximate idea of the significance of these levels, level I can be seen as having been virtually a preventive measure used when drought produced harvest problems albeit without significant damage. Levels II and III represented a considerable loss in the agricultural production and levels IV and V were invoked when nearly the entire crop was in jeopardy and general supply problems and subsistence crisis were impending. These levels allow quantifying "pro pluvia" rogations on an ordinal scale.

"Pro serenitate" rogations were held when a period of continuous rainfall jeopardized the progress of harvests. Long-term grain crops could be lost if long wet spells occurred at critical phases of agricultural activity, especially during the sowing and ripening of crops. In these situations the municipal and ecclesiastical authorities did not develop a system with as many levels as in the case of drought.

The study of rogations series has been developed for two cities in Catalonia (northeastern Spain): Barcelona (6 m a.s.l.) and Gerona (75 m a.s.l.); Toledo (512 m a.s.l.) on the central plateau; and Seville (10 m a.s.l.) in the Guadalquivir River valley in southwestern Spain. In addition, the study has been augmented with the flooding series of Lerida (155 m a.s.l.) and Tortosa (9 m a.s.l.) in western and southern Catalonia respectively, and drought and flood records in Malaga (7 m a.s.l.) on the Andalusian Mediterranean coast, Granada (670 m a.s.l.) in the vicinity of the Sierra Nevada mountains, the small town of Loja (495 m a.s.l.) near Granada, and a variety of documents contained in the local archives of Granada and Almeria (7 m a.s.l.). The study period is completely covered by documentary sources in similar conditions of homogeneity in all cases with the exception of Granada, where only the old transaction record books for the years 1497-1502, 1512-1522, 1556 and 1566 have survived. Fortunately, there is a complete series (1488-1600) in Loja, which is located 40 km from Granada and has similar climatological characteristics (Figure 8).

10. Conclusions and Perspectives

Some general conclusions may be drawn with regards to the documentary evidence thus far evaluated and analyzed: within central Europe (including northern Italy and non-Turkish Hungary) the types of evidence from which climatic information is drawn are quite similar. The basic type is the chronicle, usually containing lists of episodes which were thought to be memorable to the community for which the document was written. The question as to why so much care was taken to record weather events has hardly been investigated yet. It would be particularly worthwhile to relate this issue to the almost boundless literature on risk perception (e.g. Renn et al., 1992). It needs to be stressed that the type of classical chronicle devoted to the memorable events of everyday life does not exist in Spain. This also holds for weather diaries which emerged as a new type of source in the sixteenth century (Pfister et al., this volume).

There seems to be a relationship between the production of climatic records, the level of literacy and economic activity. This is most clearly seen from the example of the Czech Republic and Switzerland, where the density and quality of the data basis improves considerably from the second third of the century when springs and summers became warmer and drier. This relationship also holds for Hungary despite the continuous warfare against the Turks. In Germany this rise of intellectual activity seems to have taken place somewhat earlier than in the three countries mentioned before. On the other hand, such a trend is not mentioned in the pertinent sections of this article for Italy and Spain.

The potential of documentary data is far from being exhausted. Even in countries seemingly poor in palaeoclimatic documentary records, new types of promising data are waiting to be discovered, as Martin-Vide and Barriendos (1995) have convincingly shown from the example of rogations for Spain (and the overseas Spanish colonies). Outside Spain the existence of this kind of source was just known from a footnote in Le Roy Ladurie's "Times of Feast, Times of Famine" (1972). The Spanish scholars demonstrated that rogations were a response to real environmental stress and that they were administered in a standardized way throughout the Spanish world. In recent years Barriendos showed that rogation ceremonies are area-covering, continuous, quasi-homogeneous and quantifiable. To sum it up: Rogations are for Spain what vine harvest dates are for the climate history of France.

Continuous data from economic sources were less systematically explored. Most promising are those types of records which are in some way related to the timing of agricultural activities. A good example are dated records on wages paid for agricultural field work mentioned in the section on the Czech Republic. Similar records are also available for Germany (Militzer, 1993). Tithe auctions are another

harvest. The amount of the bidding had to be recorded and many of these records are dated. This proxy indicator seems to also be available for Germany (Bauernfeind, 1993). Data on wine production are another promising indicator as shown for Switzerland. They may be found in all the European regions where grapevines are grown. It is true that this evidence needs to be carefully verified and submitted to statistical analysis. On the other hand, it may yield long continuous series which are at the same time related to climatic parameters, economic activities (Landsteiner, this volume) and public perception (Behringer, this volume).

The evidence on extreme events is by far the most important concerning the present debate on the greenhouse effect. In contrast to other parameters, for which some substitute from natural archives is often available albeit with a lower time resolution, documentary data are the only evidence known to exist for reconstructing time series of natural disasters prior to the twentieth century. Conclusions solely based on twentieth-century evidence may be gravely misleading unless the natural variability in the decennial frequency of natural disasters is explored for recent centuries (de Kraker, this volume).

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