HISTORICAL CLIMATOLOGY IN EUROPE – THE STATE OF THE ART

RUDOLF BRÁZDIL[1], CHRISTIAN PFISTER[2], HEINZ WANNER[3],
HANS VON STORCH[4] and JÜRG LUTERBACHER[3]

[1]*Institute of Geography, Masaryk University, Kotlářská 2, CZ-611 37 Brno, The Czech Republic*
E - mail: brazdil@sci.muni.cz
[2]*Institute of History/NCCR Climate, University of Bern, Unitobler, CH-3000 Bern 9, Switzerland*
[3]*NCCR Climate, University of Bern, Hallerstrasse 12, CH-3012 Bern, Switzerland*
[4]*GKSS-Research-Center, Max Planck Strasse 1, D-21502 Geesthacht, Germany*

Abstract. This paper discusses the state of european research in historical climatology. This field of science and an overview of its development are described in detail. Special attention is given to the documentary evidence used for data sources, including its drawbacks and advantages. Further, methods and significant results of historical-climatological research, mainly achieved since 1990, are presented. the main focus concentrates on data, methods, definitions of the "Medieval Warm Period" and the "Little Ice Age", synoptic interpretation of past climates, climatic anomalies and natural disasters, and the vulnerability of economies and societies to climate as well as images and social representations of past weather and climate. The potential of historical climatology for climate modelling research is discussed briefly. Research perspectives in historical climatology are formulated with reference to data, methods, interdisciplinarity and impacts.

1. Introduction

Recent decades have witnessed a growing interest in past climate variability and climate change. This is related to the study of global warming resulting from the anthropogenic enhancement of the greenhouse effect (Houghton et al., 1996, 2001). Corresponding investigations were based mainly on global temperature series since the 1850s (Jones et al., 1986) or the 1880s (Hansen and Lebedeff, 1987; Vinnikov et al., 1990). These global series were further systematically updated and studied in many papers (e.g., Jones et al., 1999, 2001; Hansen et al., 1999, 2001). Historical climate analyses have improved the estimates of anthropogenic effects on climate by providing a more accurate understanding of the natural background climate variability. On a local or regional scale, many instrumental series from individual stations or regions exist, some of them reaching back as far as the 17th century (such as temperature series of Central England since 1659 – see Manley, 1974, or precipitation series for Kew, England since 1697 – Wales-Smith, 1971; Paris precipitation from the 1680s onwards – see Slonosky, 2002; temperature and pressure series from Paris and London – see Legrand and LeGoff, 1992; Slonosky et al., 2001) or the early 18th

century (homogenised daily temperature and pressure European series – see for   36
instance Jones, 2001; Bergström and Moberg, 2002; Camuffo, 2002a,b,c; Cocheo   37
and Camuffo, 2002; Jones and Lister, 2002; Maugeri et al., 2002a,b; Moberg et al.,   38
2000, 2002). Prior to these periods and prior to the establishment of national me-   39
teorological networks, information on past climates must necessarily be drawn   40
from non-instrumental man-made sources and from proxy evidence obtained from   41
natural archives. A historical source on climate is a document, i.e. a unit of in-   42
formation such as a manuscript, a piece of printed matter (book, newspaper etc.),   43
a picture or an artefact (e.g. a flood mark or an inscription on a house) which   44
refers to weather patterns or impacts of climate. The blanket term of documentary   45
evidence includes all kinds of man-made sources. Documentary evidence may in-   46
clude several types of data. For example, chronicles contain descriptive data (i.e.   47
descriptions of weather spells) that are often combined with documentary proxy-   48
data, i.e. observed features in the cryosphere (e.g. snowfalls, snow cover), the   49
hydrosphere (e.g. floods and low water tables) and the biosphere (e.g. stages of   50
vegetation).   51

Documentary evidence is the basis of many papers on historical climatology   52
(Brázdil, 2000, 2002; Pfister, 2001; Pfister et al., 2001). These papers have pro-   53
duced high-resolution climate reconstructions including time series of climatic   54
anomalies and natural disasters during the period when the effect of human so-   55
ciety on nature took place mainly at local or regional scales. Observed climate   56
variability was primarily the result of natural forcings such as solar or vol-   57
canic forcing or an interaction of ocean–atmosphere forcing without important   58
anthropogenic effects (greenhouse gases, aerosols, etc.). Historical climatology   59
contributes significantly to the understanding of climate processes prior to sys-   60
tematic human influence on the global atmosphere beginning with the industrial   61
revolution.   62

This paper provides an overview of the state of the art of historical clima-   63
tology in Europe. It points to novel fields and research priorities. The devel-   64
opment of historical climatology is outlined in Section 2. Section 3 discusses   65
the various sources of data as well as their temporal and geographic extent in   66
Europe. It also gives a detailed overview of the strong points and the draw-   67
backs of documentary data. An overview of the most important research top-   68
ics is provided in Section 4. In Section 5 significant research results achieved   69
since 1990, during the period of the most progressive development of histori-   70
cal climatology, are presented. Special attention is given to data and methods,   71
the climate paradigm of the last millennium, synoptic views on the past cli-   72
mate and extremes, climatic anomalies and natural disasters, the vulnerability   73
of economies and societies, images and social representations of past climatic   74
anomalies and natural disasters as well as to the potential of historical climatology   75
for climate modelling. Section 6 formulates future research priorities in historical   76
climatology.   77

78 ## 2. The Development of Historical Climatology

79 The development of the historical climatology may be introduced by describing the
80 few definitions that exist in the literature. Balandin (1975) was among the first to
81 use the term in his compilation of natural disasters from Russian chronicles. Ac-
82 cording to Ingram et al. (1978) historical climatology is "*concerned with the study*
83 *and climate interpretation of descriptive documentary evidence*". This definition
84 focuses on the word "historical" and is connected to the period for which written
85 records are available. However, in recent years the term "historical data" has been
86 used in a more fundamental way, merely reflecting the fact that the evidence refers
87 to some period in the past. "Historical data", surprisingly, has even been subsumed
88 under recent series of instrumental measurements (e.g. Vose et al., 1992). Thus, the
89 term "historical data" is becoming ambiguous and misleading. It therefore seems
90 advisable to avoid it altogether and to replace it with "documentary data". This
91 term is on the same level as the many kinds of data known from natural archives
92 (Pfister et al., 1999b).

93 Fairbridge (1987) expanded the term to the entire Holocene, characterising his-
94 torical climatology "*as the study of the climate through the time-range of civilised*
95 *Homo sapiens during the period in which human have developed the arts of writing*
96 *and the construction of permanent dwellings and other structures relating to their*
97 *maintenance and culture. This time-range varies from region to region. With respect*
98 *to the world's continually inhabited town Jericho in the Jordan valley, which was*
99 *established 10,000 years ago, the Holocene epoch became, however, the logical and*
100 *ultimate time frame of historical climatology*." This definition includes the entire
101 Holocene that seems to interfere with the definition of palaeoclimatology (Bradley,
102 1999).

103 Hagedorn and Glaser (1990) speak about "historical palaeoclimatology" instead
104 of historical climatology, "*which comprises that period for which the direct and/or*
105 *indirect written climatic information is available*". It is close to the concept of
106 Bradley (1999) who presents documentary data ("historical documentary records")
107 among proxy data for palaeoclimatic reconstructions. However, in Chapter 11 of
108 his book he uses also the term historical climatology. Glaser (1996) uses the term
109 historical climatology, but he leaves open its position with respect to palaeoclima-
110 tology.

111 Thus, the field began as a mostly technical approach of describing climate and
112 its variation during historical times and its impact on societies; recently the field is
113 changing towards a truly interdisciplinary field, where natural and social scientists
114 interact (von Storch and Stehr, 1997). In this spirit, following Pfister et al. (2001),
115 historical climatology is defined as a research field situated at the interface of cli-
116 matology and (environmental) history, dealing mainly with documentary evidence
117 and using the methodology of both climatology and history. It is directed towards
118 the following three objectives:

(i)   It aims at reconstructing temporal and spatial patterns of weather and **119**
      climate as well as climate-related natural disasters for the period prior **120**
      to the creation of national meteorological networks (mainly for the last **121**
      millennium).   **122**

(ii) It investigates the vulnerability of past societies and economies to climate **123**
      variations, climate extremes and natural disasters.   **124**

(iii) It explores past discourses and the social representations of the climate. **125**

The term "historical climatology" is also used in a completely different way. **126**
For example, in the United States, this term designates serial temperature and **127**
precipitation data from the period of network observations (Quinlan et al., 1987). **128**
The term "historical climatology" has also been used simply as a synonym for time **129**
series analysis of past instrumental observations (Kaas et al., 1996).   **130**

The beginnings of a scientific historical climatology, as we define it, are traced **131**
back to the late 19th and early 20th centuries. The Swiss physicist Louis Dufour **132**
(1870) was the first to discover the value of dates on the opening of vine harvests for **133**
the reconstruction of temperatures in the pre-instrumental period. He was followed **134**
by the French climatologist Alfred Angot (1885) who provided a catalogue of **135**
documentary evidence in France (Angot, 1895). In Switzerland, Eduard Brückner **136**
(Brückner, 1890; Stehr and von Storch, 2000a) analysed both instrumental and **137**
historical data over many parts of the world and documented transient climate **138**
variations, with a preferred time scale of 35 years, in great detail since 1790. In **139**
Germany, the climatologist Gustav Hellmann (e.g. 1921, 1926) was another pioneer **140**
of compiling documentary evidence in a scientific way. Another early synthesis was **141**
prepared in England by Charles Ernest Pelham Brooks (1926). Interestingly, he **142**
did not make any distinguishment between contemporary and non-contemporary **143**
sources. The same applies to the compilation made by Dutch journalist Cornelis **144**
Easton (1928) on winter temperatures. Over the following decades a number of **145**
climatologists provided isolated papers on partial reconstructions of past climate **146**
in Europe (see e.g. Lenke, 1964, 1968; Manley, 1974; Flohn, 1979, 1985, 1993). **147**

A milestone was the influential monograph of the French historian Emmanuel **148**
Le Roy Ladurie (1967) on the climate of the last millennium and its impact on **149**
society and history. Following the general paradigm after the demise of the cli- **150**
matic determinism, that social phenomena are supposed to be explained by social **151**
processes, Le Roy Ladurie was very reluctant to admit any societal relevance of **152**
climatic variations. The British climatologist Hubert Horace Lamb (1913–1997) **153**
became his most prominent opponent. He described and analysed the climate fluc- **154**
tuations of the last millennium in his voluminous work (see e.g. Lamb, 1965, **155**
1977, 1982, 1984, 1987, 1991). Lamb (1977) adopted the simple system of in- **156**
dices devised by Brooks (1926) for winter temperatures and summer precipitation **157**
and Easton (1928) for winter temperatures, and he was the first to devise synop- **158**
tic charts of pre-instrumental surface pressure distributions based on documentary **159**
data. Together with the German climatologist Hermann Flohn (e.g., Flohn, 1981), **160**

161 he was among the scientists who pointed out that societies would do well learning
162 some lessons provided by past climate. In 1979 Lamb helped to organise the first
163 International Conference on Climate and History which brought together a consid-
164 erable number of climatologists and historians (Wigley et al., 1981).
165   From the late 1970s the method of temperature and precipitation indices was
166 refined by the Swiss historian Christian Pfister in order to assess monthly and
167 seasonal temperature and precipitation for Switzerland from documentary data.
168 Based upon these reconstructions he then investigated the vulnerability of the major
169 agro-ecological regions to climatic fluctuations (Pfister, 1984, 1988b).
170   In 1987, the Belgian Pierre Alexandre (1987) published a capacious book on
171 the medieval climate in Western Europe (see also Yan et al., 1997). He tried to sys-
172 tematically apply the rules of historical sources criticism as was suggested earlier,
173 e.g. by Bell and Ogilvie (1978), Wigley (1978) and Ingram et al. (1981). Although
174 his book was a milestone for the critical analysis of medieval records, his method
175 of applying the system of intensity indices was not appropriate (Ornato, 1988).
176 Another problem of Alexandre's book is the lack of detailed information about
177 described events from the original sources. It means that researchers utilising his
178 reports must go back to original material. For example, Brázdil and Kotyza (1995)
179 criticised his reports from the Czech Lands with regards to their completeness,
180 interpretation and derived indices. The handling of medieval records and the recon-
181 struction of medieval climate was further developed by Pfister et al. (1996, 1998)
182 and Schwarz-Zanetti (1998). Neumann (1985) investigated the classical Greek and
183 Roman literature for references to climatic change. Panessa (1991) compiled a
184 substantial number of sources on the climate and environmental history of Ancient
185 Greece. For the Byzantine world a handsome synthesis covering the entire medieval
186 period from 300 to 1500 AD was recently provided by Telelis (2000, in press; see
187 also Stathakopoulos, 2003).
188   Over the 1990s, climate research was stimulated by discussion related to the
189 enhanced greenhouse effect. Therefore the interest for studies on climatic change
190 prior to the human-induced time period also grew rapidly. A loose network of
191 scholars engaged in historical climatology emerged in this context around research
192 programmes of the European Science Foundation (see e.g. Frenzel et al., 1992,
193 1994) and the European Union. For example, 50 geographers, environmental histo-
194 rians, palaeoecologists, physicists and meteorologists originating from 15 European
195 countries engaged in the study of the Late Maunder Minimum (LMM), as the pe-
196 riod from 1675 to 1715 was called (e.g. Frenzel et al., 1994; Wanner et al., 1994,
197 1995) and subsequently this period became a focus for further climatological anal-
198 yses (e.g. Pedersen, 1996; Barriendos, 1997; Alcoforado et al., 2000; Luterbacher,
199 2001; Luterbacher et al., 2001; Xoplaki et al., 2001; Shindell et al., 2001, 2003;
200 von Storch, in press; Zinke et al., in press).
201   Based on a critical evaluation of the sources and methodology used by Pfister
202 (1984) in Switzerland, the creation of a series of temperature and precipitation in-
203 dices was extended to the Czech Republic (Brázdil, 1996), Germany (Glaser, 1997),

Hungary (Rácz, 1999) and the Low countries (i.e. the present-day Netherlands and 204
Belgian Flanders – van Engelen et al., 2000, 2001). Corresponding index series for 205
these regions and partly for Italy and Poland were presented for the 16th century 206
by Glaser et al. (1999b). Ogilvie and Farmer (1997) published temperature and 207
precipitation indices for England for the period AD 1200–1439. Alcoforado et al. 208
(2000) and Xoplaki et al. (2001) developed monthly temperature and precipitation 209
indices for the Late Maunder Minimum period for Portugal and Greece, respec- 210
tively. Instead of index series, time series quantified in terms of temperature (°C) and 211
precipitation (mm or %) units and expressed, for instance, in the form of anomalies 212
from a more recent reference period (e.g. 1901–1960) forms a set of climatological 213
analyses that are easily comparable. Pfister and Brázdil (1999) calculated such aver- 214
age series of temperature and precipitation anomalies in Central Europe for the 16th 215
century by weighted averaging of data from Germany, Switzerland and the Czech 216
Republic. Similar quantitatively interpreted series, based mainly on documentary 217
evidence in Europe, are available for Switzerland (Pfister, 1984, 1999), Germany 218
(Glaser et al., 1999a; Glaser, 2001), the low countries (van den Dool et al., 1978; 219
Buisman and van Engelen, 1995, 1996, 1998, 2000; van Engelen et al., 2000, 2001; 220
Shabalova and van Engelen, 2003), Hungary (Rácz, 1999), Andalusia (southern 221
Spain; Rodrigo et al., 1999, 2001) and on the decadal scale for the Czech Republic 222
(Brázdil, 1996). 223

A further step in climate reconstruction was achieved by Guiot (1992) who used 224
a combination of documentary proxy evidence, European and Moroccan tree-ring 225
data and ^{18}O data from Greenland to provide annual temperature estimates from 226
AD 1068–1979 for the area 35°N–55°N and 10°W–20°E. He found a significant 227
connection between Northwest Europe and the Central Mediterranean region (Italy) 228
during the 'Little Ice Age', while the Western Mediterranean region (Spain, Mo- 229
rocco) had not experienced any significant cooling. Mann et al. (2000) later on used 230
a multi-proxy predictor network, including a combination of documentary data and 231
natural proxy data, in order to derive seasonal and annual temperature patterns for 232
Europe back to the mid-18th century. Further, Luterbacher et al. (1999, 2000, 2001, 233
2002a,b, 2004) were able, statistically, to derive spatial charts of monthly (back 234
to 1659) and seasonal (back to 1500) reconstructions of temperature, sea level 235
pressure, 500-hPa geopotential height fields, North Atlantic Oscillation and other 236
circulation indices as well as precipitation from documentary and early instrumen- 237
tal series for the whole of Europe (see Section 5.2). Luterbacher and Xoplaki (2003) 238
recently derived gridded and spatially averaged temperature and precipitation series 239
over the last 500 years for the Mediterranean land area. 240

Another recent development is the attempt to reconstruct climate and climate 241
variations outside the regions for which documentary data are available. Two ap- 242
proaches are in use, namely an empirical statistical one, and the approach with the 243
use of physical climate models. 244

The empirical statistical line of research is using the statistical upscaling concept, 245
i.e., regional reconstructions of temperature and precipitation in Europe are used 246

247 to estimate the state of the North Atlantic Oscillation (NAO) and other parameters
248 of atmospheric circulation (e.g. Luterbacher et al., 1999, 2002a,b; Schmutz et al.,
249 2000; Wanner et al., 2001). But the NAO influence on temperature and precipitation
250 at specific locations can vary with time (see e.g. Jacobeit et al. 2001; Pozo-Vazquez
251 et al., 2001; Slonosky and Yiou, 2002; Jones et al., 2003a). The empirical approach
252 is limited by the necessary condition that the empirically determined upscaling
253 relationship remains stationary during the course of time, which does not seem
254 always to be the case (Schmutz et al., 2000; Luterbacher et al., 2002a,b; Zorita and
255 González-Rouco, 2002).
256   The dynamical line of research relies on physical climate models (energy bal-
257 ance, radiative–convective or general circulation models – GCMs). These models
258 have been integrated subject for reconstructed forcing factors such as volcanic
259 aerosols in the stratosphere, greenhouse gas concentrations and solar luminosity
260 variations for several hundred years (e.g., Cubasch et al., 1997; Crowley, 2000;
261 Fischer-Bruns et al., 2002; Bauer et al., 2003; Zorita et al., in press). This has be-
262 come possible after significant progress has been made in reconstructing the history
263 or relevant time-variable forcing factors, in particular the atmospheric load of vol-
264 canic aerosols and the output of the Sun (Crowley, 2000). The response of physical
265 climate models of different complexity to this forcing history can be used to estimate
266 past climate variations (for example, see Section 5.7) and to determine the sensitiv-
267 ity of the climate system to external forcing. The skill of the dynamic approach is
268 limited not only because of computation restrictions, the need to parameterise vari-
269 ous important physical processes, and the incomplete knowledge about the forcing
270 factors. It is also limited because the state of the climate system is only partially de-
271 termined by external factors (Hasselmann, 1976; Cubasch et al., 1994; von Storch
272 and Hasselmann, 1996). The recently developed concept of "Data Assimilation
273 Through Upscaling and Nudging" – DATUN (see von Storch et al., 2000; Widmann
274 et al., in press) may overcome this problem, but the method is still in its infancy.
275   Over the period of the greatest advances in historical climatology, historians
276 turned away from the study of climate as a potential impact factor, even within
277 fields of potential vulnerability such as demography or agrarian history (Pfister,
278 2001). The discourse about the potential impact of climate on society and his-
279 tory continues to suffer from the legacy of climatic determinism (for an account,
280 see e.g., von Storch and Stehr, 1997; Stehr and von Storch, 2000b). According
281 to this school of thought (e.g., Brückner, 1890; Semple, 1911; Huntington, 1925;
282 Markham, 1947), the skills and properties of people, the changing political power
283 configurations, suicide rates, stock market variations and many other psychological,
284 intellectual and social attributes and processes are the outcome of climatic condi-
285 tions and variability. Together with other types of environmental determinism, this
286 theory was solidly discredited in the latter half of the 20th century; at present, how-
287 ever, these views are still present in everyday life. In the social and cultural sciences,
288 Emile Durkheim's principle (Durkheim, 1982) that social phenomena have to be
289 explained as the result of other social processes dominates the discourse. Hardly

any reputable contemporary social and cultural scientist advocates the principle 290
that environmental conditions have a direct, unmediated impact on social life. This 291
obviously represents somewhat of a problem since much of the debate about an- 292
thropogenic climate change and its impact on modern societies is implicated in this 293
issue. As a result, natural scientists, less aware of and less affected by past debates 294
among cultural and social scientists often summon everyday knowledge in order 295
to refer to the ways and the strength in which climate impacts acquire on society. 296
As a result, a not insignificant part of climate impact research is indebted to the 297
ideology of climatic determinism. 298

Fortunately, more recently, there is a growing interest in cultural history in the 299
perception and the ways of coping with climatic anomalies and natural disasters. 300
An excellent example is the analysis by Pfister and Brändli (1999) of the societal 301
response to flooding in the mid-19th century in Switzerland, which ultimately led 302
to beneficial legislation against logging in the Alpine mountains although the law 303
was based on the false premise that such logging was responsible for the frequent 304
floods the country experienced at that time. The Swiss case study may serve as a 305
relevant analogue for contemporary public discourse on natural disasters, human 306
influences and social impacts. Another such case is the description by Brönnimann 307
(2002), who showed that the same symbols of climate change (palms and glaciers) 308
were used in the early 20th as in the late 20th century. The most recent concern 309
about anthropogenic climate change is historically not a new phenomenon. It was 310
described by Brückner (1890) and more broadly by von Storch and Stehr (2000, 311
2002). Further debate on this topic occurred recently (September 2002, Göttingen, 312
Germany) at a conference on the "Cultural consequences of the Little Ice Age" 313
(Behringer et al., in press). 314

The main achievements of the period since 1990 are listed in Table I. They are 315
discussed in somewhat more detail in subsequent sections of the paper. 316

3. The Potential and the Limitations of Documentary Data   317

The data base for historical–climatological research can be broadly categorised as 318
being either direct or indirect data. The direct data can be thought of as descriptive 319
documentary data, for example narrative descriptions of weather patterns or early 320
instrumental measurements. Indirect or documentary proxy data reflects the impact 321
of weather on elements in the hydrosphere, the cryosphere or the biosphere (e.g. 322
floods, the freezing of waterways or the beginning/end of grain or wine harvest). 323
According to their origin, indirect data can be either man-made or based on natural 324
proxy evidence (Figure 1). 325

Documentary data are the only kind of palaeoclimatic data that are based on 326
direct observations of different meteorological parameters (temperature, precipita- 327
tion, snow-cover, sea ice distribution, cloudiness, wind, lake levels etc.) in terms of 328
narrative descriptions and/or early instrumental measurements. For this reason they 329

TABLE I
Main achievements in historical climatology in Europe since 1990

(i) Broader use of traditional documentary evidence including new kinds of sources (see Section 5.1). Building up and improving historical climatological data bases (e.g. HISKLID for Germany, EURO-CLIMHIST for Europe) (http://www.euroclimhist.com/; Dietrich, 2003).

(ii) Standardisation of the methodology of intensity indices (see Section 4.1).

(iii) Validating the intensity indices (see Sections 4.2 and 4.3).

(iv) Multiproxy mapping (see Section 5.2).

(v) Statistical derivation of spatial variability of temperature, air pressure and precipitation distribution for the whole of Europe (see Section 5.2).

(vi) Defining the Medieval Warm Period (MWP) and the Little Ice Age (LIA) (see Section 5.3).

(vii) Climatological and statistical analyses of climatic anomalies and natural disasters (see Section 5.4).

(viii) Impacts of climate and natural disasters on and the adaptation strategies of past societies (see Sections 5.5 and 5.6).

(ix) First extended reconstructions of global climate conditions with full climate models, as a response to time variable forcing factors (volcanic aerosol load, solar output, greenhouse gas loads) (see Section 5.7).

Archives / Information	Natural		Man-made	
direct observation of weather and climate or **instrumental measurement** of meteorological parameters			**D o c u m e n t a r y** **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. • **cultural:** rogations • **pictorial** material:	**non-organic** • water levels • snow fall • freezing of water bodies • snow cover, etc. • **epigraphical** • archeological remains

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

330 can be used both for verification of extreme values in natural proxies such as tree
331 rings (see e.g. Vogel et al., 1996; Brázdil et al., 2002a) and for detailed descriptions
332 of past weather such as after major volcanic eruptions (see e.g. Stothers, 1996,
333 1999, 2000; Demarée et al., 1998; Demarée and Ogilvie, 2001). Most importantly

they are the only evidence that is directly related to the socio-economic impacts of   **334**
rare but significant disasters such as intense storms, severe floods, and long-lasting   **335**
droughts in the period prior to the organisation of instrumental network observa-   **336**
tions. For this reason, reconstructions based on documentary data play an important   **337**
role in the enhanced greenhouse debate.   **338**

Moreover, apart from vine harvest dates, a great variety of other documentary   **339**
proxy data were discovered over the past 25 years. Direct or indirect references to   **340**
physical and biological indicators of the environment are more or less systematically   **341**
included in narrative sources, as many observers were well aware that their records   **342**
included a subjective bias. Compared to descriptive documentary data which are   **343**
limited by the activity of the observer, some kinds of documentary proxy data,   **344**
inasmuch they are produced by administrative routine (e.g. vine harvest dates), are   **345**
available over periods of several centuries.   **346**

Early instrumental records made before the beginning of systematic meteorolog-   **347**
ical observations, in most cases cover only short periods or have sporadic character.   **348**
Lack of detailed knowledge of the instruments and of their locations makes linkage   **349**
to the modern reference period difficult and requires careful homogenisation (e.g.,   **350**
Wishman et al., 1998; Moberg et al., 2000; Brázdil et al., 2002b; Camuffo and   **351**
Jones, 2002). Beginnings of instrumental observations in Europe have been sum-   **352**
marised, for instance, by Frisinger (1977), Kington (1988), and in a greater detail   **353**
they were described by Camuffo (2002a). The basis for it was the invention of some   **354**
meteorological instruments by Galileo Galilei (1564–1642), his students and fol-   **355**
lowers in Italy. It was realised that the value of instrumental observations would be   **356**
importantly enhanced if measurements could be made simultaneously at different   **357**
places. The first international meteorological network, called Rete Medicea, started   **358**
between the years 1653–1654 with ten European stations. It was established by the   **359**
Grand Duke of Tuscany and a founder of the Accademia del Cimento (Academy of   **360**
Experiments) in Florence (in 1657), Ferdinand II, and his brother Prince Leopold   **361**
de' Medici. The network ceased to function after the Accademia del Cimento was   **362**
disbanded in 1667.   **363**

Johann Kanold, a doctor in Breslau (i.e. Wrocaw, Poland), organised the first   **364**
network of correspondents in Central Europe and published quarterly instrumen-   **365**
tal measurements and weather reports from 1717 to 1726 in "Sammlung von   **366**
Natur- und Medicin, wie auch hierzu gehörigen Kunst- und Literatur-Geschichten"   **367**
(Kanold, 1718–1727; see also Hellmann, 1914; Brázdil and Valášek, 2002; Munzar,   **368**
2002). It was continued from 1727–1730 by Andreas Elias Büchner, a professor of   **369**
medicine at Erfurt (Germany), in "Miscellanea Physico-Medico-Mathematica, oder   **370**
angenehme, curieuse und nützliche Nachrichten von Physical- und Medicinischen-,   **371**
auch dahin gehörigen Kunst- und Literatur-Geschichten".   **372**

Another attempt to organise an international meteorological network was done   **373**
in 1723 by James Jurin, secretary of the Royal Society of London (Jurin, 1723).   **374**
This network existed between 1724 and 1735 and observations were published in   **375**
the Philosophical Transactions.   **376**

377   In 1780, Karl Theodor, the elector of the Palatinate, set up the most important
378 early international network in the form of the "Societas Meteorologica Palatina." At
379 the time of its largest extension, the network of this society comprised 39 stations
380 ranging from Greenland to Rome and from La Rochelle (France) to Moscow. All
381 the stations used standardised instruments and made their observations according to
382 the regulations issued by the society with annual publishing of their results during
383 1780–1792 (Kington, 1988).
384   Some of the very early measurements have been systematically analysed. One
385 of the pioneers of instrumental observations was Louis Morin, a physician in Paris.
386 His observations, including three daily readings of temperature and pressure, were
387 carried out in 1665–1713 (Legrand and LeGoff, 1992; Pfister and Bareiss, 1994).
388 Based on observations of Nicolaus Cruquius, a cartographer and hydraulic engineer,
389 the Delft/Rijnsburg series (the Netherlands) of monthly temperatures for 1706–
390 1734 was rediscovered and published by van Engelen and Geurts (1985). Another
391 of their compilations shows an example of a basic metadata of early instrumental
392 measurements (Geurts and van Engelen, 1992). Kington (1988) collected a list of
393 many further instrumental records in Europe, made during the 1780s.
394   Meteorological activities of many physicians were connected with the neo-
395 Hippocratic hypothesis about the relations between the climate and human health. It
396 had its origin in Hippocratos of Chios (born about 460 – died probably in 377 B.C.), a
397 Greek physician and philosopher, who considered a disease as the failure of balance
398 between the organism and the environment, including the weather and climate.
399 Hippocrates' ideas appeared in modern times in the work of the English physician,
400 Thomas Sydenham, (1624–1689) who believed that atmospheric conditions played
401 an important role in diseases. The action of the climate on man was, according
402 to 18th century physicians, due to the effect of air which man inhales. The effort
403 in quantifying the effect of meteorological conditions then led the physicians to
404 perform meteorological observations (Demarée, 1996).
405   Descriptive documentary evidence includes both direct data about the weather
406 and about phenomena and events dependent on the weather. This is an exception-
407 ally rich source, including written reports from annals, memoirs and chronicles,
408 daily weather reports, personal and official correspondence, travel diaries, eco-
409 nomic records, pictures, leaflet newspapers, early journalism, ship logbooks etc.
410 Epigraphic records of extreme weather (for instance floods) include inscriptions
411 and marks on stones, rocks, bridges or buildings. Such records may contain either
412 sporadic or continuously recorded data. In all cases it needs to be assessed whether
413 a source is contemporary, i.e. whether authors witnessed the events they describe or
414 whether these events at least occurred during their life-time. Observations, which
415 were copied from other documents or compilations, often contain transcription er-
416 rors in the dates of observations (e.g. Bell and Ogilvie, 1978; Ingram et al., 1981;
417 Schwarz-Zanetti, 1998). If events were copied from other chronicles, misdating
418 occurred frequently. For instance, Bell and Ogilvie (1978) showed a spurious mul-
419 tiplication of a storm flood event in Flanders on 16 November 1377: Weikinn's

(1958–2002) compilation includes seven different references to this event dated   **420**
from 1374 to 1377, based on one single original source (Chronicon comitum Flan-   **421**
drensium). Correct dating is a difficult problem. In 1582 Pope Gregory reconciled   **422**
the old Julian calendar to an exact degree by cutting off 10 days. Dates prior to   **423**
this year need to be corrected accordingly (Bachmann, 1984; Alexandre, 1987).   **424**
Gregory's reform was only adopted piecemeal, even in the catholic world. Thus, it   **425**
must be assessed for every territory, whether the 'old' or the 'new' style was even-   **426**
tually used. For example, England adopted the New Style by an Act of Parliament   **427**
as late as 1752 (Grotefend, 1982). Furthermore, there is a considerable variation   **428**
in the beginning of the year. In the Middle Ages no less than seven possibilities   **429**
were known. Most medieval sources are tacit with respect to the dating which they   **430**
used (von Brandt, 1996). For events in 'winter', many sources give just one year for   **431**
identification. In this case it must be derived from the context or from other sources   **432**
whether the 'old' or the 'new' year is meant (Pfister, 1992). Roman numbers that   **433**
were in use into the late 17th or early 18th century are particularly error-prone.   **434**
An example is provided by Camuffo and Enzi (1992): The 18th century chronicler   **435**
Giuseppe Toaldo through a reading error, changed an X into II, transforming the   **436**
year MDXI (1511) into MDIII (1503), and wrote that the artillery of Pope Julius II   **437**
crossed the frozen river Po in this year. This statement was then propagated as an   **438**
independent event, in addition to the correctly reported event of 1511. In his critical   **439**
catalogue of more than 3500 "climatic texts" from AD 1000 to 1425 Alexandre   **440**
(1987) lists 300 inconsistencies of this kind (for critical evaluation of medieval   **441**
weather reports see e.g. Malewicz, 1980 for Poland, Brázdil and Kotyza, 1995   **442**
for the Czech Lands and Kiss, 1999, 2000 for eastern Central Europe). Suspicion   **443**
should be thrown on compilations of climatic events, including recent ones, for   **444**
which it is not assured that sources were critically evaluated.   **445**

   In interpreting medieval documents the particular conditions in which the doc-   **446**
uments were created need to be considered. Many manuscripts are anonymous and   **447**
the year of composition is not given. Analyses of handwriting yield only approxi-   **448**
mate results. Occasionally authorship may be derived from personal remarks in the   **449**
text. Even if the name of an author is known, their exact lifetime is often ignored.   **450**
Thus, it may be difficult to assess whether an author actually witnessed the event   **451**
described. Before the art of printing was invented in the 15th century, books had to   **452**
be copied by hand. During the Early and High Middle Ages this was done in the   **453**
scriptoria of monasteries. For this purpose manuscripts were frequently exchanged   **454**
between monasteries. As a consequence, chronicles may have survived in a number   **455**
of copies which are not entirely identical and which are today often deposited in   **456**
libraries of different countries or private collections. The philological work of crit-   **457**
ical text edition attempts to assess which is the oldest manuscript – the archetype –   **458**
and to establish its relationship with the more recent copies (van Caenegem, 1979;   **459**
Faulstich, 1996).   **460**

   Uncritical use of documentary data is not only found in compilations of weather   **461**
reports from different sources (such as Strnadt, 1790; Amberg, 1890; Hennig, 1904;   **462**

463 Weikinn, 1958–2002), but it is also found in more recent publications of authors
464 who are not so familiar with documentary evidence (for example Bernhardt and
465 Mäder, 1987 used as basic data reports of Hennig, 1904). Moreover, Hennig's (1904)
466 reports have also been used as the basic data source for description of past weather
467 patterns in Western Europe (e.g. Barash, 1989). Questionable reconstructions of
468 climate from documentary data should not be blamed on the chroniclers without
469 justification. Rather an improper interpretation of data by the researcher should be
470 assumed.
471   Archaeological data, including for instance evidence of extinction and desertion
472 of settlements, are often taken as resulting from the long-term effects of climate
473 and/or climatic extremes, but the connection with climate is in many cases am-
474 biguous (Brázdil and Kotyza, 1995). In most cases, a direct effect appears unlikely,
475 but deteriorating climatic conditions may have aggravated problems in the social
476 organisation and functioning. On the other hand, DeMenocal (2001) has presented
477 four case studies drawn from New and Old World civilisations, integrating detailed
478 archaeological and palaeoclimatic records, in which he has shown their societal
479 responses to prolonged droughts, including population dislocations, urban aban-
480 donment and state collapse.
481   Using records from natural archives or series of documentary proxy data (e.g.
482 wine harvest dates) the climatic signal needs to be extracted from a series of proxy
483 data. As a rule, the climatic information obtained relates to a certain type of me-
484 terological data, such as air temperature or precipitation, with a time resolution
485 of months or longer. The most frequently used natural proxies are those relating
486 to the historical fluctuations of glacier tongues, changes in the composition of ice
487 cores, tree rings (ring width and density of late wood), pollen-profiles, varved sedi-
488 ments taken from the sea floor or from lake floors, erosion furrow fills, geothermic
489 evidence, speleothem records, corals, etc. (e.g., Holzhauser, 1997; Bradley, 1999;
490 Huang et al., 2000; Proctor et al., 2000, 2002; Baker et al., 2002; Zinke et al., in
491 press). However, most reconstructions from natural archives cannot be broken down
492 to seasonal or monthly resolution and they do not always yield a distinct separation
493 of the effects of temperature and precipitation (Bradley, 1999). But this high reso-
494 lution is needed for investigating climatic impacts on societies. Mann et al. (2000)
495 recently published warm and cold-season European reconstructions for Europe
496 back to 1760. The uncertainties, however, are quite large for these estimates.
497   Series of documentary proxy data are mostly drawn from administrative records.
498 Often such series are long, continuous and quasi-homogeneous so that they can
499 be calibrated against instrumental measurements. Documentary proxy data may
500 reflect the beginning of agricultural activities such as the grain or the vine harvest,
501 agricultural production (e.g. yield of vineyards), the time of freezing and opening up
502 of sea-ports or inland waterways, or that of religious ceremonies (e.g. Pfister, 1979,
503 1981, 1984; Tarand and Kuiv, 1994; Martín-Vide and Barriendos, 1995; de Kraker,
504 1999; Brázdil and Kotyza, 2000), or the sailing time needed for routine journeys
505 (e.g., García et al., 2000).

Phenology which is "*the art of observing life cycles, phases or activities of plants* **506**
and animals in their temporal occurrence throughout the year" (Lieth, 1974), has **507**
gained attention within the global change community over the last few years as **508**
an important indicator for global change (Menzel, 2002). A trend towards earlier **509**
spring phenophases during the last 50 years taken from a wide range of different **510**
data has been reported for the northern mid-latitudes. Menzel and Estrella (2001) **511**
provide an overview over the data sets known in this community. However, only a **512**
few historical data sets reaching back further than 50 years have been analysed (e.g. **513**
Sparks and Carey, 1995; Maak and von Storch, 1997; Nordli, 2001) even though **514**
plant observations carried out by volunteers and amateurs date back for several **515**
centuries (Pfister, 1992). **516**

Documentary proxy data is made up of a broad variety of indicators that are as **517**
different among themselves as natural proxy data. Each kind of documentary proxy **518**
data needs to be calibrated against (early) instrumental series and is restricted to **519**
specific periods of the year in the same way as natural proxy data. **520**

In relation to natural proxy data, descriptive documentary data has its advantages **521**
and limitations, which are respectively detailed below (Pfister et al., 1999b): **522**

  (i) Good dating control and high temporal resolution. **523**
 (ii) Clear distinguishment of meteorological elements in the narrative reports **524**
       (e.g. temperature, precipitation, snow cover, wind). **525**
(iii) Focus on anomalies and natural disasters. **526**
 (iv) Taken together they cover all months and seasons (even autumn). **527**

The following drawbacks are mentioned (Pfister et al., 1999b): **528**

  (i) Discontinuous structure of the records (due to the death of observers). **529**
 (ii) Bias by the selective perceptions of observers. **530**
(iii) Mathematical analysis is simple but robust, however this may be a drawback **531**
       for the acceptance of results in the scientific community. **532**

The geographical range of documentary data depends on (Pfister, 2001): **533**

  (i) The sedentary presence of literate individuals. This excludes the high alti- **534**
       tudes and high latitudes. **535**
 (ii) An appropriate institutional and cultural framework (e.g. the existence of **536**
       conventions, the existence of local elites in towns). **537**
(iii) A tradition of keeping chronicles of extraordinary events based on eyewit- **538**
       ness observations. **539**

As far as Western and Central Europe is concerned, the temporal range is re- **540**
stricted to the past millennium. Over that period the density and quality of infor- **541**
mation increases as follows (Pfister, 2001): **542**

  (i) Prior to AD 1300: Reports of socio-economically significant anomalies and **543**
       (natural) disasters. **544**

545   (ii) 1300–1500: More or less continuous reports on characteristics of summers
546   and winters (to some extent also on those of spring and autumn) including
547   reference to "normal" conditions.
548   (iii) 1500–1800: Almost complete description of monthly weather, to some
549   extent also of daily weather. Growing number and diversity of continuous
550   series of documentary proxy data produced by the early modern local,
551   regional and state bureaucracies.
552   (iv) 1680–1860: Instrumental measurements made by isolated individuals. First
553   short-lived international network observations (e.g. Breslau-Network and
554   Palatine-Network).
555   (v) From 1860: Instrumental observations in the framework of national and
556   international meteorological networks.

557 The list needs to be understood in a cumulative way, i.e. older kinds of climate
558 observations are not replaced but superposed by more recent ones. In sum, the
559 quality of the data improves, their density and their time resolution increases and
560 their spatial coverage extends over time.

561 Outside the Byzantine empire (see e.g. Telelis, 2000, 2003; Stathakopoulos,
562 2003) the conditions mentioned above were met first in the reign of Charlemagne
563 (9th century AD) that includes most of the territory of contemporary Germany and
564 France, Belgium and the Netherlands, Switzerland and Northern Italy, as well as in
565 Ireland (Crawford, 1989) and to some extent in England. From about AD 1050 the
566 tradition of keeping chronicles spread to the territories of contemporary Catalonia
567 (Spain), the Czech Republic, Denmark, Hungary, Iceland, Poland and Slovakia, later
568 on also to the Baltic, Russia and the territory of contemporary Finland. Records
569 from southeastern Europe are scanty until the 18th century.

570   4. Methods of Analysis

571 A possible procedure of data analysis and climate reconstruction is shown in
572 Figure 2. It usually starts with the search of suitable documentary data or natu-
573 ral proxy indicators that are able to define a high amount of climate variability
574 of a certain climate variable like temperature, precipitation, air pressure, etc. All
575 proxies are then transformed into a time series with a clearly defined temporal
576 resolution. In the case of natural proxies this is often a very complex procedure
577 requiring specialised laboratories applying sophisticated physical and chemical
578 analysis techniques. In the case of documentary data, the statistical transformation
579 into ordinal data in the form of a time series of indices is also a great challenge
580 requiring a broad statistical and dynamical understanding.

581 4.1. THE DERIVATION OF PROXY SERIES BASED ON DOCUMENTARY EVIDENCE

582 In most cases a climate reconstruction involves different kinds of documentary
583 data. If the data-basis is broad enough, one may expect that the strengths and
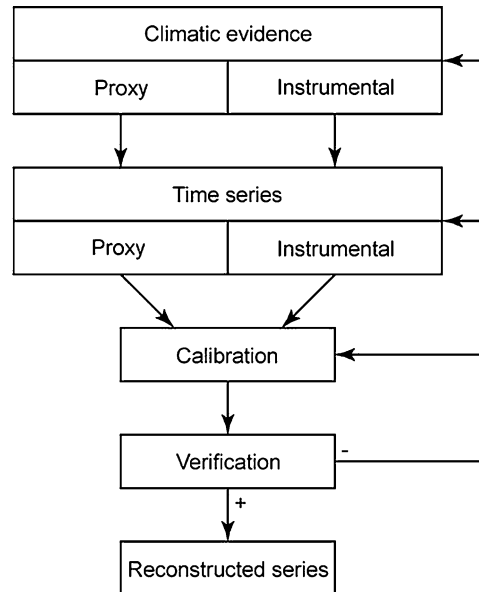
Figure 2. The process of climate reconstruction, including documentary data (Brázdil, 2002).

weaknesses of different data types control and complement each other to a certain **584**
degree (Pauling et al., 2003). The first step in the procedure includes evaluation of **585**
available documentary data with consideration of critical analysis of sources, author **586**
and/or institutional framework, calibration of documentary proxy data, etc. The **587**
comparison and cross-checking of data from different documentary sources, both **588**
direct and indirect, should allow assessment of an unequivocal climatic tendency, **589**
within a given temporal and spatial domain. This tendency is expressed in form **590**
of an intensity index for temperature and/or precipitation which is attributed to **591**
the month or season under investigation (Pfister, 2001). Series of intensity indices **592**
obtained from documentary evidence should overlap the period of instrumental **593**
measurements. This is only possible for a few cases and very distinct periods **594**
(Pauling et al., 2003). **595**

Useful values from documentary evidence are obtained by transforming the **596**
basic data into simple and weighted temperature and precipitation indices on an **597**
ordinal scale. Simple monthly indices use a three-term classification (temperature: **598**
1 warm, 0 normal, −1 cold; precipitation: 1 wet, 0 normal, −1 dry). Weighted **599**
monthly indices are based on a seven-term classification for temperature (3 ex- **600**
tremely warm, 2 very warm, 1 warm, 0 normal, –1 cold, –2 very cold, –3 extremely **601**
cold) and for precipitation correspondingly. Seasonal or annual indices are obtained **602**
by summation of monthly values. Thus, in simple indices the three-month seasonal **603**
values (e.g. DJF, MAM, JJA, SON) can fluctuate from –3 to 3, weighted ones from **604**
–9 to 9. In order to make weighted indices compatible with the simple ones, they **605**
can be divided by 3 and issued with one decimal place. Compilation depends on **606**
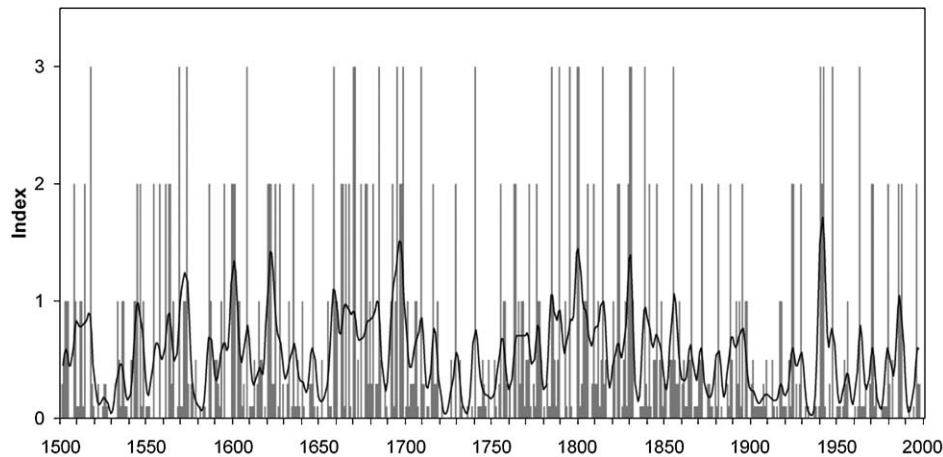
Figure 3. Fluctuations of ice winter index in the western Baltic in 1501–1995 (data in Koslowski and Glaser, 1999). Smoothed by a 10-year Gaussian filter.

607 the density and quality of the basic information, and is to some extent affected by
608 the subjectivity of the researcher.
609   Scaling into ordinal numbers is an obvious step when dealing with documentary
610 data. To mention some examples, Wang et al. (1991) scaled climate indicators for
611 definition of warm/cold climate index in China from 0 to 3 (0 – no records, 1 –
612 existing, 2 – severe, 3 – extremely severe), while van Engelen et al. (2001) used an
613 ordinal scale from 1 to 9 for reconstruction of winter (from 1 – extremely mild to 9
614 – extremely severe) and summer (from 1 – extremely cool to 9 – extremely warm)
615 temperatures in the low countries. The index approach is also applied to proxy
616 documentary data. Koslowski and Glaser (1999) developed an ice winter index
617 (Figure 3) from accumulated areal ice volume along the German Baltic coast with
618 gradation of winter severity types: 0 – weak, 1 – strong, 2 – very strong, 3 – extreme.
619   Pfister (1999) suggested to begin reconstruction of intensity indices from the in-
620 strumental period, where most variables are available and then to work subsequently
621 backwards, where less and less details are known. This approach called "Wetter-
622 nachhersage" (i.e. backward-reconstruction) should not be done chronologically,
623 but according to types of anomalies.
624   Prior to further elaboration of this method (i.e. calibration, verification and
625 reconstruction), three important questions have to be asked:

626   (i) Which are the best predictors?
627   (ii) Which are the best sites for an accurate prediction?
628   (iii) Which are the best methods to sort out best predictors and sites and to get
629   valuable spatio-temporal reconstructions?

630 In recent years sophisticated methods were developed to give answers to these
631 questions (e.g., Bradley, 1996; Kaplan et al., 1997; Evans et al., 1998; Jones et al.,

1998; Mann et al., 1998, 2000; Luterbacher et al., 2002a, 2002b, 2004; Mann, 2002; **632**
Bradley et al., 2003). In a recent paper by Pauling et al. (2003) it was shown that an **633**
optimised combination of high quality natural and documentary proxies can yield **634**
better results than using only one of the two types. **635**

4.2. CALIBRATION **636**

The aim of calibration is to determine the relation (response function, transfer **637**
function) between the proxy indicator (predictor) and the meteorological element **638**
(predictand) for the calibration period in which both values of the given proxy and **639**
the measured values of the meteorological element (such as sea surface temperature, **640**
land surface temperature, air pressure, precipitation) are available. **641**

According to scientific standards the validity of any kind of data needs to be **642**
verified by applying suitable statistical methods and using independent data. For **643**
this reason series of intensity indices obtained from documentary evidence should **644**
overlap the period of instrumental measurements. However, the usual methods of **645**
calibration can rarely be applied in historical climatology. The reason is that in **646**
most cases the qualitatively best observers switched to instrumental observation **647**
when meteorological instruments became available at reasonable prices by about **648**
the mid-18th century. This modified the way in which they coined their weather **649**
descriptions. Therefore results from first class non-instrumental diaries rarely in- **650**
clude the period of early instrumental observations (Pauling et al., 2003). A notable **651**
exception from this practice is an example from the Czech Lands, where systematic **652**
visual weather observations continued in parallel with early instrumental measure- **653**
ments at the station Prague-Klementinum, which has allowed validation of the **654**
descriptive weather reports (Brázdil et al., 2003a). Similarly, on the basis of visual **655**
observations at the Potsdam station it was shown that subjectively registered val- **656**
ues have a high correlation with measured parameters (Werner and Gerstengarbe, **657**
2003). **658**

In order to statistically validate the indices a suitable approach has to be de- **659**
veloped. This is documented here, using the example of winter and summer tem- **660**
peratures for Germany, Switzerland and the Czech Republic (Glaser et al., 1999b) **661**
(Tables II–IV). The first step shown was to find the correlation coefficients between **662**
real temperature series at four different sites and the series of intensity indices that **663**
were obtained from the same instrumental series. The high correlation coefficients **664**
in Table II demonstrate that indices can express the main features of temperature **665**
variability based on measured data for the selected Central European stations. The **666**
reduction of explained variance is only a few percent when transforming the instru- **667**
mental readings into ordinal data. Thus, depending on the number of degrees of free- **668**
dom in the chosen ordinal scale, real temperature variations are very well estimated **669**
by the indices. In a second step, the correlation between individual stations, both **670**
measured temperature and the index data derived from instrumental observations is **671**

TABLE II

Correlation coefficients between measured series and indexed series of air temperature for four Central European stations in 1901–1960 (all values are statistically significant at the 95% level) (Glaser et al., 1999b)

Stations	Winter	Spring	Summer	Autumn	Year
Basel (Switzerland)	0.89	0.91	0.91	0.93	0.92
Frankfurt (Germany)	0.89	0.91	0.93	0.93	0.87
Potsdam (Germany)	0.86	0.92	0.92	0.92	0.87
Prague (Czech Rep.)	0.89	0.93	0.90	0.89	0.87

TABLE III

Correlation coefficients between measured series (M) and indexed series (I) of seasonal temperatures for four Central European stations in 1901–1960 (winter and summer) (all values are statistically significant at the 95% level) (Glaser et al., 1999b)

Stations	Series	Basel	Frankfurt	Potsdam	Prague
Basel	M	1.00	0.92	0.79	0.85
	I	1.00	0.79	0.56	0.68
Frankfurt	M	0.87	1.00	0.93	0.96
	I	0.84	1.00	0.72	0.85
Potsdam	M	0.62	0.83	1.00	0.96
	I	0.64	0.72	1.00	0.84
Prague	M	0.77	0.87	0.87	1.00
	I	0.68	0.78	0.81	1.00

TABLE IV

Correlation coefficients between indexed series of seasonal temperatures for Germany, Switzerland and the Czech Republic during the 16th century (winter and summer) (all values are statistically significant at the 95% level) (Glaser et al., 1999b)

Region	Germany	Switzerland	Czech Republic
Germany	1.00	0.68	0.79
Switzerland	0.75	1.00	0.59
Czech Republic	0.73	0.73	1.00

672 calculated. Table III shows the summer and winter interstation correlations based on
673 the reference period 1901–1960. In all cases the index series have lower interstation
674 correlations than the instrumental series, which indicates that the index series have
675 lower decorrelation length scales (Daley, 1993) than instrumental measurements.

A comparison of these results with inter-country correlations between 16th century **676**
indices derived from documentary data for Germany, Switzerland and the Czech **677**
Republic (Table IV) shows similar magnitude and significance to those obtained **678**
in the modern period. However, these interstation correlations are perhaps artifi- **679**
cially enhanced due to the fact that country average temperatures are used instead **680**
of individual station series. Nonetheless, it may be concluded that the reduction **681**
in correlation (for index data on an ordinal scale compared to instrumental data **682**
on a continuous scale) is rather small, which points to the spatial validity of the **683**
corresponding indexed series. **684**

4.3. VERIFICATION **685**

Prior to the reconstruction, the transfer functions have to be verified in a different **686**
time period, or at least a cross-validation procedure has to be carried out if the data **687**
series is rather short (Michaelsen, 1984). The relationship obtained in a calibration **688**
period is applied to a so-called verification period, for which the values of the **689**
meteorological element are estimated from the documentary data. These estimations **690**
are then compared with the measured values. Several verification tests developed **691**
for dendroclimatological reconstructions (see Cook et al., 1994) are also suitable **692**
for reconstructions based on documentary data. Other simple statistical measures, **693**
including for instance the correlation coefficient, the root-mean-square error and the **694**
t-test for the paired values, may be used to compare the measured and reconstructed **695**
values (see e.g. Brázdil and Kotyza, 2000). It is also advisable to investigate how **696**
the variability of the series obtained can be best expressed by the given transfer **697**
function. In view of the normally rather short lengths of both the calibration and **698**
verification periods in relation to the entire period for which the reconstruction is **699**
developed, it is practical and useful to exchange them and repeat the procedure **700**
before the next step. **701**

4.4. RECONSTRUCTION **702**

If the transfer function obtained expresses the variability of the meteorological **703**
element under consideration with satisfactory precision, the chronology of the proxy **704**
can be used for climatic reconstruction. The major problem of this reconstruction **705**
method is that the transfer functions, many derived from relatively modern periods, **706**
may be nonstationary, as is case with the NAO (Schmutz et al., 2000; Cook et al., **707**
2002; Luterbacher et al., 2002a). It can be, for instance, a case that the phenological **708**
series were affected by changes in the crop mix, the introduction of new varieties of **709**
crops or by the introduction of harvest technology (e.g. combines) (Pfister, 2001). **710**
Also, local phenomena, like urbanisation, may interfere with the representativity of **711**
local data for regional variations. The problem of nonstationarity can be ameliorated **712**

713 by considering a sufficiently long calibration time period (Cook et al., 2002). It is
714 therefore suggested to test the stationarity of the data used in order to assess the
715 reliability of the transfer function (Rutherford et al., 2003).

5. Recent Developments

716

5.1. NEW KINDS OF DOCUMENTARY DATA

717

718 After 1990 the databases with documentary data existing in many European coun-
719 tries have been significantly extended with further weather notes from documentary
720 evidence (e.g., for the 16th century, see Pfister et al., 1999a). Great progress was
721 achieved, for instance, after the discovery of a great number of previously un-
722 known weather diaries, its statistical analysis, graphical presentation on the basis
723 of weather symbols and utilisation for assessing new series of indices (e.g. Tyrrell,
724 1995; Telelis, 1998; Brázdil and Kotyza, 1996, 1999; Pfister et al., 1999c; Börngen
725 and Tetzlaff, 2000; Bokwa et al., 2001; Brázdil and Kiss, 2001; Limanówka, 2001).
726 These daily records may be used effectively not only for detailed description of
727 weather patterns for specific occasions in the past, but also for deriving monthly
728 temperature and precipitation indices. Recently, Werner and Gerstengarbe (2003)
729 showed that the frequency and type of precipitation and cloud cover for Pots-
730 dam, 1893–2000, characterise significant climatic variations and strongly confirm
731 the results obtained from measured climatic parameters. This knowledge signifi-
732 cantly enhances the potential of traditional visual daily weather records for climatic
733 reconstructions.
734 Rodrigo et al. (1998) analysed climatic information in private correspondence
735 of the Jesuit order in Castille (Spain) for 1634–1648. They showed prevalence of
736 intense rainfall and cold waves in that period. Retsö (2002) used correspondence
737 letters to characterise winter weather patterns from the early 16th century in Sweden.
738 In recent years the discovery of new data sources with climatological poten-
739 tial has facilitated further analyses in regions not previously investigated in detail.
740 For instance, in Spain the Catholic Church organised rogation services (rogativas)
741 directed to end climatic stress-situations connected with long dry ("pro pluvia"
742 rogationes) or wet spells ("pro serenitate" rogationes) which jeopardised the crops
743 (Martín-Vide and Barriendos, 1995). For droughts, the municipal and ecclesiasti-
744 cal authorities developed a system of activities in which five levels of rogationes
745 can be distinguished. Level I was used as a preventative measure when drought
746 had not yet exerted significant damage. Levels II and III were applied when the
747 agricultural production had already suffered substantially. Levels IV and V were
748 invoked when the entire crop was in jeopardy and the danger of subsistence crises
749 were impending. Barriendos (1997) used rogation data for analysis of climate in
750 the Iberian Peninsula in the period 1675–1715. Similar data about rogations from
751 Erice (western Sicily) were used for the reconstruction of drought spells during

the period 1565–1915 (Piervitali and Colacino, 2001). Rodrigo et al. (1999, 2001) 752
used, among other documentary sources, religious chronicles, and books of city 753
and church archives in order to reconstruct the seasonal precipitation variability 754
in southern Spain (Andalusia) and the winter North Atlantic Oscillation back to 755
AD 1500.   756

Some documentary data have long been recognised as potential climatic indica- 757
tors. For example, Brückner (1890) used the dates of freezing of rivers and water 758
bodies as a useful index for winter temperature conditions. Camuffo (1987) studied 759
freezing of the Venetian Lagoon since the 9th century in relation to winters in West- 760
ern Europe and England. Kajander (1993) reconstructed a series of ice break-up 761
dates for the Tornio River (the border between Finland and Sweden) for 1693– 762
1993, based on different documentary data. They correlate very well with local 763
mean April-May temperatures and show that the ice break-up occurs on average 764
thirteen days earlier now compared to the Maunder Minimum period, which cor- 765
responds to a mean warming in April-May by about 2 °C (Klingbjer and Moberg, 766
2003). Ogilvie (1996) analysed sea-ice conditions along the coast of Iceland for 767
1601–1850. Koslowski and Glaser (1999) developed a winter ice index with integer 768
values, from 0 (no ice) in warm winters to 3 (continuous ice) in severe winters for 769
the western Baltic Sea for the period 1501–1995. Figure 3 displays remarkable 770
periods of severe winters in the 1510s, around 1570 and 1600, between 1615 and 771
1625, in the 1660s, in the 1690s and around 1800. Jevrejeva (2001) and Jevrejeva 772
and Moore (2001) used many historical chronicles of break-up dates at Riga to 773
reconstruct the winter sea ice severity in the northern Baltic Sea back to the early 774
16th century.   775

Economic information, mainly about harvest and vintage, are traditional sources 776
of data in historical climatology (e.g., Pfister, 1979, 1981; Le Roy Ladurie and 777
Baulant, 1980; Lauer and Frankenberg, 1986; Glaser, 1991; Souriau and Yiou, 778
2001). Some new evidence of economic character has appeared in Europe after 779
1990. Tarand and Kuiv (1994) used series of the beginning of the rye harvest in the 780
regions of Estonia, Latvia and Finland for reconstruction of the mean April–July 781
temperatures in the period 1671–1949. Later this data, together with the first day 782
of ice-break up in Tallin port and on the rivers in northern Estonia, was used for re- 783
construction of the Tallin temperature series (Tarand and Nordli, 2001). De Kraker 784
(1999) utilised data from accounts of dikes protecting a polder region in northern 785
Flanders as proxy for the study of the occurrence of high tides, storms and storm 786
surges in the period 1488–1609. Later he extended this study on the period from 787
AD 1000 up to the present (de Kraker, 2002). Camuffo et al. (2000) analysed long 788
series of sea storms since the 8th century in the Adriatic Sea and Western Mediter- 789
ranean which caused widespread devastation in Venice and Barcelona. Střeštík and 790
Verö (2000) showed significant correlation between the length of new grapevine 791
sprouts measured systematically since 1740 in Köszeg (Hungary) and March–April 792
temperatures. Nordli (2001) used dates of crop sowing from farmers' diaries for re- 793
construction of April–August average temperatures in Norway and for testing local 794

795 instrumental temperature records from the 19th century. In the another investigation,
796 Nordli et al. (2002, 2003) compiled a series of April-August temperatures of Vest-
797 landet (western Norway) for 1734–2002 combining instrumental data, grain harvest
798 dates and dated terminal moraines of the glaciers Nigardsbreen and Storbreen.
799   Climatic information can also be derived from economic data concerning taxa-
800 tion. Grove and Battagel (1983), analysing data from general tax commissions from
801 Sunnfjord Fogderi (Norway), found a substantial decline in rural prosperity between
802 1667 and 1723. This is documented in tax relief proceedings connected with serious
803 physical damage (floods, avalanches, landslides). Documentary sources of cereal
804 taxes collected in the Canary Islands have been used to construct a complete and
805 reliable wheat and barley production series for the period 1595–1836 (García et al.,
806 2003). The cereal growth period in this region, including the months October–
807 March, covers the whole rainy season in the islands, making these crops adequate
808 to characterise the precipitation at annual scales. Brázdil and Valášek (2003) and
809 Brázdil et al. (2003b) showed the potential of records of tax reduction to study past
810 meteorological and hydrological extremes and their impacts.
811   A new kind of para-phenological indicator, similar to vine harvest dates, was
812 discovered for Switzerland by Pfister (1979). Prior to the grain harvest, the tithe to
813 be paid in grain had to be assessed for fiscal reasons. It was then sold by auction to
814 wealthy farmers who had to bring the amount of grain purchased to the barn of the
815 bailiff after threshing. The date of the auction immediately preceded the harvest and
816 it can be used as a reliable proxy for the timing of the harvest. Highly significant
817 correlations were found with temperature in May and June (Pfister, 1979). Recent
818 investigations have shown that tithe auctions were also common in Austria and in
819 Germany (Bauernfeind, 1993; Egger and Weigelt, 2000).
820   Another proxy indicator was recently discovered in the account books of the
821 town Louny in north-west Bohemia (the Czech Republic). The account kept track
822 of wages paid by the municipality on Saturday for work carried out in the preceding
823 week. As this list is very detailed, it also relates to work that depended on weather
824 and climate, e.g. cutting ice at the water mills and on the Ohře River, cleaning snow
825 from the roads, repairing bridges after floods etc. The references to the harvest are
826 particularly conclusive, because they are connected to the ripening of grain and
827 thus to the temperature patterns in the months preceding the harvest. Brázdil and
828 Kotyza (2000) have drawn on this proxy evidence to reconstruct winter and spring-
829 summer temperature patterns in the Czech Lands over the period 1450–1632 (with
830 some gaps). Autumn is less densely documented than the other seasons, because
831 the climatic conditions had a smaller impact on traditional societies at this time.
832 However some climatic information can be drawn from the sugar content of wine,
833 in order to assess warmth and sunshine in September (Pfister, 1984). It is assumed
834 that similar results presented in Brázdil and Kotyza (2000) might be obtained from
835 the account books of many other towns in Central Europe and beyond.
836   Information derived from ship logbooks is another important source of evidence.
837 This may greatly increase our knowledge of conditions over sea and ocean areas,

in particular the prevailing winds that, in most weather diaries are recorded but 838
not very consistently. A great abundance of naval logbooks are known to exist 839
in the marine archives of the ancient great Powers, but only a tiny fraction of 840
these sources have been investigated so far. For instance, Wheeler (1995) analysed 841
weather records in the logbooks of Nicholas Pocock for 1766–1776. Frydendahl 842
and Frich (1996) collected more than 50,000 observations of wind direction and 843
force from logbooks in the Øresund area for the period 1675–1715. The authors 844
concluded that the frequencies of northerly and north-westerly wind directions 845
were higher and the winds stronger than in the modern period 1951–1980. García 846
et al. (2000) estimated atmospheric circulation in the North Atlantic in the periods 847
1551–1650 and 1717–1737 based on sailing times of the Spanish ships to America. 848
Historical accounts of the voyages of the Manila galleons were used for the study 849
of changes in the atmospheric circulation of the tropical Pacific Ocean during the 850
16th-18th centuries (Garcia et al., 2001). In addition, the logbooks' information 851
might be effectively used for description of weather patterns of important historical 852
events such as the Battle of Trafalgar in 1805 (Wheeler, 2001) or during the voyage 853
of individual ships (e.g. Wheeler, 2003). Further progress is expected from the 854
EC Framework V project 2000–2003 called CLIWOC (Climatological database 855
for the World's oceans 1750–1850 – see http://www.ucm.es/info/cliwoc) which is 856
trying "to realise the scientific potential of logbook climatic data and to produce a 857
database of daily weather observations for the world's oceans between 1750 and 858
1850". 859

From the previous overview it follows that research in historical climatology in 860
Europe is geographically unbalanced. Although some potential of different kinds 861
of documentary evidence exists more or less in the every European country, only 862
some have been used in systematic historical-climatological investigations (such as 863
the Czech Republic, Germany, England, Hungary, Italy, the Netherlands, Norway, 864
Poland, Spain and Switzerland). Further studies from other countries in the Adriatic 865
region (Penzar and Penzar, 1997) and the territory of Austria (Strömmer, 2003), 866
Crete (Grove and Conterio, 1995), Greece (Repapis at al., 1989; Xoplaki et al., 867
2001), the Italian Alps (Bonardi, 1996, 2000), Slovakia (Brázdil and Kiss, 2001), 868
Slovenia (Ogrin, 2002), Romania (Cernovodeanu and Binder, 1993) and Russia (e.g. 869
Borisenkov and Pasetskiy, 1988; Borisenkov, 1992; Lyakhov, 1992; Chernavskaya, 870
1995; Popova, 2001) are needed to help resolve finer spatial and temporal scales 871
of past climate variability. Hitherto the availability of such dense and rich data sets 872
has allowed very accurate climate reconstructions in the Atlantic-European area 873
for the last several centuries (Luterbacher et al., 1999, 2000, 2002b, 2004). 874

5.2. REORIENTATION TOWARDS A SYNOPTIC VIEW   875

Most of the climate reconstructions over say the last 1000 years focus on temper- 876
ature (e.g. Bradley and Jones, 1993; Briffa et al., 1998, 2001; Mann et al., 1998, 877

878 1999; Crowley, 2000; Crowley and Lowery, 2000; Jones et al., 2001; Mann, 2001;
879 Briffa and Osborn, 2002; Esper et al., 2002). This fact hinders a detailed dynamical
880 analysis of atmospheric processes as it is known from studies based on reanalysis
881 data or long model integrations. Even the sparse data make it difficult to reconstruct
882 the important state variables such as radiation, surface temperature, air pressure,
883 wind, humidity and precipitation. Future studies have to pursue this goal. It is one
884 of the merits of historical climatology to try to extend the number of analysed
885 parameters in order to get a better understanding of past synoptic processes and
886 regimes in this way. At this stage only some of these elements have been reasonably
887 well reconstructed (Wanner and Luterbacher, 2002).
888   Significant progress, however, has been made in reconstructing the variations of
889 relevant time-variable forcing factors like the atmospheric load of volcanic aerosols
890 and the output of the sun (Crowley, 2000). These variations may be fed into dif-
891 ferent types of physical climate models (energy balance, radiative–convective or
892 GCMs), which can be used to estimate the response of the climate system to vari-
893 able external forcing and thus provide a first guess of how the climate actually may
894 have varied (for an example, see Section 5.7). However, since the climate state is
895 composed of an externally forced deterministic component and a stochastic part
896 related to internal dynamics of the climate system, the exact historical state can
897 not be simulated with very high precision. The application of data assimilation
898 methods (e.g., Robinson et al., 1998) such as DATUN (von Storch et al., 2000) can
899 help to improve their precision. The first attempts to reconstruct average seasonal
900 atmospheric pressure at sea level using different documentary evidence from the
901 Atlantic-European region were made by Lamb (1987). Such reconstructions were
902 based on the assumption that anomalies in temperature and precipitation must be
903 related to circulation fluctuations caused by changes in the positions of the pre-
904 vailing pressure systems and lower tropospheric advection of typical air masses
905 (as reflected, e.g., by the fluctuations of the NAO index). Circulation patterns dur-
906 ing months with pronounced temperature and/or precipitation anomalies during
907 the instrumental period can, to a certain extent, be used as analogues for similar
908 anomaly patterns in the past (Jacobeit, 1997). Extension of the data base related to
909 documentary data in the 1990s (Pfister et al., 1994) has made it possible to iden-
910 tify more reliably circulation changes in terms of mean monthly sea level pressure
911 (SLP) maps. Such maps have been developed for the Late Maunder Minimum pe-
912 riod (1675–1704) by Wanner et al. (1994, 1995). Similar to the reconstructions by
913 Lamb (1987), they are subject to the disadvantage that they cannot be tested statis-
914 tically since the subjective maps are representing prevalent conditions rather than
915 real monthly means (Jacobeit et al., 1999); prevalent characteristics, however, dis-
916 regarding intermediate deviations, might be smoothed out if integrated into strictly
917 mean conditions as in the objective grids. Further, subjective maps might suffer
918 from some overestimation since descriptive informations often tend to emphasize
919 anomalies. Objective reconstructions are more approaching mean conditions, thus
920 being more consistent with recent reference data. On the other hand, with only few

data for statistical reconstructions, resulting grids tend to diminish in variability and   921
subjective maps based on documentary sources might better succeed in reproduc-   922
ing distinct circulation patterns, at least for outstanding anomalies with sufficient   923
descriptive information (Luterbacher et al., 2002b).   924

Attempts to compare circulation patterns in the 16th century with the 20th   925
century analogues for selected cold and warm winters and summers have been   926
made by Jacobeit et al. (1999). Statistically improved mean monthly SLP maps   927
for the Late Maunder Minimum period (1675–1715) were later reconstructed by   928
Luterbacher et al. (2000). This reconstruction, utilising both proxy and instrumental   929
records, was based on a canonical correlation analysis (CCA), with the standardised   930
station and documentary data as predictors and the SLP fields as predictands. In a   931
more recent paper, Luterbacher et al. (2002b) used a principal component regression   932
analysis to reconstruct gridded SLP for the eastern Atlantic-European area. Based on   933
early instrumental measurements and intensity indices derived from documentary   934
evidence, seasonal (1500–1658) and monthly (1659–1999) SLP was reconstructed   935
and subsequently used for an EOF analysis. Figure 4 shows the first three EOFs   936
of winter SLP anomalies from 1500 to 1999 and their associated score series.   937
The first pattern represents the classical zonal or NAO like structure, the second   938
shows a large pole east of Great Britain, and the third one depicts the classical   939
meridional flow situation over Europe. The first NAO like pattern accounts for 55%   940
of winter SLP variance. Its time series shows a high variability with a mixture of   941
positive and negative values before 1950 but mostly highly positive ones during   942
the last 30 years, a fact which is well known from many NAO studies (Wanner   943
et al., 2001). The combination of such pressure reconstructions with temperature   944
and precipitation data will not only form an excellent basis for model validation,   945
it will also lead to a better understanding of the dynamical processes for earlier   946
centuries (Wanner and Luterbacher, 2002). It has been demonstrated by Zorita   947
and González-Rouco (2002) that the converse is also true and that models can be   948
used to investigate the reliability of reconstructions. As mentioned in Section 4.4,   949
a major limitation of reconstruction methods is the possible non-stationarity of   950
the transfer function. Zorita and González-Rouco (2002) have used output from   951
a long GCM integration to generate 'pseudo-proxy' data. They showed that the   952
time-series behaviour of reconstructed meteorological elements are dependent on   953
the used training (calibration) data set. Sometimes large biases can occur.   954

5.3. DEFINING THE MEDIEVAL WARM PERIOD AND THE LITTLE ICE AGE   955

The climate of the last millennium, not only in Europe but also in other regions, has   956
traditionally been thought of as a time span including a "Medieval Warm Period"   957
(MWP), followed by a period of climatic deterioration, a "Little Ice Age" (LIA)   958
and the current warming phase. Lamb (1965, 1977, 1984), based almost solely on   959
evidence from Western Europe and the North Atlantic region, placed the MWP   960
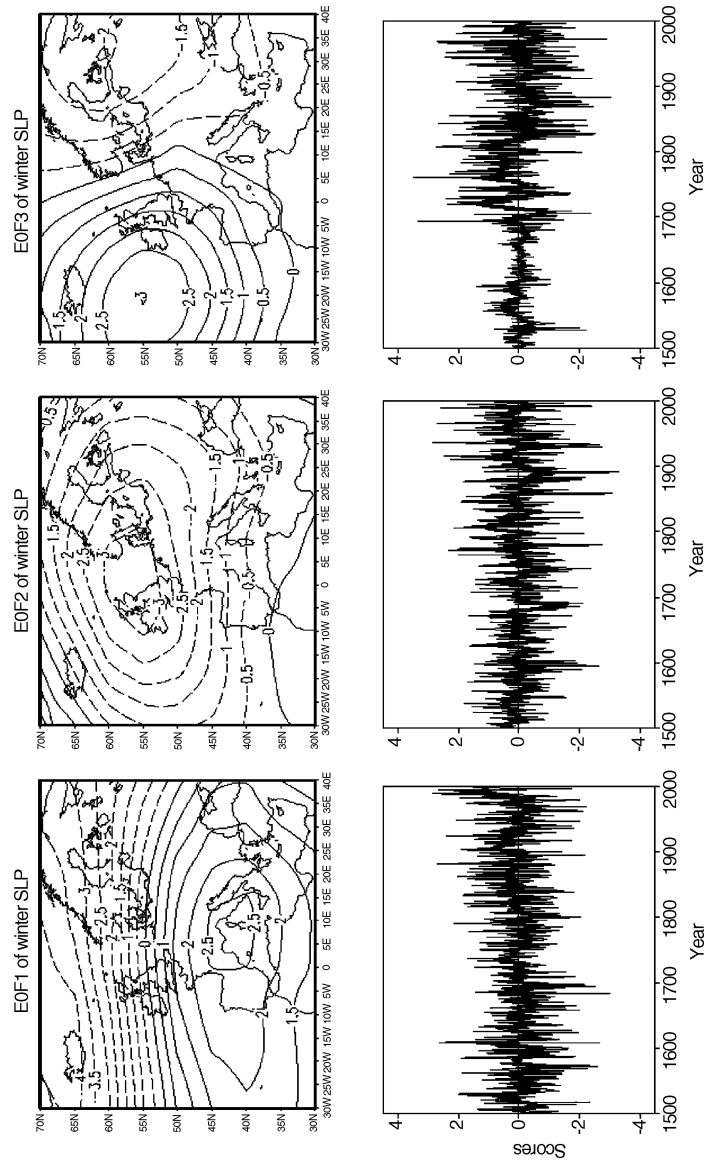
Figure 4. Top: patterns of the first three EOFs of winter SLP anomalies 1500–1999 (anomalies in hPa; contour interval 0.5 hPa). The last nine winters are reanalysis data (Kistler et al., 2001). The first EOF accounts for 55%, the second 23% and the third EOF 17%, respectively, of the winter SLP variance. Solid lines indicate positive values, and dashed lines mark negative values. Bottom: Corresponding normalised time components (scores) of the first three EOFs. The thick line is the 9-point low pass filtered time series. For clarity of the figures, the monthly (DJF) scores for the post-1659 period were averaged to one seasonal winter value for the respective years (from Luterbacher et al., 2002b).

in the period 950–1200 (but in 1150–1300 for the greater part of Europe), and **961**
the LIA in 1550–1850, with the most pronounced phase in the period 1550–1700. **962**
These terms have commonly been used not only by climatologists but also by those **963**
working in related sciences (e.g. Appleby, 1981; Chernavskaya, 1992; Fagan, 2000; **964**
Buckland and Wagner, 2001; Kociánová, 2002). Many books and proceedings have **965**
been devoted to climate especially during the MWP and the LIA (e.g., Grove, 1988; **966**
Bradley and Jones, 1992; Mikami, 1992; Hughes and Diaz, 1994a; Jones et al., 1996; **967**
Fagan, 2000; Ogilvie and Jónsson, 2001). **968**

This schematic division of the last millennium directed research in historical **969**
climatology to the analysis of these periods (e.g. Lamb, 1980; Rodrigo et al., 1995). **970**
However, from recent analyses it is concluded that the timing of these key periods **971**
primarily depends on the availability and the time resolution of proxy data and of **972**
the regional setting. More recent research has reassessed this paradigm (Bradley, **973**
2000; Bradley et al., 2003; Soon and Baliunas, 2003). For instance, while Lamb **974**
(1977) placed the start of the "Little Ice Age" in the mid-16th century, Porter (1986), **975**
on the basis of glacial studies in the Northern Hemisphere, considered that it had **976**
already begun around AD 1250. Fluctuations of the longest Alpine glacier, the Great **977**
Aletsch glacier, included during the last millennium a smaller advance at about AD **978**
1120 and three extreme maxima around AD 1350, 1650 and 1860 (Figure 5). **979**
However, the maximum in 1350 is only radiocarbon dated and a substantial dating **980**
error, in the order of tenths years has to be allowed for. On the other hand, the **981**
corresponding advance of Gorner glacier (Canton of Valais, Swiss Alps) has been **982**
dendrochronologically dated by a more reliable method. This glacier reached a **983**
maximum around 1385 (Holzhauser, 1997, 2002; Holzhauser and Zumbühl, 1999) **984**
which agrees well with the available documentary evidence (Pfister, 1988a). Jones **985**
and Bradley (1992) avoided defining universally applicable dates for the onset and **986**
end of the LIA due to great regional variations. Based on documentary evidence, **987**
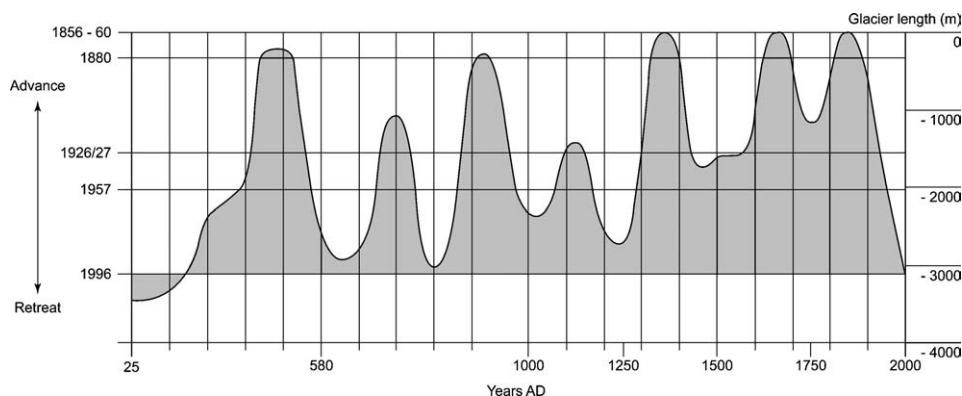

Figure 5. Fluctuations in the length of the Grosser Aletsch glacier (the Alps, Switzerland) in the last 2000 years (corrected according to Holzhauser and Zumbühl, 1999).

988 Pfister et al. (1996, 1998) concluded from analyses of winter temperature proxies
989 that the LIA started in Central Europe shortly after AD 1300.
990   Similar inconsistencies are related to the term "Medieval Warm Period" (Hughes
991 and Diaz, 1994a), where the evidence compared to the LIA is scarcer. After com-
992 piling existing knowledge about the MWP, Hughes and Diaz (1994b) judged that
993 "*it is impossible at present to conclude from the evidence gathered here that there
994 is anything more significant than the fact that in some areas of the globe, for some
995 part of the year, relatively warm conditions may have prevailed . . . the available
996 evidence does not support a global Medieval Warm Epoch . . .*". Besides the dis-
997 cussion of whether the MWP had a global extent (Broecker, 2001), it is generally
998 believed that, in the hemispheric scale, temperatures were not higher than during the
999 second part of the 20th century (Crowley and Lowery, 2000). Similarly, according
1000 to Bradley et al. (2003) the balance of existing evidence does not point to a high
1001 medieval period that was as warm as or warmer than the late 20th century. Ogilvie
1002 et al. (2000), after combining documentary evidence with proxy data from natural
1003 archives such as ice cores and marine sediments, speaks about favourable condi-
1004 tions in the North Atlantic region during AD 800–1100 (without danger of sea ice)
1005 that allowed Vikings to explore and inhabit Iceland, Greenland and Newfoundland
1006 (so-called "Vínland"). Temperatures in this region were higher during AD 800–
1007 1100 than in the following centuries, but not more than 1–2 °C. Esper et al. (2002),
1008 analysing selected tree-ring chronologies from 14 sites in the Northern Hemisphere
1009 extratropics, found that the MWP may have begun there in the early 900s. In
1010 their reconstruction, the warmest period covers the interval AD 950–1045 with a
1011 peak around 990 (for the MWP in Eastern Mediterranean see also Telelis, 2000,
1012 in press).
1013   The concepts of the MWP and LIA have also been discussed in other terms
1014 than temperature only. According to Grove (2001a, 2001b) the term "Little Ice
1015 Age" relates to the dimension of glaciers rather than directly to climate (see also
1016 Matthes, 1939, 1940). The "Little Ice Age" was the most recent period during
1017 which glaciers maintained an expanded position in most parts of the globe, with
1018 their fronts oscillating around advanced positions. These fluctuations resulted from
1019 a combination of changes in seasonal temperature and precipitation patterns, but
1020 according to Grove (2001a,b) the LIA is not a climatic term as such. Stine (1998),
1021 based on his drought studies from the Western United States, proposed another term
1022 for the overall period of the MWP as the "Medieval Climatic Anomaly" (MCA),
1023 which removes the emphasis on the temperature. Wanner et al. (2000) have coined
1024 the term of "Little Ice Age Type Events" (LIATES) for the phases of glacier advance.
1025 Consequently, the "Medieval Warm Period" can be defined as the period between
1026 the glacial advances of the LIA and a preceding phase of glacial expansion late
1027 in the penultimate millennium (see Figure 5) (Grove and Switsur, 1994). In this
1028 warmer period, climatic conditions caused glacier mass balances to be negative,
1029 and volumes of glaciers to be reduced, so that their fronts melted back substantially,
1030 albeit with minor variations. In the light of the recent discussion about greenhouse

gas induced global warming an elucidation of the processes that led to the MWP **1031**
is a research topic with high priority. It needs to be stressed that neither the MWP **1032**
nor the LIA were periods of unbroken warm or cold climate respectively (Wanner **1033**
et al., 2000; Grove, 2001a,b). The distinct problem is further accentuated by the **1034**
estimates of Northern Hemisphere (NH) annual mean temperatures since AD 1000 **1035**
reconstructed by Mann et al. (1999) from different proxy series (tree rings, ice cores, **1036**
documentary evidence, corals). This series shows a gradual decline of temperatures **1037**
over the last millennium (no sudden onset of the LIA) and a dramatic increase during **1038**
the 20th century with the warmest decade in the 1990s and 1998 as the warmest year **1039**
(Figure 6). **1040**

The climate variability of the NH is considerably different to that of European **1041**
climate variability reconstructed using documentary evidence. Guiot (1992) de- **1042**
veloped series of European temperature anomalies for AD 1068–1979 based on **1043**
documentary and biological evidence (Figure 6). This series represents the average **1044**
over 20 reconstructed gridpoints covering the area 35°N–55°N and 10°W–20°E. **1045**
Luterbacher et al. (2004) recently developed highly resolved spatio-temporal tem- **1046**
perature reconstructions for European land areas back to AD 1500. Their estimates **1047**
were obtained utilising a multivariate statistical approach combining long instru- **1048**
mental temperature and pressure series, documentary proxy data and for the earlier **1049**
period (before 1659) a few seasonally resolved temperature proxy reconstructions **1050**
from Greenland ice cores and tree ring data from Scandinavia and Siberia. The **1051**
annual anomalies of the results of both studies are compared in Figure 6 using the **1052**
same geographical area as Guiot (1992). **1053**

As expected, in the common period of all three series 1500–1979 the corre- **1054**
lation of the unfiltered data is highest between the two European series (0.54). **1055**
However, it has to be born in mind that the rather high correlation between the two **1056**
European series is inflated due to several common predictors (e.g. the Central Eng- **1057**
land temperature series, temperatures from Switzerland). Luterbacher et al. (2004) **1058**
used more predictors than Guiot (1992), including many homogenised temperature **1059**
and pressure series from different sites in Europe (mainly since the early-18th cen- **1060**
tury). Furthermore, they used documentary proxy evidence from different European **1061**
places that were not available to Guiot (1992) and the new reconstruction is based **1062**
on 0.5×0.5 degree grid boxes (i.e., resolution around 60 km over land), which **1063**
provides more regional details. Moreover, the new reconstruction was made on **1064**
monthly (back to 1659) and seasonal (1500–1658) level. Summarising these facts, **1065**
Luterbacher et al. (2004) used much more data than did Guiot (1992), which allows **1066**
a more skilfull reconstruction. The new reconstruction is more highly resolved both **1067**
in time and space, allowing the study of regional monthly and seasonal temperature **1068**
changes and extremes, which are not visible on the annual level. **1069**

The similarities between the NH series of Mann et al. (1999) and the two **1070**
European temperature estimates are, as expected, weaker. The corresponding cor- **1071**
relations for annual unfiltered values are 0.32 (Luterbacher et al., 2004) and 0.21 **1072**
(Guiot, 1992) respectively, both significant at the 99.9% level. Though highly **1073**
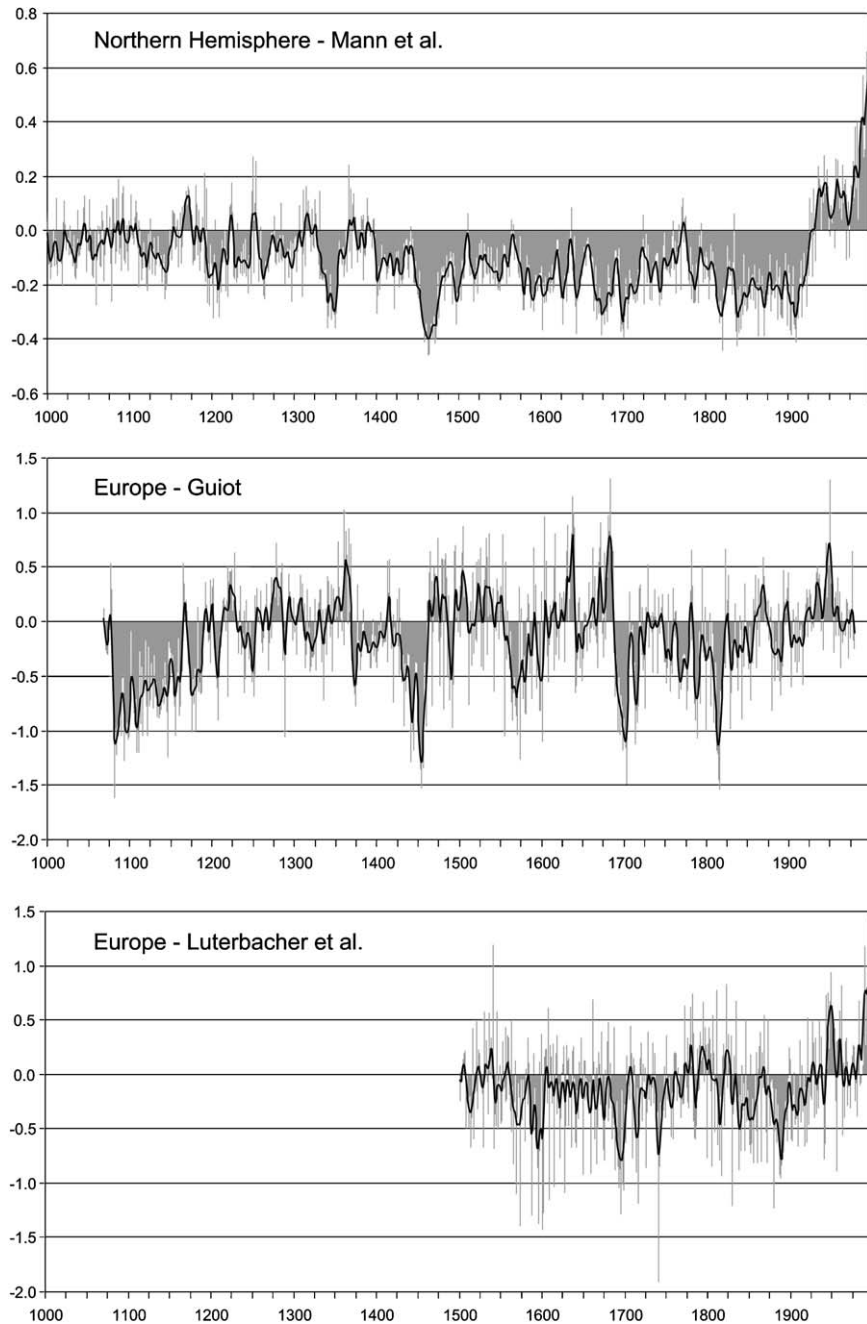
Figure 6. Fluctuations in annual Northern Hemisphere (Mann et al., 1999) and European temperature anomalies (°C) according to Guiot (1992) and Luterbacher et al. (2004) during the last millennium. Reference period 1902–1980 for Mann et al. (1999) and Luterbacher et al. (2004) and 1851–1979 for Guiot (1992). The three time-series have been smoothed by a 10-year Gaussian filter. The scale for Northern Hemisphere temperature is different from both European series.

significant, only between 4 and 9% of common variability is shared between **1074**
the European and the Northern Hemisphere annual temperature reconstructions. **1075**
It should be mentioned that the European reconstructions are not fully independent **1076**
from the reconstruction of Mann et al. (1999) as they share some basic data; hence **1077**
the correlations may be an overestimate.   **1078**

It is obvious that a temperature reconstruction for Europe must exhibit notable **1079**
differences compared to a NH reconstruction as Europe is only a small part of the **1080**
entire hemisphere. Nevertheless, instrumental data for the last 140 years (Hansen **1081**
et al., 1999, 2001) reveal a relatively strong connection between the NH land tem- **1082**
perature north of 20°N and European land areas (25°W–40°E; 35°N–70°N). The **1083**
correlation is 0.62 for winter and reaches 0.75 for summer and the entire year. **1084**
The correlations between the proxy-data-based reconstructions for Europe (Guiot, **1085**
1992; Luterbacher et al., 2004) and that for the NH (Mann et al. 1999) reveal a **1086**
markedly weaker relationship compared to that found in the instrumental data. **1087**
This can mainly be attributed to uncertainties in the reconstructions, but could also **1088**
partly reflect different de-coupling and climate behaviour at the continental scale **1089**
compared to the entire NH.   **1090**

A striking feature (Figure 6) is the significantly greater variability on almost all **1091**
time scales in case of the European temperature reconstructions compared to the **1092**
NH. This may be, amongst other factors, due to certain types of signals (e.g., the **1093**
influence of climate forcings such as volcanic, solar, internal oscillations) which are **1094**
stronger in the European reconstructions than on the Northern Hemisphere scale. **1095**

Pauling et al. (2003) investigated the importance of proxies for seasonal **1096**
European and North Atlantic temperature field reconstructions. Their study anal- **1097**
ysed the importance of several different types of proxy series for the reconstruction **1098**
of climate in different parts of Europe, allowing for 'teleconnections' between the **1099**
geographical location where the proxy data was collected and the part of Europe for **1100**
which temperature is reconstructed. For boreal winter (October–March) they found **1101**
that documentary evidence was most important for much of continental Europe, **1102**
while a speleothem from Scotland was the most important proxy (among those used **1103**
in the analysis) for both Iceland and the western Mediterranean region. Tree-ring **1104**
data had most importance both for the eastern Mediterranean and parts of north- **1105**
ern Fennoscandia. For summer temperature reconstructions, tree-ring data had the **1106**
largest importance for most of Europe, while documentary data and the Scottish **1107**
speleothem had relevance for various smaller parts of Europe. These findings can, **1108**
however, not be generalized as they refer only to the actual selection of proxy data **1109**
analysed. Once new proxy data are becoming available, it may turn out that these **1110**
will be more important for some regions than, for example, the Scottish speleothem. **1111**

Based on various types of proxy data, Bradley and Jones (1993) calculated **1112**
an average series of summer temperature anomalies for Europe since AD 1400 **1113**
(Figure 7). This series shows, for decadal values in the common period of 1500– **1114**
1979, statistically significant correlations with the reconstructed summer temper- **1115**
atures of Prague in the Czech Republic (0.49) and Switzerland (0.39), while the **1116**
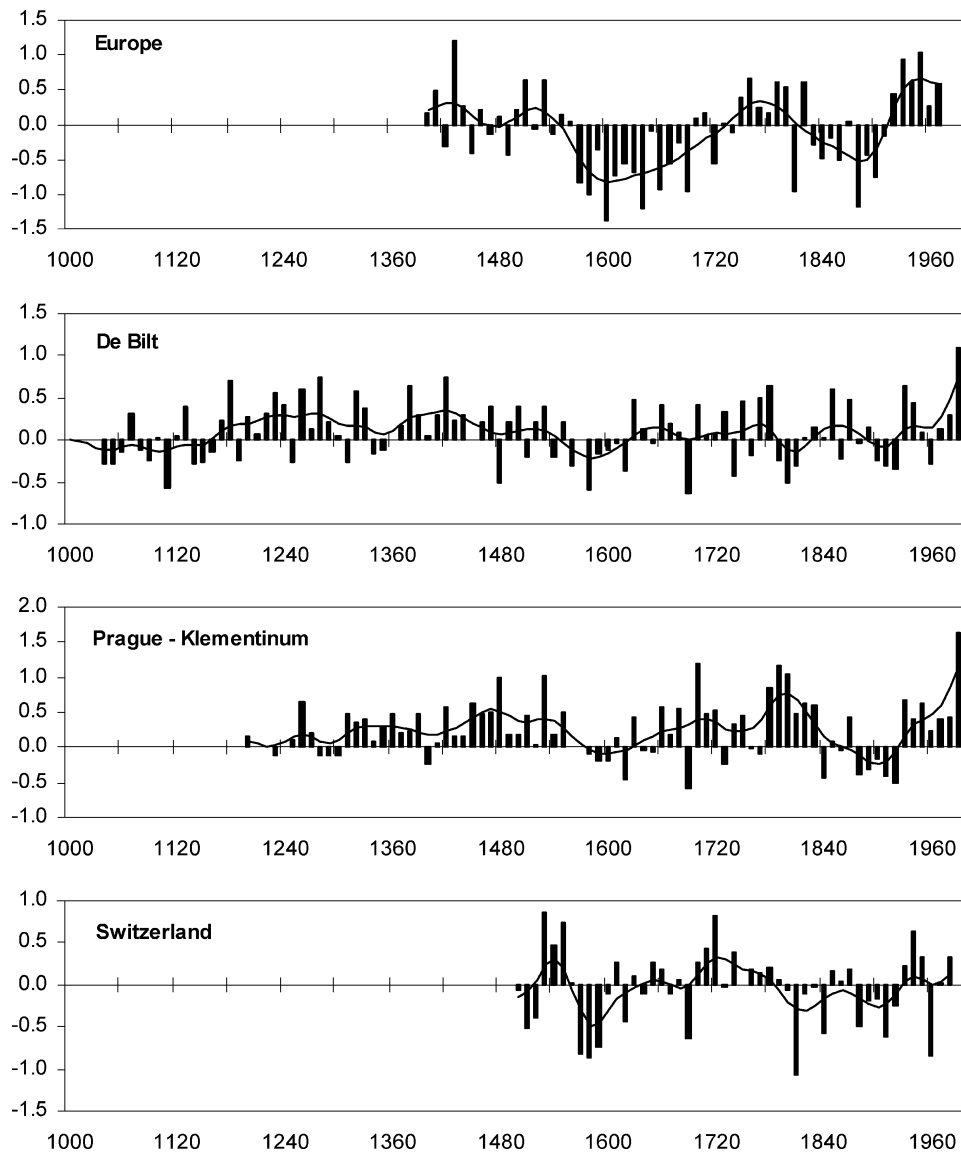
Figure 7. Fluctuations in decadal anomalies of summer temperatures (°C) in Europe over the last millennium (reference period 1901–1960), smoothed by a 10-decade Gaussian filter): (a) Europe (Bradley and Jones, 1993), (b) De Bilt – the Netherlands (van Engelen et al., 2000, 2001), (c) Prague-Klementinum – the Czech Republic (Brázdil, 1996), (d) Switzerland (Pfister, 1999).

1117   correlation with the station De Bilt in the Netherlands (0.25) is not significant.
1118   The Czech Republic series and the De Bilt series were not used in the European
1119   series by Bradley and Jones (1993), but the latter included the Swiss series. In
1120   the modern period 1900–1979, the correlations with the Bradley and Jones (1993)
       series are much stronger (0.65 for De Bilt, 0.54 forSwitzerland, 0.70 for the Czech

Republic). These results show that significant correlations exist between reconstruc- **1121**
tions of some local to regional Central European series and the European average, **1122**
but they also show that the correlations can vary substantially in time – indicating **1123**
time-varying reliability of the reconstructions. **1124**

Recently, Jones et al. (2003a) using both long European instrumental records **1125**
and longer European and Chinese documentary series showed that winters have **1126**
warmed relative to summers over the last 200 years compared to earlier in the past **1127**
millennium. They concluded that it may give erroneous indications of the past, if **1128**
proxies that are indicative of summer conditions are used to reconstruct annual **1129**
mean temperatures. This could potentially be a serious problem, as many natural **1130**
proxy data are sensitive to summer conditions while relatively few are sensitive to **1131**
winter and the other two seasons. **1132**

Detailed studies of climate fluctuations and their spatial structure in Europe, **1133**
based mainly on documentary evidence, have been undertaken for the 16th century **1134**
(Pfister et al., 1999a) and for the Late Maunder Minimum period in 1675–1715 **1135**
(e.g. Frenzel et al., 1994; Barriendos, 1997; Alcoforado et al., 2000; Xoplaki et al., **1136**
2001). Apart from temporal reconstructions for Germany (Glaser et al., 1999a) and **1137**
the low countries (van Engelen et al., 2000, 2001) there are no other European **1138**
temperature reconstructions with annual resolution available since AD 1000. The **1139**
challenge remains to assess temperature series for Central Europe over the last **1140**
millennium using data and reconstructions from other countries. **1141**

5.4. CLIMATIC ANOMALIES AND NATURAL DISASTERS **1142**

The terms "climatic anomaly" or "extreme event" are used here to describe a sub- **1143**
stantial deviation of a single value in a time series from an arithmetic mean or from a **1144**
trend, i.e. in association with short-term events (Pfister, 1999). On the other hand the **1145**
term "natural disaster" focuses on the effects of extreme events upon human soci- **1146**
eties. In other words, whether a rare event becomes a disaster depends on the social **1147**
conditions. Disasters are classified both in terms of material (money equivalent) and **1148**
immaterial damages (i.e. victims). However, the helplessness of the victims, their **1149**
dependence on help from the outside, provides a common denominator (Pfister, **1150**
2002). **1151**

In the context of the enhanced greenhouse effect debate, the potential anthro- **1152**
pogenic influences on climate are often blamed for environmental risks, in particular **1153**
climatic anomalies and natural disasters (Stehr and von Storch, 1995; Ungar, 1999). **1154**
While weather extremes usually have immediate consequences, the effects of cli- **1155**
matic anomalies may be time lagged. This was demonstrated by Pfister's (1999) **1156**
study of anomalies in monthly temperature and precipitation in Switzerland during **1157**
the period 1496–1995, which took into account occurrence of warm or cold, dry or **1158**
wet conditions, and their combinations. In the period 1560–1895, overlapping for **1159**
the most part with the LIA, 71% of anomalous months were cold, of these 40% were **1160**
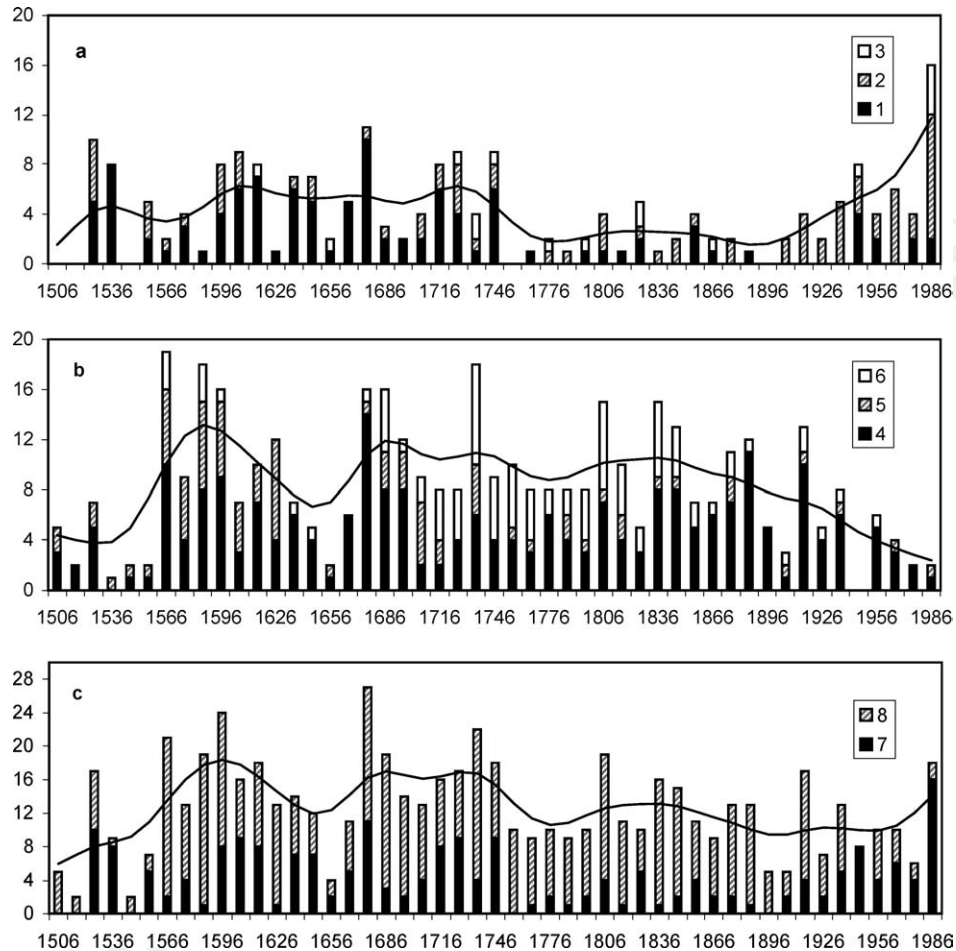
Figure 8. Decadal frequencies of warm (a), cold (b) and warm + cold (c) monthly temperature anomalies in Switzerland in the period 1506–1995 (data in Pfister, 1999): 1 – warm, 2 – warm–dry, 3 – warm–wet, 4 – cold, 5 – cold–wet, 6 – cold–dry, 7 – warm, warm–dry, warm–wet, 8 – cold, cold–wet, cold–dry. Smoothed by a 10-decade Gaussian filter. Years on the *x*-axis always mean the first year of the respective decade.

1161 rated cold, 17% cold–dry and 14% cold–wet. Between 1896 and 1988 the propor-
1162 tion of months that were anomalously cold dropped to 56%, while between 1988
1163 and 1997 cold anomalies completely disappeared. Figures 8a and 8b show decadal
1164 frequencies of individual months classified as warm (a) and cold (b) anomalies.
1165 More pronounced climate variability from the latter half of the 16th century to the
1166 mid-18th century is evident in Figure 8c, which shows the total frequency of both
1167 warm and cold anomalies combined.
1168   Natural disasters have always affected human affairs to some degree, as they do
1169 at the present time, when the material damage they cause is increasing and more

devastating. In the world, the material damage has grown by a factor of fourteen **1170** between the 1950s and the 1990s. Most, if not all of this increase, are the result **1171** of a greater intensity of settlements and constructions in potentially dangerous **1172** areas (Münchener Rück, 1999). The issue of whether the number and severity of **1173** "extreme events" has increased as a result of the enhanced greenhouse effect is **1174** highly controversial. In particular the following issues are not settled (Karl and **1175** Easterling, 1999): **1176**

 (i) Whether the observed process of global warming is projected to the fre- **1177**
      quency and intensity of meteorological extremes. **1178**
 (ii) Whether and to what extent the human society becomes more sensitive to **1179**
      impacts of meteorological extremes. **1180**
(iii) Whether the perception of meteorological extremes is to a greater extent **1181**
      affected by media. **1182**

Accurate observations (comparable to the modern standard) of meteorological ex- **1183** tremes (e.g. gales, hailstorms, tornadoes) and hydrological extremes (e.g. floods) **1184** are, as a rule, bound to the period in which the given element or phenomenon was **1185** systematically observed within a network. This period rarely extends over more **1186** than hundred years. Documentary data are the only kind of evidence that allows **1187** pushing back the record of such extremes into the past for several more centuries. **1188** The more extreme an event, the more evidence are available and the more detailed **1189** they are providing information about their intensity, seasonality, causes and impacts **1190** of disasters (Pfister, 1999; Brázdil, 2000). Moreover such reconstructions may at **1191** least partly provide analogue-cases for the present. **1192**

Certain limitations of this kind of evidence, however, have to be kept in mind. **1193** It is spatially and temporally discontinuous and limited to those events that had a **1194** significant impact on society. For the Czech Republic a series of strong wind events **1195** based on documentary evidence has been compiled since AD 1500 (Figure 9). Two **1196** periods before 1900 stand out in which such events were particularly frequent: The **1197** first one is the 1580s–1590s (also the 1640s), the second is the time between 1770 **1198** and 1900. It is open to debate whether such fluctuations are rather an effect of a **1199** changing density of records than the product of changing climate parameters. A **1200** conspicuous increase in frequencies since 1900 is due to a systematic research of **1201** newspaper reports, whereas up to that time the data were obtained only from clas- **1202** sical documentary evidence (such as chronicles, annals, letters etc.). Significantly **1203** lower numbers of events were recorded in the 1940s and in the 1950s. In the first **1204** case it was connected with the period of World War II with priority of other type of **1205** reports than about weather extremes. In the second case it was related to the period **1206** of political fanaticism after the onset of Communism in the former Czechoslo- **1207** vakia. Reports, about weather disasters, did not fit to official ideology that the "new **1208** man" will manage nature and its processes (Dobrovolný and Brázdil, 2003; Brázdil **1209** et al., in press). Other similarly analysed European series are shorter and related **1210** to documentary data and systematic (instrumental) observations at one particular **1211**
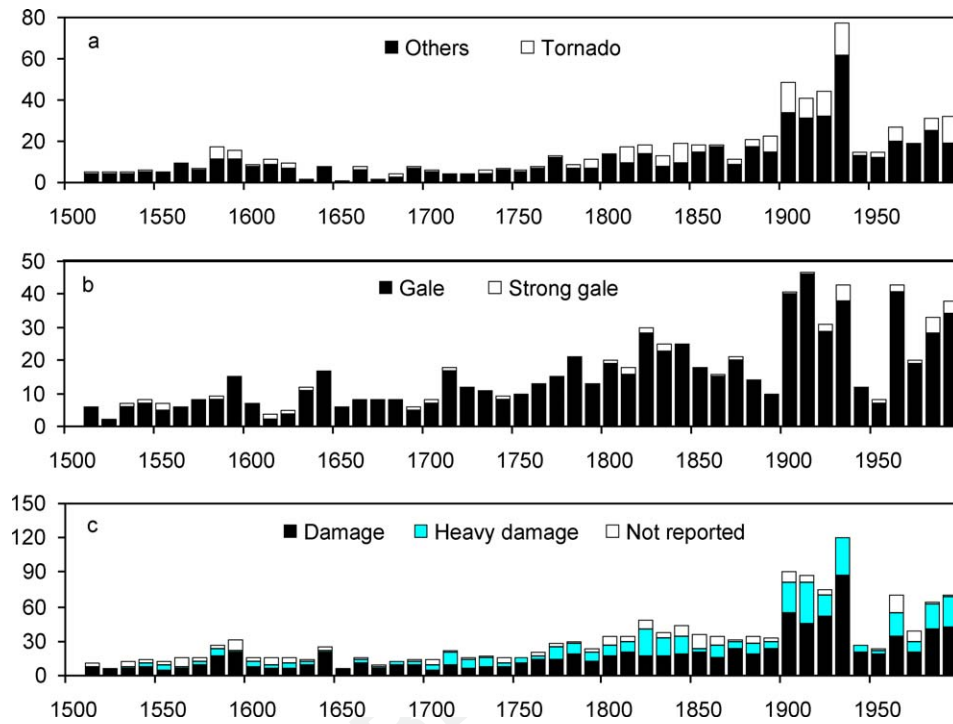
Figure 9. Fluctuations in decadal frequencies of the occurrence of strong winds (based on documentary evidence) connected with convective storms (tornadoes and others) (a), gales (b) and case of strong winds with damage (c) in the Czech Republic over the period AD 1500–1999 (Brázdil et al., 2004). Years indicate the first year of the respective decade.

1212 place (e.g. Dawson et al., 1997; Schiesser et al., 1997; Sweeney, 2000; Hickey,
1213 2003).
1214   Many scientific investigations that focus on the causes, the seasonality and the
1215 intensity of climatic anomalies and extremes do not consider the societal conse-
1216 quences, while other studies address both questions simultaneously. Only a certain
1217 part of climatic anomalies and extremes, however, generates damage. For instance,
1218 according to Brázdil et al. (1998), in the years 1957–1995, all the material damage
1219 and the loss of lives related to weather extremes in southern Moravia (the Czech
1220 Republic) was due to only about 6% of all thunderstorms and about 23% of all
1221 hailstorms. This knowledge corresponds to similar results by Changnon (1997) for
1222 the USA where only 5–10% of all thunderstorms and 10–25% of all hail produce
1223 damage. Systematic records of the impact of extremes are useful for the compilation
1224 of their chronologies. De Kraker (1999, 2002) utilised data from accounts of dikes
1225 protecting a polder region in northern Flanders to trace the occurrence of high tides,
1226 storms and storm surges in the past millennium. The magnitude of impacts is, to a
1227 considerable extent, a result of the interaction between physical parameters and the
1228 vulnerability of societies; the latter involves the awareness and the preparedness

for such events (e.g., in the adaptation of land use and the setting up of a warning **1229** system), which fluctuates in both space and time. Systematic time series of the **1230** material and immaterial damages were only recently established for the 19th and **1231** 20th century Switzerland (Pfister, 2002), though such data could also be obtained **1232** for other countries using documentary sources such as chronicles, newspapers and **1233** – for the last decades – the records of insurance companies, if these have survived. **1234**

Floods and storms are counted among the most devastating natural disasters, as **1235** in Central Europe the examples of the "millennium flood" in July 1342 (Bork et al., **1236** 1998; Tetzlaff et al., 2001) and of the recent catastrophic flood in August 2002 **1237** demonstrated (Kachelmann, 2002; Mudelsee et al., 2003). Records of major histor- **1238** ical floods were included into compilations of flood reports already quite long ago **1239** (e.g., see Pötzsch, 1784; Weikinn, 1958–2002; Jones et al., 1984). This evidence, **1240** however, was not systematically analysed from a scientific point of view until re- **1241** cently. Flood series as well as individual severe flood events in the pre-instrumental **1242** period in Europe have been subject to several recent studies (e.g., see Pfister and **1243** Hächler, 1991; Camuffo and Enzi, 1996; Krahe, 1997; Brázdil, 1998; Glaser, **1244** 1998; Deutsch et al., 2000; Schmidt, 2000; Tol and Langen, 2000; Williams and **1245** Archer, 2000; Munzar, 2001; Deutsch and Pörtge, 2002). For instance, Barriendos **1246** and Martín-Vide (1998) investigated flood magnitude and frequency within the **1247** context of climatic variability for the last centuries for central Spain and Catalonia. **1248** The authors report on the importance of documentary data to illustrate the high **1249** sensitivity of flood magnitude and frequency to the climatic variability. They found **1250** periods with high flood frequency over the last centuries with similar seasonal **1251** distribution compared to present conditions. Brázdil et al. (1999) analysed in detail **1252** the severity and frequency of floods during the 16th century in different European **1253** drainage areas. They found a prevalence of flood occurrence during the second half **1254** of the 16th century for Central European and Andalusian rivers, while Italian and **1255** Catalonian rivers had a higher occurrence of floods during the first half of the same **1256** century. Heavy Rhine floods in Basle (Switzerland) appeared on average each 9.5 **1257** years since 1496 up to 1882 while in the following 112 years the average return pe- **1258** riod lengthened to 18.7 years. No truly extreme flood event was observed between **1259** 1882 and 1994 (Pfister, 1999). Benito et al. (2003) analysed not only the frequency **1260** of flooding in the Tagus basin (central Spain) over the last millennium, but based **1261** on water-level marks and other documentary evidence and using a hydraulic **1262** model, they also estimated the peak discharges of floods. They concluded that **1263** flood magnitude and frequency is highly sensitive to the climatic variability. Llasat **1264** et al. (2003) investigated the flash flood of June 2000 in Catalonia and compared **1265** it with the floods that have occurred since the 14th century. They concluded, that **1266** comparable catastrophic events have been recorded at least once each century and **1267** that they are associated with similar meteorological situations. Mudelsee et al. **1268** (2003) studied long records of winter and summer floods of the Elbe and Oder **1269** rivers. They found a decrease in winter flood occurring in both rivers for the past **1270** 80 to 150 years, while summer floods show no trend. Additionally, the authors **1271**
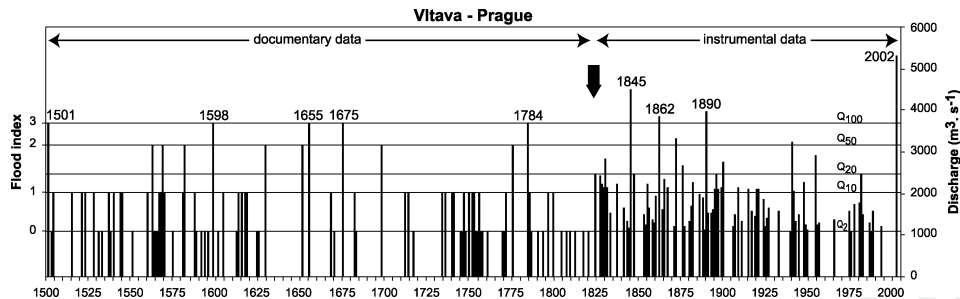
Figure 10. Chronology of floods on the Vltava at Prague in AD 1500–2002 – a synthesis of documentary evidence and instrumental records. Left: floods according to documentary data interpreted in the scale 0–3 (for explanation see Sturm et al., 2001). Right: measured peak discharges during floods with *n*-year water levels; for instance, Q_{20} corresponds to the peak discharge rate with return period of 20 years.

1272 detected significant long-term changes in flood occurrence rates in the 16th–19th
1273 centuries.
1274   Following a series of severe flood events in Europe since the 1990s (e.g., in
1275 the Rhine and the Meuse area in December 1993 and January 1995, the Oder and
1276 the Morava area in July 1997, the Vltava and the Elbe in August 2002) a Swiss-
1277 German-Czech research project named FLOODRISK was initiated to investigate
1278 the frequency of severe floods in Central Europe back to AD 1500 on the basis of
1279 documentary data (Wanner et al., 2004). A particular focus was set on the study of
1280 natural variability because the question is regularly asked as to whether such events
1281 in recent times are just an expression of natural climate variability or rather a result of
1282 recent global warming (Weichselgartner, 2000; Sturm et al., 2001; Hesselink, 2002).
1283   Figure 10 represents the chronology of floods with peak discharge rates
1284 ≥ 1090 m$^3 \cdot$ s^1 (this peak discharge rate corresponds to the return period of 2 years,
1285 further denoted as "2-year water") in the Vltava at Prague during AD 1500–2002.
1286 Regular measurements started there in 1825. Floods before 1825 were derived from
1287 documentary evidence. The flood of August 2002 due to continuous precipitation
1288 during three days, with 17 victims and material damage around 80 billion Czech
1289 crowns (around 1/10 of the national budget value), was estimated to be a "500-year
1290 water" (5160 m$^3 \cdot$ s^1). It has only one known analogue, the case from July 1432
1291 which was known as "a flood of millennium" in Bohemia. Between this flood and
1292 the event in the year 2002, the February flood of 1784 due to ice movement was
1293 taken to be the highest with a calculated peak discharge rate, according to water-
1294 marks of 4580 m$^3 \cdot$ s^1. Flood intensity indices (on a scale from 0 to 3) from the
1295 pre-instrumental period, based on documentary evidence (Sturm et al., 2001), are
1296 also shown in Figure 10. This figure shows two long periods with no severe floods,
1297 namely between 1675 and 1784 and 1890 and 2002. On the other hand, the second
1298 part of the 16th century and most of the 19th century belonged to the most severe
1299 flood periods. During 1630–1730 the recorded number of floods with lower index
1300 might be influenced by some gaps in the documentary evidence. There is a necessity

to take in consideration natural and anthropogenic changes in the catchment area **1301**
during some centuries (e.g. land-use) as well as the fact that extreme floods can **1302**
significantly alter the character and the course of a river.   **1303**

The historical flood series clearly suggests decadal scale variability. But the **1304**
data set itself does not clearly answer the question of whether this time series is **1305**
representing a purely stochastic process. In recent years, the first attempts have **1306**
been undertaken to study the relation between the flood frequency and atmospheric **1307**
circulation changes (e.g., Hirschboeck, 1987; Jacobeit et al., 2003; Wanner et al., **1308**
2004). In general, it can be stated that flooding catastrophies in larger areas appear **1309**
to develop in preferred locations and can be linked to anomalous atmospheric **1310**
circulation patterns. These patterns persist over a longer period of days and weeks **1311**
and lead to a strengthened humidity transport from the oceans to the continents. **1312**

It is still a topic of intense research to find the mechanisms that link the process **1313**
of warming at the global level and other large scale forcing factors with features **1314**
such as severe anomalies and hazards at the regional level. This has yet to be done, **1315**
because the public opinion is very sensitive to extremes which occur near or within **1316**
the region where they live. Last, but not least, it is controversial regarding how far **1317**
natural hazards are purely natural and how far they are aggravated by human activity **1318**
(e.g. Weichselgartner, 2000; Houghton et al., 2001; Hesselink, 2002; Mudelsee **1319**
et al., 2003).   **1320**

5.5. CLIMATIC IMPACTS AND THE VULNERABILITY OF PAST ECONOMIES   **1321**
AND SOCIETIES   **1322**

Whereas the study of future climatic impacts on humankind has developed into a **1323**
well-funded avenue of research, the climatic vulnerability of past societies has only **1324**
found a limited attention. To some extent this is connected to the long tradition **1325**
of climatic determinism which postulated that climate has been one of the most **1326**
powerful factors in determining the course of human history (e.g. Huntington, **1327**
1907, 1925; Markham, 1947; Claiborne, 1970). Particularly crude and unscientific **1328**
examples of this position were recently provided by Beck (1993) and Hsü (2000). **1329**

From the early 20th century social scientists such as Emile Durkheim vigorously **1330**
reacted against this school of thought by framing the axiom that social issues **1331**
could solely be explained by social factors (Glaeser, 1994). Durkheim's axiom **1332**
is still believed by many social scientists today, and this is one of the obstacles to **1333**
interdisciplinary co-operation between natural and social sciences. A more adequate **1334**
position, avoiding both extremes of rejecting any role of the natural environment and **1335**
of assigning it a dominant role, was formulated by the German geographer Wilhelm **1336**
Lauer (1981): "*Climate shapes the theatre in which human existence – the history of* **1337**
the human race – takes place, sets borders for that which can happen on the earth, **1338**
but certainly does not determine what happens or will happen. Climate introduces **1339**
problems that man has to solve. Whether he solves them, or how he solves them, is **1340**

1341 *left to his fantasy, his will, and his formative activities. Or, expressed in a metaphor:*
1342 *climate does not compose the text for the development drama of mankind, it does*
1343 *not write the movie script, that man does alone.*"
1344   Another point was the lack of continuous, homogeneous and quantitative high-
1345 resolution evidence of temperature and precipitation needed for the building of
1346 appropriate models. Finally, the use of blanket terms such as the MWP and LIA
1347 in comparisons of climatic conditions with developments in human history and
1348 society was not very helpful, because it overshadowed the complexity of the task
1349 and lead to hasty conclusions. The topic of climatic change was investigated again
1350 after World War II by members of the French Annales School such as Fernand
1351 Braudel and Emmanuel Le Roy Ladurie. In the well-known "History of Climate"
1352 Le Roy Ladurie (1967) pointed out that: "*In the long term the human consequences*
1353 *of climate seem to be slight, perhaps negligible, and certainly difficult to detect.*"
1354 Wigley et al. (1985) provided a basic study concerning historical climate impact
1355 assessments.
1356   The issue of whether climatic change had a significant impact on "history"
1357 is controversial (Brown, 2001). However, it should not be overlooked that both
1358 "climate" and "history" are blanket terms located on such a high level of abstraction
1359 that relationships between them cannot be investigated according to the rules of
1360 scientific methodology. In order to become more meaningful, the issue needs to be
1361 broken down to lower scales of analysis, e.g. by putting a focus on specific human
1362 activities and/or needs in relation to a given set of climatic variables. For the needs
1363 of pre-industrial societies, it primarily concerns the availability of biomass (e.g.
1364 food, fodder) and energy (e.g. wind, water-power, draught animals), followed by
1365 the processes of population dynamics (e.g. patterns of diseases and epizootics, as
1366 well as fertility of men and live-stock), and transport and communications as well
1367 as military and naval operations. Undoubtedly, beneficial climatic effects tend to
1368 enlarge the scope of human action, whereas climatic shocks restrict it or, in the worst
1369 case lead to emergency situations. The impact of sequences of climatic events on
1370 energy availability and population dynamics depends on the environmental, cultural
1371 and historical context (Pfister, 2001).
1372   Models of climatic effects on society are often framed as a chain of causation
1373 (Kates, 1985). Climatic patterns have a first order or biophysical impact on agri-
1374 cultural production or on the outbreak of diseases or epizootics (e.g. Pfister, 1984).
1375 These may have second-order effects on prices of food or raw materials which
1376 may then ramify into the wider economy and society (third-order impacts). In the
1377 late 19th century, economists and geographers such as Stanley Jevons and Eduard
1378 Brückner were looking for climatic cycles, because climate was still an important
1379 determinant of food prices (Stehr and von Storch, 2000a). The concept of "Little
1380 Ice Age Type-Impacts" (LIATIMP) was recently proposed by Pfister (in press).
1381 LIATIMP also stands for a numerical model that simulates biophysical impacts
1382 on agriculture based on climatic data and comprise cold and rainy mild-summers,
1383 chilly springs and rainy autumns. Prior to the mid-20th century such situations

affected all agricultural resources at the same time (for 17th century Saxony, see **1384** Militzer, 1996, 1998). It was demonstrated that the level of LIATIMP was signifi- **1385** cantly higher during the period 1568–1630 than during the previous and subsequent **1386** decades.   **1387**

Baten (2002) studied human stature as an indicator for nutritional status. He **1388** argued that European climate in the 18th century significantly influenced nutritional **1389** status as measured with anthropometric indices on a quinquennial or decadal basis. **1390** According to him there was a causal chain leading from warmer (colder) winters **1391** to higher (lower) grain and protein production, and these factors determined real **1392** wages and finally human stature.   **1393**

Bauernfeind (1993) looked into grain price formation on the Nuremberg market **1394** (southern Germany) from AD 1339 to 1670. After having controlled prices for cur- **1395** rency devaluation he concluded that long-term trends of grain prices were primarily **1396** caused by both the growth and decline of population and climate variations. Bauern- **1397** feind and Woitek (1999) analysed quantitatively the impact of seasonal temperature **1398** and precipitation on the price fluctuations of several commodities, including rye, **1399** butter and honey, at Nuremberg, Cologne, Augsburg and Munich (Germany) during **1400** the period 1490–1620. It turned out that in the last third of the 16th century climatic **1401** changes became the most significant factor affecting food prices.   **1402**

Brázdil and Durd'áková (2000) studied series of prices for rye, wheat, barley **1403** and oats for Brno, Dačice and Olomouc (the Czech Republic) for the 16th–18th **1404** centuries. A focus was put on 61 years of crisis, in which prices stood at a very high **1405** level. According to the authors the relation to a poor harvest and to adverse weather **1406** in the given or in the preceding year was obvious in 67% of the crisis years. This **1407** result points to the fact that climate is only one, albeit an important factor affecting **1408** subsistence levels in agrarian societies.   **1409**

Wine was another important source of income for institutions and for the landed **1410** gentry on the basis of tithes, taxes or sharecropping. In Central Europe viticulture is **1411** at its northern limit and therefore the growth, yield and sugar content of grapes are **1412** very dependent on climate. Landsteiner (1999) compared wine production in four **1413** areas north of the Alps – the Zurich area, Württemberg, Lower Austria and western **1414** Hungary – over the period 1550–1630. In all regions wine production slumped from **1415** the 1580s initiating a long series of consecutive crop failures continuing until the **1416** late 1590s or the early 1600s. This calamity is attributed to a 15-year downturn of **1417** summer temperatures north of the Alps (Pfister and Brázdil, 1999). In lower Austria **1418** the collapse of wine production and hence high prices, led the public to switch from **1419** wine to beer consumption. The Hapsburg Emperor, who drew a substantial part of **1420** his income from wine production, had to double the heavy export duty on wine in **1421** order to be able to meet the interests on the state debt. Moreover harvest failures put **1422** a severe strain on the budgets of urban wine producers, and deficient grain harvests **1423** reduced the real wages of the vinedressers by 50% (Landsteiner, 1999).   **1424**

The farther we move away from first-order impacts, the greater is the com- **1425** plexity of the factors masking the climatic effect. It is easier to investigate the **1426**

1427 effects of short-term (annual and interannual) impacts. In dealing with the effects
1428 of multidecadal climate variations we have to account for modifications in the
1429 economic, institutional and environmental setting so extensively as to vitiate any
1430 attempt at strict comparison or measurement. Most climatic impacts were related to
1431 food scarcity or famines. In most cases, impacted societies had developed adaptive
1432 and adjustive mechanisms to buffer climatic shocks and to avoid risk by growing
1433 different kinds of crops (e.g. Barriendos and Dannecker, 1999). Moreover, param-
1434 eters such as social stratification and governance need to be considered. This is
1435 illustrated by Brázdil et al. (2001) who investigated the consequences of the well-
1436 known European subsistence crises in 1770–1771 for the Czech Lands. A long
1437 wet spell in mid-summer together with other weather, economic and social factors,
1438 caused a dramatic surge in grain prices leading to dearth, diseases and extremely
1439 high population mortality (Figure 11). Although the Imperial Court in Vienna took
1440 measures for relief, one tenth of the population died in Bohemia during those years.
1441 The dearth lead to a change in the diet of the poor strata of society, and this became
1442 one of the triggers for the subsequent uprising of serfs in 1775.
1443   In other parts of central Europe the demographic consequences of this climatic
1444 impact were less dramatic, because the social buffers were adequate. This is demon-
1445 strated from the example of the Swiss Canton of Bern, where the level of mortality
1446 did not rise despite the adverse weather (Pfister, 1978), because the system of lo-
1447 cal and regional poor-relief was well developed. However, the level of community
1448 taxes rose sharply as a consequence (Flückiger-Strebel, 2002). The comparison
1449 of these two examples, the Czech Lands and the Canton of Bern highlights the
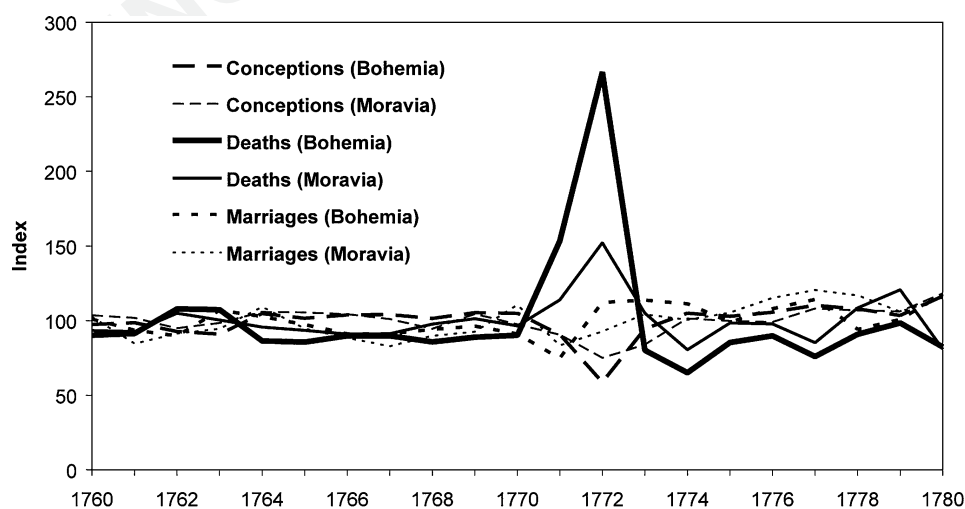1450 social dimension of food poverty, which may be aggravated or alleviated by the

Figure 11. Fluctuations in indices of conceptions, deaths and marriages in Bohemia and Moravia (the Czech Republic) in the period 1760–1780 (100 is average of 1760–1780) (Brázdil et al., 2001).

management of the crisis by the authorities (Newman, 1990). More regional exam- **1451**
ples are needed in order to get a coherent view on the many dimensions that are **1452**
related to this issue. **1453**

When studying the effect of climatic variations on past societies, little can be **1454**
learned from the management of recent or ongoing climate variations, simply since **1455**
the societal conditions, in terms of organisation, technology and demography have **1456**
changed. The impact of climate variations and extremes is non-stationary. How- **1457**
ever, the way people think about climate, how they perceive extremes, is changing **1458**
much less. Therefore, the aspect of "images and social representation" discussed **1459**
in the next section is of great practical importance for the ongoing discourse about **1460**
anthropogenic climate change and how people, nations and societies will deal with **1461**
the threat of global warming. **1462**

5.6. IMAGES AND SOCIAL REPRESENTATIONS OF CLIMATIC ANOMALIES **1463**
AND NATURAL DISASTERS **1464**

A cultural history of environmental affairs stresses the point that a certain attitude **1465**
to nature depends on a particular world-view or view on nature that is changeable **1466**
with time (Glacken, 1967). If we understand culture as the construction of reality, **1467**
then weather, climate and natural disasters become a part of the cultural history of **1468**
mankind (Kempe, 2003). This kind of research is still in its infancy (e.g., Rebetez **1469**
Beniston, 1992; Rebetez, 1996; Coates, 1998; Fleming, 1998; Favier and Granet- **1470**
Abisset, 2000; Jankovic, 2000; Coeur, 2003; Groh et al., 2003; Jakubowski-Tiessen **1471**
and Lehmann, 2003; Kempe and Rohr, 2003; Stuber, 2003). Historical climatology **1472**
is called to participate in investigating the ideas and images and social representa- **1473**
tions of climatic anomalies and natural disasters. It is a multidisciplinary field that **1474**
involves also cultural historians, historians of religion and mentality and linguists. **1475**
The contribution of historical climatology might be twofold: On the one hand, **1476**
historical climatologists are familiar with the sources in which historical percep- **1477**
tions of weather are found, where quasi "objective" observations and superstitious **1478**
interpretations of anomalies can be part of the same records. On the other hand, **1479**
historical climatologists have produced high-resolution quantitative reconstructions **1480**
of weather and climate. This kind of statistical product derived from the original **1481**
evidence may be needed to rectify views, which cast doubt on the reality of the **1482**
extreme phenomena that are described in the records. **1483**

Behringer (1999), who investigated the connections between witchcraft and cli- **1484**
mate in Europe, is a good example for dealing with climate and social representation. **1485**
Although in popular imagination witchcraft has traditionally been seen as one of **1486**
the major causes for hailstorms, Christian ecclesiastical authorities in the Early and **1487**
High Middle Ages refused to accept such accusations. It was only in the 1380s that **1488**
magic and weather-making became increasingly prominent in inquisitorial trials. **1489**
During the 1480s the Church finally accepted the image of the weather-making **1490**

1491 witch. This was mainly the work of the Alsatian Dominican friar Heinrich Kramer,
1492 who summarised these ideas in his notorious *Malleus maleficarum*, The Witches'
1493 Hammer, published in 1486.
1494   Harsh criticism by humanists at the beginning Reformation temporarily stopped
1495 inquisitorial witchcraft persecution in the early 16th century. The debate was re-
1496 sumed in the 1560s and accompanied by a debate on weather-making because this
1497 was the most important charge against suspected witches. Though witches were cer-
1498 tainly made responsible for all kinds of bad luck, weather is especially important
1499 in an agrarian society. Crop failure caused increases in prices, malnutrition, rising
1500 infant mortality and, finally, epidemics. Starting in the 1560s, a series of witch pan-
1501 ics shook European societies and were followed by attempts to legalise witchcraft
1502 persecutions. From the 1580s to the end of the 1620s, persecution increased to a
1503 previously unknown extent, when thousands of persons were burnt in many parts of
1504 Western and Central Europe. This period coincides with the decade long downturn
1505 in climate that leads to a long-term deterioration of the living conditions of the ma-
1506 jority of the people. New research demonstrates that the persecution was indeed not
1507 only demanded but also organised by the population. Accusations and persecutions
1508 were synchronous in far-away countries, not connected by dynastic, confessional,
1509 economic or other links. This demonstrates the importance of the climatic factor
1510 as a contributing explanation (Behringer, 1999). It seems that climatic change and
1511 variability is becoming a significant topic in the history of mentalities.
1512   Another example is the lengthy list of cases when Europeans and North Amer-
1513 icans believed to be subject to man-made climate change (von Storch and Stehr,
1514 2000, 2002). This list includes the witches just mentioned, but also the concern
1515 about newly installed lightning rods, redirection of ocean currents, nuclear ex-
1516 plosions, deforestation and many more. Von Storch and Stehr (2000, 2002) claim
1517 that the concept of adverse anthropogenic climate change is an integral part of the
1518 Western culture, so that relating weather extremes to anthropogenic causes is easily
1519 accepted as plausible.

1520 5.7. POTENTIAL OF HISTORICAL CLIMATOLOGY FOR CLIMATE MODELLING

1521 Recently, the first attempts were made to reconstruct climate variations during the
1522 last few hundred years using dynamic climate models forced with reconstructed time
1523 series of forcings. One such study was conducted by Fischer-Bruns et al. (2002).
1524 With the state-of-the-art climate model ECHO-G, the effect of time varying solar
1525 and volcanic-aerosol forcing has been simulated. This model is composed of the
1526 atmospheric GCM ECHAM4 with T-30 resolution and an oceanic circulation model
1527 HOPE-G with T-42 resolution (for more details, see Zorita et al., in press). During
1528 the winters 1675–1710 a marked global cooling was simulated. This event mimics,
1529 in terms of broad patterns and time mean intensity, the strong cooling "Late Maunder
1530 Minimum" (LMM, 1675–1710) period in Europe documented in various historical
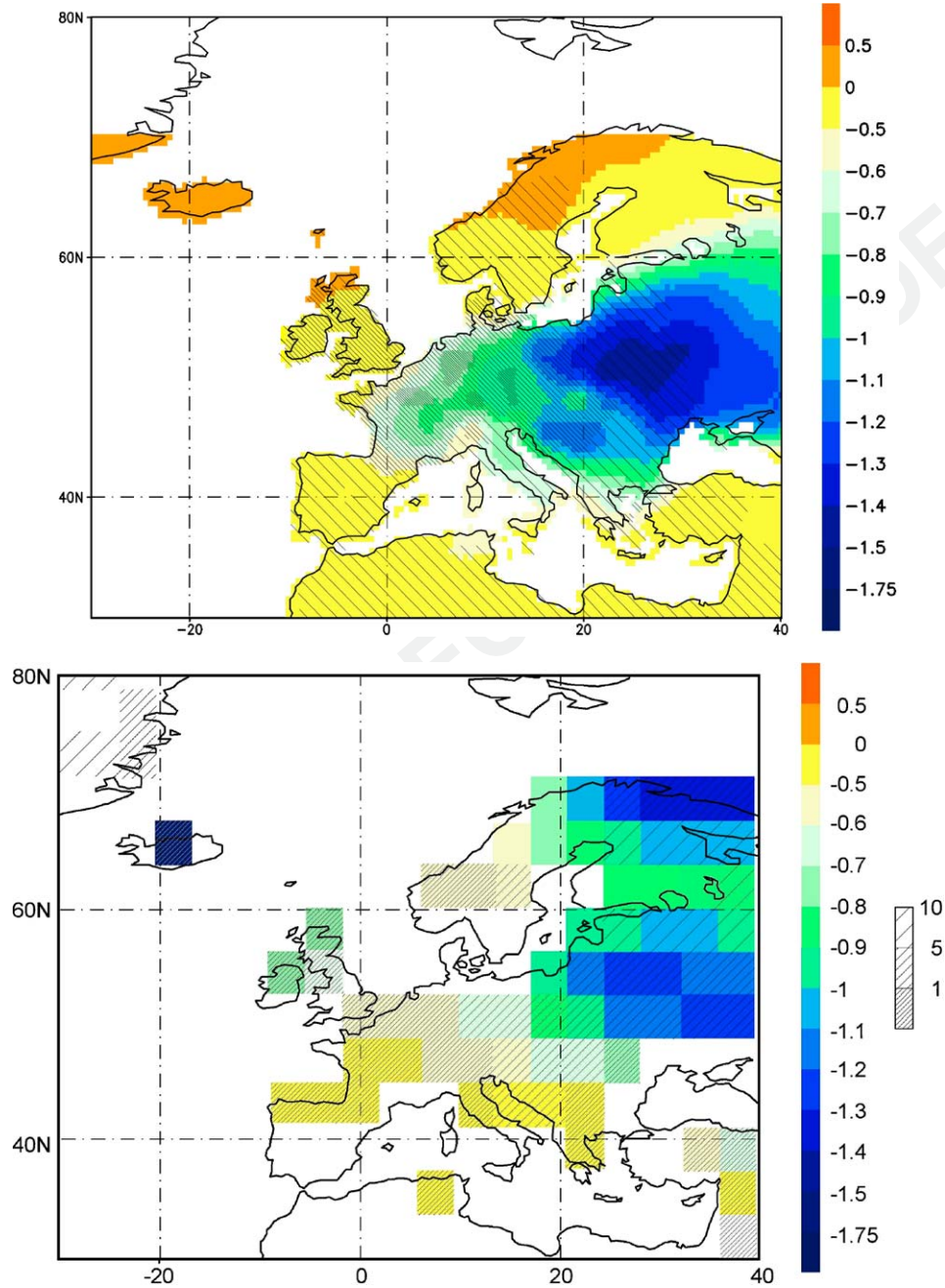
Figure 12. Representation of the winter temperature deviation during the Late Maunder Minimum, 1675–1710 vs. 1550–1800, according to historical reconstructions (top; Luterbacher et al., 2004) and a simulation with the climate models ECHO-G (bottom; von Storch, 2004). The hatching in the top diagram represents the proportion of described variance (>40, 70 and 90%) and in the bottom diagram the risk for rejection the null hypothesis of no change (10, 5 and 1%).

1531 sources and early instrumental time series. Figure 12 shows the mean temperature
1532 change (1675–1710 minus 1550–1800) in Europe as reconstructed by Luterbacher
1533 et al. (2004) from historical evidence and as simulated by the ECHO-G model.
1534 The hatching indicates the statistical confidence of the features, i.e., non-hatched
1535 features are quite uncertain, whereas dense hatching represents high confidence.
1536   This comparison of a climate reconstruction based on documentary and in-
1537 strumental data with results from a model run using reconstructed external forcing,
1538 serves as an early example of how historical climatology and dynamic climate mod-
1539 elling can supplement each other in our efforts towards improved understanding of
1540 past climatic variability and how the climate system responds to external forcings.
1541 The LMM modelled by the forced ECHO-G integration (Zorita et al., in press) is
1542 causally related to the solar and volcanic forcing anomalies in the preceding decades
1543 and during the LMM. The model simulation has the advantage that it provides the
1544 climatic state of the whole globe. According to this model, the temperatures were
1545 lower everywhere north of about 30°S during the LMM than in the earlier and later
1546 times, with a marked cooling of the Labrador Sea. In this simulation the cooling
1547 in Europe is not simply related to anomalous easterly winds over the region, but to
1548 a general more widespread cooling. A survey among a variety of proxy data from
1549 ice cores, corals and other data supports this notion of an almost global response
1550 (Zinke et al., in press).

1551   **6. Conclusions**

1552 Historical climatology has made a great deal of progress after 1990, due to an
1553 important extension of its research possibilities. Based on the current evaluation of
1554 its present state, it is possible to formulate prospects of future investigations in this
1555 research field. They can be summarised as follows:

1556   (i) Completion of the existing databases. Cross-referencing and combination
1557   of different data for achievement of the most complete reconstruction of
1558   past climates.
1559 (ii) Compilation of further series of temperature and precipitation indices for
1560   different countries of Europe. Assess average temperature and precipita-
1561   tion indices from these series. Develop average series for major regions of
1562   Europe.
1563 (iii) Improvement of the mathematical-statistical tools used for reconstructing
1564   temperature and precipitation series from documentary evidence.
1565 (iv) Compilation of time series of weather and climate extremes and natural
1566   disasters. Evaluation in terms of severity, seasonality, causes, impacts and
1567   evolution over time.
1568   (v) Improvement of statistical tools for estimating past circulation patterns and
1569   spatial representation of temperature and precipitation conditions.

(vi)   Closer co-operation with climate modellers and use of GCM outputs to **1570**
        study climate forcing and to augment attempts to reconstruct past climate **1571**
        states by skilfully combining empirical evidence and dynamical knowledge **1572**
        encoded in dynamical climate models (with avoiding circularity).   **1573**

(vii) Co-operation with economists, historians, anthropologists, sociologists and **1574**
        archaeologists in order to investigate the impact of past climate fluctuations **1575**
        and extremes upon the economy, human health and well-being, and to **1576**
        understand the social mechanisms to adapt to climate change and extremes. **1577**

(viii) Investigations into images and social representations of past weather, cli- **1578**
        mate and climatic extremes in co-operation with psychologists, historians **1579**
        and anthropologists. Comparison of the imagined climate with the "real" **1580**
        climate reconstructed from different kinds of evidence.   **1581**

Historical climatology is not only an academically attractive activity; it is of **1582**
utmost importance for the contemporary discussion about ongoing anthropogenic **1583**
climate change. It is providing information about the range of "natural variations" **1584**
of a climate very close to the present one. After successful reconstructions of the **1585**
climate of the 20th century have been completed (Houghton et al., 2001), joint **1586**
efforts to reconstruct the climate of the 19th and 18th century should be pursued. **1587**
Such reconstructions would provide a considerably improved basis for the problem **1588**
of detecting and attributing ongoing climate change. By documenting the responses **1589**
of past societes to perceptions and realities of climate change, useful strategies may **1590**
be discovered for improving the ability of present day innovative networks to deal **1591**
with this issue (Sarewitz and Pielke, 2000).   **1592**

There is a hope that historical climatology will further develop not only in Europe **1593**
and eastern Asia (such as China, Japan, Korea), where there exist great scientific **1594**
and data potentials, in particular as regards documentary data, but also in other **1595**
parts of the world, such as Latin America (Metcalfe et al., 2002) and potentially **1596**
the Islamic World.   **1597**

1609 Štěpánková, Jarmila Macková and Radek Neužil (Brno) for technical help
1610 with some figures.

References

1612 Alcoforado, M.-J., de F. Nunes, M., Garcia J. C., and Taborda, J. P.: 2000, 'Temperature and precipi-
1613   tation reconstruction in southern Portugal during the Late Maunder Minimum (AD 1675–1715)',
1614   *Holocene* **10**, 333–340.
1615 Alexandre, P.: 1987, *Le climat en Europe au Moyen Age. Contribution à l'historie des variations*
1616   *climatiques de 1000 à 1425, d'après les sources narratives de l'Europe occidentale*, École des
1617   Hautes Études en Sciences Sociales, Paris, 825 pp.
1618 Amberg, B.: 1890, *Beiträge zur Chronik der Witterung und verwandter Naturerscheinungen mit*
1619   *besonderer Rücksicht auf das Gebiet der Reuss und der angrenzenden Gebiete der Aare und des*
1620   *Rheines*, Jahresber. Höh. Lehranst. Luzern, 86 pp.
1621 Angot, A.: 1885, 'Etude sur les Vendanges en France', Annales du Bureau Central Météorologique de
1622   France, publiées par E. Mascart. Année 1883. I. Étude des orages en France et Mémoires divers.
1623   Paris, B.29–B.120 (sic!).
1624 Angot, A.: 1895, *Première catalogue des observations météorologiques faites en France depuis*
1625   *l'origine jusqu'en 1850*, Annales du Bureau Central Météorologique de France, Paris.
1626 Appleby, A. B.: 1981, 'Epidemics and Famine in the Little Ice Age', in Rotberg, R. I., and Rabb, T.
1627   K. (eds.), *Climate and History. Studies in Interdisciplinary History*, Princeton University Press,
1628   Princeton, New Jersey, pp. 63–83.
1629 Bachmann, H.: 1984, *Kalenderarithmetik*, Juris, Zürich, 104 pp.
1630 Baker, A., Proctor, C. J., and Barnes, W. L.: 2002, 'Stalagmite lamina doublets: A 1,000 year record
1631   of severe winters in NW Scotland?', *Int. J. Climatol.* **22**, 1339–1345.
1632 Balandin, R. K.: 1975, *Puls zemnikh stichiy*, Mysl, Moskva, 206 pp. German translation: *Naturkatas-*
1633   *trophen. Der Pulsschlag der Naturgewalten*. Teubner, Leipzig 1988.
1634 Barash, S. I.: 1989, *Istoriya neurozhayev i pogody v Evrope (po XVI v. n. e.)*, Gidrometeoizdat,
1635   Leningrad, 238 pp.
1636 Barriendos, M.: 1997, 'Climatic variations in the Iberian Peninsula during the late Maunder Minimum
1637   (AD 1675–1715): An analysis of data from rogation ceremonies', *Holocene* **7**, 105–111.
1638 Barriendos, M. and Dannecker, A.: 1999, 'La sequia de 1812-1824 en la costa central catalana.
1639   Consideraciones climaticas e impacto social del evento', in Nadal, R., José, M. and Martín-Vide,
1640   J. (eds.), *La climatologia espanola en los albores del siglo XXI*, Villassar de Mar, pp. 53–62.
1641 Barriendos, M. and Martín-Vide, J.: 1998, 'Secular climate oscillations as indicated by catastrophic
1642   floods in the Spanish Mediterranean coastal area (14th–19th centuries)', *Clim. Change* **38**, 473–
1643   491.
1644 Baten, J.: 2002, 'Human stature and climate: The impact of past climate on living standards', in Wefer,
1645   G., Berger, W. H., Behre, K.-E., and Jansen, E. (eds.), *Climate Development and History in the*
1646   *North Atlantic Realm*, Springer-Verlag, Berlin, Heidelberg, New York, Barcelona, Hong Kong,
1647   London, Milan, Paris, Tokyo, pp. 327–338.
1648 Bauer, E., Claussen, M., Brovkin, V., and Huenerbein, A.: 2003, 'Assessing climate forcings of the
1649   Earth system for the past millennium', *Geophys. Res. Lett.* **30**, 1276–1279.
1650 Bauernfeind, W.: 1993, *Materielle Grundstrukturen im Spätmittelalter und der Frühen Neuzeit,*
1651   *Preisentwicklung und Agrarkonjunktur am Nürnberger Getreidemarkt von 1339 bis 1670*, Uni-
1652   versitätsbund Erlangen-Nürnberg, 320 pp.
1653 Bauernfeind, W. and Woitek, U.: 1999, 'The influence of climatic change on price fluctuations in
1654   Germany during the 16th century price revolution', *Clim. Change* **43**, 303–321.

Beck, R. A.: 1993, 'Viewpoint: Climate, liberalism and intolerance', *Weather* **48**, 63–64.   **1655**

Behringer, W.: 1999, 'Climatic change and witch-hunting: The impact of the Little Ice Age on **1656**
    mentalities', *Clim. Change* **43**, 335–351.   **1657**

Behringer, W., Lehmann, H., and Pfister, C. (eds.): in press, *Kulturelle Konsequenzen der Kleinen* **1658**
    Eiszeit - Cultural Consequences of the Little Ice Age, Vandenhoek & Ruprecht, Göttingen.   **1659**

Bell, W. T. and Ogilvie, A. E. J.: 1978, 'Weather compilations as a source of data for the reconstruction **1660**
    of European climate during the medieval period', *Clim. Change* **1**, 331–348.   **1661**

Benito, G., Diéz-Herrero, A., and Fernández de Villalta, M.: 2003, 'Magnitude and frequency of **1662**
    flooding in the Tagus basin (Central Spain) over the last millennium', *Clim. Change* **58**, 171– **1663**
    192.   **1664**

Bergström, H. and Moberg, A.: 2002, 'Daily air temperature and pressure series for Uppsala (1722– **1665**
    1998)', *Clim. Change* **53**, 213–252.   **1666**

Bernhardt, K. and Mäder, C.: 1987, 'Statistische Auswertung von Berichten über bemerkenswerte **1667**
    Witterungsereignisse seit dem Jahre 1000', *Z. Meteorol.* **37**, 120–130.   **1668**

Bokwa, A., Limanówka, D., and Wibig, J.: 2001, 'Pre-instrumental weather observations in Poland **1669**
    in the 16th and 17th centuries', in Jones, P. D., Ogilvie, A. E. J., Davies, T. D., and Briffa, K. **1670**
    R. (eds.), *History and Climate: Memories of the Future?*, Kluwer Academic/Plenum Publishers, **1671**
    New York, Boston, Dordrecht, London, Moscow, pp. 9–27.   **1672**

Bonardi, L.: 1996, 'Elementi per una storia del clima nella montagna lombarda centro-orientale', **1673**
    Rivista Geografica Italiana **103**, 405–430.   **1674**

Bonardi, L.: 2000, 'Le cause climatiche del Maximum Glaciale del periodo 1815–1820 nelle Alpi **1675**
    Lombarde: un ipotesi qualitativa', *Terra glacialis* **3**, 9–22.   **1676**

Borisenkov, Ye. P.: 1992, 'Documentary evidence from the U.S.S.R.', in Bradley, R. S. and Jones, P. **1677**
    D. (eds.), *Climate Since A.D. 1500*, Routledge, London and New York, pp. 171–183.   **1678**

Borisenkov, Ye. P. and Pasetskiy, V. M.: 1988, *Tysyatcheletnaya letopis neobytchaynykh yavleniy* **1679**
    prirody, Mysl, Moskva, 524 pp.   **1680**

Bork, H. R., Bork, H., Dalchow, C., Faust, B., Piorr, H.-P., and Schatz, T.: 1998, *Landschaftsentwick-* **1681**
    lung in Mitteleuropa. Wirkungen des Menschen auf Landschaften, Klett-Perthes, Gotha, Stuttgart, **1682**
    328 pp.   **1683**

Börngen, M. and Tetzlaff, G.: 2000, 'The weather report during 1652–1659 of Mauritius Knauer **1684**
    at Langheim (NE Bavaria, Germany) as a source of quantitative data', *Meteorol. Zeitschrift* **9**, **1685**
    308–317.   **1686**

Bradley, R. S.: 1996, 'Are there optimum sites for global paleotemperature reconstruction?', in Jones, **1687**
    P. D., Bradley, R. S., and Jouzel, J. (eds.), *Climatic Variations and Forcing Mechanisms of the* **1688**
    Last 2000 Years, Springer-Verlag, Berlin, Heidelberg, New York, pp. 603–624.   **1689**

Bradley, R. S.: 1999, *Paleoclimatology. Reconstructing Climates of the Quaternary*, Academic Press, **1690**
    San Diego, London, Boston, New York, Sydney, Tokyo, Toronto, 610 pp.   **1691**

Bradley, R. S.: 2000, 'Climate paradigms for the last millennium', *PAGES Newsletter* **8**, 2–3.   **1692**

Bradley, R. S., Briffa, K. R., Cole, J. E., Hughes, M. K., and Osborn, T. J.: 2003, 'The climate of the **1693**
    last millennium', in Alverson, K., Bradley, R. S., and Pedersen, T. F. (eds.), *Paleoclimate, Global* **1694**
    Change and the Future, Springer Verlag, Berlin, Heidelberg, New York, pp. 105–141.   **1695**

Bradley, R. S., Hughes, M. K., and Diaz, H. F.: 2003, 'Climate in medieval time', *Science* **302**, **1696**
    404–405.   **1697**

Bradley, R. S. and Jones, P. D. (eds.): 1992, *Climate Since A.D. 1500*, Routledge, London and New **1698**
    York, 679 pp.   **1699**

Bradley, R. S. and Jones, P. D.: 1993, "Little Ice Age' summer temperature variations: their nature **1700**
    and relevance to recent global warming trends', *Holocene* **3**, 387–396.   **1701**

Brázdil, R.: 1996, 'Reconstructions of past climate from historical sources in the Czech lands', in **1702**
    Jones, P. D., Bradley, R. S., and Jouzel, J. (eds.), *Climatic Variations and Forcing Mechanisms of* **1703**
    the Last 2000 Years, Springer-Verlag, Berlin, Heidelberg, New York, pp. 409–431.   **1704**

Brázdil, R.: 1998, 'The history of floods on the rivers Elbe and Vltava in Bohemia', *Erfurter Geogr. Studien* **7**, 93–108.

Brázdil, R.: 2000, 'Historical climatology: Definition, data, methods, results', *Geogr. Čas.* **52**, 99–121.

Brázdil, R.: 2002, 'Patterns of climate in Central Europe since Viking times', in Wefer, G., Berger, W. H., Behre, K.-E., and Jansen, E. (eds.), *Climate Development and History in the North Atlantic Realm*, Springer-Verlag, Berlin, Heidelberg, New York, Barcelona, Hong Kong, London, Milan, Paris, Tokyo, pp. 355–368.

Brázdil, R., Dobrovolný, P., Štekl, J., Kotyza, O., Valášek, H., and Jež, J.: in press, *History of Weather* **Q1** *and Climate in the Czech Lands VI. Strong winds*, Masaryk University, Brno.

Brázdil, R. and Duřiáková, M.: 2000, 'The effect of weather factors on fluctuations of grain prices in the Czech Lands in the 16th–18th centuries', *Prace Geograficzne UJ* **108**, 19–25.

Brázdil, R., Glaser, R., Pfister, C., Dobrovolný, P., Antoine, J.-M., Barriendos, M., Camuffo, D., Deutsch, M., Enzi, S., Guidoboni, E., Kotyza, O., and Rodrigo, F. S.: 1999, 'Floods events of selected European rivers in the sixteenth century', *Clim. Change* **43**, 239–285.

Brázdil, R. and Kiss, A.: 2001, 'Daily weather observations at Košice, Slovakia, in the period 1677–1681', *Meteorol. Čas.* **4**, 3–14.

Brázdil, R. and Kotyza, O.: 1995, *History of Weather and Climate in the Czech Lands I (Period 1000-1500)*, Zürcher Geographische Schriften 62, Zürich, 260 pp.

Brázdil, R. and Kotyza, O.: 1996, *History of Weather and Climate in the Czech Lands II. The Earliest Daily Observations of the Weather in the Czech Lands*, Masaryk University, Brno, 178 pp.

Brázdil, R. and Kotyza, O.: 1999, *History of Weather and Climate in the Czech Lands III. Daily Weather Records in the Czech Lands in the Sixteenth Century II*, Masaryk University, Brno, 228 pp.

Brázdil, R. and Kotyza, O.: 2000, *History of Weather and Climate in the Czech Lands IV. Utilisation of Economic Sources for the Study of Climate Fluctuation at Louny and Surroundings in the Fifteenth-Seventeenth Centuries*, Masaryk University, Brno, 350 pp.

Brázdil, R., Štìpánek, P., and Vais, T.: 1998, 'Časová a prostorová analýza bouøek, krupobití a extrémních srážek v jižní èásti Moravy v období 1946–1995', *Meteorol. Zpr.* **51**, 45–52.

Brázdil, R., Štìpánková, P., Kyncl, T., and Kyncl, J.: 2002a, 'Fir tree-ring reconstruction of March-July precipitation in southern Moravia (Czech Republic), 1376–1996', *Clim. Res.* **20**, 223–239.

Brázdil, R. and Valášek, H.: 2002, 'Meteorologická mìøení a pozorování v Zákupech v letech 1718-1720', *Geografie – Sbor. Čes. Geogr. Spol.* **107**, 1–22.

Brázdil, R. and Valášek, H.: 2003, 'Use of historic data in studying damage due to natural disasters at the domain of Pernštejn in the period 1694–1718 and as a source of information for the study of meteorological and hydrological extremes', *Meteorol. Čas.* **6**, 3–13.

Brázdil, R., Valášek, H., Luterbacher, J., and Macková, J.: 2001, 'Die Hungerjahre 1770–1772 in den böhmischen Ländern. Verlauf, meteorologische Ursachen und Auswirkungen', *Österreichische Zeitschrift für Geschichtswissenschaften* **12**, 44–78.

Brázdil, R., Valášek, H., and Macková, J.: 2003a, 'Climate in the Czech Lands during the 1780s in light of the daily weather records of parson Karel Bernard Hein of Hodonice (southwestern Moravia): Comparison of documentary and instrumental data', *Clim. Change* **60**, 297–327.

Brázdil, R., Valášek, H., and Sviták, Z.: 2003b, 'Meteorological and hydrological extremes in the Dietrichstein domains of Dolní Kounice and Mikulov between 1650 and 1849 according to official economic records of natural disasters', *Geogr. Čas.* **55**, 325–353.

Brázdil, R., Valášek, H., Sviták, Z., and Macková, J.: 2002b, *History of Weather and Climate in the Czech Lands V. Instrumental meteorological measurements in Moravia up to the end of the eighteenth century*, Masaryk University, Brno, 250 pp.

Briffa, K. R., Jones, P. D., Schweingruber, F. H., and Osborn, T. J.: 1998, 'Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years', *Nature* **393**, 450–455.

Briffa, K. R. and Osborn, T. J.: 2002, 'Blowing hot and cold', *Science* **295**, 2227–2228.　　　**1755**

Briffa, K. R., Osborn, T. J., Schweingruber, F. H., Harris, I. C., Jones, P. D., Shiyatov, S. G., and **1756**
　　Vaganov, E. A.: 2001, 'Low-frequency temperature variations from a northern tree-ring-density **1757**
　　network', *J. Geophys. Res.* **106**, 2929–2941.　　　**1758**

Broecker, W. S.: 2001, 'Was the Medieval Warm Period global?', *Science* **291**, 1497–1499.　　　**1759**

Brooks, C. E. P.: 1926, *Climate Trough the Ages. A study of the Climatic Factors and Their Variations*, **1760**
　　Ernest Benn Limited, London, 439 pp.　　　**1761**

Brown, N.: 2001, *History and Climate Change. A Eurocentric Perspective*, Routledge, London and **1762**
　　New York, 391 pp.　　　**1763**

Brönnimann, S.: 2002, 'Picturing climate change', *Clim. Res.* **22**, 87–95.　　　**1764**

Brückner, E.: 1890, Klimaschwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen **1765**
　　der Diluvialzeit, Geographische Abhandlungen herausgegeben von Prof. Dr. Albrecht Penck in **1766**
　　Wien, E. D. Hölzel, Wien and Olmütz, 325 pp.　　　**1767**

Buckland, P. C. and Wagner, P. E.: 2001, 'Is there an insect signal for the "Little Ice Age?"', *Clim.* **1768**
　　Change **48**, 137–149.　　　**1769**

Buisman, J. and van Engelen, A.: 1995–2000, *Duizend Jaar Weer, Wind en Water in de Lage Landen*, **1770**
　　Franeker, Van Wijnen, vol. 1–1300 (1995), 656 pp.; vol. 2, 1300–1450 (1996), 690 pp.; vol. 3, **1771**
　　1450–1575 (1998), 808 pp.; vol. 4, 1575–1675 (2000), 767 pp.　　　**1772**

Camuffo, D.: 1987, 'Freezing of the Venetian Lagoon since the 9th century A.D. in comparison to **1773**
　　the climate of Western Europe and England', *Clim. Change* **10**, 43–66.　　　**1774**

Camuffo, D.: 2002a, 'History of the long series of the air temperature in Padova (1725-today)', *Clim.* **1775**
　　Change **53**, 7–75.　　　**1776**

Camuffo, D.: 2002b, 'Calibration and instrumental errors in early measurements of air temperature', **1777**
　　Clim. Change **53**, 297–330.　　　**1778**

Camuffo, D.: 2002c, 'Errors in early temperature series arising from changes in style of measuring **1779**
　　time, sampling schedule and number of observations', *Clim. Change* **53**, 331–354.　　　**1780**

Camuffo, D. and Enzi, S.: 1992, 'Critical analysis of archive sources for historical climatology of **1781**
　　Northern Italy', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *European Climate Reconstructed* **1782**
　　from Documentary Data: Methods and Results, Gustav Fischer Verlag, Stuttgart, Jena, New York, **1783**
　　pp. 65–74.　　　**1784**

Camuffo, D. and Enzi, S.: 1996, 'The analysis of two bi-millenary series: Tiber and Po river floods', **1785**
　　in Jones, P. D., Bradley, R. S., and Jouzel, J. (eds.), *Climatic Variations and Forcing Mechanisms* **1786**
　　of the Last 2000 Years, Springer-Verlag, Berlin, Heidelberg, New York, pp. 433–450.　　　**1787**

Camuffo, D. and Jones, P. (eds.): 2002, *Improved Understanding of Past Climate Variability from* **1788**
　　Early Daily European Instrumental Sources, Kluwer Academic Publishers, Dordrecht, Boston, **1789**
　　London, 392 pp.　　　**1790**

Camuffo, D., Secco, C., Brimblecombe, P., and Martin-Vide, J.: 2000, 'Sea storms in the Adriatic Sea **1791**
　　and the Western Mediterranean during the last millennium', *Clim. Change* **46**, 209–223.　　　**1792**

Cernovodeanu, P. and Binder, P.: 1993, *Cavalerii apocalipsului. Calamitatile naturale din trecutul* **1793**
　　Romaniei (pana la 1800), SILEX – Casa de Editura, Presa si Impresariat S.R.L., Bucuresti, 255 **1794**
　　pp.　　　**1795**

Changnon, D.: 1997, 'Damaging storms in the United States: Selection of quality data and monitoring **1796**
　　indices', in *Workshop on Indices and Indicators for Climate Extremes*, NCDC, NOAA, Asheville, **1797**
　　24 pp.　　　**1798**

Chernavskaya, M. M.: 1992, 'Botanical indicators of the Little Ice Age in the Russian Plain', in **1799**
　　Mikami, T. (ed.), *Proceedings of the International Symposium on the Little Ice Age Climate*, **1800**
　　Tokyo Metropolitan University, Tokyo, pp. 65–70.　　　**1801**

Chernavskaya, M. M.: 1995, 'Klimat yevropeyskoy tchasti Rossii vo vtoroy polovine XVII i pervoy **1802**
　　tchetverti XVIII vekov po istoritcheskim dannym', *Izvestiya Russkoy Akademii Nauk—Ser. Geogr.* **1803**
　　1995, 97–107.　　　**1804**

1805 Claiborne, R.: 1970, *Climate, Man, and History*, Norton, New York, 444 pp.
1806 Coates, P.: 1998, *Nature. Western Attitude Since Ancient Times*, Politiy Press, Oxford, 246 pp.
1807 Cocheo, C. and Camuffo, D.: 2002, 'Corrections of systematic errors and data homogenisation in the
1808 Padova series (1725-today)', *Clim. Change* **53**, 77–100.
1809 Coeur, D.: 2003, *La Maîtrise des Inondations dans la Plaine de Grenoble (XVIIe–XXe Siècle): Enjeux*
1810 *Techniques, Politiques et Urbains*. 3 Vols Typoscript. Université Pierre Mendès France, Institut
1811 d'Urbanisme de Grenoble, Grenoble, 808 pp.
1812 Cook, E. R., Briffa, K. R., and Jones, P. D.: 1994, 'Spatial regression methods in dendroclimatology:
1813 A review and comparison of two techniques', *Int. J. Climatol.* **14**, 379–402.
1814 Cook, E. R., D'Arrigo, R. D., and Mann, M. E.: 2002, 'A well-verified, multiproxy reconstruc-
1815 tion of the winter North Atlantic Oscillation Index since A.D. 1400', *J. Climate* **15**, 1754–
1816 1764.
1817 Crawford, M. E. (ed.): 1989, *Famine: The Irish Experience 900-1900, Subsistence Crises and Famines*
1818 *in Ireland*, John Donald Publishers LTD, Edinburgh, 242 pp.
1819 Crowley, T. J.: 2000, 'Causes of climate change over the past 1000 years', *Science* **289**, 270–
1820 277.
1821 Crowley, T. J. and Lowery, T. S.: 2000, 'How warm was the Medieval Warm Period?', *Ambio* **29**,
1822 51–54.
1823 Cubasch, U., Santer, B. D., Hellbach, A., Hegerl, G., Höck, H., Maier-Reimer, E., Mikolajewicz, U.,
1824 Stössel, A., and Voss, R.: 1994, 'Monte Carlo climate change forecasts with a global coupled
1825 ocean-atmosphere model', *Clim. Dyn.* **10**, 1–19.
1826 Cubasch, U., Voss, R., Hegerl, G., Waskewitz, J., and Crowley, T. J.: 1997, 'Simulation of the influence
1827 of solar radiation variations on the global climate with an ocean-atmosphere general circulation
1828 model', *Clim. Dyn.* **13**, 757–767.
1829 Daley, R.: 1993, *Atmospheric Data Analysis*, Cambridge University Press, New York, 457 pp.
1830 Dawson, A. G., Hickey, K., McKenna, J., and Foster, I. D. L.: 1997, 'A 200-year record of gale
1831 frequency, Edinburgh, Scotland: possible link with high-magnitude volcanic eruptions', *Holocene*
1832 **7**, 337–341.
1833 de Kraker, A. M. J.: 1999, 'A method to assess the impact of high tides, storms and storm surges as
1834 vital elements in climatic history: The case of stormy weather and dikes in the northern part of
1835 Flanders, 1488 to 1609', *Clim. Change* **43**, 287–302.
1836 de Kraker, A. M. J.: 2002, 'Historic storms in the North Sea area, an assessment of the storm data,
1837 the present position of research and the prospects for future research', in Wefer, G., Berger, W.
1838 H., Behre, K.-E., and Jansen, E. (eds.), *Climate Development and History in the North Atlantic*
1839 *Realm*, Springer-Verlag, Berlin, Heidelberg, New York, Barcelona, Hong Kong, London, Milan,
1840 Paris, Tokyo, pp. 415–434.
1841 Demarée, G. R.: 1996, 'The neo-hippocratic hypothesis—an integrated 18th century view on medicine,
1842 climate and environment', *Zeszyty Naukowe Uniwersytetu Jagielloñskiego – Prace Geograficzne*
1843 **102**, 515–518.
1844 Demarée, G. R. and Ogilvie, A. E. J.: 2001, 'Bons Baisers d'Islande: Climatic, Environmental, and
1845 Human Dimensions Impacts of the Lakagígar Eruption (1783–1784) in Iceland', in Jones, P. D.,
1846 Ogilvie, A. E. J., Davies, T. D., and Briffa, K. R. (eds.), *History and Climate: Memories of the*
1847 *Future?*, Kluwer Academic/Plenum Publishers, New York, Boston, Dordrecht, London, Moscow,
1848 pp. 219–246.
1849 Demarée, G. R., Ogilvie, A. E. J., and Zhang, D.: 1998, 'Further documentary evidence of Northern
1850 Hemispheric coverage of the great dry fog of 1783', *Clim. Change* **39**, 727–730.
1851 DeMenocal, P. B.: 2001, 'Cultural responses to climate change during the Late Holocene', *Science*
1852 **292**, 667–673.
1853 Deutsch, M. and Pörtge, K.-H.: 2002, *Hochwasserereignisse in Thüringen*, Thüringer Landesanstalt
1854 für Umwelt und Geologie, Schriftreihe 63, Jena, 99 pp.

Deutsch, M., Pörtge, K. H., and Teltscher, H. (eds.): 2000, *Beiträge zum Hochwasser/ Hochwasser-* **1855**
    schutz in Vergangenheit und Gegenwart, Erfurter Geographische Studien 9, Erfurt, 239 pp.   **1856**

Q1 Dietrich, U.: 2003, 'Using Java and XML in interdisciplinary research: A new data-gathering tool for **1857**
    historians as used with EuroClimHist', *Historical Methods*, submitted.   **1858**

Dobrovolný, P. and Brázdil, R.: 2003, 'Documentary evidence on strong winds related to convective **1859**
    storms in the Czech Republic since AD 1500', *Atmos. Res.* **67/68**, 95–116.   **1860**

Dufour, M. L.: 1870, 'Problème de la variation du climat', *Bulletin de la Société Vaudoise des Sciences* **1861**
    naturelles **10**, 359–556.   **1862**

Durkheim, E.: 1982, *The Rules of Sociological Method: And Selected Texts on Sociology and Its* **1863**
    Method, Macmillan, London, 264 pp.   **1864**

Easton, C.: 1928, *Les hivers dans l'Europe occidentale*, E. J. Brill, Leyde, 210 pp.   **1865**

Egger, C. and Weigelt, H.: 2000, *Text-Schrift-Codex*, Oldenbourg, 391 pp.   **1866**

Esper, J., Cook, E. R., and Schweingruber, F. H.: 2002, 'Low-frequency signals in long **1867**
    tree-ring chronologies for reconstructing past temperature variability', *Science* **295**, 2250– **1868**
    2253.   **1869**

Evans, M. N., Kaplan, A., and Cane, M. A.: 1998, 'Optimal sites for coral-based reconstruction of **1870**
    global sea surface temperature', *Paleoceanography* **13**, 502–516.   **1871**

Fagan, B.: 2000, *The Little Ice Age. How climate made history 1300–1850*, Basic Books, New York, **1872**
    246 pp.   **1873**

Fairbridge, R. W.: 1987, 'Climate variation, historical record', in Oliver, J. E. and Fairbridge, R. W. **1874**
    (eds.), *The Encyclopedia of Climatology*, Van Nostrand Reinhold Company, New York, pp. 305– **1875**
    323.   **1876**

Faulstich, W.: 1996, Medien und Öffentlichkeit im Mittelalter 800-1400, Vandenhoek und Ruprecht, **1877**
    Göttingen, 298 pp.   **1878**

Favier R. and Granet-Abisset, A. M. (eds.): 2000, *Histoire et Mémoire des risques naturels*, in Actes **1879**
    du séminaire international: Histoire et Mémoire des risques naturels en région de montagne 25- **1880**
    26-22-1999, Grenoble, 281 pp.   **1881**

Fischer-Bruns, I., Cubasch, U., von Storch, H., Zorita, E., Gonzáles-Rouco, F., and Luterbacher, J.: **1882**
    2002, 'Modelling the Late Maunder Minimum with a 3-dimensional OAGCM', *CLIVAR Ex-* **1883**
    changes **7**, 59–61.   **1884**

Fleming, J. R.: 1998, *Historical Perspectives on Climate Change*, Oxford University Press, Oxford, **1885**
    194 pp.   **1886**

Flohn, H.: 1979, 'Zwei Bayerische Wetterkalender aus der Reformationszeit', in Mayer, H., Gietl, **1887**
    G., and Enders, G. (eds.), *Festschrift Albert Baumgartner*, Wissenschaftliche Mitteilungen des **1888**
    Meteorologischen Instituts der Universität München **35**, pp. 173–177.   **1889**

Flohn, H.: 1981, 'Short-term climatic fluctuations and their economic role', in Wigley, T. M. L., **1890**
    Ingram, M. J., and Farmer, G. (eds.), *Climate and History. Studies in past climates and their* **1891**
    impact on Man, Cambridge University Press, Cambridge, London, New York, New Rochelle, **1892**
    Melbourne, Sydney, pp. 310–318.   **1893**

Flohn, H.: 1985, 'A critical assessment of proxy data for climatic reconstruction', in Tooley, M. J. and **1894**
    Sheail, G. M. (eds.), *The Climatic Scene. Essays in Honour of Gordon Manley*, George Allen & **1895**
    Unwin, London, pp. 93–103.   **1896**

Flohn, H.: 1993, 'Climatic evolution during the last millennium: What can we learn from it?', in Eddy, **1897**
    J. A. and Oeschger, H. (eds.), *Global Changes in the Perspective of the Past*, John Wiley & Sons, **1898**
    Chichester, New York, Brisbane, Toronto, Singapore, pp. 295–316.   **1899**

Flückiger-Strebel, E.: 2002, *Zwischen Wohlfahrt und Staatsökonomie. Armenfürsorge auf der* **1900**
    bernischen Landschaft im 18. Jahrhundert, Chronos, Zürich, 425 pp.   **1901**

Frenzel, B., Pfister, C., and Gläser, B. (eds.): 1992, *European Climate Reconstructed from Doc-* **1902**
    umentary Data: Methods and Results, Gustav Fischer Verlag, Stuttgart, Jena, New York, **1903**
    265 pp.   **1904**

1905 Frenzel, B., Pfister, C., and Gläser, B. (eds.): 1994, *Climatic Trends and Anomalies in Europe 1675-*
1906   *1715. High Resolution Spatio-Temporal Reconstructions from Direct Meteorological Observa-*
1907   *tions and Proxy Data. Methods and Results*, Gustav Fischer Verlag, Stuttgart, Jena, New York,
1908   480 pp.
1909 Frisinger, H. H.: 1977, *The History of Meteorology: to 1800*, Science History Publications, New York,
1910   148 pp.
1911 Frydendahl, K. and Frich, P.: 1996, '50,000 weather observations from Danish logbooks 1675–1715',
1912   in Pedersen, E. S. (ed.), *North European Climate Data in the Latter Part of the Maunder Minimum*
1913   *Period A.D. 1675-1715*, AmS Varia **25**, pp. 27–31.
1914 Garcia, R. R., Díaz, H. F., García Herrera, R., Eischeid, J., del R. Prieto, M., Hernández, E., Gimeno,
1915   L., Durán, F. R., and Bascary, A. M.: 2001, 'Atmospheric circulation changes in the Tropical
1916   Pacific inferred from the voyages of the Manila galleons in the sixteenth-eighteenth centuries',
1917   *Bull. Am. Meteorol. Soc.* **82**, 2435–2455.
1918 García, R., Gimeno, L., Hernández, E., Prieto, R., and Ribera, P.: 2000, 'Reconstructing the North
1919   Atlantic atmospheric circulation in the 16th, 17th and 18th centuries from historical sources',
1920   *Clim. Res.* **14**, 147–151.
1921 García, R., Macias, A., Gallego, D., Hernández, E., Gimeno, L., and Ribera, P.: 2003, 'Reconstruction
1922   of the precipitation in the Canary Islands for the period 1595–1836', *Bull. Am. Meteorol. Soc.* **84**,
1923   ES68–ES77.
1924 Geurts, H. A. M. and van Engelen, A. F. V.: 1992, *Beschrijving antieke meetreeksen*, Koninklijk
1925   Nederlands Meteorologisch Instituut 165-V, De Bilt, 310 pp.
1926 Glacken, C. J.: 1967, *Traces on the Rhodian Shore*, University of California Press, Berkeley, Los
1927   Angeles, London, 763 pp.
1928 Glaeser, B.: 1994, 'Soziologie der Umwelt: Misere, Traditionen, Perspektive', in Huib, E. (ed.),
1929   *Pathways to Human Ecology, from Observation to Commitment*, Lang, Bern, pp. 115–132.
1930 Glaser, R.: 1991, *Klimarekonstruktion für Mainfranken, Bauland und Odenwald anhand direkter und*
1931   *indirekter Witterungsdaten seit 1500*, Gustav FischerVerlag, Stuttgart, New York, 175 pp.
1932 Glaser, R.: 1996, *Beiträge zur Historischen Klimatologie in Mitteleuropa seit dem Jahr 1000*, Habili-
1933   tationsschrift zur Erlangung der Veni Legendi, Geographisches Institut der Universität Würzburg,
1934   510 pp.
1935 Glaser, R.: 1997, 'On the course of temperature in central Europe since the year 1000 AD', *Hist. Soc.*
1936   *Res.* **22**, 59–87.
1937 Glaser, R.: 1998, 'Historische Hochwässer im Maingebiet - Möglichkeiten und Perspektiven auf der
1938   Basis der Historischen Klimadatenbank Deutschland (HISKLID)', *Erfurter Geogr. Studien* **7**,
1939   109–128.
1940 Glaser, R.: 2001, *Klimageschichte Mitteleuropa. 1000 Jahre Wetter, Klima, Katastrophen*, Primus
1941   Verlag, Darmstadt, 227 pp.
1942 Glaser, R., Beyer, U., and Beck, C.: 1999a, 'Die Temperaturentwicklung in Mitteleuropa seit dem
1943   Jahr 1000 auf der Grundlage quantifizierter historischer Quellentexte', *Tübinger Geogr. Studien*
1944   **125**, 23–46.
1945 Glaser, R., Brázdil, R., Pfister, C., Dobrovolný, P., Barriendos Vallvé, M., Bokwa, A., Camuffo, D.,
1946   Kotyza, O., Limanówka, D., Rácz, L., and Rodrigo, F. S.: 1999b, 'Seasonal temperature and
1947   precipitation fluctuations in selected parts of Europe during the sixteenth century', *Clim. Change*
1948   **43**, 169–200.
1949 Groh, D., Kempe, M., and Mauelshagen, F. (eds.): 2003, *Naturkatastrophen. Beiträge zu ihrer Deu-*
1950   *tung, Wahrnehmung und Darstellung in Text und Bild von der Antike bis ins 20. Jahrhundert*,
1951   Gunter Narr Verlag, Tübingen, 242 pp.
1952 Grotefend, H.: 1982, *Taschenbuch der Zeitrechnung des deutschen Mittelalters und der Neuzeit*, 12th
1953   edn., Hahn, Hannover, 223 pp.
1954 Grove, J.: 1988, *The Little Ice Age*, Methuen & Co., London, 498 pp.

Grove, J. M.: 2001a, 'The initiation of the "Little Ice Age" in regions round the North Atlantic', *Clim.* **1955**
    Change **48**, 53–82.   **1956**
Grove, J.: 2001b, 'The onset of the Little Ice Age', in Jones, P. D., Ogilvie, A. E. J., Davies, T. D., and **1957**
    Briffa, K. R. (eds.), *History and Climate: Memories of the Future?*, Kluwer Academic/Plenum **1958**
    Publishers, New York, Boston, Dordrecht, London, Moscow, pp. 153–185.   **1959**
Grove, J. M. and Battagel, A.: 1983, 'Tax records from western Norway, as an index of Little Ice Age **1960**
    environmental and economic deterioration', *Clim. Change* **5**, 265–282.   **1961**
Grove, J. M. and Conterio, A.: 1995, 'The climate of Crete in the sixteenth and seventeenth centuries', **1962**
    Clim. Change **30**, 223–247.   **1963**
Grove, J. M. and Switsur, R.: 1994, 'Glacial geological evidence for the Medieval Warm Period', **1964**
    Clim. Change **26**, 143–169.   **1965**
Guiot, J.: 1992, 'The combination of historical documents and biological data in the reconstruction of **1966**
    climate variations in space and time', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *European* **1967**
    Climate Reconstructed from Documentary Data: Methods and Results, Gustav Fischer Verlag, **1968**
    Stuttgart, Jena, New York, pp. 93–104.   **1969**
Hagedorn, H. and Glaser, R.: 1990, 'Zur methodischen Konzeption und Regionalisierung in der **1970**
    Paläoklimatologie', *Berliner Geogr. Abh.* **53**, 251–260.   **1971**
Hansen, J. and Lebedeff, S.: 1987, 'Global trends of measured surface temperature', *J. Geophys. Res.* **1972**
    92, 13,345–13,372.   **1973**
Hansen, J., Ruedy, R., Glascoe, J., and Sato, M.: 1999, 'GISS analysis of surface temperature change', **1974**
    J. Geophys. Res. **104**, 30,997–31,022.   **1975**
Hansen, J., Ruedy, R., Sato, M., Imhoff, M., Lawrence, L., Easterling, D., Peterson, T., and Karl, T.: **1976**
    2001, 'A closer look at United States and global surface temperature change', *J. Geophys. Res.* **1977**
    106, 23,947–23,963.   **1978**
Hasselmann, K.: 1976, 'Stochastic climate models. Part I. Theory', *Tellus* **28**, 473–485.   **1979**
Hellmann, G.: 1914, 'Die Vorläufer der Societas Meteorologica Palatina', *Beiträge zur Geschichte* **1980**
    der Meteorologie **1**, 139–147.   **1981**
Hellmann, G.: 1921, *Die Meteorologie in den deutschen Flugschriften und Flugblättern des XVI.* **1982**
    Jahrhunderts, Abhandlungen der Preussischen Akademie der Wissenschaften, Physikalisch- **1983**
    mathematische Klasse 1, 96 pp.   **1984**
Hellmann, G.: 1926, *Die Entwicklung der meteorologischen Beobachtungen in Deutschland von den* **1985**
    ersten Anfängen bis zur Einrichtung staatlicher Beobachtungsnetze, Abhandlungen der Preussis- **1986**
    chen Akademie der Wissenschaften, Physikalisch-mathematische Klasse 1, 25 pp.   **1987**
Hennig, R.: 1904, *Katalog bemerkenswerter Witterungsereignisse von den ältesten Zeiten bis zum* **1988**
    Jahre 1800, Abh. Königl. Preuss. Meteorol. Inst. 2, Berlin, 93 pp.   **1989**
Hesselink, A. W.: 2002, *History makes a river. Morphological changes and human interference in the* **1990**
    river Rhine, The Netherlands, University of Utrecht, Utrecht, 346 pp.   **1991**
Hickey, K. R.: 2003, 'The storminess record from Armagh Observatory, Northern Ireland, 1796– **1992**
    1999', *Weather* **58**, 28–35.   **1993**
Hirschboeck, K. K.: 1987, 'Catastrophic flooding and atmospheric circulation anomalies', in Mayer, **1994**
    L. and Nash, D. B. (eds.), *Catastrophic Flooding*, Allen & Unwin, Boston, pp. 23–56.   **1995**
Holzhauser, H.: 1997, 'Fluctuations of the Grosser Aletsch Glacier and the Gorner Glacier during **1996**
    the last 3200 years: New results', in Frenzel, B., Boulton, G. S., Gläser, B., and Huckriede, U. **1997**
    (eds.),*Glacier Fluctuations During the Holocene*, Gustav Fischer Verlag, Stuttgart, Jena, Lübeck, **1998**
    Ulm, pp. 35–58.   **1999**
Holzhauser, H.: 2002, 'Dendrochronologische Auswertung fossiler Hölzer zur Rekonstruktion **2000**
    der nacheiszeitlichen Gletschergeschichte', *Schweizerische Zeitschrift für Forstwesen* **15**, 317– **2001**
    337.   **2002**
Holzhauser, H. and Zumbühl, H.: 1999, 'Holocene glacial fluctuations', in Spreafico, M., Weingartner, **2003**
    R., and Leibundgut, C. (eds.),*Hydrological Atlas of Switzerland,* No. 3.8, Bern.   **2004**

2005 Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., and
2006   Johnson, C. A. (eds.): 2001, *Climate Change 2001: The Scientific Basis*, Cambridge University
2007   Press, Cambridge, 881 pp.
2008 Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., and Maskell, K.
2009   (eds.): 1996, *Climate Change 1995. The Science of Climate Change*, Cambridge University Press,
2010   Cambridge, 572 pp.
2011 Hsü, K. J.: 2000, *Klima macht Geschichte. Menschheitsgeschichte als Abbild der Klimaentwicklung*,
2012   Orell Füssli, Zürich, 334 pp.
2013 Huang, S., Pollack, H. N., and Shen, P.-Y.: 2000, 'Temperature trends over the past five centuries
2014   reconstructed from borehole temperatures', *Nature* **403**, 756–758.
2015 Hughes, M. K. and Diaz, H. F. (eds.): 1994a, *The Medieval Warm Period*, Kluwer Academic Publishers,
2016   Dordrecht, Boston, London, pp. 109–342.
2017 Hughes, M. K. and Diaz, H. F.: 1994b, 'Was there a 'Medieval Warm Period' and if so, where and
2018   when?', *Clim. Change* **26**, 109–142.
2019 Huntington, E.: 1907, *The Pulse of Asia. A Journey in Asia Illustrating the Geographical Basis of
2020   History*, Houghton Mifflin, Boston, 245 pp.
2021 Huntington, E.: 1925, *Civilization and Climate*, Yale University Press, New Heaven, 453 pp.
2022 Ingram, M. J., Underhill, D. J., and Farmer, G.: 1981, 'The use of documentary sources for the
2023   study of past climates', in Wigley, T. M. L., Ingram, M. J., and Farmer, G. (eds.), Climate and
2024   History. Studies in past climates and their impact on Man, Cambridge University Press, Cambridge,
2025   London, New York, New Rochelle, Melbourne, Sydney, pp. 180–213.
2026 Ingram, M. J., Underhill, D. J., and Wigley, T. M. L.: 1978, 'Historical climatology', *Nature* **276**,
2027   329–334.
2028 Jacobeit, J.: 1997, 'Atlantisch-europäische Bodenluftdruckfelder ombrothermisch anomaler Monate in
2029   Mitteleuropa als Hilfsmittel für die synoptische Interpretation analoger Anomalien im historischen
2030   Klima und in zukünftigen Klimaszenarien', *Petermanns Geographische Mitteilungen* **141**, 139–
2031   144.
2032 Jacobeit, J., Glaser, R., Luterbacher, J., and Wanner, H.: 2003, 'Links between flood events in central
2033   Europe since AD 1500 and large-scale atmospheric circulation modes', *Geophys. Res. Lett.* **30**,
2034   21-1–21-4.
2035 Jacobeit, J., Jönsson, P., Bärring, L., Beck, C., and Ekström, M.: 2001, 'Zonal indices for Europe
2036   1780–1995 and running correlations with temperature', *Clim. Change* **48**, 219–241.
2037 Jacobeit, J., Wanner, H., Koslowski, G., and Gudd, M.: 1999, 'European surface pressure patterns
2038   for months with outstanding climatic anomalies during the sixteenth century', *Clim. Change* **43**,
2039   201–221.
2040 Jakubowski-Tiessen, M. and Lehmann, H. (eds.): 2003, *Um Himmels Willen. Religion in Katastro-
2041   phenzeiten*, Vandenhoeck, Göttingen, 358 pp.
2042 Jankovic, V.: 2000, Reading the skies. A cultural history of English Weather, 1650–1820, Manchester
2043   University Press, Manchester, 272 pp.
2044 Jevrejeva, S.: 2001, 'Severity of winter seasons in the northern Baltic Sea during 1529–1990', *Clim.
2045   Res.* **17**, 55–62.
2046 Jevrejeva, S. and Moore, J. C.: 2001, 'Singular Spectrum Analysis of Baltic Sea ice conditions and
2047   large-scale atmospheric patterns since 1708', *Geophys. Res. Lett.* **28**, 4503–4506.
2048 Jones, P. D.: 2001, 'Early European instrumental records', in Jones, P. D., Ogilvie, A. E. J., Davies,
2049   T. D., and Briffa, K. R. (eds.), *History and Climate: Memories of the Future?*, Kluwer Aca-
2050   demic/Plenum Publishers, New York, Boston, Dordrecht, London, Moscow, pp. 55–77.
2051 Jones, P. D. and Bradley, R. S.: 1992, 'Climatic variations over the last 500 years', in Bradley, R. S.
2052   and Jones, P. D. (eds.), *Climate Since A.D. 1500*, Routledge, London and New York, pp. 649–665.
2053 Jones, P. D., Bradley, R. S., and Jouzel, J. (eds.): 1996, *Climatic Variations and Forcing Mechanisms
2054   of the Last 2000 Years*, NATO ASI Series, Springer, Berlin, Heidelberg, New York, 649 pp.

Jones, P. D., Briffa, K. R., Barnett, T., and Tett, S.: 1998, 'High resolution paleoclimatic records for **2055** the last millennium: Interpretation, integration and comparison with General Circulation Model **2056** control-run temperature', *Holocene* **8**, 455–471.   **2057**

Jones, P. D., Briffa, K. R., and Osborn, T. J.: 2003a, 'Changes in the Northern Hemisphere annual **2058** cycle: Implications for paleoclimatology?', *J. Geophys. Res.* **108**, ACL 13-1–13-7.   **2059**

Jones, P. D. and Lister, D. H.: 2002, 'The daily air temperature record for St. Petersburg (1743–1996), **2060** *Clim. Change* **53**, 253–267.   **2061**

Jones, P. D., New, M., Parker, D. E., Martin, S., and Rigor, I. G.: 1999, 'Surface air temperature and **2062** its changes over the past 150 years', *Rev. Geophys.* **37**, 173–199.   **2063**

Jones, P. D., Ogilvie, A. E. J., and Wigley, T. M. L.: 1984, *Riverflow Data for the United Kingdom:* **2064** *Reconstructed Data Back to 1844 and Historical Data Back to 1556*, Climatic Research Unit, **2065** Norwich, 157 pp.   **2066**

Jones, P. D., Osborn, T. J., and Briffa, K. R.: 2001, 'The evolution of climate over the last millennium', **2067** *Science* **292**, 662–667.   **2068**

Jones, P. D., Osborn, T. J., and Briffa, K. R.: 2003b, 'Pressure-based measures of the NAO: A **2069** comparison and an assessment of changes in the strength of the NAO and in its influence on surface **2070** climate parameters', in Hurrell, J. W., Visbeck, M., Kushnir, Y., and Ottersen, G. (eds.), *The North* **2071** *Atlantic Oscillation: Climatic Significance and Environmental Impact*, American Geophysical **2072** Union, Washington, pp. 51–62.   **2073**

Jones, P. D., Raper, S. C. B., Bradley, R. S., Diaz, H. F., Kelly, P. M., and Wigley, T. M. L.: 1986, 'North- **2074** ern Hemisphere surface air temperature variations: 1851–1984', *J. Climatol. Appl. Meteorol.* **25**, **2075** 161–179.   **2076**

Jurin, J.: 1723, 'Invitatio ad Observationes Meteorologicas communi consilio instituendas', *Philo-* **2077** *sophical Transactions* **32**, 422–427.   **2078**

Kaas, E., Tian-shi, L., and Schmith, T.: 1996, 'Statistical hindcast of wind climatology in the north **2079** Atlantic and north-western European region', *Clim. Res.* **7**, 97–110.   **2080**

Kachelmann, J.: 2002, *Die grosse Flut. Unser Klima, unsere Umwelt, unsere Zukunft*, Rowohlt, **2081** Hanburgh, 270 pp.   **2082**

Kajander, J.: 1993, 'Methodological aspects on river cryophenology exemplified by a tricentennial **2083** break-up time series from Tornio', *Geophysica* **29**, 73–95.   **2084**

Kanold, J.: 1718–1727, *Sammlung von Natur- und Medicin-, wie auch hierzu gehörigen Kunst- und* **2085** *Literatur-Geschichten*, Breslau.   **2086**

Kaplan, A., Kushnir, Y., Cane, M. A., and Blumenthal, M. B.: 1997, 'Reduced space optimal analysis **2087** for historical datasets: 136 years of Atlantic sea surface temperature', *J. Geophys. Res.* **102**, 27,835– **2088** 27,860.   **2089**

Karl, T. S. and Easterling, D. R.: 1999, 'Climate extremes: Selected review and future research **2090** directions', *Clim. Change* **42**, 309–325.   **2091**

Kates, R. W.: 1985, 'The interaction of climate and society', in Kates, R. W., Ausubel, J. H., and **2092** Berberian, M. (eds.), *Climate Impact Assessment. Studies of the Interaction of Climate and Society*, **2093** Wiley, Chichester, New York, Brisbane, Toronto, Singapore, pp. 3–36.   **2094**

Kempe, M.: 2003, 'Noah's flood: The genesis story and natural disasters in Early Modern Times', **2095** *Environ. Hist.* **9**, 151–171.   **2096**

Kempe, M. and Rohr, C.: 2003, 'Coping with the unexpected natural disasters and their perception in **2097** history', Environ. Hist. **9** (Special Issue), 128 pp.   **2098**

Kington, J.: 1988, *The Weather of the 1780s over Europe*, Cambridge University Press, Cambridge, **2099** 166 pp.   **2100**

Kiss, A.: 1999, 'Some weather events in the fourteenth century II (Angevin period: 1301–1387)', **2101** *Acta Climatol. Univ. Szegediensis* **32-33**, 51–64.   **2102**

Kiss, A.: 2000, 'Weather events during the first Tartar invasion in Hungary (1241–42)', *Acta Geogr.* **2103** *Szegediensis* **37**, 149–156.   **2104**

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., van den Dool, H., Jenne, R., and Fiorino, M.: 2001, 'The NCEP-NCAR 50-year reanalysis: Monthly means CD-ROM and documentation', *Bull. Am. Meteorol. Soc.* **82**, 247–267.

Klingbjer, P. and Moberg, A.: 2003, 'A composite monthly temperature record from Tornedalen in northern Sweden 1802-2002', *Int. J. Climatol.*, **23**, 1465–1494.

Kociánová, M.: 2002, 'Otázka projevù chladných období postglaciálu v krkonošské tundøe', *Opera Concortica* **39**, 143–151.

Koslowski, G. and Glaser, R.: 1999, 'Variations in reconstructed ice winter severity in the Western Baltic from 1501 to 1995, and their implications for the North Atlantic Oscillation',*Clim. Change* **41**, 175–191.

Krahe, P.: 1997, 'Hochwasser und Klimafluktuationen am Rhein seit dem Mittelalter', in Immendorf, R. (ed.),*Hochwasser. Natur im Überfluss*?, C. F. Müller, Heidelberg, pp. 57–82.

Lamb, H. H.: 1965, 'The early medieval warm epoch and its sequel', *Palaeogeogr. Palaeoclimatol. Paleoecol.* **1**, 13–37.

Lamb, H. H.: 1977, *Climate: Present, Past and Future*, vol. 2: *Climatic History and the Future*, Methuen, London, 835 pp.

Lamb, H. H.: 1980, 'Weather and climate patterns of the Little Ice Age', in Oeschger, H., Messerli, B., and Svilar, M. (eds.), *Das Klima: Analysen und Modelle, Geschichte und Zukunft*, Springer-Verlag, Berlin, Heidelberg, New York, pp. 149–160.

Lamb, H. H.: 1982, *Climate, History and the Modern World*, Methuen, London, 387 pp.

Lamb, H. H.: 1984, 'Climate in the last thousand years: Natural climatic fluctuations and change', in Flohn, H. and Fantechi, R. (eds.), *The Climate of Europe: Past, Present and Future*, D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, pp. 25–64.

Lamb, H. H.: 1987, 'What can historical records tell us about the breakdown of the Medieval warm climate in Europe in the fourteenth and fifteenth centuries—an experiment', *Beitr. Phys. Atmosph.* **60**, 131–143.

Lamb, H. H.: 1991, *Historic Storms of the North Sea, British Isles and Northwest Europe*, Cambridge University Press, Cambridge, 204 pp.

Landsteiner, E.: 1999, 'The crisis of wine production in late sixteenth-century central Europe: Climatic causes and economic consequences', *Clim. Change* **43**, 323–334.

Lauer, W.: 1981, *Klimawandel und Menschheitsgeschichte auf dem mexikanischen Hochland*, Akademie der Wissenschaften und Literatur Mainz, Abhandlungen der mathematisch-naturwissenschaftlichen Klasse, No. 2, 49 pp.

Lauer, W. and Frankenberg, P.: 1986, *Zur Rekonstruktion des Klimas im Bereich der Rheinpfalz seit Mitte des 16. Jahrhundert mit Hilfe von Zeitreihen der Weinquantität und Weinqualität*, Gustav Fischer Verlag, Stuttgart, New York, 54 pp.

Legrand, J.-P. and LeGoff, M.: 1992, *Les observations météorologiques de Louis Morin*, Monographie 6, Direction de la Météorologie Nationale, Paris, 128 pp.

Lenke, W.: 1964, 'Untersuchungen der ältesten Temperaturmessungen mit Hilfe des strengen Winters 1708–1709', *Ber. Deutsch. Wetterd.* **92**, 3–45.

Lenke, W.: 1968, 'Das Klima Ende des 16. und Anfang des 17. Jahrhunderts nach Beobachtungen von Tycho Brahe auf Hven, Leonhard III Treuttwein in Fürstenfeld und David Fabricius in Ostfriesland', *Ber. Deutsch. Wetterd.* **110**, 49 pp.

Le Roy Ladurie, E.: 1967, *L'histoire du climat depuis l'au mil*, Flammarion, Paris, 413 pp. English translation: *Times of Feast, Times of Famine: A History of Climate Since the Year 1000*, George Allen & Unwin, London 1972, 428 pp.

Le Roy Ladurie, E. and Baulant, M.: 1980, 'Grape harvests from the fifteenth through the nineteenth centuries', *J. Interdisciplin. Hist.* **10**, 839–849.

Lieth, H.: 1974, *Phenology and Seasonal Modeling*, Springer-Verlag, Berlin, Heidelberg, New York, 444 pp.

Limanówka, D.: 2001, *Rekonstrukcja warunków klimatycznych Krakowa w pierwszej polowie XVI wieku*, Instytut Meteorologii i Gospodarki Wodnej, Warszawa, 176 pp.

Llasat, D. C. M., Rigo, T., and Barriendos, M.: 2003, 'The 'Montserrat-2000' flash-flood event: A comparison with the floods that have occurred in the northeastern Iberian Peninsula since the 14th century', *Int. J. Climatol.* **23**, 453–469.

Luterbacher, J.: 2001, 'The Late Maunder Minimum (1675–1715)—climax of the 'Little Ice Age' in Europe', in Jones, P. D., Ogilvie, A. E. J., Davies, T. D., and Briffa, K. R. (eds.), *History and Climate: Memories of the Future?*, Kluwer Academic/Plenum Publishers, New York, Boston, Dordrecht, London, Moscow, pp. 29–54.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and Wanner, H.: 2004, 'European seasonal and annual temperature variability, trends and extremes since 1500', *Science* **303**, 1499–1503.

Luterbacher, J., Rickli, R., Tinguely, C., Xoplaki, E., Schüpbach, E., Dietrich, D., Hüsler, J., Ambühl, M., Pfister, C., Beeli, P., Dietrich, U., Dannecker, A., Davies, T. D., Jones, P. D., Slonosky, V., Ogilvie, A. E. J., Maheras, P., Kolyva-Machera, F., Martín-Vide, J., Barriendos, M., Alcoforado, M. J., Nunes, M. F., Jónsson, T., Glaser, R., Jacobeit, J., Beck, C., Philipp, A., Beyer, U., Kaas, E., Schmith, T., Bärring, L., Jönsson, P., Rácz, Lj Wanner, H.: 2000, 'Monthly mean pressure reconstructions for the Late Maunder Minimum period (AD 1675–1715)', *Int. J. Climatol.* **20**, 1049–1066.

Luterbacher, J., Rickli, R., Xoplaki, E., Tinguely, C., Beck, C., Pfister, C., and Wanner, H.: 2001, 'The Late Maunder Minimum (1675–1715)—a key period for studying climatic variability and decadal scale climate change in Europe', *Clim. Change* **49**, 441–462.

Luterbacher, J., Schmutz, C., Gyalistras, D., Xoplaki, E., and Wanner, H.: 1999, 'Reconstruction of monthly NAO and EU indices back to AD 1675', *Geophys. Res. Lett.* **26**, 2745–2748.

Luterbacher, J. and Xoplaki, E.: 2003, '500-year winter temperature and precipitation variability over the Mediterranean area and its connection to the large-scale atmospheric circulation', in Bolle, H.-J. (ed.), *Mediterranean Climate—Variability and Trends*, Springer Verlag, Berlin, Heidelberg, New York, pp. 133–153.

Luterbacher, J., Xoplaki, E., Dietrich, D., Jones, P. D., Davies, T. D., Portis, D., Gonzales-Rouco, J. F., von Storch, H., Gyalistras, D., Casty, C., and Wanner, H.: 2002a, 'Extending North Atlantic Oscillation reconstructions back to 1500', *Atmos. Sci. Lett.* **2**, 114–124.

Luterbacher, J., Xoplaki, E., Dietrich, D., Rickli, R., Jacobeit, J., Beck, C., Gyalistras, D., Schmutz, C., and Wanner, H.: 2002b, 'Reconstruction of sea level pressure fields over the eastern North Atlantic and Europe back to 1500', *Clim. Dyn.* **18**, 545–561.

Lyakhov, M. E.: 1992, 'Ekstremalnyye termitcheskiye usloviya v tsentralnoy Rossii i tsentralnoy Evrope v XIII-XIV vekakh', *Materialy meteorologitcheskikh issledovaniy* **15**, 156–170.

Maak, K. and von Storch, H.: 1997, 'Statistical downscaling of monthly mean air temperature to the beginning of the flowering of Galanthus nivalis L. in Northern Germany', *Int. J. Biometeorol.* **41**, 5–12.

Malewicz, H. M.: 1980, *Zjawiska przyrodnicze w relacjach dziejopisarzy polskiego ̨redniowiecza*, Ossolineum, Wroc"aw, Warszawa, Kraków, Gdañsk, 188 pp.

Manley, G.: 1974, 'Central England temperatures: monthly means 1659 to 1973', *Quart. J. R. Meteorol. Soc.* **100**, 389–405.

Mann, M. E.: 2001, 'Climate during the past millennium', *Weather* **56**, 91–102.

Mann, M. E.: 2002, 'The value of multiple proxies', *Science* **297**, 1481–1482.

Mann, M. E., Bradley, R. S., and Hughes, M. K.: 1998, 'Global-scale temperature patterns and climate forcing over the past six centuries', *Nature* **392**, 779–787.

Mann, M. E., Bradley, R. Sj Hughes, M. K.: 1999, 'Northern Hemisphere temperatures during the past millennium: inferences, uncertainties, and limitations', *Geophys. Res. Lett.* **26**, 759–762.

2205 Mann, M. E., Gille, E., Bradley, R. S., Hughes, M. K., Overpeck, J. T., Keimig, F. T., and Gross, W.:
2206   2000, 'Global temperature patterns in past centuries: An interactive presentation', *Earth Interact.*
2207   **4**, 1–29.
2208 Markham, S. F.: 1947, *Climate and the Energy of Nations*, Oxford University Press, London, New
2209   York, Toronto, 240 pp.
2210 Martín-Vide, J. and Barriendos, M.: 1995, 'The use of rogation ceremony records in climatic recon-
2211   struction: a case study from Catalonia (Spain)', *Clim. Change* **30**, 201–221.
2212 Matthes, F.: 1939, 'Report of Committee on Glaciers', *Trans. Am. Geophys. Union* **20**, 518–523.
2213 Matthes, F.: 1940, 'Committee on Glaciers, 1939–40', *Trans. Am. Geophys. Union* **21**, 396–406.
2214 Maugeri, M., Buffoni, L., and Chlistovsky, F.: 2002a, 'Daily Milan temperature and pressure series
2215   (1763–1998): History of the observations and data and metadata recovery', *Clim. Change* **53**,
2216   101–117.
2217 Maugeri, M., Buffoni, L., Delmonte, B., and Fassina, A.: 2002b, 'Daily Milan temperature and pressure
2218   series (1763–1998): Completing and homogenising the data', *Clim. Change* **53**, 119–149.
2219 Menzel, A.: 2002, 'Phenology. Its importance to the global change community', *Clim. Change* **54**,
2220   379–385.
2221 Menzel, A. and Estrella, N.: 2001, 'Plant phenological changes', in Walther, G.-R., Burga, C. A., and
2222   Edwards, P. J. (eds.), *"Fingerprints" of Climate Change. Adapted Behaviour and Shifting Species
2223   Ranges*, Kluwer Academic Publishers, New York, London, pp. 123–138.
2224 Metcalfe, S. E., del Prieto, M. R., Endfield, G. H., Davies, S. J., and O'Hara, S. L.: 2002, 'The potential
2225   of archival sources for reconstructing climate and climate-related processes in Latin America',
2226   *PAGES News* **10**, 11–14.
2227 Michaelsen, J.: 1984, 'Cross-validation in statistical climate forecast models', *J. Climate* **26**, 1589–
2228   1600.
2229 Mikami, T. (ed.): 1992, *Proceedings of the International Symposium on the Little Ice Age Climate*,
2230   Tokyo Metropolitan University, Tokyo, 342 pp.
2231 Militzer, S.: 1996, 'Klima - Klimageschichte - Geschichte. Status und Perspektiven von
2232   Klimageschichte und Historischer Klimawirkungsforschung', *Geschichte in Wissenschaft
2233   und Unterricht* **47,** 71–88.
2234 Militzer, S.: 1998, 'Sachsen- Klimatatsachen und Umriss von Klimawirkungen im 17. Jahrhundert', in
2235   Schirmer, U. (ed.), *Sachsen im 17. Jahrhundert: Krise, Krieg und Neubeginn*, Sax Verlag, Beucha,
2236   pp. 69–100.
2237 Moberg, A., Bergström, H., Ruiz Krigsman, J., and Svanered, O.: 2002, 'Daily air temperature and
2238   pressure series for Stockholm (1756–1998)', *Clim. Change* **53**, 171–212.
2239 Moberg, A., Jones, P. D., Barriendos, M., Bergström, H., Camuffo, D., Cocheo, C., Davies, T. D.,
2240   Demarée, G., Martín-Vide, J., Maugeri, M., Rodriguez, R., and Verhoeve, T.: 2000, 'Day-to
2241   day temperature variability trends in 160- to 275-year-long European instrumental records', *J.
2242   Geophys. Res.* **205**, 22,849–22,868.
2243 Mudelsee, M., Börngen, M., Tetzlaff, G., and Grünewald, U.: 2003, 'No upward trends in the occur-
2244   rence of extreme floods in central Europe', *Nature* **425**, 166–169.
2245 Munzar, J.: 2001, 'Summer floods in Central Europe in 1813—an analogy to floods of 1997', *Moravian
2246   Geogr. Rep.* **9**, 29–40.
2247 Munzar, J.: 2002, 'Environmetal history of Central Europe in the first half of the 18th century (ac-
2248   cording to the so-called Wroclaw collection)', *Moravian Geogr. Rep.* **10**, 37–45.
2249 Münchener Rück: 1999, *Topics 2000: Natural Catastrophes—The Current Position*, Münchener Rück,
2250   München, 126 pp.
2251 Neumann, J.: 1985, 'Climatic change as a topic in the classical Greek and Roman literature', *Clim.
2252   Change* **7**, 441–454.
2253 Newman, L. F. (ed.): 1990, *Hunger in History. Food Shortage, Poverty and Deprivation*, Basil Black-
2254   well, Oxford, 429 pp.

Nordli, P. Ø.: 2001, 'Reconstruction of nineteenth century summer temperatures in Norway by proxy data from farmers' diaries', *Clim. Change* **48**, 201–218.

Nordli, P. Ø., Lie, Ø., Nesje, A., and Dahl, S. O.: 2002, *Spring/Summer Temperature Reconstruction Western Norway 1734-2002*, DNMI-Rapport 26/02 Klima, Oslo, 47 pp.

Nordli, P. Ø., Lie, Ø., Nesje, A., and Dahl, S. O.: 2003, 'Spring-summer temperature reconstruction in western Norway 1734–2003: A data-synthesis approach', *Int. J. Climatol.* **23**, 1821–1841.

Ogilvie, A. and Farmer, G.: 1997, 'Documenting the Medieval climate', in Hulme, K. and Barrow, E. (eds.), *Climates of the British Isles: Present, Past and Future*, Routledge, London and New York, pp. 112–133.

Ogilvie, A. E. J.: 1996, 'Sea-ice conditions off the coasts of Iceland A.D. 1601–1850 with special reference to part of the Maunder Minimum period (1675–1715)', *AmS-Varia* **25**, 9–12.

Ogilvie, A. E. J., Barlow, L. K., and Jennings, A. E.: 2000, 'North Atlantic climate AD 1000: Millennial reflections on the Viking discoveries of Iceland, Greenland and North America', *Weather* **55**, 34–45.

Ogilvie, A. E. J. and Jónsson, T. (eds.): 2001, *The Iceberg in the Mist: Northern Research in Pursuit of a "Little Ice Age"*, Kluwer Academic Publishers, Dordrecht, Boston, London, 263 pp.

Ogrin, D.: 2002, 'Dry and wet years in submediterranean Slovenia from the 14th to the mid-19th century', *Acta Univ. Palacki. Olomuc. Fac. Rer. Nat.—Geographica* **37**, 55–62.

Ornato, E.: 1988, 'L'exploitation des sources narratives médiévales dans l'histoire du climat: à propos d'un ouvrage récent', *Histoire & Mesure* **3**, 403–449.

Panessa, G.: 1991, *Fonti Greche e Latine per la storia dell'ambiente e del clima nel mondo Greco*, Scuola Normale Superiore di Pisa, Pisa, vol. 1, pp. 1–541; vol. 2, pp. 542–1024.

Pauling, A., Luterbacher, J., and Wanner, H.: 2003, 'Evaluation of proxies for European and North Atlantic temperature field reconstructions', *Geophys. Res. Lett.* **30**, CLM 2-1–CLM 2-4.

Pedersen, E. S. (ed.): 1996, *North European Climate Data in the Latter Part of the Maunder Minimum Period A.D. 1675–1715*, Museum of Archaeology Stavanger, 66 pp.

Penzar, I. and Penzar, B.: 1997, 'Weather and climate notes on the Adriatic up to the middle of the 19th century', *Geofizika* **14**, 47–82.

Pfister, C.: 1978, 'Climate and Economy in Eighteenth-Century Switzerland', *J. Interdisciplin. Hist.* **9**, 223–243.

Pfister, C.: 1979, 'Getreide-Erntebeginn und Frühsommertemperaturen im schweizerischen Mittelland seit dem frühen 17. Jahrhundert', *Geogr. Helv.* **34**, 23–25.

Pfister, C.: 1981, 'Die Fluktuationen der Weinmosterträge im Schweizerischen Weinland vom 16. bis ins frühe 19. Jahrhundert', *Schweizer Zeitschrift für Geschichte* **31**, 445–491.

Pfister, C.: 1984, *Klimageschichte der Schweiz 1525-1860. Das Klima der Schweiz und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft*, Paul Haupt, Bern, 184 pp.

Pfister, C.: 1988a, 'Variations in the spring-summer climate of Central Europe from the High Middle Ages to 1850', in Wanner, H. and Siegenthaler, U. (eds.), *Long and Short Term Variability of Climate*, Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, pp. 57–82.

Pfister, C.: 1988b, 'Fluctuations du climat et prix céréaliers en Europe 16ème–20ème siècles', *Annales E.S.C.***1/1988**, 25–53.

Pfister, C.: 1992, 'Monthly temperature and precipitation patterns in Central Europe from 1525 to the present. A methodology for quantifying man-made evidence on weather and climate', in Bradley, R. S. and Jones, P. D. (eds.),*Climate Since A.D. 1500*, Routledge, London and New York, pp. 118–142.

Pfister, C.: 1999, *Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496-1995)*, Verlag Paul Haupt, Bern, Stuttgart, Wien, 304 pp.

Pfister, C.: 2001, 'Klimawandel in der Geschichte Europas. Zur Entwicklung und zum Potenzial der historischen Klimatologie', *Österreichische Zeitschrift für Geschichtswissenschaften* **12**, 7–43.

Pfister, C.: 2002, 'Naturkatastrophen und Naturgefahren in geschichtlicher Perspektive. Ein Einstieg', in Pfister, C. (ed.), *Am Tag danach. Zur Bewältigung von Naturkatastrophen in der Schweiz 1500-2000*, Verlag Paul Haupt, Bern, Stuttgart, Wien, pp. 11–26 (also available in French: Le Jour d'après. Surmonter les catastrophes naturelles: le cas de la Suisse enter 1500 et 2000. Berne 2002, traduit par Véronique Mange).

Pfister, C.: in press, 'Weeping in the snow. The second Period of Little Ice Age-Type Impacts, 1570 to 1630', in Behringer, W., Lehmann, H., and Pfister, C. (eds.), *Kulturelle Konsequenzen der Kleinen Eiszeit - Cultural Consequences of the Little Ice Age*, Vandenhoek & Ruprecht, Göttingen. **Q1**

Pfister, C. and Bareiss, W.: 1994, 'The climate in Paris between 1675 and 1715 according to the Meteorological Journal of Louis Morin', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *Climatic Trends and Anomalies in Europe 1675-1715*, Gustav Fischer Verlag, Stuttgart, Jena, New York, pp. 151–171.

Pfister, C. and Brázdil, R.: 1999, 'Climatic variability in sixteenth-century Europe and its social dimension: A synthesis', *Clim. Change* **43**, 5–53.

Pfister, C., Brázdil, R., and Glaser, R. (eds.): 1999a, *Climatic Variability in Sixteenth-Century Europe and its Social Dimension*, Kluwer Academic Publishers, Dordrecht, Boston, London, 351 pp.

Pfister, C., Brázdil, R., Glaser, R., Barriendos, M., Camuffo, D., Deutsch, M., Dobrovolný, P., Enzi, S., Guidoboni, E., Kotyza, O., Militzer, S., Rácz, L., and Rodrigo, F. S.: 1999b, 'Documentary evidence on climate in sixteenth-century Europe', *Clim. Change* **43**, 55–110.

Pfister, C., Brázdil, R., Glaser, R., Bokwa, A., Holawe, F., Limanowka, D., Kotyza, O., Munzar, J., Rácz, L., Strömmer, E., and Schwarz-Zanetti, G.: 1999c, 'Daily weather observations in sixteenth-century Europe', *Clim. Change* **43**, 111–150.

Pfister, C., Brázdil, R., Obrebska-Starkel, B., Starkel, L., Heino, R., and von Storch, H.: 2001, 'Strides made in reconstructing past weather and climate', *Eos - Transactions American Geophysical Union* **82**, 248.

Pfister, C. and Brändli, D.: 1999, 'Rodungen im Gebirge - Überschwemmungen im Vorland: Ein Deutungsmuster macht Karriere', in Sieferle, R. P. and Greunigener, H. (eds.), *Natur-Bilder. Wahrnehmungen von Natur und Umwelt in der Geschichte,* Campus Verlag, Frankfurt, New York, pp. 9–18.

Pfister, C. and Hächler, S.: 1991, 'Überschwemmungskatastrophen im Schweizer Alpenraum seit dem Spätmittelalter. Raum-zeitliche Rekonstruktion von Schadenmustern auf der Basis historischer Quellen', in Glaser, R. and Walsh, R. (eds.): *Historische Klimatologie in verschiedenen Klimazonen*, Würzburger Geographische Arbeiten 80, Würzburg, pp. 127–148.

Pfister, C., Kington, J., Kleinlogel, G., Schüle, H., and Siffert, E.: 1994, 'High resolution spatio-temporal reconstructions of past climate from direct meteorological observations and proxy data', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *Climatic Trends and Anomalies in Europe 1675-1715*, Gustav Fischer Verlag, Stuttgart, Jena, New York, pp. 329–375.

Pfister, C., Luterbacher, J., Schwarz-Zanetti, G., and Wegmann, M.: 1998, 'Winter air temperature variations in western Europe during the Early and High Middle Ages (AD 750–1300)', *Holocene* **8**, 535–552.

Pfister, C., Schwarz-Zanetti, G., and Wegmann, M.: 1996, 'Winter severity in Europe: the fourteenth century', *Clim. Change* **34**, 91–108.

Piervitali, E. and Colacino, M.: 2001, 'Evidence of drought in Western Sicily during the period 1565-1915 from liturgical offices', *Clim. Change* **49**, 225–238.

Popova, V. V.: 2001, 'Kolebaniya osadkov na Russkoy ravnine za posledneye tysyatcheletiye', *Izvestiya Akademii Nauk – Ser. Geogr.* **2001**, 42–49.

Porter, S. C.: 1986, 'Pattern and forcing of Northern Hemisphere glacier variations during the last millennium', *Quarter. Res.* **26**, 27–48.

Pötzsch, C. G.: 1784, *Chronologische Geschichte der grossen Wasserfluthen des Elbstroms*, Walther, Dresden, 232 pp.

Pozo-Vazquez, D., Esteban-Parra, M. J., Rodrigo, F. S., and Castro-Díez, Y.: 2001, 'A study of NAO variability and its possible non-linear influences on European surface temperature', *Clim. Dyn.* **17**, 701–715.

Proctor, C. J., Baker, A., and Barnes, W. L.: 2002, 'A three thousand year record of N Atlantic climate', *Clim. Dyn.* **19**, 449–454.

Proctor, C. J., Baker, A., Barnes, W. L., and Gilmour, M. A.: 2000, 'A thousand year speleothem proxy record of North Atlantic climate from Scotland', *Clim. Dyn.* **16**, 815–820.

Quinlan, F. T., Karl, T. R., and Williams, C. N. Jr.: 1987, *United States Historical Climatology Network (HCN) serial temperature and precipitation data*, NDP019. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Rácz, L.: 1999, *Climate History of Hungary Since 16th Century: Past, Present and Future*, Centre for Regional studies of Hungarian Academy of Sciences, Pécs, 158 pp.

Rebetez, M.: 1996, 'Public expectation as an element of human perception of climate change', *Clim. Change* **32**, 495–509.

Rebetez Beniston, M.: 1992, *Perception du temps et du climat: une analyse du climat de suisse romande sur la base des dictions populaires*, Editions Stratus, Oron-la-Ville, 102 pp.

Repapis, C. C., Schuurmans, C. J. E., Zerefos, C. S., and Ziomas, J.: 1989, 'A note on the frequency of occurrence of severe winters as evidenced in monastery and historical records from Greece during the period 1200–1900 A.D.', *Theor. Appl. Climatol.* **39**, 213–217.

Retsö, D.: 2002, 'A contribution to the history of European winters: Some climatological proxy data from early-sixteenth century Swedish documentary sources', *Clim. Change* **52**, 137–173.

Robinson, A. R., Lermusiaux, P. F. J., and Sloan III, N. Q.: 1998, 'Data assimilation', in Brink, K. H. and Robinson, A. R. (eds.), *The Global Coastal Ocean. Processes and Methods. The Sea*, vol. 10, John Wiley & Sons Inc., New York, pp. 541–593.

Rodrigo, F. S., Esteban-Parra, M. J., and Castro-Diez, Y.: 1995, 'The onset of the Little Ice Age in Andalusia (southern Spain): Detection and characterization from documentary sources', *Annales Geophysicae* **13**, 330–338.

Rodrigo, F. S., Esteban-Parra, M. J., and Castro-Diez, Y.: 1998, 'On the use of the Jesuit order private correspondence records in climate reconstructions: A case study from Castille (Spain) for 1634–1648 A.D.', *Clim. Change* **40**, 625–645.

Rodrigo, F. S., Esteban-Parra, M. J., Pozo-Vázquez, D., and Castro-Díez, Y.: 1999, 'A 500-year precipitation record in Southern Spain', *Int. J. Climatol.* **19**, 1233–1253.

Rodrigo, F. S., Pozo-Vazquez, D., Esteban-Parra, M. J., and Castro-Diez, Y.: 2001, 'A reconstruction of the winter North Atlantic Oscillation Index back to AD 1501 using documentary data in southern Spain', *J. Geophys. Res.* **106**, 14,805–14,818.

Rutherford, S., Mann, M. E., Delworth, T. L., and Stouffer, R. J.: 2003, 'Climate field reconstruction under stationary and nonstationary forcing', *J. Climate* **16**, 462–479.

Sarewitz, D. and Pielke, R., Jr.: 2000, 'Breaking the Global-Warming gridlock', *Atlant. Mon.* July 2000, 55–64.

Schiesser, H. H., Pfister, C., and Bader, J.: 1997, 'Winter storms in Switzerland north of the Alps 1864/1865–1993/1994', *Theor. Appl. Climatol.* **58**, 1–9.

Schmidt, M.: 2000, *Hochwasser und Hochwasserschutz in Deutschland vor 1850. Eine Auswertung alter Quellen und Karten*, Oldenbourg-Industrieverlag, München, 350 pp.

Schmutz, C., Luterbacher, J., Gyalistras, D., Xoplaki, E., and Wanner, H.: 2000, 'Can we trust proxy-based NAO reconstructions', *Geophys. Res. Lett.* **27**, 1135–1138.Schwarz-Zanetti, G.: 1998, *Grundzüge der Klima- und Umweltgeschichte des Hoch- und Spätmittelalters in Mitteleuropa*, Studentendruckerei Zürich, Zürich, 131 pp.

Semple, E. C.: 1911, *Influences of Geographic Environment, on the Basis of Ratzel's System of Anthropo-Geography*, Holt, Rinehart and Winston, New York, 170 pp.

2405 Shabalova, M. V. and van Engelen, A. F. V.: 2003, 'Evaluation of a reconstruction of winter and
2406   summer temperatures in the Low countries', *Clim. Change* **58**, 219–242.
2407 Shindell, D. T., Schmidt, G. A., Mann, M. E., Rind, D., and Waple, A.: 2001, 'Solar forcing of regional
2408   climate change during the Maunder Minimum', *Science* **294**, 2149–2152.
2409 Shindell, D. T., Schmidt, G. A., Miller, R. L., and Mann, M. E.: 2003, 'Volcanic and solar forcing of
2410   climate change during the preindustrial era', *J. Climate* **16**, 4094–4107.
2411 Slonosky, V. C.: 2002, 'Wet winters, dry summers? Three centuries of precipitation data from Paris',
2412   *Geophys. Res. Lett.* **29**, 1-1–1-4.
2413 Slonosky, V. C., Jones, P. D., and Davies, T. D.: 2001, 'Instrumental pressure observation from the
2414   17th and 18th centuries: London and Paris', *Int. J. Climatol.* **21**, 285–298.
2415 Slonosky, V. C. and Yiou, P.: 2002, 'Does the NAO index represent zonal flow? The influence of the
2416   NAO on North Atlantic surface temperature', *Clim. Dyn.* **19**, 17–30.
2417 Soon, W. and Baliunas, S.: 2003, 'Proxy climatic and environmental changes of the past 1000 years',
2418   *Clim. Res.* **23**, 89–110.
2419 Souriau, A. and Yiou, P.: 2001, 'Grape harvest dates for checking NAO paleoreconstructions', *Geo-
2420   phys. Res. Lett.* **28**, 3895–3898.
2421 Sparks, T. H. and Carey, P. D.: 1995, 'The responses of species to climate over two centuries: An
2422   analysis of the Marsham Phenological Record 1736–1947', *J. Ecol.* **83**, 321–329.
2423 Stathakopoulos, D.: 2003, 'Reconstructing the climate of the Byzantine world: State of the problem and
2424   case studies', in Laszlovszky, J. and Szabó, P. (eds.), *People and Nature in Historical Perspective*,
2425   Central European University and Archeolingua Publishing House, Budapest, pp. 247–261.
2426 Stehr, N. and von Storch, H.: 1995, 'The social construct of climate and climate change', *Clim. Res.*
2427   **5**, 99–105.
2428 Stehr, N. and von Storch, H.: 2000a, *Eduard Brückner - The Sources and Consequences of Climate
2429   Change and Climate Variability in Historical Times*, Kluwer Academic Publishers, Dordrecht,
2430   Boston, London, 338 pp.
2431 Stehr, N. and von Storch, H.: 2000b, 'Von der Macht des Klimas. Ist der Klimadeterminismus nur
2432   noch Ideengeschichte oder relevanter Faktor gegenwärtiger Klimapolitik?', *Gaia* **9**, 187–195.
2433 Stine, S.: 1998, 'Medieval climatic anomaly in the Americas', in Issar, A. S. and Brown, N. (eds.),
2434   *Water, Environment and Society in Times of Climatic Change*, Kluwer Academic Publishers,
2435   Dordrecht, Boston, London, pp. 43–67.
2436 Stothers, R. B.: 1996, 'The great dry fog of 1783', *Clim. Change* **32**, 79–89.
2437 Stothers, R. B.: 1999, 'Volcanic dry fogs, climate cooling and plague pandemics in Europe and the
2438   Middle East', *Clim. Change* **42**, 713–723.
2439 Stothers, R. B.: 2000, 'Climatic and demographic consequences of the massive volcanic eruption of
2440   1258', *Clim. Change* **45**, 361–374.
2441 Strnadt, A.: 1790, *Chronologische Verzeichniss der Naturbegebenheiten im Königreiche Böhmen,
2442   vom Jahre Christi 633 bis 1700*, Gerrlische Buchhandlung, Prag, 123 pp.
2443 Strömmer, E.: 2003, Klima-Geschichte. Methoden der Rekonstruktion und historische Perspektive.
2444   Ostösterreich 1700 bis 1830, Franz Deuticke, Wien, 325 pp.
2445 Støeštík, J. and Verö, J.: 2000, 'Reconstruction of the spring temperatures in the 18th century based
2446   on the measured lengths of grapevine sprouts', *Idöjárás* **104**, 123–136.
2447 Stuber, M.: 2003, 'Divine punishment or object of research? The resonance of earthquakes, floods,
2448   epidemics and famine in the correspondence network of Albrecht von Haller', Environ. Hist. 9,
2449   173–193.
2450 Sturm, K., Glaser, R., Jacobeit, J., Deutsch, M., Brázdil, R., Pfister, C., Luterbacher, J., and Wanner,
2451   H.: 2001, 'Hochwasser in Mitteleuropa seit 1500 und ihre Beziehungen zur atmosphärischen
2452   Zirkulation', *Petermanns Geographische Mitteilungen* **145**, 14–23.
2453 Sweeney, J.: 2000, 'A three-century storm climatology for Dublin 1715–2000', *Irish Geography***33**,
2454   1–14.

Tarand, A. and Kuiv, P.: 1994, 'The beginning of the rye harvest—a proxy indicator of summer 2455
climate in the Baltic area', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *Climatic Trends* 2456
and Anomalies in Europe 1675-1715, Gustav Fischer Verlag, Stuttgart, Jena, New York, pp. 61– 2457
72.   2458
Tarand, A. and Nordli, Ø. P.: 2001, 'The Tallinn temperature series reconstructed back half a millen- 2459
nium by use of proxy data', *Clim. Change* **49**, 189–199.   2460
Telelis, I. G.: 1998, 'The climate of Tübingen A.D. 1596–1605, on the basis of Martin Crusius' 2461
Diarium', *Environ. Hist.* **4**, 53–74.   2462
Telelis, I.: 2000, 'Medieval Warm Period and the beginning of the Little Ice Age in Eastern Mediter- 2463
ranean. An approach of physical and anthropogenic evidence', in Belke, K., Hild, F., Koder, J., and 2464
Soustal, P. (eds.), *Byzanz als Raum. Zu Methoden und Inhalten der historischen Geographie des* 2465
Östlichen Mittelmeerraumes, Veröffentlichung der Kommission für die Tabula Imperii Byzantini, 2466
Denkschrift 7, pp. 223–243.   2467
Telelis, I.: in press, *Meteorological Phenomena and Climate in Byzantium: Approach of sources'* 2468
information and empirical indications concerning climatic fluctuations in Eastern Mediterranean 2469
and the Middle East (A.D. 300–1500), Academy of Athens, Ponimata No. 5, Athens, (in Greek 2470
with English summary).   2471
Tetzlaff, G., Börngen, M., and Raabe, A.: 2001, 'Das Jahrtausendhochwasser von 1342 und seine 2472
meteorologische Ursachen', in *Nürnberger Wasserwirtschaftstage*, ATV-DVWK Landesverband 2473
Bayern, pp. 5–22.   2474
Tol, R. S. J. and Langen, A.: 2000, 'A concise history of Dutch river floods', *Clim. Change* **46**, 2475
357–369.   2476
Tyrrell, J. G.: 1995, 'Paraclimatic statistics and the study of climate change: The case of the Cork 2477
region in the 1750s', *Clim. Change* **29**, 231–245.   2478
Ungar, S.: 1999, 'Is strange weather in the air? A study of U.S. national network news coverage of 2479
extreme weather events', *Clim. Change* **41**, 133–159.   2480
van Caenegem, R. C.: 1979, Guide to the Sources of Medieval History, North Holland Publishing 2481
Company, Amsterdam, 428 pp.   2482
van den Dool, H. M., Krijnen, H. J., and Schuurmans, C. J. E.: 1978, 'Average winter temperatures at 2483
De Bilt (the Netherlands): 1634-1977', *Clim. Change* **1**, 319–330.   2484
van Engelen, A. F. V., Buisman, J., and IJnsen, F.: 2000, 'Reconstruction of the Low countries tem- 2485
perature series AD 764–1998', in Mikami, T. (ed.), *Proceedings of the International Conference* 2486
on Climate Change and Variability—Past, Present and Future, Tokyo Metropolitan University, 2487
Tokyo, pp. 151–157.   2488
van Engelen, A. F. V., Buisman, J., and IJnsen, F.: 2001, 'A millennium of weather, winds and water 2489
in the Low Countries', in Jones, P. D., Ogilvie, A. E. J., Davies, T. D., and Briffa, K. R. (eds.), 2490
History and Climate: Memories of the Future?, Kluwer Academic/Plenum Publishers, New York, 2491
Boston, Dordrecht, London, Moscow, pp. 101–124.   2492
van Engelen, A. F. V. and Geurts, H. A. M.: 1985, *Nicolaus Cruquius (1675–1754) and his mete-* 2493
orological observations, Koninklijk Nederlands Meteorologisch Instituut 165-IV, De Bilt, 155 2494
pp.   2495
Vinnikov, K. Ya., Groisman, P. Ya., and Lugina, K. M.: 1990, 'Empirical data on contemporary global 2496
climate changes (temperature and precipitation)', *J. Climate* **3**, 662–677.   2497
von Brandt, A.: 1996, *Werkzeug des Historikers*, 14th edn., Kohlhammer, Stuttgart, 246 pp. 2498
von Storch, H.: in press, 'A discourse about quasi-realistic climate models and their applications in 2499
paleoclimatic studies', in Fischer, H., Kumke, T., Lohmann, G., Flöser, G., Miller, H., von Storch, 2500
H., and Negendank, J. F. W. (eds.), *The KIHZ project: towards a synthesis of Holocene proxy data* 2501
and climate models, Springer Verlag, Berlin, Heidelberg, New York.   2502
von Storch, H., Cubasch, U., González-Rouco, F. J., Jones, J. M., Widmann, M., and Zorita, E.: 2503
2000, 'Combining paleoclimatic evidence and GCMs by means of Data Assimilation Through 2504

2505 Upscaling and Nudging (DATUN)', in *11th Symposium on Global Change Studies*, American
2506 Meteorological Society, pp. 28–31.
2507 von Storch, H. and Hasselmann, K.: 1996, 'Climate variability and change', in Hempel, G. (ed.), *The*
2508 *Ocean and the Poles. Grand Challenges for European Cooperation*, Gustav Fischer Verlag, Jena,
2509 Stuttgart, New York, pp. 33–58.
2510 von Storch, H. and Stehr, N.: 1997, 'The case for the social sciences in climate research', *Ambio* **26**,
2511 66–71.
2512 von Storch, H. and Stehr, N.: 2000, 'Climate change in perspective. Our concerns about global warming
2513 have an age-old resonance', *Nature* **405**, 615.
2514 von Storch, H. and Stehr, N.: 2002, 'Towards a history of ideas of anthropogenic climate change', in
2515 Wefer, G., Berger, W. H., Behre, K.-E., and Jansen, E. (eds.), *Climate Development and History*
2516 *in the North Atlantic Realm*, Springer-Verlag, Berlin, Heidelberg, New York, Barcelona, Hong
2517 Kong, London, Milan, Paris, Tokyo, pp. 17–23.
2518 Vogel, R. B., Egger, H., and Schweingruber, F. H.: 1996, 'Interpretation extremer Jahrringwerte in
2519 der Schweiz anhand von klima-historischen Aufzeichnungen zwischen 1525 und 1800 A.D.',
2520 *Vierteljahrsschrift der Natf. Ges. Zürich* **141**, 65–76.
2521 Vose, R. S., Schmoyer, R. L., Steuer, P. M., Peterson, T. C., Heim, R., Karl, T. R., and Eischeid, J.:
2522 1992, *The global historical climatology network: long-term monthly temperature, precipitation,*
2523 *sea level pressure, and station pressure data*, Report ORNL/CDIAC-53, NDP-041.
2524 Wales-Smith, G. B.: 1971, 'Monthly and annual totals of rainfall representative of Kew, Surrey, for
2525 1697 to 1970', *Meteorol. Mag.* **100**, 345–362.
2526 Wang, R., Wang, S., and Fraedrich, K.: 1991, 'An approach to reconstruction of temperature on a
2527 seasonal basis using historical documents from China', *Int. J. Climatol.* **11**, 381–392.
2528 Wanner, H., Beck, C., Brázdil, R., Casty, C., Deutsch, M., Glaser, R., Jacobeit, J., Luterbacher, J.,
2529 Pfister, C., Pohl, S., Sturm, K., Werner, P. C., and Xoplaki, E.: 2004, 'Dynamic and socioeconomic
2530 aspects of historical floods in Central Europe', *Erdkunde* **58**, 1–16.
2531 Wanner, H., Brázdil, R., Frich, P., Frydendahl, K., Jonsson, T., Kington, J., Pfister, C., Rosenørn, S.,
2532 and Wishman, E.: 1994, 'Synoptic interpretation of monthly weather maps for the late Maunder
2533 Minimum (1675–1704)', in Frenzel, B., Pfister, C., and Gläser, B. (eds.), *Climatic Trends and*
2534 *Anomalies in Europe 1675–1715*, Gustav Fischer Verlag, Stuttgart, Jena, New York, pp. 401–
2535 424.
2536 Wanner, H., Brönnimann, S., Casty, C., Gyalistras, D., Luterbacher, J., Schmutz, C., Stephenson,
2537 D. B., and Xoplaki, E.: 2001, 'North Atlantic Oscillation—concepts and studies', *Surveys in*
2538 *Geophysics* **22**, 321–382.
2539 Wanner, H., Holzhauser, H., Pfister, C., and Zumbühl, H.: 2000, 'Interannual to century scale climate
2540 variability in the European Alps', *Erdkunde* **54**, 62–69.
2541 Wanner, H. and Luterbacher, J.: 2002, 'The LOTRED approach—a first step towards a "paleoreanal-
2542 ysis" for Europe', *PAGES News* **10**, 9–11.
2543 Wanner, H., Pfister, C., Brázdil, R., Frich, P., Frydendahl, K., Jónsson, T., Kington, J., Lamb, H. H.,
2544 Rosenørn, S., and Wishman, E.: 1995, 'Wintertime European circulation patterns during the late
2545 Maunder Minimum cooling period (1675–1704)', *Theor. Appl. Climatol.* **51**, 167–175.
2546 Weichselgartner, J.: 2000, 'Hochwasser als soziales Ereignis. Gesellschaftliche Faktoren einer
2547 Naturgefahr', *Hydrologie und Wasserbewirtschaftung* **44**, 122–131.
2548 Weikinn, C.: 1958–2002, *Quellentexte zur Witterungsgeschichte Europas von der Zeitwende bis zum*
2549 *Jahre 1850. Hydrographie*, Akademie-Verlag, Teil 1 (Zeitwende-1500), 1958; Teil 2 (1501–1600),
2550 1960; Teil 3 (1601–1700), 1961; Teil 4 (1701–1750), 1963; Teil 5 (1751–1800), 2000; Teil 6
2551 (1801–1850), 2002.
2552 Werner, P. C. and Gerstengarbe, F.-W.: 2003, 'Visual meteorological observations as indicators of
2553 climate changes, derived from long-term time series of the Potsdam station', *Meteorol. Zeitschrift*
2554 **12**, 47–50.

Wheeler, D.: 1995, 'The weather vocabulary of an eighteenth-century mariner: The log-books of **2555**
    Nicholas Pocock, 1740–1821', *Weather* **50**, 298–304.   **2556**
Wheeler, D.: 2001, 'The weather of the European Atlantic seabord during October 1805: An excercise **2557**
    in historical climatology', *Clim. Change* **48**, 361–385.   **2558**
Wheeler, D.: 2003, 'The weather during the voyage of the Royal Spanish Mail Ship Grimaldi, **2559**
    February–March 1795', *Weather* **58**, 20–28.   **2560**
Widmann, M., Jones, J., and von Storch, H.: in press, 'Reconstruction of large-scale atmospheric **2561**
    circulation and data assimilation in palaeoclimatology', *PAGES Newsletter*.   **2562**
Wigley, T. M. L.: 1978, 'Climatic change since 1000 AD', in *Évolution des atmosphères planétaries* **2563**
    et climatologie de la terre, Centre national d'etudes spatiales, Toulouse, pp. 313–323.   **2564**
Wigley, T. M. L., Huckstep, N. J., Ogilvie, A. E. J., Farmer, G., Mortimer, R., and Ingram, M. J.: **2565**
    1985, 'Historical climate impact assessments', in Kates, R. W., Ausubel, J. H., and Berberian, **2566**
    M. (eds.), *Climate Impact Assessment. Studies of the Interaction of Climate and Society*, Wiley, **2567**
    Chichester, New York, Brisbane, Toronto, Singapore, pp. 529–563.   **2568**
Wigley, T. M. L., Ingram, M. J., and Farmer, G. (eds.): 1981,*Climate and History. Studies in Past* **2569**
    Climates and Their Impact on Man, Cambridge University Press, Cambridge, 530 pp.   **2570**
Williams, A. and Archer, D.: 2000, 'The use of historic flood information in the English Midlands to **2571**
    improve risk assessment', *Hydrol. Sci. J.* **47**, 67–76.   **2572**
Wishman, E., Frenzel, B., and Weiss, M. M. (eds.): 1998, *Documentary Climatic Evidence for 1750–* **2573**
    1850 and the fourteenth century, Gustav Fischer Verlag, Stuttgart, Jena, Lübeck, Ulm, 192 pp. **2574**
Xoplaki, E., Maheras, P., and Luterbacher, J.: 2001, 'Variability of climate in meridional Balkans **2575**
    during the periods 1675–1715 and 1780–1830 and its impact on human life', *Clim. Change* **48**, **2576**
    581–615.   **2577**
Yan, Z., Alexandre, P., and Demarée, G.: 1997, 'Narrative warm/cold variations in continental western **2578**
    Europe, AD 708–1426', *Science in China* **40**, 509–517.   **2579**
Zinke, J., von Storch, H., Müller, B., Zorita, E., Rein, B., Mieding, H. B., Miller, H., Lücke, A., **2580**
    Schleser, G. H., Schwab, M. J., Negendank, J. F. W., Kienel, U., González-Rouco, J. F., Dullo, C., **2581**
    and Eisenhauser, A.: in press, 'Evidence for the climate during the Late Maunder Minimum from **2582**
    proxy data available within KIHZ', in Fischer, H., Kumke, T., Lohmann, G., Flöser, G., Miller, **2583**
    H., von Storch, H., and Negendank, J. F. W. (eds.), *The KIHZ Project: Towards A Synthesis of* **2584**
    Holocene Proxy Data and Climate Models, Springer Verlag, Berlin, Heidelberg, New York.   **2585**
Zorita, E. and González-Rouco, J. F.: 2002, 'Are temperature-sensitive proxies adequate for North **2586**
    Atlantic Oscillation reconstructions?', *Geophys. Res. Lett.* **29**, 14–17.   **2587**
Zorita, E., von Storch, H., González-Rouco, F., Cubasch, U., Luterbacher, J., Legutke, S., Fischer- **2588**
    Bruns, I., and Schlese, U.: in press, 'Transient simulation of the climate of the last five centuries **2589**
    with an atmosphere-ocean coupled model: The Late Maunder Minimum and the Little Ice Age', **2590**
    Meteorol. Zeitschrift.   **2591**

Query

Q1. Au: Please update the reference.