Theor Appl Climatol (2010) 100:163–189
DOI 10.1007/s00704-009-0170-5

ORIGINAL PAPER

European floods during the winter 1783/1784: scenarios of an extreme event during the 'Little Ice Age'

Rudolf Brázdil · Gaston R. Demarée · Mathias Deutsch · Emmanuel Garnier · Andrea Kiss · Jürg Luterbacher · Neil Macdonald · Christian Rohr · Petr Dobrovolný · Petr Kolář · Kateřina Chromá

Received: 7 January 2009 / Accepted: 23 June 2009 /

Abstract The Lakagígar eruption in Iceland during 1783 was followed by the severe winter of 1783/1784, which was characterised by low temperatures, frozen soils, ice-bound watercourses and high rates of snow accumulation across much of Europe. Sudden warming coupled with rainfall led to rapid snowmelt, resulting in a series of flooding phases across much of Europe. The first phase of flooding occurred in late December 1783–early January 1784 in England, France, the Low Countries and historical Hungary. The second phase at the turn of February–March 1784 was of greater extent, generated by the melting of an unusually large accumulation of snow and river ice, affecting catchments across France and Central Europe (where it is still considered as one of the most disastrous known floods), throughout the Danube catchment and in southeast Central Europe. The third and final phase of flooding occurred mainly in historical Hungary during late March and early April 1784. The different impacts and consequences of the above floods on both local and regional scales were reflected in the economic and societal responses, material damage and human losses. The winter of 1783/1784 can be considered as typical, if severe, for the Little Ice Age period across much of Europe.

1 Introduction

Recent floods have caused large parts of Europe to re-evaluate flood risk, as several high-magnitude flood events have occurred during the last two decades, such as July

R. Brázdil (✉) · P. Dobrovolný · P. Kolář · K. Chromá
Institute of Geography, Masaryk University,
Kotlářská 2,
611 37 Brno, Czech Republic
e-mail: brazdil@geogr.muni.cz

G. R. Demarée
Royal Meteorological Institute of Belgium,
Ringlaan 3,
1180 Brussels, Belgium

M. Deutsch
Saxonian Academy of Sciences in Leipzig,
Karl-Tauchnitz-Straße 1,
04107 Leipzig, Germany

E. Garnier
Laboratory of the Sciences of the Climate and the Environment
(UMR CEA-CNRS), CE Saclay, Orme des Merisiers,
F-91 191 Gif-sur-Yvette and UMR-CNRS CRHQ,
University of Caen,
Caen, France

A. Kiss
Department of Physical Geography and Geoinformatics,
University of Szeged,
Egyetem u. 2,
6722 Szeged, Hungary

J. Luterbacher
Department of Geography, Justus-Liebig University,
Senckenbergstrasse 1,
35390 Giessen, Germany

N. Macdonald
Department of Geography, University of Liverpool,
Liverpool L69 7ZT, UK

C. Rohr
Department of History, University of Salzburg,
Rudolfskai 42,
5020 Salzburg, Austria

1997 and August 2002 in Central Europe (e.g. Bronstert et al. 1998; Kundzewicz et al. 1999; Matějíček and Hladný 1999; Ulbrich et al. 2003a, b); November 1998 and March 2001 in Hungary and the Ukraine (Szlávik 2003a, b, c); May/June 1999, July 2005 and August 2007 in Switzerland (Bezzola and Hegg, 2007; KOHS 2007; Jaun et al. 2008; Schmutz et al. 2008); October/November 2000 and July 2007 in England and Wales (Marsh 2007; Marsh and Hannaford 2007), events that have caused loss of human life and considerable material damage. Recent global warming is very likely caused by anthropogenic activity (Solomon et al. 2007), which may increase the frequency and severity of flood events in the future (e.g. May et al. 2002; Milly et al. 2002; Christensen and Christensen 2003; Parry et al. 2008). The study of historical flooding with respect to meteorological causes, frequency, severity and human impacts provides important information in developing future flood risk management strategies (Brázdil et al. 2005b, 2006b), with historical hydrological analysis increasingly applied in development planning (e.g. England and Wales; PPS 25 2006).

Investigations of historical floods have concentrated on the analyses of long-term flood series (e.g. Brázdil et al. 1999, 2005a; Pfister 1999; Tol and Langen 2000; Sturm et al. 2001; Benito et al. 2003, 2008; Jacobeit et al. 2003; Mudelsee et al. 2003, 2006; Glaser and Stangl 2004; Wanner et al. 2004; Barriendos and Rodrigo 2006; Böhm and Wetzel 2006; Cyberski et al. 2006; Macdonald et al. 2006; Rohr 2006) or the study of individual cases of extreme flooding (e.g. Fügner 1995; Militzer et al. 1999; Deutsch 2000; Tetzlaff et al. 2001; Deutsch and Pörtge 2002; Brázdil et al. 2006a; Bürger et al. 2006; Thorndycraft et al. 2006). The meteorological and hydrological characteristics of severe floods are normally analysed and extent of flood damage assessed in relation to loss of life and material damage. Previous studies have focused on the floods of February 1784 at sites in Germany (Glaser and Hagedorn 1990; Heuser-Hildebrandt 2005), the Czech Lands (Elleder and Munzar 2004; Brázdil et al. 2005a), Belgium and its surrounding regions (Demarée 2006) and more generally in Western and Central Europe (Munzar et al. 2005; Kolář 2008), but little consideration has been given to the cause, mechanisms and impact at a European scale.

Developing on the studies outlined above, this paper concentrates on the detailed analysis of floods across Europe during the severe winter of 1783/1784. The meteorological and hydrological information for this period is analysed with respect to weather variations, daily weather and sea level pressure patterns. The paper considers floods occurring in Western and Central Europe from December 1783 to April 1784 and their related impacts on indigenous populations. Finally, our results are discussed in relation to long-term climatic variability.

2 Hydrometeorological data

A network of meteorological stations, ranging from Greenland to Rome and from La Rochelle (France) to Pyschminsk (the Ural Mountains), was established by the Societas Meteorologica Palatina in 1780 under the guidance of Karl Theodor, the elector of the Palatinate, providing a valuable series of records for the winter of 1783/1784. All stations used standardised instruments and made their observations according to the regulations issued by the Society (e.g. observing times at 0700, 1400 and 2100 hours mean local time), with the observations published annually for 1780–1792 in the *Ephemerides* of the Society (for more details, see Traumüller 1885 and Kington 1974).

Other important meteorological networks operating in the 1780s include the network of the Société Royale de Médecine established in 1776 in Paris, with a network that extended beyond the borders of France (Kington 1970). A meteorological network of 21 stations in Bavaria was operated by the Bavarian Academy of Science in Munich under the direction of Franz Xaver Epp (Society of Jesus (SJ)) (Lüdecke 1997), with several stations from the Bavarian network also active in the Mannheim network (for an overview of meteorological stations making weather observations in the 1780s, see Kington 1988).

Hydrological measurements were limited during this period, with a small number of sites recording water levels on stage-boards; for example, measurements are available for the Danube in Vienna-Tabor from 1 January 1784. The Vienna-Tabor measurements were made under the direction of the K. K. Wasserbau-Administrator Jean-Baptiste Bréquin (1712–1785) and were published in the *Wiener Zeitung* until his death in January 1785 (Schönburg-Hartenstein and Zedinger 2004). Water-level measurements of the River Danube at Buda are available for the studied period as they were published in the *Ephemerides* of the Societas Meteorologica Palatina; however, from 20 December 1783 until 9 April 1784, no information was recorded as a result of drift ice on the river.

Meteorological and hydrological measurements can be complemented by direct and proxy data derived from a variety of documentary sources (e.g. Brázdil et al. 2005b, 2006b and references therein), including:

1. Annals, chronicles, memory books and memoirs

Documentary accounts record in varying degrees of detail the course of the 1784 floods, along with the direct impacts and consequences to local populations. For example, a memory book kept in the rectory at Počaply on the River Elbe in Bohemia described the flood in the following way (Kaněra 1900, pp. 205–206): “On the 30 December 1783 the Elbe froze in such a way that by morning [31 December] it was possible to walk over the ice and on the 28 February [1784] at midnight the ice started to break, with a terrible crack. At approximately 5 a.m. the ice moved and went away without causing damage. But at 5 p.m. the water rose so fast, that in half an hour it rose at the rectory up to the height of 2 ells [156 cm] and rose further until 11 p.m. It achieved a height of 3 ells 8 inches [254 cm] in the rectory and remained in this level up to the evening of the following day [29 February] … A mass on the Sunday [29 February] could not be provided because the water in the church was 2 ells [156 cm] high …" Writers sometimes compared the 1784 flood with other events; for example, in Western Europe with the 1740 flood: "It results from it that the water level was about 11 feet and a few inches [more than 340 cm] higher than in 1740." (Thelen 1784); "At 9 o'clock (after reports from Cologne) it stood 17 feet [518 cm] above the level of 1740." (von Berger 1784). On the River Pegnitz in Nürnberg, it was compared to the catastrophic flood at the end of the 1595 winter (Nonne 1784; Will 1784).

2. Weather diaries

The contents of weather diaries vary but normally include daily visual weather records, sometimes combined with early instrumental measurements and descriptive accounts of extreme or unusual events, such as floods and their devastating consequences. Several such diaries exist in France, for example, the diary of the bookseller Hardy (Bibliothèque Nationale de France, Ms 6680-6677), which contains ~90 hydrometeorological readings between 1 December 1783 and 31 March 1784. A police lieutenant's weather diary from Nancy Dorival (Library of Nancy, Ms 1310–1323) provides a valuable testimony for Lorraine (bisected by the River Moselle); as the owner of a thermometer and a barometer, he devoted over 15 pages of his diary to the winter 1783/1784, including observations concerning the number of freezing days, presence of snow and high water levels relative to buildings. In Timişoara (Romania), J. C. Klapka, a royal pharmacist of Moravian origin recorded pressure and temperature during the winter of 1783/1784 (Eötvös Loránd University Library, no. E 40). S. Benkö (1794), a doctor in Miskolc (Hungary) provides an account of the weather and flood events during the winter of 1783/1784 in his diary.

3. Correspondence (letters)

Correspondence often contains information concerning the views or thoughts of an individual, including flood events that occurred in their region; they often include a description of the weather and resulting damage. This is particularly important in rural regions where alternative sources are often absent (Macdonald et al. 2009). In several cases, letters were inserted into newspaper reports, a common practice across much of Europe in the eighteenth and nineteenth centuries. The *Wiener Zeitung* (28 February 1784, no. 17, p. 411) reported heavy snowfall based on letter from Spišská Sobota in central Slovakia from 14 February: "Quite recently the snow fell so frequently that a neighbour had to open an exit from the house. The violent storm wind that has raged uninterruptedly for three days and threatened every moment the roofs of the houses has finally died down without having caused considerable damage in our area. The sadder is the news that we received from other areas. People say that in Stoß [Štós], a village at the border between the Zips [Spiš] and Abaujwarer [Abov] County, the upper half of the city tower collapsed and brought by this much damage to other houses and to the people. At Joß [Jasov], a place in the last named County, many houses were partly ruined and their roofs were taken away. With fear one sees now everywhere approaching a sudden thaw in the weather."

4. Special prints

On the occasion of disastrous floods, special newssheets or booklets were printed and distributed. In many cases, booklets detailing the contemporary flood event also provide comparison to previous floods, with the intention of informing and therefore reducing the potential consequences of similar future floods. For example, booklets published by Thelen (1784) and an unknown author (Anonymous 1784a) describe the severity of the winter and extent of flooding in Cologne, Germany. A poem describing the catastrophic flooding at Meißen (River Elbe) was published by Thiele (1785), with an anonymous author (1784b) also providing a detailed depiction of flooding in the Elbe catchment.

5. Official economic records

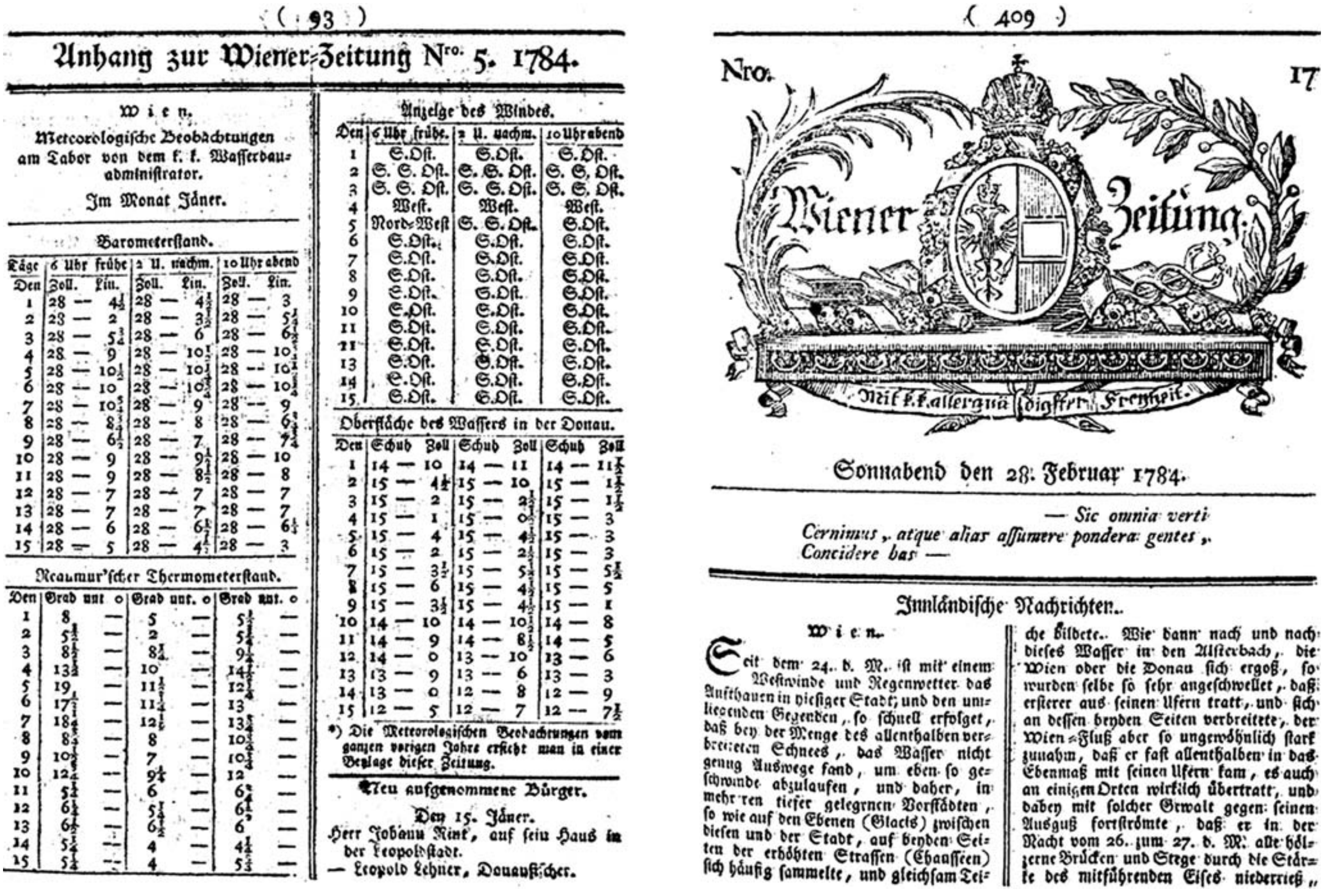
Economic records provide data collected in connection with any economic activity or procedure which relates to the flooding; examples include expenditure for the reparation of bridges and footbridges, buying material for repairs, financial assistance to the affected and applications for tax abatement on the grounds of damage suffered. For example, on 8 March 1784, the municipal of Gebesee (near Erfurt, Germany) reported to the local board in Tennstedt the disastrous situation of the dykes near the River Gera following the floods of late February (District-Archive Sömmerda, Gebesee A, no. 888). In Hungary, information concerning the 1784 flood events appeared as separate applications for help, or in requests for tax reductions (e.g. Érd: Fejér County Archives, IV-A-73: F 51 no. 172, 501/1784) or were systematically included in town/municipal/regional protocols (e.g. *Banat Protocols*: Hungarian National Archives, A 101). In France, engineers responsible for managing the ship canal linking the Mediterranean Sea with the Atlantic Ocean recorded "major events" at almost a daily frequency (Archives of the Canal du Midi, liasse 663). Instrumental data (temperature, rainfall) and descriptive accounts document the freezing and intermittent flooding of rivers and canals near Toulouse, Béziers and Trèbes throughout the winter of 1783/1784. The Municipal Acts record all cases involving decisions made by town councillors, which often include details of economic and societal impacts resulting from the extreme weather conditions. Similar cases were recorded in Hungary where floods and the waterworks of major rivers were systematically catalogued, e.g. the Mureş flood event (Hungarian National Archives, C 127, Vol. 2. 60).

6. Newspapers and journals

Newspapers and journals provide some of the most important documentary information, as they describe the courses, causes and impacts of the floods and often include a detailed enumeration of the damages. For example, Berger (1784) reported an "ice flood" in the journal *Dreßdnische Gelehrte Anzeigen auf das Jahr 1784*; similarly, Ursinus (1784) described in the same journal the 1784 flood and compared this event with other extreme floods in the River Elbe. The *Wiener Zeitung*, which appeared twice a week, included not only numerous reports on heavy rain, floods and cold weather related to Austria, Bohemia, France, Germany, historical Hungary, Italy, Portugal, Russia and Spain but also instrumental meteorological and demographic data from Vienna (Fig. 1). Similarly, in France, the *Journal de Paris* reported daily the water level observed at the bridge de la Tournelle, while the *Gazette de France* reported on the rigours of the winter and the extent of flooding in Paris, across France and in other European cities.

7. Pictorial documentation

Several contemporary pictures express the situation during the 1784 floods (for Meißen, see Förster 2001; for Würzburg, see Glaser 2001; for Prague, see Brázdil et al. 2003 and for Vienna, see Strömmer 2003). Careful consideration must be given to the use of pictures, as they may reflect an author's imagination, experience or perception, rather than an accurate depiction of an event (Fig. 2).



(93)

Anhang zur Wiener-Zeitung Nro. 5. 1784.

Wien.

Meteorologiſche Beobachtungen am Tabor von dem k. k. Waſſerbau-adminiſtrator.

Im Monat Jäner.

Barometerſtand.

Täge	6 Uhr frühe		2 U. nachm.		10 Uhr abend	
Den	Zoll.	Lin.	Zoll.	Lin.	Zoll.	Lin.
1	28 —	4½	28 —	4½	28 —	3
2	28 —	2	28 —	3½	28 —	5¼
3	28 —	5¾	28 —	6	28 —	6½
4	28 —	9	28 —	10½	28 —	10¼
5	28 —	10½	28 —	10¼	28 —	10½
6	28 —	10	28 —	10¾	28 —	10¾
7	28 —	10¾	28 —	9	28 —	9
8	28 —	8¾	28 —	8	28 —	6¾
9	28 —	6½	28 —	7	28 —	7¾
10	28 —	9	28 —	9½	28 —	10
11	28 —	9	28 —	8½	28 —	8
12	28 —	7	28 —	7	28 —	7
13	28 —	7	28 —	7	28 —	7
14	28 —	6	28 —	6½	28 —	6¼
15	28 —	5	28 —	4½	28 —	3

Reaumur'ſcher Thermometerſtand.

Den	Grad unt. o		Grad unt. o		Grad unt. o	
1	8	—	5	—	5½	—
2	5½	—	2	—	5¼	—
3	8½	—	8¼	—	9¼	—
4	13½	—	10	—	14½	—
5	19	—	11½	—	12¾	—
6	17½	—	11¼	—	13	—
7	18¼	—	12½	—	13¾	—
8	8¾	—	8	—	10¾	—
9	10½	—	7	—	10¾	—
10	12¼	—	9¼	—	12	—
11	5½	—	6	—	6¾	—
12	6¼	—	5¼	—	6½	—
13	6½	—	6½	—	6	—
14	5¼	—	4	—	4½	—
15	5¼	—	4	—	5½	—

Anzeige des Windes.

Den	6 Uhr frühe.	2 U. nachm.	10 Uhr abend
1	S. Oſt.	S. Oſt.	S. Oſt.
2	S. S. Oſt.	S. S. Oſt.	S. S. Oſt.
3	S. S. Oſt.	S. S. Oſt.	S. S. Oſt.
4	Weſt.	Weſt.	Weſt.
5	Nord-Weſt	S. S. Oſt.	S. Oſt.
6	S. Oſt.	S. Oſt.	S. Oſt.
7	S. Oſt.	S. Oſt.	S. Oſt.
8	S. Oſt.	S. Oſt.	S. Oſt.
9	S. Oſt.	S. Oſt.	S. Oſt.
10	S. Oſt.	S. Oſt.	S. Oſt.
11	S. Oſt.	S. Oſt.	S. Oſt.
21	S. Oſt.	S. Oſt.	S. Oſt.
13	S. Oſt.	S. Oſt.	S. Oſt.
14	S. Oſt.	S. Oſt.	S. Oſt.
15	S. Oſt.	S. Oſt.	S. Oſt.

Oberfläche des Waſſers in der Donau.

Den	Schuh	Zoll	Schuh	Zoll	Schuh	Zoll
1	14 —	10	14 —	11	14 —	11½
2	15 —	4½	15 —	10	15 —	1½
3	15 —	2	15 —	2½	15 —	1½
4	15 —	1	15 —	0½	15 —	3
5	15 —	4	15 —	4½	15 —	3
6	15 —	2	15 —	2½	15 —	3
7	15 —	3½	15 —	5½	15 —	5½
8	15 —	6	15 —	4½	15 —	5
9	15 —	3½	15 —	4½	15 —	1
10	14 —	10	14 —	10½	14 —	8
11	14 —	9	14 —	8½	14 —	5
12	14 —	0	13 —	10	13 —	6
13	13 —	9	13 —	6	13 —	3
14	13 —	0	12 —	8	12 —	9
15	12 —	5	12 —	7	12 —	7½

*) Die Meteorologiſchen Beobachtungen vom ganzen vorigen Jahre erſieht man in einer Beylage dieſer Zeitung.

Neu aufgenommene Bürger.

Den 15. Jäner.

Herr Johann Rink, auf ſein Haus in der Leopoldſtadt.

— Leopold Lehner, Donaufiſcher.

(409)

Nro. 17

Wiener Zeitung.

Mit k. k. allergnädigſter Freyheit.

Sonnabend den 28. Februar 1784.

— Sic omnia verti
Cernimus, atque alias aſſumere pondera gentes,
Concidere has —

Innländiſche Nachrichten.

Wien.

Seit dem 24. d. M. iſt mit einem Weſtwinde und Regenwetter das Aufthauen in hieſiger Stadt, und den umliegenden Gegenden, ſo ſchnell erfolget, daß bey der Menge des allenthalben verbreiteten Schnees, das Waſſer nicht genug Auswege fand, um eben ſo geſchwinde abzulaufen, und daher, in mehreren tiefer gelegenen Vorſtädten, ſo wie auf den Ebenen (Glacis) zwiſchen dieſen und der Stadt, auf beyden Seiten der erhöhten Straſſen (Chauſſeen) ſich häufig ſammelte, und gleichſam Teiche bildete. Wie dann nach und nach dieſes Waſſer in den Alſterbach, die Wien oder die Donau ſich ergoß, ſo wurden ſelbe ſo ſehr angeſchwellet, daß erſterer aus ſeinen Ufern tratt, und ſich an deſſen beyden Seiten verbreitete, der Wien-Fluß aber ſo ungewöhnlich ſtark zunahm, daß er faſt allenthalben in das Ebenmaß mit ſeinen Ufern kam, es auch an einigen Orten wirklich übertratt, und dabey mit ſolcher Gewalt gegen ſeinen Ausguß fortſtrömte, daß er in der Nacht vom 26. zum 27. d. M. alle hölzerne Brücken und Stege durch die Stärke des mitführenden Eiſes niederriß,

Fig. 1 Pages from the *Wiener Zeitung* with reports detailing the extreme hydrometeorological events during the winter of 1783/1784: *left* hydrometeorological data (air pressure, temperature, wind, water level) for Vienna-Tabor (17 January 1784, no. 5, p. 93); *right* description of the thaw weather and its consequences for Vienna (28 February 1784, no. 17, p. 409)

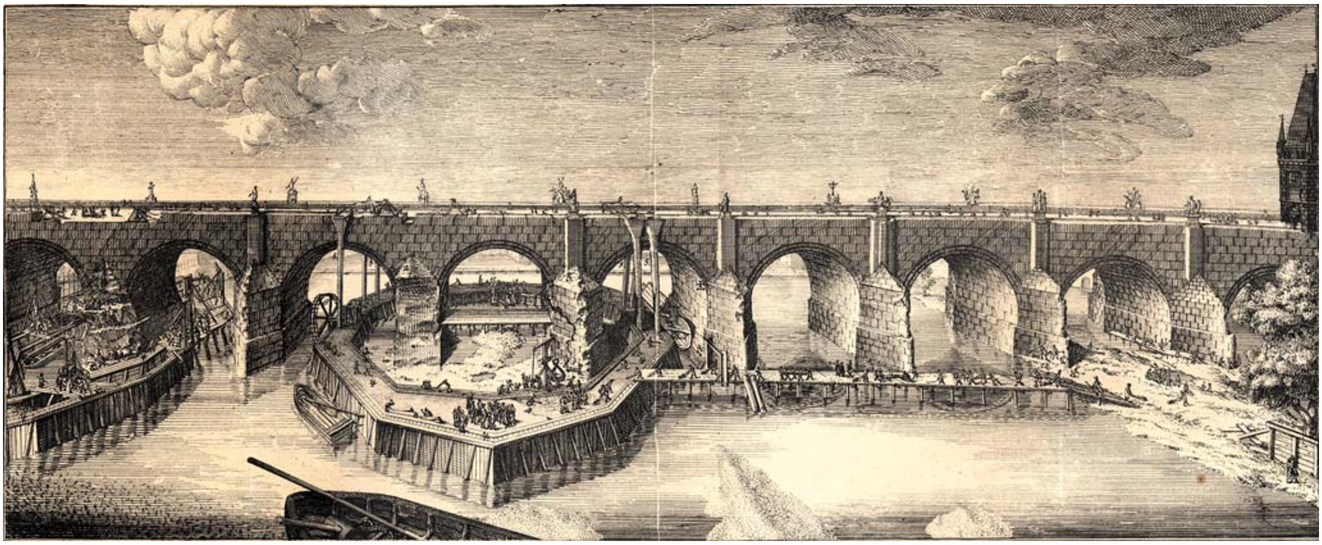


Fig. 2 Restoration of Charles Bridge in Prague, damaged during the flood on 28 February 1784 (K. Salzer, copperplate engraving, Museum of the City of Prague, catalogue no. 1.324)

8. Sources of religious content

The 1784 flood was used in several sermons by priests as an example of the Lord's punishment to the people; for example, the priest Heinrich Coenen saw 'the misery experienced by the people of Mülheim on the Rhine in the time of this flood not as a mere coincidence, or as an unavoidable natural event, but openly claimed that it was a deserved punishment for their sins. The Lord has punished them, but will cease to punish them if they live along the rules of the [Catholic] religion' (Coenen 1784). Other similar examples are the sermons of the priests Aloys Merz (1784) from Augsburg, Christian Wilhelm Demler (1784) from Jena and Johann Gottlob Hartmann (1784) from the village of Eutzsch, near Wittenberg (River Elbe).

9. Stall-keepers' and market songs

The horrors of the disastrous floods became a dramatic topic in stall-keeper and market songs; an example is the stall-keepers' song describing the 1784 flood in Prague and Bohemia (Truchlivá novina 1784).

10. Chronogramme

Chronogrammes were common in eighteenth century Western and Central Europe and were frequently written in Latin or German verse or prose to commemorate events. In a chronogramme, specific letters are interpreted as a roman numeral (in capital letters or in bold) and indicate the year of an event. For example, a Latin chronogramme about the catastrophic February 1784 floods comes from the town of Linn near Krefeld (Germany) and reads as: E*X*T*V*BERATO RHENO ***LI*NNA PER *C*RE*V*E*LDI*A*M*** PANE ET NA*VI*B*V*S *LI*BERATA EST [with the Rhine flooded, Linn has been liberated with bread and ships by way of Krefeld] (Creutz 1924–1925).

11. Early scientific papers and communications

The severity of the 1784 floods resulted in several papers detailing their occurrence, meteorological causes and impacts. A direct response of the 1784 floods was the publication by Christian Gottlieb Pötzsch in Dresden of an extended flood chronology for the River Elbe, based on historical sources from Bohemia and Germany (Pötzsch 1784). A number of reports concerning the 1784 floods are included in the compilation by Weikinn (2000).

12. Epigraphic sources

The water levels reached during the 1784 floods were marked (chiselled, carved or drawn) on to buildings, bridges, gates etc. across Europe (for example, the "Schiffervorstadt" in Pirna, Germany). Watermarks should be assessed for their originality but provide valuable information on flood extent and level (a detailed discussion of epigraphic records is provided by Deutsch et al. 2006; Munzar et al. 2006; Macdonald 2007), particularly when estimating past flood discharges (for Prague, see Novotný 1963).

3 Weather in the winter 1783/1784 in Europe

3.1 Weather patterns in Europe

Fluctuation in daily temperature and precipitation (Fig. 3) are documented for Central England in the diary of Thomas Barker (precipitation and weather descriptions) and the

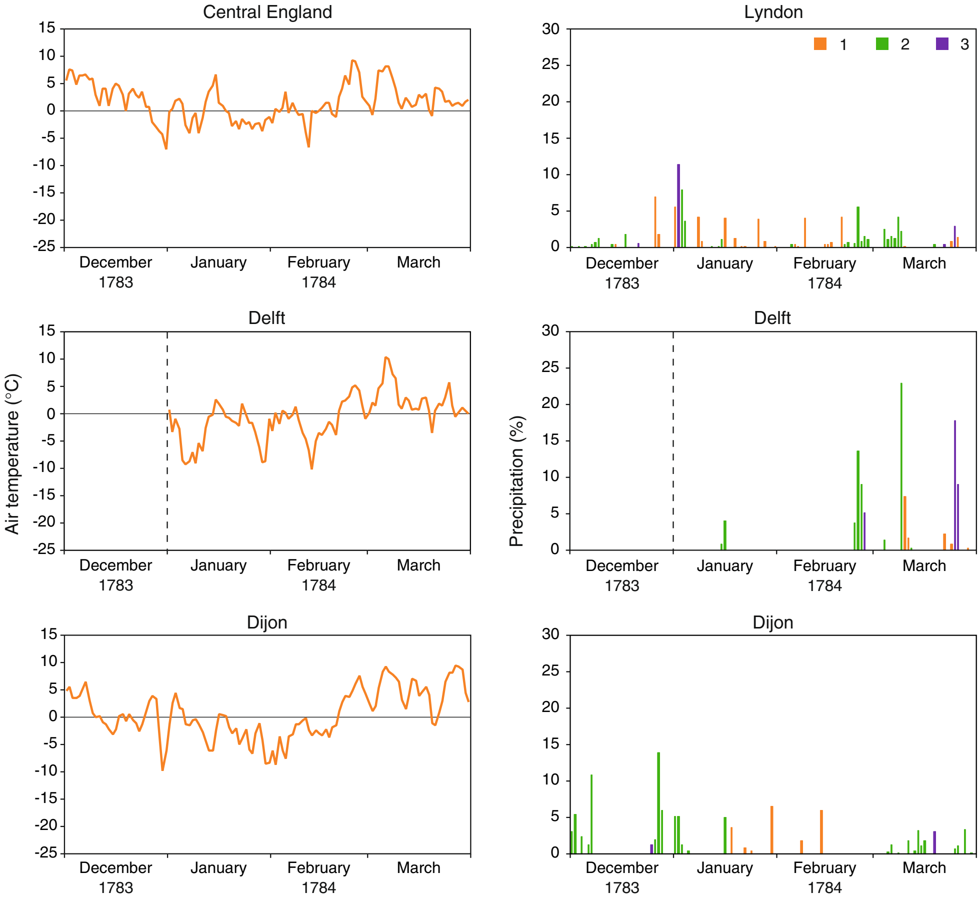


Fig. 3 Fluctuation of mean daily temperatures and daily precipitation totals for selected meteorological stations in Europe from 1 December 1783 to 31 March 1784. As different units are used for precipitation measurements, daily totals are expressed as a percentage of the precipitation total for 1 December 1783–31 March 1784: *1* snow, *2* rain, *3* mixed

Central England Temperature Series (Parker et al. 1992) and for sites across Europe from the stations of the Societas Meteorologica Palatina (Ephemerides Societatis Meteorologicae Palatinae 1785, 1786) in the cities of: Delft (the Netherlands), Dijon (France), Tegernsee (Germany), Erfurt (Germany), Prague (Bohemia) and Budapest (Hungary). Despite shorter series for Delft and problems with some observations (e.g. incomplete precipitation measurements in Prague), mean daily air temperatures at these stations were below 0°C for periods in December and during most of January and a large part of February 1784. The intensity of the negative temperatures across Europe increased in a west–east direction, culminating in the lowest temperatures in Central Europe during the first 10 days of January. The long duration of low temperatures resulted in the freezing of watercourses, such as the 118 cm thick layer of ice that formed on the River Vltava in Prague. The frequent snowfalls resulted in significant snow cover across much of Europe, with maximum snow depths reaching 40 cm in Belgium (Demarée 2006) and up to several metres in Bohemia (with up to 7 m in upland areas and about 60 cm in the lowlands) (Brázdil et al. 2005a). A sudden increase in temperature coupled with intense rainfall resulted in snowmelt and the breakup of river ice during the latter part of February 1784, with positive daily temperatures prevailing during March 1784 across much of Europe. In addition to these hydrometeorological phenomena, strong winds were reported for several parts of Western, Southern and East-Central Europe, particularly the British, French, Spanish and Portuguese Atlantic coastlines and also in the Adriatic Sea. Nevertheless, this study will focus on the events related to floods.

3.2 Sea level pressure patterns

Reconstructions of atmospheric circulation have been developed for specific North Atlantic–European regions (see Lamb and Johnson 1966; Briffa et al. 1986, 1987; Cook et al. 1994; Jones et al. 1999; Luterbacher et al. 2002; Küttel et al. 2009). Reconstructed monthly sea level pressure (SLP) fields from December 1783 to March 1784 and their anomalies with respect to the 1961–1990 reference period are shown in Fig. 4 (Luterbacher et al. 2002). The SLP fields are reconstructed statistically using long and reliable station pressure series from different areas of Europe. During December 1783 and January 1784, large parts of Europe were influenced by high pressure conditions. In January, the western Russian high pressure connected with the Azores anticyclone. The corresponding anomaly figures indicate above normal SLP over Northern Europe and below normal SLP over the Atlantic connected

Fig. 3 (continued)

with anomalous easterly flow towards Central Europe. The February and March 1784 SLP patterns are similar with a weak Azores high and Western Russian high. The corresponding anomalous SLP pattern for February 1784 points to above (below) SLP over Northern Europe (Mediterranean). In March 1784, an anomalous northerly to northwesterly flow towards Central Europe prevailed, a result of positive anomalies in the west and negative values over large parts of the continent.

4 Floods in the winter 1783/1784 in Europe

As large areas of Europe accumulated a significant snowpack resulting from prolonged periods of temperatures below freezing, during which watercourses and soils were frozen, the potential for severe flooding increased. Sudden warming accompanied with intense rainfall favourable for the movement of ice flows on rivers and intense snowmelt resulted in three phases of flooding across Europe: the first at the turn of 1783/1784, the second at the end of February 1784 and third a month later at the end of March. The spatial and temporal extents of these flood events are discussed below.

4.1 Floods at the end December 1783–beginning January 1784

In southern France, December 1783 was very wet; engineers of the Canal du Midi in Languedoc reported

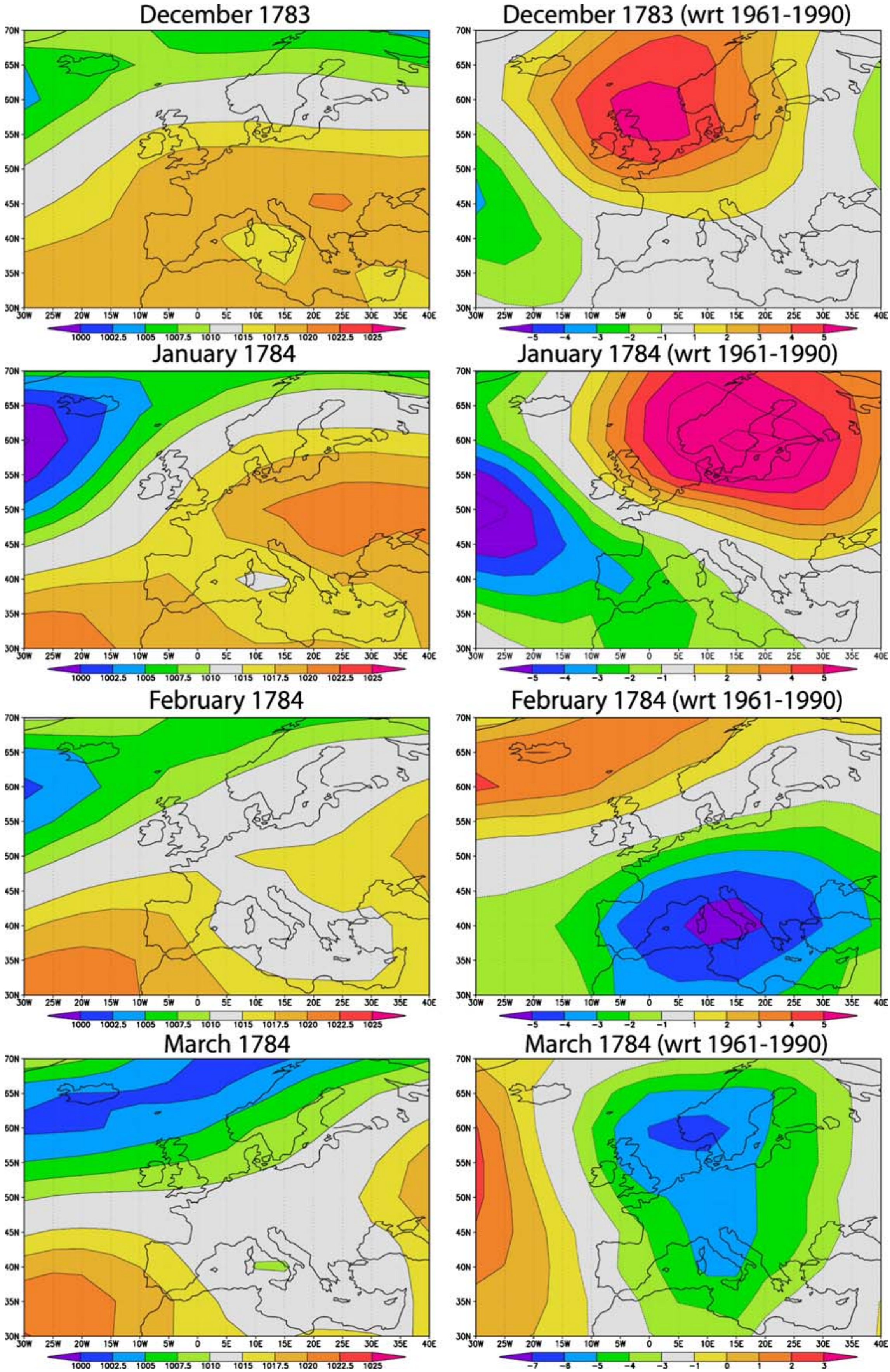

December 1783
December 1783 (wrt 1961-1990)
January 1784
January 1784 (wrt 1961-1990)
February 1784
February 1784 (wrt 1961-1990)
March 1784
March 1784 (wrt 1961-1990)
70N
65N
60N
55N
50N
45N
40N
35N
30N
30W 25W 20W 15W 10W 5W 0 5E 10E 15E 20E 25E 30E 35E 40E
1000 1002.5 1005 1007.5 1010 1015 1017.5 1020 1022.5 1025
−5 −4 −3 −2 −1 1 2 3 4 5
−7 −8 −5 −4 −3 −1 0 1 2 3

Fig. 4 Monthly SLP (hPa) patterns (*left*) from December 1783 to March 1784 in the Atlantic–European region and their anomalies (*right*) with respect to the 1961–1990 climatology (Luterbacher et al. 2002). The figure is drawn with the KNMI climate explorer tool (courtesy Dr. Oldenborgh)

heavy rainfall between 6 and 9 December, followed by rising water levels in the rivers (Garonne and Orb), which interrupted local shipping from 14 December. To the south in Roussillon, the chronicle of the Cathedral St-Jean of Perpignan (Departmental archives of the Pyrénées-Orientales, 1 J 163/2) refers to sustained rains and a disastrous flood that broke through dykes on the River Tet between 13 and 20 December. Frosts arrived at the end of December with the Canal du Midi frozen for 24 h on 30 December, followed at the beginning of January 1784 with an episode of heavy rain.

The onset of cold weather in mainland Europe, a result of high pressure at the end of December, corresponded to warming in the British Isles caused by an inflow of warm and moist air from the southwest, as evidenced in reconstructed daily SLP fields from 30 December 1783 to 2 January 1784 (Fig. 5).

At the beginning of January 1784, the first floods occurred in Western Europe (Fig. 6, part 1). The first flood was recorded in Tadcaster (~15 km southwest of York) on 2 January, resulting in the destruction of a bridge, while a flood in Thetford (~50 km northeast of Cambridge) caused significant damage to the town, leading to the destruction of the bridge as a result of the rapid rise in river level following a sudden thaw. A similar account from the town of Ely (~25 km north of Cambridge), describes severe flooding resulting from a thaw, with residents obliged to live in the upper floors (*Public Advertiser,* 09/01/1784, Issue: 15482). Flooding in Ireland on the rivers Dodder (a tributary of the River Liffey that enters the Irish Sea at Dublin) and Avoca (at Arklow, ~65 km south of Dublin) on 2–3 January suggest that eastern Ireland suffered significant flooding, with considerable loss of life, property and material goods.

In mainland Europe, the Scheldt catchment (Fig. 6, part 2) was affected by flooding at the beginning of January 1784 as a consequence of snowmelt and ice movement, with flooding recorded in the tributaries (Lys, Dender, Durme, Nete,

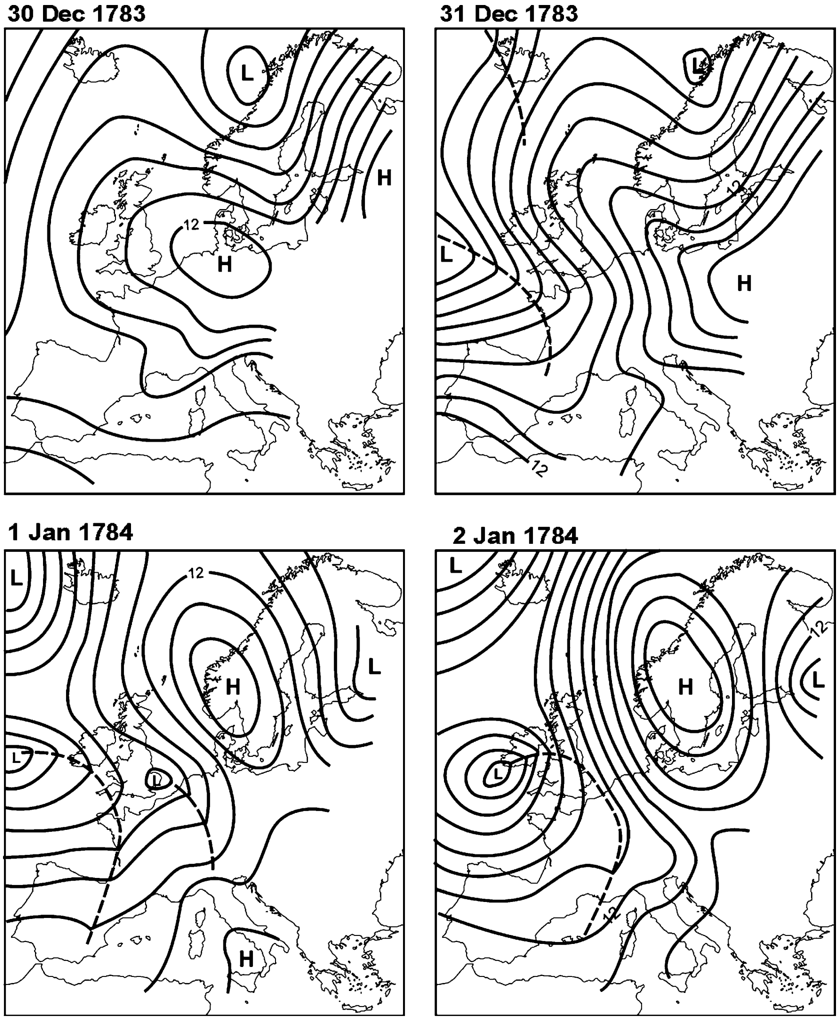


Fig. 5 Reconstructed daily SLP fields in Europe from 30 December 1783 to 2 January 1784 (Kington 1988): *H* high, *L* low. Isobars are drawn at 4 hPa intervals, with the 1012 hPa isobar being marked '12'. Stippled lines indicate fronts

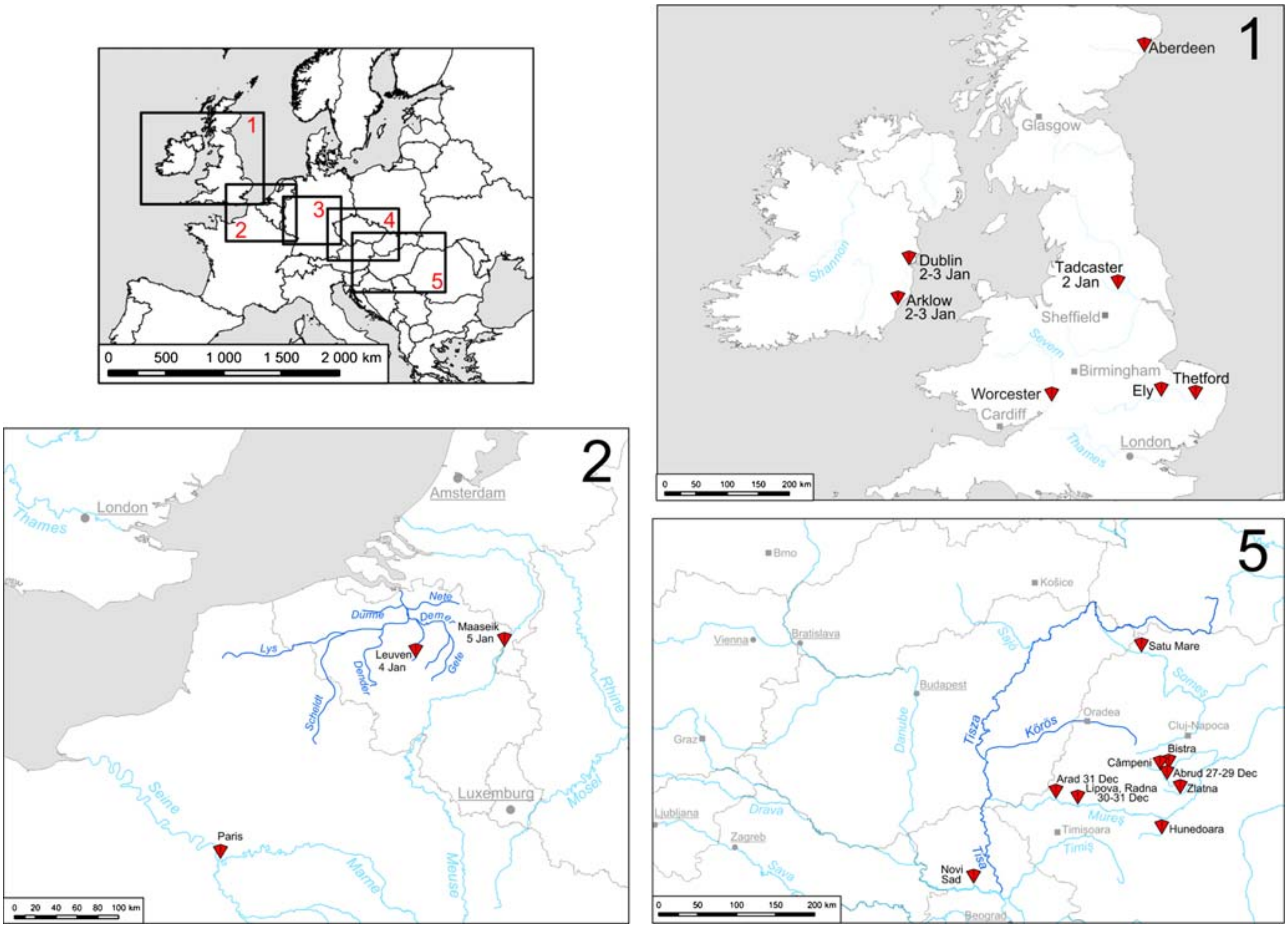


Fig. 6 Selected locations (with dates) and rivers (*in dark blue*) with recorded floods in December 1783–January 1784 in Western and Central Europe, according to documentary sources

Demer and Gete). At Louvain (Belgium) on the River Dijle, flooding on 4 January 1784 resulted in houses and streets being submerged to a depth greater than that witnessed in 20 years. In the neighbouring Meuse catchment, high water was recorded on the frozen river at Maaseik on 27 December 1783, with reports from Dutsch Venlo describing the breaking of ice on the River Meuse on 5 January 1784, with damage to ships in the harbour and on the beach, mainly in the area near Blerick (Demarée 2006).

In Paris, the River Seine started to freeze from 15 December; on 27–29 of December, snow fell in a "prodigious quantity as we had not seen for a very long time" preventing the movement of pedestrians and horse-drawn carriages (Bibliothèque Nationale de France, Ms 6680-6677). A sudden increase in temperature led to snowmelt in early January, causing the River Seine to flood, the waters rose 3 m above the normal level at the de la Tournelle Bridge, raising fears in the press of a flood comparable to the disastrous 1764 event (Fig. 7).

In Austria, the water level of the River Danube was relatively high after heavy rainfall during December 1783. According to the detailed weather reports of the *Wiener Zeitung*, a period of extreme cold from 4–9 January 1784 with temperatures around −12.5°C during the day resulted in ice covering the Danube to a depth of greater than two ft in thickness (63 cm); the daily mean temperature remained below zero for most of the period until late February.

Newspaper accounts from historical Hungary (*Pressburger Zeitung*, 17–24 January 1784, no. 5–7, 18 February 1784, no. 14; *Magyar Hírmondó*, 21–24 January 1784, no. 6–7 and *Presspůrské Noviny*, 23 January 1784, no. 7) and Vienna (*Wiener Zeitung*, 17–24 January, no. 5–7) describe frosty weather with large quantities of snow until 26 December 1783, when sudden rapid warming, accompanied by rainfall and a mild south wind caused widespread flooding. The greatest flood extent and material damage occurred on the tributaries of the River Tisza (with an ice flood on the Upper Tisza, Szamos/Someş, Körös/Criş, Maros/Mureş) and the lower Danube at Novi Sad (present-day Serbia; Fig. 6, part 5). Along the River Someş, several settlements were flooded and bridges destroyed. The conditions in the Mureş catchment in central and southern Transylvania and on the

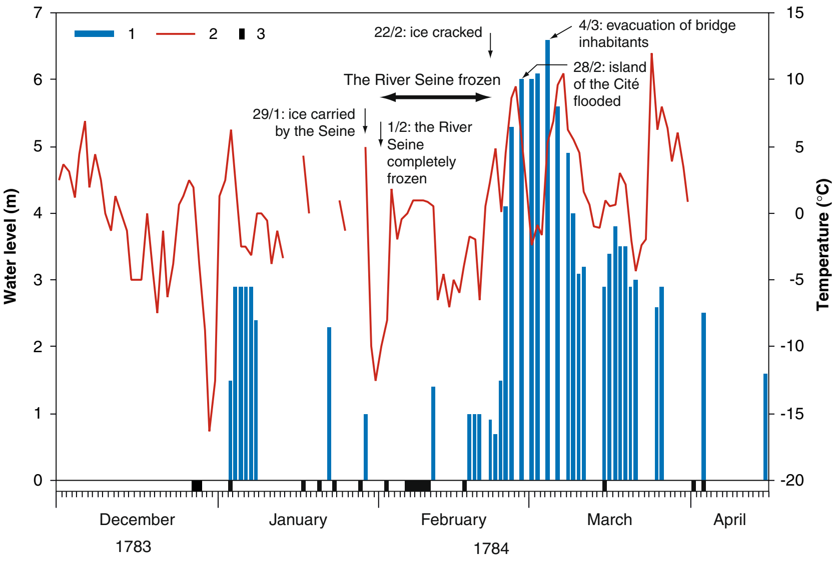


Fig. 7 Fluctuations in daily mean temperatures and the water level measured at the de la Tournelle Bridge on the River Seine in Paris from 1 December 1783 to 14 April 1784: *1* water level, *2* temperature, *3* day with snowfall

southeastern Great Hungarian Plain (present-day western Romania) were severe. Entire villages, numerous bridges and large areas of cultivated land were washed away in the valleys of the Apuseni, Poiana Rusca and Gurghiu Mountains (southern Carpathians) with extensive inundation of the lowlands, which subsequently refroze. Extensive damage occurred in Radna and Lipova, where practically all the houses were damaged or destroyed and three people died. In Arad (Romania), the maximum inundation was reached on 31 December 1783–1 January 1784 with floodwaters inundating the town and surrounding region. Even though the flood waters dropped in level, they still remained within the town and surrounding districts and subsequently refroze as temperatures dropped in early January (Kiss et al. 2006).

4.2 Floods from February–early March 1784

After a long-lasting frosty period, a strong southwesterly airflow led to an increase in temperature and heavy rainfall, resulting in extreme floods over large parts of Western and Central Europe; eastern Central Europe also experienced a number of significant floods in early March (Fig. 8). The severity of the flooding can be related to the accumulated snowpack thickness and water content of the snow, rainfall, catchment characteristics, orography and presence of river ice.

4.2.1 Floods in Western Europe

The first documented flooding of this period occurred on 31 January in southern France, where the flood waters of the River Loira at Orleans washed away boats loaded with wood and wine; the cities of Bordeaux and Perpignan were also affected by this flood (McCloy 1941). In Britain, the first flood was recorded on 5 February on the River Severn in Worcester, with a letter published in the *Public Advertiser* (14/02/1784, Issue: 15513) providing a valuable insight into the weather during these months: “It is now seven weeks since the rigour of the season set in here, in which time the River Severn has been frozen up three times, [a] circumstance never known here in the memory of the oldest inhabitant. A thaw came on last Thursday [5 February], and on Friday [6 February] the river was by the flood cleared of the ice in little more than one hour; but before ten at night it was again frozen at the bridge, and the river is now full to the tops of the banks and covered entirely with ice near five miles.”

Contemporary documents suggest that warming began on 21 February with a thaw, which is supported by data from the Central England Temperature (CET) series (Parker et al. 1992), though some regions of England document earlier floods resulting from thaw, suggesting that significant snowmelt may have occurred during daylight hours, whilst evening temperatures reduced mean daily temperatures below freezing. Generally, in Britain, little is mentioned of flooding during this period, though the severity of the weather is widely reported; the *London Chronicle* (24/02/1784, Issue: 4263) contains a letter from Edinburgh (February 21) providing a brief glimpse into the severity of the weather in Scotland: “The river Clyde is so filled with ice that there has been no communication between Glasgow and Greenock by water these last seven weeks. By accounts from the North we learn, that the storms of snow are more severe than ever, so that the poor people are in a very distressed condition for want of meal, and many of the sheep and cattle are dying. In many places very liberal contributions have been made for the relief of the poor.” The extent of the societal impact of the severe weather may have indirectly reduced the likelihood of floods being recorded.

In mainland Europe, the first flood occurred in central France on 18–19 February with further flooding in northern

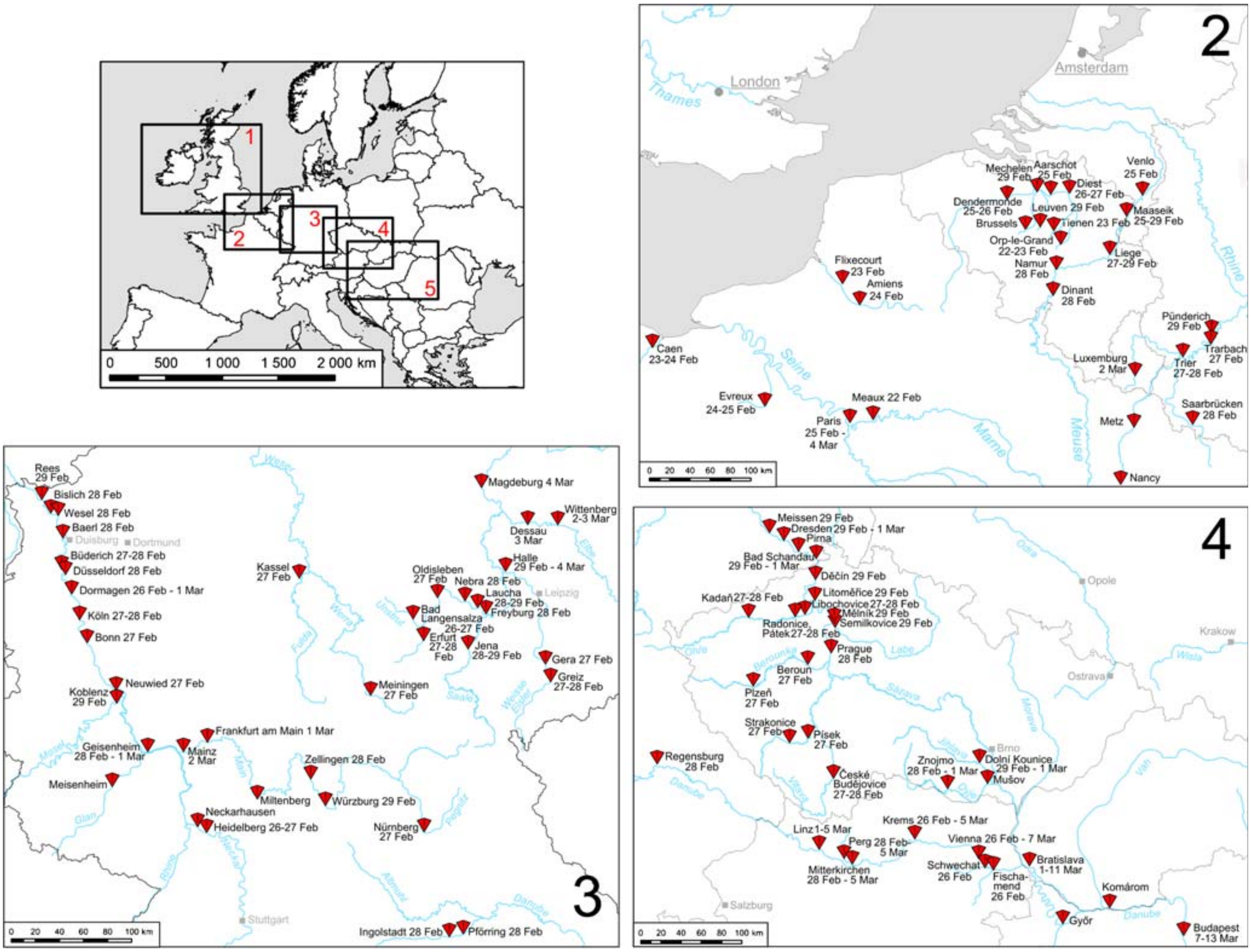


Fig. 8 Selected locations (with dates) with recorded floods at the turn of February–March 1784 in Western and Central Europe, according to documentary sources

France a day later (Fig. 8, part 2). In the Loira catchment, the towns of Orleans, Blois and Tours suffered considerable damage with the destruction of flood walls and large areas submerged under water. In Evreux on the River Iton, water levels recorded a height of 6 ft [183 cm] on 24–25 February. In Caen on the River Orne (Normandy), water is described as running through the streets for 8 days, with the floods described as "crétine" or "crétinous", meaning a combination of heavy rainfall and high tide, which elevated the river level and resulted in the flooding of the city and its surrounding area (Garnier 2007a). At Amiens on the River Somme (northern France), flooding from 24 February increased the water level by up to 12 ft [365 cm] and caused extensive damage. During the following days, floods occurred in eastern France, with the greatest material damage in the region of Nancy and Méty, in the Mosel catchment (McCloy 1941).

The River Seine in Paris was frozen on 1 February (Fig. 7), with 18 cm of snow falling on 8 February alone. The degradation of the weather during the winter affected not just humans but also the wildlife, with wolves recorded around Paris on 18 February. Warming caused rapid snowmelt, and according to the *Journal de Paris* (Bibliothèque Nationale de France, Ms 6680-6677), the River Seine on 20 February was 90 cm above its usual level; by 25 February, it reached 4 m with valley floor villages flooded, and on 28 February, the Ile de la Cité (the heart of Paris) was submerged, with the river level to 5.40 m. On 29 February, the flooding became more violent, and on 2 March, it rose to a height of 5.70 m. Two days later, when the level reached 6 m, town councillors decided to evacuate the inhabitants on the bridges Notre Dame and Marie where traffic was already prohibited; the flood waters disrupted the supply of provisions into Paris, particularly wheat and wood. The *Journal de Paris* on 6 March (Bibliothèque Nationale de France, Ms 6680-6677) describes an ebb tide and discusses in detail the disaster that struck the town of Evreux in Normandy, located downstream of the River Seine. On 15 April, the same newspaper proclaimed the end of the threat, indicating that the Seine is 'in his bed' (Bibliothèque Nationale de France, Ms 6680-6677).

In Belgium (Fig. 8, part 2), the snow started to melt on 21 February 1784 and was followed several days later by the breaking of the ice. The Kleine Gete in Orp-le-Grand was the first to flood during the night of 22–23 February, with the flood wave moving along the stream and connecting with another flood wave from the Grote Gete, which culminated at Tienen on 23 February. Between 25 and 27 February, Diest and Aarschot on the River Demer were flooded, with descriptions from Diest stating that access was possible only by horse with large carriages or by boat, with the surrounding region submerged beneath the flood waters so that it looked like the sea. The town of Louvain was flooded by the River Dijle for the second time in 1784 on 27 February, with considerable damage, estimated at 200,000 gulden; further downstream, the lower part of Mechelen was flooded on 29 February. No damage occurred in Antwerp as a result of the broad river bed of the Scheldt at its estuary to the North Sea (Demarée 2006).

The Meuse catchment (Fig. 8, part 2) had a slower response following the rapid warming and rainfall when compared to the Scheldt catchment; the flood wave lasted for several days, with two peaks 2 to 3 days apart. While the first peak was related to runoff from the Belgian part of the catchment, the second resulted from the saturated French part of the catchment. The towns of Dinant and Namur as well as the area north of Maastricht were amongst the worst affected. The chronicle from Maaseik dates two peaks on 25 and 29 of February, with the last identified as the fourth flood of the year. In Dutch Venlo, the River Meuse rose from 21 to 25 February, when nearly the whole town was under water, with a level only three inches [7.5 cm] below that achieved in 1740 (Demarée 2006). The situation was exacerbated by the pressure placed on the protective flood walls as a result of ice barriers, which elevated the flood waters above the levels expected from river flow alone; their failure resulted in the flooding of the extended area within and around the towns (Demarée 2006).

The general onset of warm weather before the late February flood is well documented and evident from the reconstructed daily SLP fields from 23 to 28 February (Fig. 9). Deep cyclones north of the British Isles in the North Sea generated a warm airflow from the Atlantic Ocean to Western and Central Europe, conditions favourable for rapid snowmelt and the melting of river ice, as witnessed across much of Europe.

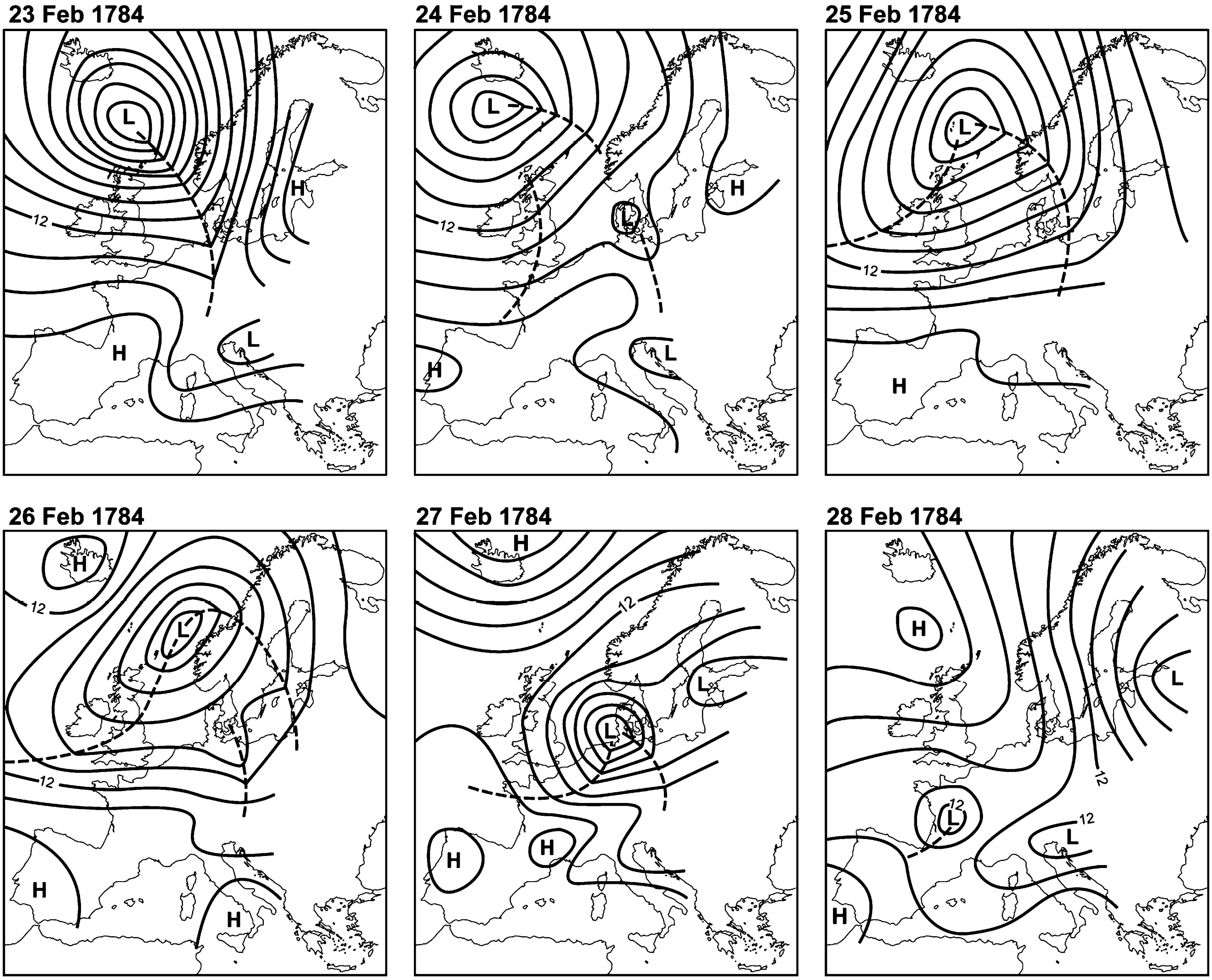
4.2.2 Floods in Central Europe

In the Main catchment (Germany; Fig. 8, part 3), a right-sided tributary of the Rhine, warming started on 23 February accompanied by windy weather, snowmelt and intense rainfall (daily precipitation totals are untypically high with respect to this part of the year). On 27–28 February, thick ice on the river cracked and started to move; its accumulation in several parts of the River Main channel caused a sudden increase in water level, with maximum levels observed from 28 February to 1 March. In Würzburg, the flood culminated on 29 February, with widespread damage resulting from high water but also the movement of ice and drifting wood. The rapid increase in water level was mirrored by a dramatic decrease in level as the ice dispersed after 1 March (Glaser and Hagedorn 1990).

As flooding moved downstream from the tributaries into the main channel of the rivers Rhine and Meuse (in the Low Countries), the situation worsened as rivers remained frozen, significantly reducing the capacity of the systems to transport runoff generated within the upper catchments. This intensified the pressure placed on flood defences as river flow was impeded by ice barriers, which upon failing resulted in significant damage (Demarée 2006).

Floods were also recorded in the Saale, Unstrut, Weiße Elster and Werra catchments in late February (Fig. 8, part 3; Deutsch and Pörtge 2002). The cold temperatures came to an end on 23 February, followed by snowmelt and rainfall on 24–25 February, which contributed to the breakup of the river ice and subsequent flooding. On the River Saale near Halle, the flood and ice-drift started on 29 February, with the upper parts of the town flooded; the following day, it had reached the saltsprings of the so-called "Hallmarket", and on 2 March, it achieved a catastrophic flood level when boats were used to evacuate people and deliver food; by 4 March 1784, the flood waters started to recede (Weißenborn 1933). In Langensalza on the River Unstrut (a tributary of the Saale), a catastrophic ice flood destroyed the protective dams around the town (Town Archives Bad Langensalza, library-no. 14). On the River Weiße Elster in Gera, ice broke on 27 February, the high water levels combined with ice flows (up to more than 1 m thick) destroying bridges and dams; the flood waters also affected the villages of Zwötzen, Milbitz and Thieschitz (Schirmer 2008). Flooding was also recorded at Meiningen on the River Werra, where the town was partly flooded, and horses from the royal stable at Castle Elisabethenburg required evacuation (Hennebergischer Altertumsforschender Verein 1834).

A sudden thaw started on 24 February as a result of a warm southern wind in Bohemia and heavy rainfall (Fig. 8, part 4), with over 40 mm falling on 26 February in Prague (according to the Vienna measure, 41.7 mm fell or 42.9 mm according to Paris standards). On 28 February, the River Vltava rose 533 cm above the normal level in Prague (Fig. 10), and ice flows damaged the pillars of the Charles Bridge (a sentry-box containing five soldiers located on the bridge collapsed into the water), with further damage below Prague towards Mělník. At Litoměřice on the River Elbe, the water level on



23 Feb 1784

24 Feb 1784

25 Feb 1784

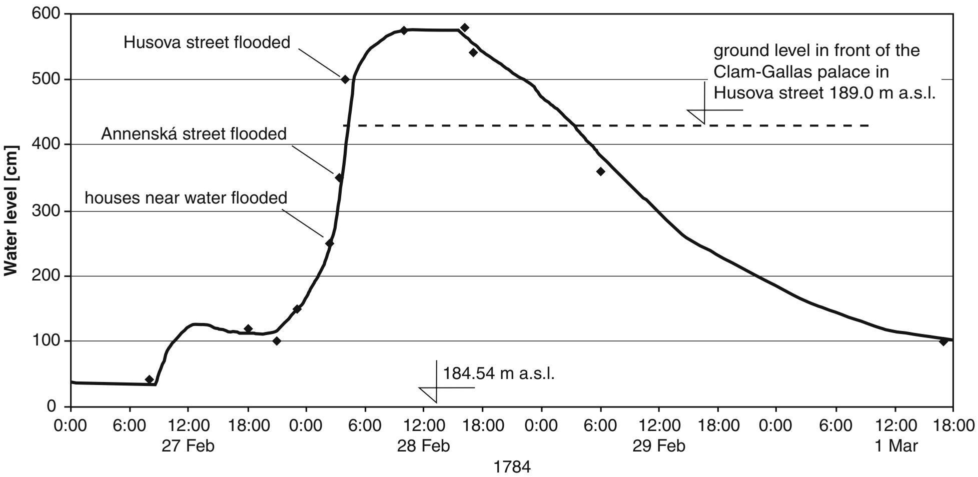
26 Feb 1784

27 Feb 1784

28 Feb 1784

Fig. 9 Reconstructed daily SLP fields in Europe from 23 to 28 February 1784 (Kington 1988): *H* high, *L* low. Isobars are drawn at 4 hPa intervals, with the 1012 hPa isobar being marked '12'. Stippled lines indicate fronts

Fig. 10 Reconstruction of the flood hydrograph for February 1784 at the Monastery of the Knights of Cross, Prague (corrected after Brázdil et al. 2005a)



29 February exceeded the level of the last disastrous flood of 15 February 1655 by 12 cm. On the same day, the flood level culminated at Děčín and on 1 March in Dresden (Brázdil et al. 2005a). According to Elleder and Munzar (2004), runoff from the lower and middle sections of the catchment was the most important component in flood generation, with only a short phase of insignificant snowmelt occurring within the mountain region.

On the River Otava at Písek (Bohemia; Fig. 8, part 4), the flood peaked on 27 February, with river ice causing considerable damage to the bridge, mills and tanners' crushers. In the evening of 27 February, the River Berounka flooded the square at Beroun, whilst at Dolní Černošice, six individuals were bankrupted as a result of the flood. On the River Dyje in the Znojmo region (Moravia), floods destroyed houses, bridges, protective dams and gardens and took five human lives. On the River Jihlava, the ice flows destroyed bridges in Pravlov and Dolní Kounice, with many buildings, barns, bridges, dams and items of farm equipment damaged in southern Moravia (Brázdil et al. 2005a).

Melting of the unusually deep snow and additional rainfall, although not as intense as in December, caused prolonged floods and inundations in several parts of historical Hungary. *Pressburger Zeitung* (10–13 March 1784, no. 20–21) and *Banat Protocols* (Vol. 2: 85r, 90v) record floods in the Timiş, Bega/Begej and lower Mureş catchments in mid-February (now northern Serbia and western Romania), which continued for several weeks, with low-lying areas flooded but without loss of human life.

The situation along the River Danube (Fig. 8, part 4) was severe as rapid snowmelt and intense rainfall in southern Germany caused extensive flooding. In Vienna, daily temperatures rose from below 0°C to 10°C on 25 and 26 February, which coupled with rainfall caused the rapid (within hours) breaking of the river ice. According to the water gauge in Vienna-Tabor, the River Danube water level started to rise in the evening of 26 February, with the steepest increase recorded on 29 February, and the river level peaked on 2 March. During the night of 26–27 February, ice and floods destroyed numerous bridges in Vienna and caused severe damage to a large number of properties in the suburbs (now within the outer districts of Vienna), such as Nussdorf to the north of the city centre. The severity of the conditions on the local populace worsened as temperatures again fell below 0°C on 29 February. The instrumental data from the water gauge at Vienna-Tabor is at first glance misleading. The water level reached its peak on the morning of 27 February (13 ft 9 in.; 429 cm) and stayed higher than 11 ft (335 cm) until the morning of 29 February. During the day, the water level decreased quickly and remained extremely low at 4 ft (122 cm) for several days from 1 March onwards. The explanation for these data are given in a report of the *Wiener Zeitung* from 10 March 1784: "By unerring signs one observes that on the 1st of this month, on the day of the highest swell, the water at the 'Schlagbrücke' was about 11 ¼ inches [29 cm] higher than in the year 1768, at the imperial and royal mint about 3 inches [8 cm], and at the imperial and royal navigation office about 2 inches higher [5 cm]. On the contrary, it stood at Tabor 2 feet and 9 inches [84 cm] lower than in the above-mentioned year. The reason for this is that the water in the Danube canal was spread more easily by breaking out frequently than in the other Danube branches."

Besides Vienna, the large cities of Linz and Krems and the lowlands in the northeastern parts of Lower Austria were hit by the ice and flood waters. As a result of the flood, high water levels were recorded over the following 10 days for a number of locations across present-day Austria.

Remarkably, no evidence of a major ice flood is recorded along the Austrian tributaries of the River Danube. Both newspapers and economic accounts (e.g. *Accounts of the bridge master*: Municipal Archive of Wels) do not reflect any extreme event or damage for the Salzach and lower Inn Rivers (Salzburg, Upper Austria, Lower Bavaria), the River Traun (Upper Austria), the River Enns (Styria, Upper and Lower Austria) and the smaller southern tributaries of the River Danube in Lower Austria. The water level in these rivers may not have been high enough to cause thick ice; in addition, the large lakes of the Salzkammergut lake district (Upper Austria) were not covered with ice in early 1784, as the *Wiener Zeitung* (25 February 1784, no. 16, p. 386) explicitly describes the state of Lake Traunsee (Upper Austria).

Having received descriptions from the northwest concerning the disastrous flood events, further suffering was anticipated in the towns downstream on the River Danube in historical Hungary (Fig. 8, part 4). In Bratislava and its surroundings, after a small flood on 1–2 March, a second and more destructive flood containing ice caused the greatest damage, with at least three casualties, as described in newspapers issued on 10 March (*Pressburger Zeitung* and *Magyar Hírmondó*, no. 20). In the following days, ice floods are documented in other towns such as Győr and Komárno/Komárom, which was referred back to in May as a "very extensive and dangerous ice flood". The flood recorded in the area of Pest and Buda occurred between 7 and 13 March, with the highest level reached during the night of 8–9 March, when the river was blocked by ice flows (*Pressburger Zeitung* and *Presspůrské Noviny*, 13 March 1784, no. 21; *Magyar Hírmondó*, 24 March 1784, no. 23). Lower-lying parts of the three towns (Pest, Buda, Óbuda) and some of the surrounding settlements (Érd, Budafok, Tétény) remained submerged for a couple of days, but compared to other, more significant flood events of the century (e.g. 1775, 1799), no loss of human life or significant damage in Pest and Buda was reported (Kiss 2007). A more dangerous situation developed to the south; on 12 March and during the following days, the River Danube ice started to crack, followed by a major ice flood (*ingens inundatio*) which occurred in the area of Baja, which "has not been observed for 15 years", the water level started to subside after 8 days (*Historia Domus Bajensis* in Kapocs and Kőhegyi 1991). Although greatly feared, according to the *Pressburger Zeitung* (20 March 1784, no. 23) and *Magyar Hírmondó* (31 March 1784, no. 25) no flood event occurred at this time, with the accumulated ice and water passing away without notable damage on the rivers of the Tisza catchment.

4.3 Floods from late March–early April 1784

In the British Isles, little flooding was recorded during March 1784. A single flood event was recorded on 8 March in eastern England and was attributed to the 'rainy and windy weather'; this event is unlikely to reflect a wider accumulation of snow and subsequent flooding in Britain as the CET series records only 2 days after 21 February with mean daily temperatures of below 0°C.

Further floods in mainland Europe were recorded at the end of March 1784. This was the fifth flood to occur at Namur (Belgium) on the Meuse and peaked on 21 March, with the water level reached during this event the greatest since 1740 (Demarée 2006). In the Czech Lands, a flood on the Sázava on 28 March is described following snowmelt in the Bohemian-Moravian Highlands (Elleder and Munzar 2004), but it was probably smaller than that recorded at the end of February.

In historical Hungary, the River Danube and its tributaries were again in flood at the end of March and at the beginning of April as a direct consequence of snowmelt and intense rainfall; floods were also recorded on several rivers in the northern Carpathians and its foothills (Fig. 11). According to reports in the *Pressburger Zeitung* and *Magyar Hírmondó*, the River Váh flooded on 27 March as a result of ice movement and snowmelt in the mountain regions, with floods removing the bridge in Sereď. The River Slaná caused considerable damage on 30 March in Rožňava after intense rainfall; while snowmelt resulted in flooding along the River Poprad in Spišská Sobota, Stráže pod Tatrami and Poprad (present Slovakia). On the same day, as a result of snowmelt and heavy rainfall, the River Gyöngyös destroyed bridges and flooded cellars in the town of Gyöngyös (*Historia Domus Gyöngyösiensis*: Library and Archives of the Franciscan Order in Hungary, VI. 5). In Miskolc, after repeated snowfalls and subsequent snowmelt, flooding occurred on 2–3 April (Benkö 1794). Floods are also recorded in several settlements at the beginning of April on the River Tisza, in the region of Szeged (Hungary). The lowland areas of the Timiş (Romania) faced a long-lasting inundation in April as recorded in the *Banat Protocols* (Vol. 1: 42v, 46r, 47r, 51r; Vol. 2: 103v–104r, 109v, 114r). The meeting of the Croatian parliament in Zagreb had to be postponed as a result of flooding on the River Sava; a minor April flood event in the lower Danube was also reported with the flood waters remaining in the area of Baja until early May

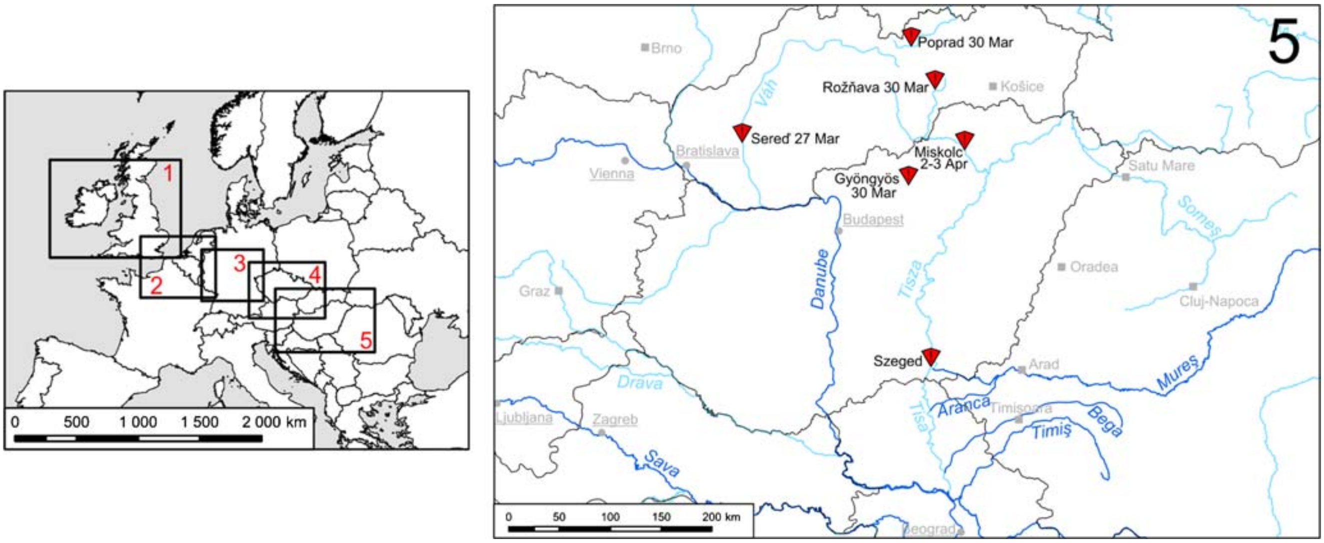


Fig. 11 Selected locations (with dates) and rivers (*in dark blue*) with recorded floods at the end of March–beginning of April 1784 in Western and Central Europe, according to documentary sources

(*Magyar Hírmondó*, 28 April 1784, no. 32; 22 May 1784, no. 39).

5 Impacts and consequences of the flood

High-magnitude flood events are often an important forcing factor in the landscape; for example, the February 1784 flood on the River Main changed the river bed morphology, while the river near Aue (Germany) undertook a lateral movement of the river channel, with considerable quantities of fluvial sediment deposited elsewhere within the catchment (Glaser and Hagedorn 1990). The natural impacts of such large floods though appear insignificant compared to the human perception, its impact on society and human activities.

Weichselgartner (2000) defines a severe flood as a social event, as a result of the consequences concerning the whole socio-economic system. Although based on documentary evidence the 1783/1784 floods did not result in high human losses, the inclement weather of the time caused a significant number of deaths. The floods caused considerable material damage in many places and had further significant consequences on local populations.

The greatest impact within the British Isles was from the severity of the winter, with numerous descriptions within newspaper accounts of the time depicting scenes of considerable suffering; “By a letter from Aberdeen we learn, that the extremes of poverty and want again stare them in the face. The storm, with little remission, has last 14 weeks, and a late harvest, like last, is expected to end in ruin to thousands of families and individuals” (*London Chronicle*, 27/03/1784, issue: 4277). The floods themselves, although severe in places in 1784, were rarely recorded as large floods within British river systems; of greater impact were floods during the period 1770–1775, with extreme floods recorded on a number of British rivers (Macdonald 2006).

The different impacts and consequences of the floods were documented in mainland Europe. The hospital at Caen asked the king for his assistance because their income from embroidery made by the patients was unable to meet the costs associated with increased wheat prices, which rose in six months from 28 to 45 pounds for a *résal* (117 litres). The February 1784 floods in French Normandy put in peril the entire regional economic fabric; for example, business districts and industrial activities at Caen dependent on water power were severely affected by frozen and then rising waters. In the great draper centre at Bernay (Normandy), nearly 198 spinning workshops were destroyed, with 70% of the textile sector suffering some damage (Garnier 2007b). At Alençon, the damage was comparable and caused extensive impoverishment to the workers; the unemployed had no alternative but to take refuge in workhouses.

Following the February 1784 floods, hygiene was recognised as a serious issue by the authorities. Thus the royal state, under the guidance of hygienists and doctors published throughout the kingdom (France) a notice entitled “Opinion on ways to reduce [the] unhealthy”. For the first time, authorities were directly involved in recommending hygienic practices and encouraged sanitation in the home, with the aim of avoiding the spread of disease. The chemist Antoine-Alexis Cadet de Vaux, in his position of Inspector General of Public Health Matters in France, published on 16 March 1784 a booklet advising on means to diminish the unhealthy impact on homes exposed to the inundations (Cadet de Vaux 1784). He describes: “After the retreat of the water, the houses that have been flooded become necessarily insalubrious. They expose the people and the animals when they return in the house without precautions to more or less serious illnesses. And if all the inhabitants of a same place experience this same influence, an epidemic results from it.” The latter sentence was written in the spirit of the neo-Hippocratic hypothesis, where considerable importance was given to epidemics, their repeated occurrence and the catastrophic consequences in the Kingdom of France. Cadet de Vaux continued further “by suggesting washing the walls and the floors immediately after the retreat of the water with water from a well, a fountain or a river. This washing will take away the viscous humidity which never dries or only with difficulties. If necessary the whole operation must be repeated three or four times. One must light a fire in the chimney and if the room is large, one must light also several stoves extending and multiplying the chimney pipes.” Finally, he suggested several general measures for improving public health, statements that can be viewed as a contribution to the emerging policy of taking care of public health matters by government; this policy was supported in France by the foundation of the ‘*Société Royale de Médecine*’ in 1776/78 with its programme of undertaking medical-meteorological observations (Demarée 2004).

In terms of assistance, private charity functioned effectively in providing support, particularly the Catholic Church. The archbishop of Paris purchased large quantities of bread and distributed it freely to the poor, while priests in the parishes of Paris undertook special collections. Symbolic of the movement of ideas, even if it remained marginal, was the mobilisation of Masonic lodges in Paris, as they gathered money to assist disaster victims. Their example of solidarity was followed shortly afterwards by the Italian actors of the King of France in the form of a show for the poor.

Following the February–March 1784 floods in France, the attitude of the royal state when faced with disaster changed; the government had previously remained indifferent to the plight of the people, but following the February–March floods, the government decided to intervene with disaster management. King Louis XVI gave for the first time a decree on 14 March 1784 providing compensation to the total cost of 3,000,000 pounds to disaster victims; this corresponded to about 1% of the annual revenue of the French monarchy (Le Roy Ladurie 2006; Garnier 2007a). The authorities had originally committed to a considerable misjudgement in the public perception of the winters severity, when Queen Marie-Antoinette requested at the end of December 1783 that she wished snow to be kept in the Paris streets for her sledging; once aware of the potential scandal, the queen donated 500 *Louis d'or* from her own pocket to the aid of Parisians. Propaganda was a powerful motivation for a monarchy engaged in a process of national centralisation; with a pamphlet published and distributed throughout the country commemorating the generosity of the king on the occasion of the terrible floods that had afflicted the country.

The authorities response to the February–March floods in central Germany can be defined as short-term (about 2 weeks thereafter), medium-term (from about 2 weeks to 6 months) and long-term (from 6 months up to 2–3 years) (Deutsch and Rost 2005). For the first two groups, the following examples can be identified:

- Arrangements for the flood victims (for example, official collections of money in Langensalza—see Town Archives Bad Langensalza, library-no. 14; collections of clothes, food and firewood in Pirna, Dresden, Meißen etc.; organisation of benefit performances in churches, theatres, restaurants and private saloons; official collections in churches in the whole Electorate of Saxony)
- Deployment of the army and/or special forces and police units, whose primary task consisted of establishing and maintaining order (prevention of looting etc., for example near the River Saale in Halle and in some villages)
- Various orders with respect to hygiene (such as orders for cleaning and disinfecting of the flooded houses)
- Official orders for repairing important buildings and objects (bakeries, bridges etc.)
- Regulations on the orderly accounting and maintaining of documents for all charitable operations

The long-term response to the floods included, for example, drafting of emergency plans for future flood events and the formation of special commissions at local and governmental level to ensure improved protection against such catastrophic floods in the future. One year after the catastrophic flood, during the cold winter in 1785, the elector of Saxony issued in February an order in which people near the River Elbe would be informed of an impending flood by canon signals (Poliwoda 2007). The Saxonian authorities also took hygiene precautions, as the town council of Dresden published a hygiene instruction in April 1785 (for more examples and details on the long-term responses to flooding in the Saxonian part of the River Elbe, see Poliwoda 2007).

The reports of the *Wiener Zeitung* provide a vivid and detailed insight into the socio-economic consequences of the flooding in Austria, Bohemia, historical Hungary and Germany. The most detailed reports concerned the situation in Vienna on 29 February and the following days, when the ice flood covered large parts of the districts on both the left and right branches of the River Danube, in particular the suburb of Leopoldstadt (currently district II in Vienna; *Wiener Zeitung*, 3 March 1784, no. 18, pp. 438–439): "Still sadder was the situation of the inhabitants in Leopoldstadt, where all houses along the bank were filled with water. The level of the water increased at many places until three feet [95 cm] so that one couldn't get [any] other way from one place to another [except] by boat. It still rose the following night considerably and what made this sad situation far worse was the persistent cold weather removing the hope of a rapid breaking up of the ice on the Danube River and increasing the misery thoroughly. The misery was meanwhile, of course, made more mild and bearable by all possible means in the power of the government, which were arranged with great wisdom and care but remained constantly enough tough for the people, who were hit by the flood."

In particular, the economic situation of the poor seems to have been disastrous during the hard winter of 1783/1784, both before and after the floods. The *Wiener Zeitung* contains several reports of donations for the poor, presumably money, but in one case also large amounts of wood. Donations are recorded from members of the Habsburg family, by aristocrats, by anonymous benefactors and by the church; individuals also provided support, such as a medical doctor in Vienna who offered to examine and cure the poor for no charge. The dean of the parish church of Krems was even honoured for his humanitarian efforts by the Emperor (Kinzl 1869). In Malá Strana, a district of Prague, the Order of the English Misses opened their garden and built an additional bridge to enable hundreds of people to escape the ice flood; they also received ill people from the Institute for the poor and cared for them over 12 days (*Wiener Zeitung*, 20 March 1784, no. 23, p. 578).

The *Wiener Zeitung* also contains detailed lists of people who died in Vienna during the following weeks. The city centre of Vienna and its suburbs ("Vorstädte") were inhabited by 209,121 people in 1783 (Weigl 2003). On an average day, about 15–25 people died; on 7 January 1784, during the peak of the early January frosts in Vienna, 53 people lost their lives. During the ice flood of late February and during the following weeks, the average mortality did not increase much (17–32 people died per day), suggesting

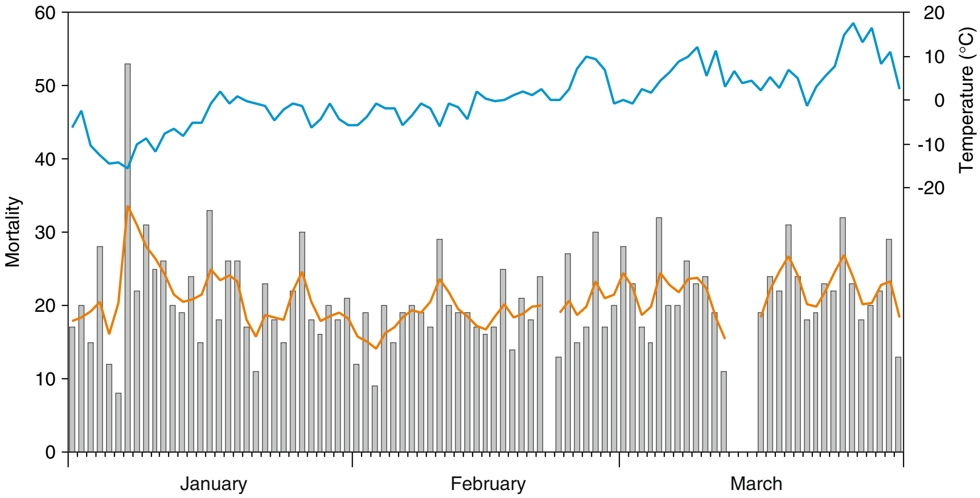


Fig. 12 Temperatures at 2 p.m. at the Vienna-Tabor water-gauge station and mortality (people dying per day) in Vienna (smoothed by 5-day Gaussian filter) from 1 January to 31 March 1784 (for data see *Wiener Zeitung*; no mortality data available for 22 February and 13–15 March 1784)

that less people were killed by the ice flood than by the extreme frost in early January (Fig. 12). The warning and evacuation systems in Vienna during the ice flood seem to have been relatively successful in reducing the loss of life. Nevertheless, the *Wiener Zeitung* also reports that several unidentified people were killed during the ice flood; they were likely to have been homeless individuals or travellers: "In February two male persons were found frozen to death in the area of Dürnkrut in the so-called Ebersdorferfeld (Lower Austria). One is about 40 years old, large, with a long-shaped face, black short-cut hair, black eye-brows and beard, wearing a Kopernitz coat, … The other is about 18 years old, large, with a round-shaped face, without beard, black short-cut hair, … They seem to have come from Moravia." (*Wiener Zeitung*, 17 March 1784, no. 22, pp. 660–661).

An indication of the severity of the late February–early March ice flood in Vienna compared to Hungary is that, according to a pamphlet published in 1789, a great amount of money was collected in Pest town (Hungary) during 1784 to help the inhabitants of Vienna who were so seriously affected by flood (Szabó Ervin Library, Budapest Collection, B614/1/1789.2.11).

Based on numerous reports published in *Pressburger Zeitung* (17–21 January 1784, no. 5–6; 18 February 1784, no. 14), *Magyar Hírmondó* (24 January 1784, no. 7), *Presspůrské Noviny* (23 January 1784, no. 7) and *Wiener Zeitung* (24 January 1784, no. 7) as well as direct orders written in the *Banat Protocols* (Vol. 2: 42r–43v, 57v), the late December–early January flood was the most severe. Regional and local authorities, the army, chamber officers and county people provided a quick and affective response, providing immediate help in both the form of well-organised community and private actions. For example, the army under instruction from chamber and regional officers in Timişoara (the centre of the former Banat region, currently in western Romania), ferried a canon to Lipova and Arad to break the ice; they also transported sufficient food for the population of Radna (a town located in another county—beyond their own responsibility). The actions of local individuals responsible for rescuing people and property were reported in great detail. In Arad during the ice flood, the army evacuated several thousand people; as a result of their actions, only three casualties were reported during the late December ice flood. As a medium-term consequence, local authorities and inhabitants in the most endangered areas, such as the town of Lipova, were well prepared in March for another flood, even though no destructive flood occurred.

The long-term consequences of the 1783/1784 floods can be identified in the lowland areas of the Rivers Mureş, Timiş and Bega (Banat region, today in Serbia and Romania), where according to the *Banat Protocols* (Vol. 1: 20r, 42v–51r, Vol. 2: 103r–114r), after a long-lasting period with frequent inundations, several settlements applied for a tax reduction on the basis of the damage caused and inability to farm the surrounding lands; some settlements were deserted with inhabitants moving to areas less prone to flooding.

6 Discussion

The extreme winter of 1783/1784 and associated floods was the first winter following the Lakagígar eruption in Iceland, which significantly influenced the weather of Europe (e.g. Stothers 1996; Demarée et al. 1998; Grattan and Pyatt 1999; Sadler and Grattan 1999; Demarée and Ogilvie 2001; Oman et al. 2006). The previous summer (1783) was notable for a dry fog; optical phenomena and heavy thunderstorms and its weather was generally characterised as dry and hot throughout Western Europe (Luterbacher et al. 2004; Pauling et al. 2006). A significant increase in human mortality in Iceland and the UK presumably

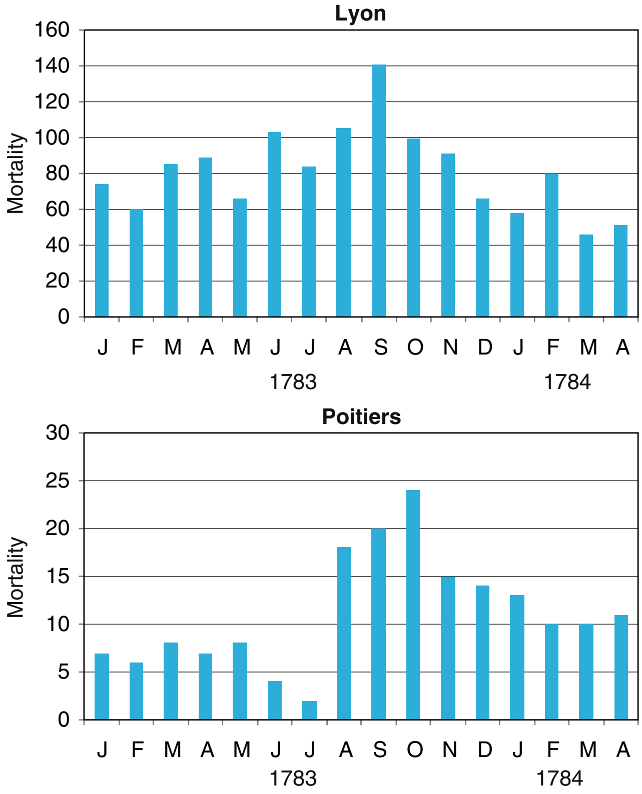


Fig. 13 Monthly mortality in Lyon and Poitiers from January 1783 to April 1784 (data: Archives Municipales de Lyon, 1G211; Archives Municipales de Poitiers, 5 MI 1052-15). The Lakagígar eruption began on 8 June 1784 and continued until February 1784, with the majority of material ejected during 1783

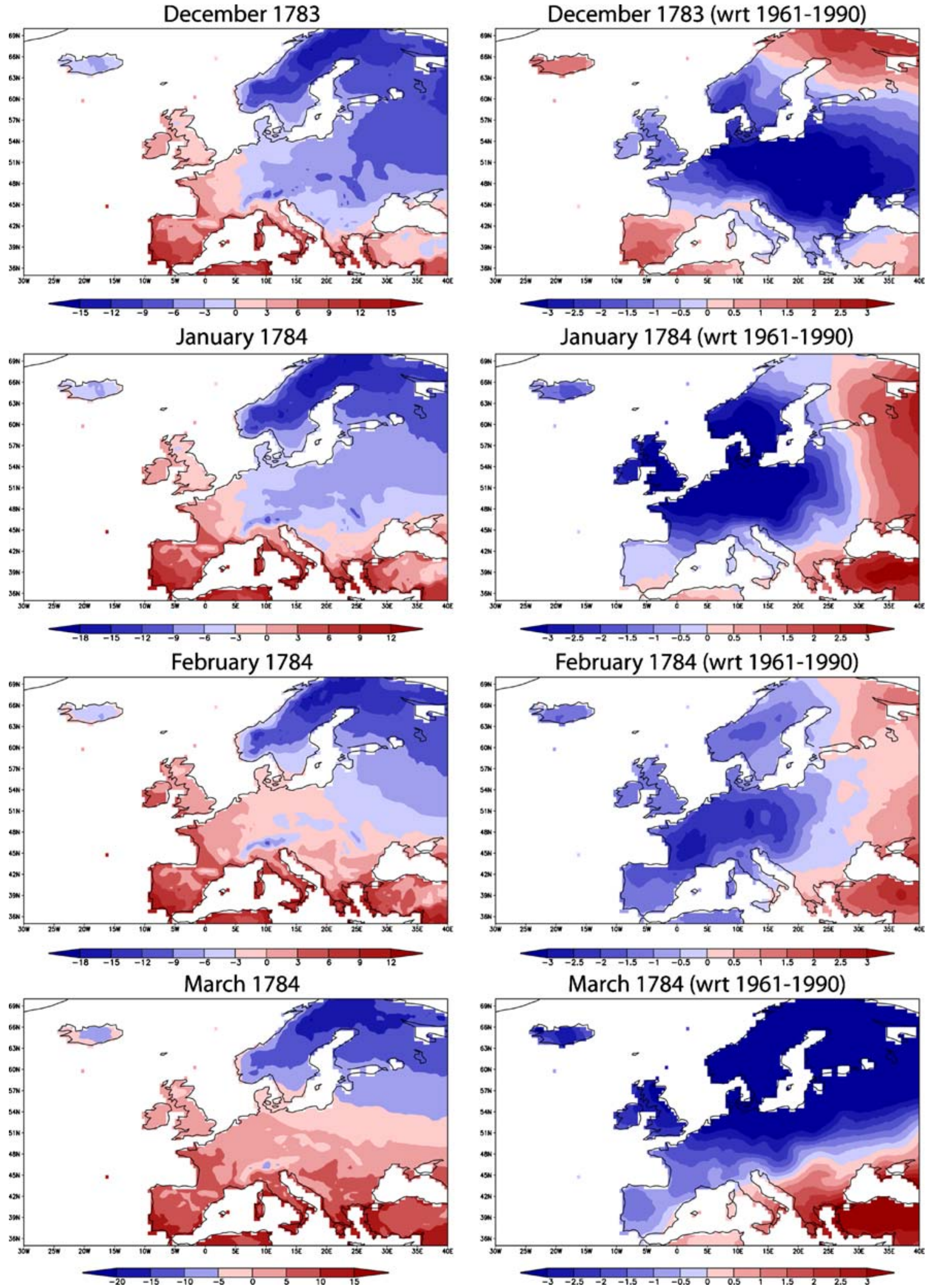
resulting from respiratory problems is noted (Grattan et al. 2003); parish registers of deaths between January 1783 and April 1784 in France (Fig. 13) confirm the results of Grattan et al. (2003), who identified an increase in mortality from July to September (maximum in September for Lyon and in October for Poitiers). In both cases, the demographic toll directly attributable to frosts and flooding during the winter of 1783/1784 was lower than the effects of the volcanic eruption, as reflected in the occurrence of 'dry fog' reported from June 1783 across much of Western Europe.

The principal mechanism responsible during the Lakagígar eruption in disturbing the climate is the injection into the stratosphere of sulphur dioxide (SO_2), altering the planetary energy budget (Stevenson et al. 2003). As the energy budget is perturbed, greater reflection of incoming radiation leads to warming of the aerosol layer and cooling of the underlying atmosphere, potentially resulting in the disturbance of the climate. The Lakagígar fissure eruption of 1783–1784 lasted for seven months releasing in excess of 15 km^3 of magma (Stevenson et al. 2003) and 122 Tg of SO_2 (Highwood and Stevenson 2003), with around 60% released during the first 6 weeks (Thordarson et al. 1996), with the ash cloud reaching troposphere levels (~10 km over Iceland during the summer). The year 1783 has been referred to as *annus mirabilis* (Year of Awe or Wonder; Steinthorsson 1992), as records throughout Europe often cite 'dry fogs' at ground level and altitude (Stothers 1996); other recorders detail the impressive sunsets throughout much of northern Europe towards the end of 1783 (Grattan and Pyatt 1999). The extreme cold of the winter of 1783/1784 was discussed by Benjamin Franklin (1785) in an address to the Manchester Literary and Philosophical Society, an indication from the period that it was considered severe.

It is, furthermore, remarkable that the Lakagígar eruption was also mentioned in the *Wiener Zeitung* in February 1784 but without drawing connections to the extreme weather situation in the winter 1783/1784. A connection between the remarkable occurrence of "fog" in summer 1783 and "fog" during the snowfall in the winter was, however, seen in an anonymous report from Klosterneuburg north of Vienna (Strömmer 2003, p. 208): "The remarkable fog, which had occurred in the last summer, was also clearly observed in the winter of 1784, except on few days. It was seen in winter during snowfall, as it was always seen in summer during rainfall. From this coincidence we may conclude easily that this special vapour, which had caused extraordinary heat and disastrous thunderstorms in summer, was also responsible for the extraordinary amount of snow and extremely cold temperatures."

Reconstructed temperature and precipitation patterns from the winter of 1783/1784 (Luterbacher et al. 2004; Xoplaki et al. 2005; Pauling et al. 2006) were evaluated against the 1961–1990 reference period (Figs. 14 and 15). Monthly temperature maps consistently show that a cold anomaly extended over the greater part of Europe (Fig. 14). In December, the cold anomaly generated a belt stretching from the North Sea to southeastern Europe, while in January, it moved to the northwest. In February, the cold belt extended from France across Central Europe, but negative anomalies were not as strong as in the other months. In March, it moved again to the northeast and across Northern Europe. Seasonal precipitation maps (Pauling et al. 2006) were constructed for the winter of 1783/1784 (Fig. 15); for the greater part of the region located to the north of the Alps, precipitation totals were close to the 1961–1990 mean, whilst the British Isles and the majority of France were significantly drier compare to the 30-year mean.

The severity of the low temperatures experienced during the winter of 1783/1784 can be placed into context using early instrumental records and/or existing temperature reconstructions (Fig. 14). The series of Central Europe, calculated from eleven homogenised temperature series (Central European Temperature series – CEuT) from stations in Germany, Switzerland, Austria and the Czech Republic since 1760 (Dobrovolný et al. 2009) shows that



December 1783

December 1783 (wrt 1961-1990)

January 1784

January 1784 (wrt 1961-1990)

February 1784

February 1784 (wrt 1961-1990)

March 1784

March 1784 (wrt 1961-1990)

Fig. 14 Monthly temperature (°C) patterns (*left*) from December 1783 to March 1784 (Luterbacher et al. 2004; Xoplaki et al. 2005) in the Atlantic–European region and their anomalies (*right*) with respect to the 1961–1990 climatology

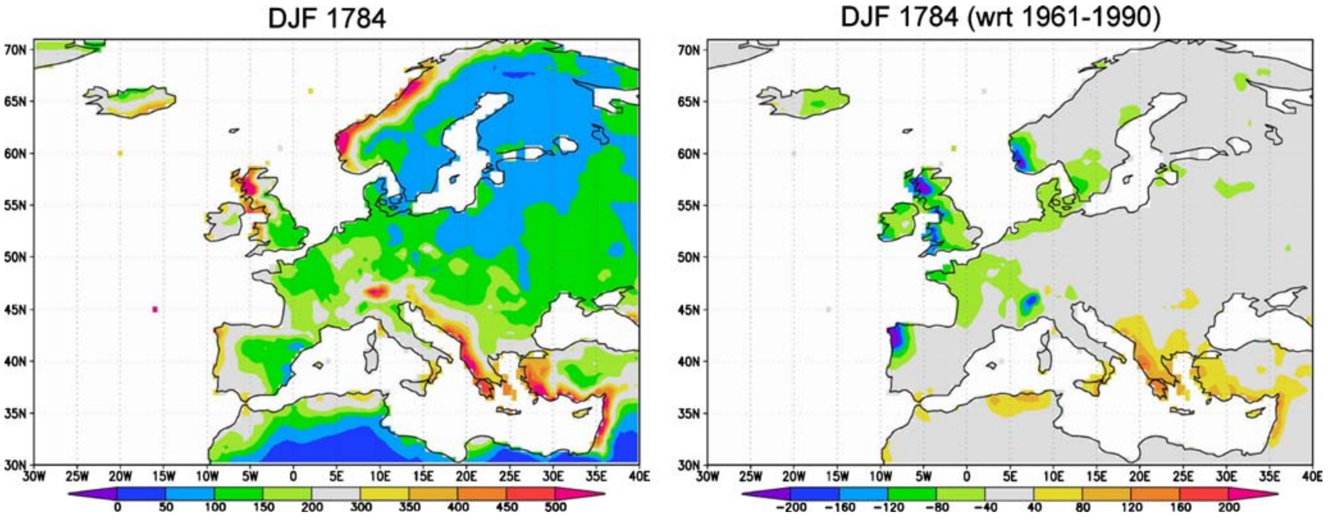


Fig. 15 Winter 1783/1784 precipitation (mm) patterns in the Atlantic-European region (*left*) and their anomalies (*right*) with respect to the 1961–1990 climatology (data source: Pauling et al. 2006). The figure is drawn with the KNMI climate explorer tool (courtesy Dr. Oldenborgh)

January 1784 was the most severe on record, with a temperature anomaly of −5.7°C with respect to the 1961–1990 reference period. Very high temperature deviations from the reference period, namely −4.0°C for February and −3.7°C for December are also recorded, with the following spring months of March (−2.2°C) and April (−3.2°C) also notable. Thus, the probability of the occurrence of such low winter temperatures (the winter anomaly was −4.5°C) has a return period greater than 50 years if calculated from the period 1760–2006. If we evaluate the severity of the 1783/1784 winter within the context of the last 500-year CEuT series (Dobrovolný et al. 2009), only 18 winter seasons with such a low mean temperature have occurred since A.D. 1500.

The general pattern identified from the CEuT series can be confirmed by data observed at individual stations; for example, according to the Prague-Klementinum observations, the 1783/1784 winter was the sixth coldest winter on record (from the beginning of regular measurements in 1775) with January 1784 recording a mean temperature of −8.8°C, the third coldest January recorded. If two-month periods are considered, then December 1783–January 1784 is the seventh coldest and January–February 1784 the tenth coldest period within the record (Brázdil et al. 2003). With 93 daily means below zero and 73 ice days (maximum daily temperature below 0°C) from November to March, the 1783/1784 winter season in Prague is ranked second in severity (Kakos and Munzar 2000).

The extreme European winter floods occurred as a result of a combination of long-lasting causative hydrometeorological factors (severe frosts, freezing of the soil, extraordinary thickness of ice on the watercourses and extreme depths of snow cover) culminating in a sudden thawing, as

Fig. 16 Epigraphic marking illustrating the water level of 28 February 1784 (above the window of the Cochem water gauge on the River Mosel, significantly exceeding all other recorded events; photo Jiří Štrupl)

a result of the rapid onset of an increase in positive air temperatures along with a strong southwesterly, later northwesterly airflow and intense rainfall.

The evidence collected shows that the main flood phase during February–March 1784 across Central Europe belonged to the most disastrous events during the past millennium. For example, Glaser and Hagedorn (1990) estimated the return period of floods on the central reach of the River Main as 400 years but between the tributaries Saale and Tauber at 250 years and on the lower Main at only 150 years. Epigraphic markings related to this event were not exceeded by any other known flood in many places, or they are among the highest recorded (Fig. 16); for example, the water level of 857 cm from the River Elbe in Dresden on 1 March 1784 was equivalent to the event of 16 August 1501 and was only exceeded by the event of 31 March 1845 (877 cm); whilst at Eibelstadt on the River Main, the 1784 watermark has never been exceeded by any other known flood (Schmidt 2000). The estimated peak discharge of the River Vltava in Prague was 4,580 m^3s^{-1} during February 1784; it is the highest winter flood since the start of flow measurements in 1825 and is only exceeded by August 2002 (5,160 m^3s^{-1}). The situation is different on the River Elbe at Děčín, where the 1784 watermark is 115 cm below the flood of 30 March 1845; potentially a result of cooling in the break between February and March that slowed snowmelt, resulting in a water level below that of March 1845 (Brázdil et al. 2005a). On the River Seine in Paris (the bridge of de la Tournelle) the February 1784 flood with its height of 6 m was exceeded by other significant floods of the eighteenth century, notably on 25 December 1740 (7.32 m) and 9 February 1764 (6.45 m).

7 Conclusion

The winter 1783/1784 can be taken as a typical, if severe, winter during the 'Little Ice Age' (e.g. Grove 2004; Matthews and Briffa 2005) characterised by heavy frosts of long duration, frozen soils and rivers and deep snow cover. These factors led to conditions favourable for flood generation when rapidly warmed as in the case of 1783/1784. These conditions affected a wide-reaching European region north of the Alps; similarities can be drawn to other known significant historical winter floods, such as in February 1655, February 1799, February–March 1830 or March 1845 (Brázdil et al. 2005a). In each case, these events had very broad social-economic impacts reflected in the loss of human lives and extensive material damage but also in activities aimed at reducing future flood risk. The floods during the winter 1783/1784 are the most spectacular covered by instrumental and documentary data at the broader European scale and provide a valuable insight into the severity and magnitude of such events.

According to the conclusions of the second working group of the Intergovernmental Panel on Climate Change (Parry et al. 2008), the continuation of recent warming trends across Europe and changes in the water cycle are likely to increase the risk of floods and droughts, with the risk of flooding expected to increase in Northern, Central and Eastern Europe. Model calculations for the 2020s predict an increased risk of winter flooding in Northern Europe, coupled with flash flooding across much of Europe. Recent 100-year return frequency floods should occur in the 2070s more frequently, not only in Northern and Northeastern Europe but also in Central and Eastern Europe.

Recent winter floods should remind us of the potential risks that they present. The sudden melting of an extensive snowpack in Central Europe (Pinto et al. 2007) caused large floods in March/April 2006, generating flows with a 100-year return period discharge recorded on the River Dyje (southern Moravia; Brázdil, Kirchner et al. 2007). Learning from past events remains an important step in better understanding and providing more effective protective measures for possible future events.

Acknowledgements This research has been supported financially by a number of organisations: R. Brázdil, P. Dobrovolný and C. Rohr by the Austrian-Czech programme of scientific cooperation in the project "Climatic Variability and Hydrometeorological Extremes in the Pre-instrumental Period" (AKTION 13/2008); M. Deutsch by the German Science Foundation in the project "Cataloguing and scientific analysis of the meteorological section of the Weikinn collection of sources in the history of Central European weather" (HE 939/ 18-3); E. Garnier by the French group GIS "Climate-Society-Environment" for the project RENASEC "Characteristics and frequency of extreme events in France from 1500 to 1900", the Centre National de la Recherche Scientifique for the project CLIMURBS and the project "Journal du Hardy" (Collège de France and UQAM); A. Kiss by EU project FP-6 no. 017008 European Climate of the Past Millennium (MILLENNIUM); J. Luterbacher by the EU/FP7 187 project ACQWA (grant 212250); N. Macdonald by an EPSRC-RGS research grant; K. Chromá by research project MŠM0021622412 (INCHEMBIOL). We are also grateful to the Museum of the City of Prague for providing permission to publish Fig. 2 and to Jiří Štrupl (Mělník) for Fig. 16. We acknowledge Marcel Küttel (University of Bern) for drawing temperature fields for December 1783–March 1784 (Fig. 14). The comments of two anonymous reviewers were greatly appreciated in the improvement of this paper.

References

Anonymous (1784a) Kurze Schilderung der am 27ten Hornung 1784 vom Rheine verursachten Eisnoth und verderblichen Ueberschwemmung der Kaiserlichen freien Reichs-Stadt Köln am Rheine nebst einigen besonderen Merkwürdigkeiten. Gedruckt im Jahre 1784. Köln, p 9

Anonymous (1784b) Historische Nachrichten von den schrecklichen Wasser-Ergießungen, von den entsetzlichen Eis-Fahrten und von den dadurch angerichteten traurigen Verwüstungen welche in den Monaten Februar und März dieses 1784sten Jahres fast in ganz Deutschland sich eräuget haben [...]. In der Scharfischen Buchdruckerey, Lauban, p 15

Barriendos M, Rodrigo FS (2006) Study of historical flood events on Spanish rivers using documentary data. Hydrol Sci J 51:765–783. doi:10.1623/hysj.51.5.765

Benito G, Diéz-Herrero A, Fernández de Villalta M (2003) Magnitude and frequency of flooding in the Tagus basin (Central Spain) over the last millennium. Clim Change 58:171–192. doi:10.1023/A:1023417102053

Benito G, Thorndycraft VR, Rico M, Sánchez-Moya Y, Sopeña A (2008) Palaeoflood and floodplain records from Spain: evidence for long-term climate variability and environmental changes. Geomorphol 101:68–77. doi:10.1016/j.geomorph.2008.05.020

Benkö S (1794) Ephemerides Meteorologico-Medicae annorum 1780 ... 1793. Tom. I, Typis Alb. Ant. Patzowsky, Vindobonae [Vienna], p 115

Berger TB (1784) Die Eißfluth. Dreßdnische Gelehrte Anzeigen auf das Jahr 1784, 13:137–138

Bezzola GR, Hegg C (eds) (2007) Ereignisanalyse Hochwasser 2005, Teil 1–Prozesse, Schäden und erste Einordnung. Bundesamt für Umwelt BAFU, Eidgenössische Forschungsanstalt WSL. Umwelt-Wissen Nr. 0707, p 215

Böhm O, Wetzel K-F (2006) Flood history of the Danube tributaries Lech and Isar in the Alpine foreland of Germany. Hydrol Sci J 51:784–798. doi:10.1623/hysj.51.5.784

Brázdil R, Glaser R, Pfister C, Dobrovolný P, Antoine J-M, Barriendos M, Camuffo D, Deutsch M, Enzi S, Guidoboni E, Kotyza O, Rodrigo FS (1999) Flood events of selected European rivers in the sixteenth century. Clim Change 43:239–285. doi:10.1023/A:1005550401857

Brázdil R, Valášek H, Macková J (2003) 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. doi:10.1023/A:1026045902062

Brázdil R, Dobrovolný P, Elleder L, Kakos V, Kotyza O, Květoň V, Macková J, Müller M, Štekl J, Tolasz R, Valášek H (2005a) Historické a současné povodně v České republice (Historical and recent floods in the Czech Republic). Masarykova univerzita, Český hydrometeorologický ústav, Brno, Praha, p 370

Brázdil R, Pfister C, Wanner H, von Storch H, Luterbacher J (2005b) Historical climatology in Europe—the state of the art. Clim Change 70:363–430. doi:10.1007/s10584-005-5924-1

Brázdil R, Kotyza O, Dobrovolný P (2006a) July 1432 and August 2002—two millennial floods in Bohemia? Hydrol Sci J 51:848–863. doi:10.1623/hysj.51.5.848

Brázdil R, Kundzewicz ZW, Benito G (2006b) Historical hydrology for studying flood risk in Europe. Hydrol Sci J 51:739–764. doi:10.1623/hysj.51.5.739

Brázdil R, Kirchner K et al. (2007) Vybrané přírodní extrémy a jejich dopady na Moravě a ve Slezsku (Selected natural extremes and their impacts in Moravia and Silesia). Masarykova univerzita, Český hydrometeorologický ústav, Ústav geoniky Akademie věd České republiky, Brno, Praha, Ostrava, p 432

Briffa KR, Jones PD, Wigley TML, Pilcher JR, Baillie MGL (1986) Climate reconstruction from tree rings: part 2, spatial reconstruction of summer mean sea-level pressure patterns over Great Britain. J Climatol 6:1–15. doi:10.1002/joc.3370060102

Briffa KR, Wigley TML, Jones PD, Pilcher JR, Hughes MK (1987) Patterns of tree-growth and related pressure variability in Europe. Dendrochronologia 5:35–59

Bronstert A, Ghazi A, Hladny J, Kundzewicz Z, Menzel L (eds) (1998) The Odra/Oder Flood in Summer 1997: Proceedings of the European Expert Meeting in Potsdam. Potsdam, Germany, 18 May 1998, PIK Report 48, p 163

Bürger K, Dostal P, Seidel K, Imbery F, Barriendos M, Mayer H, Glaser R (2006) Hydrometeorological reconstruction of the 1824 flood event in the Neckar River basin (southwest Germany). Hydrol Sci J 51:864–877. doi:10.1623/hysj.51.5.864

Cadet de Vaux AA (1784) Avis sur les moyens de diminuer l'insalubrité des habitations qui ont été exposées aux inondations. P.D. Pierres, Paris, p 16

Christensen JH, Christensen OB (2003) Severe summertime flooding in Europe. Nature 421:805–806. doi:10.1038/421805a

Coenen H (1784) Rede über die Eisfahrt und Ueberschwemmung wovon Mülheim am Rheine, den 27 und 28 Februar des gegenwärtigen 1784 Jahres getroffen worden; bei Gelegenheit des dreizehn stündigen Gebethes, den 16ten Mai vorgetragen von dasigem Pfarrherrn Heinrich Coenen auf Verlangen angesehener Freunde herausgegeben. Hermann Joseph Haas, Köln, p 8

Cook ER, Briffa KR, Jones PD (1994) Spatial regression methods in dendroclimatology—a review and comparison of two techniques. Int J Climatol 14:379–402. doi:10.1002/joc.3370140404

Creutz M (1924–1925) Rhein-Hochwasser im Jahre 1784. Die Heimat 3:191–192 4:28–29

Cyberski J, Grześ M, Gutry-Korycka M, Nachlik E, Kundzewicz ZW (2006) History of the floods on the River Vistula. Hydrol Sci J 51:799–817. doi:10.1623/hysj.51.5.799

Demarée GR (2004) The Ancien Régime instrumental meteorological observations in Belgium or the physician with lancet and thermometer in the wake of Hippocrates. Sartoniana 17:13–41

Demarée GR (2006) The catastrophic floods of February 1784 in and around Belgium—a Little Ice Age event of frost, snow, river ice ... and floods. Hydrol Sci J 51:878–898. doi:10.1623/hysj.51.5.878

Demarée GR, Ogilvie AEJ (2001) Bons Baisers d'Islande: Climatic, environmental, and human dimensions impacts of the Lakagígar eruption (1783–1784) in Iceland. In: Jones PD, Ogilvie AEJ, Davies TD, Briffa KR (eds) History and climate. Memories of the future. Kluwer Academic/Plenum, New York, pp 219–246

Demarée GR, Ogilvie AEJ, Zhang D (1998) Further documentary evidence of Northern Hemispheric coverage of the great dry fog of 1783. Clim Change 39:727–730. doi:10.1023/A:1005319607233

Demler CW (1784) Eine Predigt am Sonntage Reminiscere 1784. nach gluecklich ueberstandener schrecklicher Wassergefahr, gehalten und auf Verlangen in Druck gegeben von Christian Wilhelm Demler, Consistorialrath, Superint. und Oberpfarrer in Jena. Gedruckt und zu haben bey Johann Michael Mause, Jena, p 6

Deutsch M (2000) Zum Hochwasser der Elbe und Saale Ende Februar/Anfang März 1799. In: Deutsch M, Pörtge K-H, Teltscher H (eds) Beiträge zum Hochwasser / Hochwasserschutz in Vergangenheit und Gegenwart. Erfurter Geographische Studien 9:7–44

Deutsch M, Pörtge K-H (2002) Hochwasserereignisse in Thüringen. Thüringer Landesanstalt für Umwelt und Geologie—Schriftenreihe 63, Jena, p 99

Deutsch M, Rost KT (2005) Schwere Hochwasserereignisse in Mitteldeutschland (1500–1900) und ihre sozio-ökonomischen Folgewirkungen. In: Schenk W, Dix A (eds) Naturkatastrophen und Naturrisiken in der vorindustriellen Zeit und ihre Auswirkungen auf Siedlungen und Kulturlandschaft. Siedlungsforschung 23:209–226

Deutsch M, Grünewald U, Rost KT (2006) Historische Hochwassermarken—Ausgangssituation, Probleme und Möglichkeiten bei der heutigen Nutzung. In: Risikomanagement extremer hydrologischer Ereignisse. Beiträge zum Tag der Hydrologie 2006 in München, Forum für Hydrologie und Wasserbewirtschaftung, 15.06, Vol. 1.1, Hennef, pp 59–70

Dobrovolný P, Moberg A, Brázdil R, Pfister C, Glaser R, Wilson R, van Engelen A, Limanówka D, Kiss A, Halíčková M, Macková J, Riemann D, Luterbacher J, Böhm R (2009) Monthly and seasonal temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. Clim Change (in press)

Elleder L, Munzar J (2004) Extrémní povodeň na Vltavě a Labi v únoru 1784 jako následek mimořádných hydrometeorologických podmínek (The extreme flood of the Vltava and the Elbe in

February 1784 as a consequence of outstanding hydrometeorological patterns). Meteorol Zpr 57:125–135

Ephemerides Societatis Meteorologicae Palatinae IV (1785) Observationes anni 1783. Manheimii ex officina Novae Societatis Typographicae, Manheimii, p 805

Ephemerides Societatis Meteorologicae Palatinae V (1786) Observationes anni 1784. Manheimii ex officina Novae Societatis Typographicae, Manheimii, p 820

Förster S (2001) Die Geschichte der Stadt Meißen im Spiegel von Ereignisbildern. Eine bildkundliche Betrachtung. Meißner Beiträge zur Bauforschung 3, Meißen, p 118

Fügner D (1995) Hochwasserkatastrophen in Sachsen. Tatsachen 1. Tauchaer Verlag, Taucha, p 78

Franklin B (1785) Meteorological imaginations and conjectures. Memoirs of the Literary and Philosophical Society of Manchester 2:357–361

Garnier E (2007a) La ville face aux caprices du fleuve. L'exemple normand XVIe-XVIIIe siècle. Hist Urbaine 18:41–60

Garnier E (2007b) Les bocages normands à l'épreuve des catastrophes. Fonctions écologiques et gestion durable des milieux bocagers XVIe-XVIIIe siècle. In: Antoine A, Marguerie D (eds) Bocages et Sociétés. Presses Universitaires de Rennes, Rennes, pp 127–138

Glaser R (2001) Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen. Primus Verlag, Darmstadt, p 227

Glaser R, Hagedorn H (1990) Die Überschwemmungskatastrophe von 1784 im Maintal. Eine Chronologie ihrer witterungsklimatischen Voraussetzungen und Auswirkungen. Die Erde 121:1–14

Glaser R, Stangl H (2004) Climate and floods in Central Europe since AD 1000: data, methods, results and consequences. Surv Geophys 25:485–510. doi:10.1007/s10712-004-6201-y

Grattan JP, Pyatt FB (1999) Volcanic eruptions, dry fogs and the European palaeoenvironmental record: localised phenomena or hemispheric impacts? Glob Planet Change 21:173–179. doi:10.1016/S0921-8181(99)00013-2

Grattan J, Durand M, Taylor S (2003) Illness and elevated human mortality in Europe coincident with the Laki fissure eruption. In: Oppenheimer C, Pyle DM, Barclay J (eds) Volcanic degassing. Special publications 213. Geological Society, London, pp 401–414

Grove JM (2004) Little ice ages: ancient and modern (2 volumes). Routledge, London, p 718

Hartmann JG (1784) Predigt nach überstandner großer Wassersnoth am Sonntage Oculi 1784. in der Kirche zu Eutzsch gehalten von M. Johann Gottlob Hartmann. Pfarrern daselbst. In der Dürrischen Buchdruckerey gedruckt, Wittenberg, p 8

Hennebergischer Altertumsforschender Verein (ed) (1834) Chronik der Stadt Meiningen von 1676 bis 1834, Erster Theil. Meiningen, p 268

Heuser-Hildebrandt E (2005) Die Hochwasserkatastrophe von 1784 in Mainz. Ursachen, Auswirkungen, Krisenmanagement. In: Schenk W, Dix A (eds) Naturkatastrophen und Naturrisiken in der vorindustriellen Zeit und ihre Auswirkungen auf Siedlungen und Kulturlandschaft. Siedlungsforschung 23:131–151

Highwood E-J, Stevenson DS (2003) Atmospheric impact of the 1783–1784 Laki Eruption: part II climatic effect of sulphate aerosol. Atmos Chem Phys 3:1177–1189

Jacobeit J, Glaser R, Luterbacher J, Wanner H (2003) Links between flood events in Central Europe since AD 1500 and large-scale atmospheric circulation modes. Geophys Res Lett 30:1172. doi:10.1029/2002GL016433

Jaun S, Ahrens B, Walser A, Ewen T, Schär C (2008) A probabilistic view on the August 2005 floods in the upper Rhine catchment. Nat Hazards Earth Syst Sci 8:281–291

Jones PD, Davies TD, Lister DH, Slonosky V, Jónsson T, Bärring L, Jönsson P, Maheras P, Kolyva-Machera F, Barriendos M, Martin-Vide J, Rodriguez R, Alcoforado MJ, Wanner H, Pfister C, Luterbacher J, Rickli R, Schuepbach E, Kaas E, Schmith T, Jacobeit J, Beck C (1999) Monthly mean pressure reconstruction for Europe 1780–1995. Int J Climatol 19:347–364. doi:10.1002/(SICI)1097-0088(19990330)19:4<347::AID-JOC363>3.0.CO;2-S

Kakos V, Munzar J (2000) Zima 1829/30—nejtužší ve střední Evropě od počátku měření teploty vzduchu (The 1829/30 winter—the most severe one in Central Europe from the beginning of air temperature measurements). Meteorol Zpr 53:103–108

Kaněra CF (1900) Farní osada sv. Vojtěcha v Počáplich (The Parish of Saint Adalbert at Počaply). Nákladem vlastním, Terezín, p 342

Kapocs N, Kőhegyi M (eds) (1991) Historia Domus Bajensis. In: Chronik des Franziskanerkonvents in Baja, Bd. 1. 1694–1840. Türr István Múzeum, Baja, pp 134–135

Kington JA (1970) A late eighteenth century source of meteorological data. Weather 25:169–175

Kington J (1974) The Societas Meteorologica Palatina: an eighteenth century meteorological society. Weather 29:416–426

Kington J (1988) The weather of the 1780s over Europe. Cambridge University Press, Cambridge, p 164

Kinzl J (1869) Chronik der Städte Krems, Stein und deren nächster Umgebung. Mit den Freiheitsbriefen beider Städte und den Schriftstücken ihrer gewerblichen Innungen vom Jahre 985–1869. Max Pammer's Buchdruckerei, Krems, p 637

Kiss A (2007) "Suburbia autem maxima in parte videntur esse deleta"—Danube icefloods and the pitfalls of urban planning: Pest and its suburbs in 1768–1799. In: Kovács Cs (ed) From villages to cyberspace. University Press, Szeged, pp 271–282

Kiss A, Sümeghy Z, Danku G (2006) 1783–1784. évi szélsőséges tél és a Maros jeges árvize (Severe winter of 1783–1784 and the iceflood on the Maros river). In: Kiss A, Mezősi G, Sümeghy Z (eds) Táj, környezet és társadalom / Landscape, Environment and Society. SzTE, Szeged, pp 353–362

KOHS (Kommission Hochwasserschutz im Schweizerischen Wasserwirtschaftsverband) (2007) Auswirkungen der Klimaänderung auf den Hochwasserschutz in der Schweiz. Wasser Energie Luft 99:55–60

Kolář P (2008) Počasí a povodně ve střední a západní Evropě v zimě 1783/84 (Weather and floods in Central and Western Europe in the 1783/84 winter). Bc. thesis. Masarykova univerzita, Brno, p 56

Kundzewicz ZW, Szamałek K, Kowalczak P (1999) The Great Flood of 1997 in Poland. Hydrol Sci J 44:855–870

Küttel M, Xoplaki E, Gallego D, García-Herrera R, Luterbacher J, Allan R, Barriendos M, Jones PD, Wanner H (2009) The importance of ship log data: reconstructing North Atlantic, European and Mediterranean Sea Level Pressure fields back to 1750. Clim Dynam (in press). doi:10.1007/s00382-009-0577-9

Lamb HH, Johnson AI (1966) Secular variations of the atmospheric circulation since 1750. Geophys Mem 110. HMSO for Meteorological Office, London, p 125

Le Roy Ladurie E (2006) Histoire humaine et comparée du climat. Disettes et révolutions 1740–1860. Fayard, Paris, p 598

Luterbacher J, Xoplaki E, Dietrich D, Rickli R, Jacobeit J, Beck C, Gyalistras D, Schmutz C, Wanner H (2002) Reconstruction of sea-level pressure fields over the eastern North Atlantic and Europe back to 1500. Clim Dynam 18:545–561. doi:10.1007/s00382-001-0196-6

Luterbacher J, Dietrich D, Xoplaki E, Grosjean M, Wanner H (2004) European seasonal and annual temperature variability, trends and extremes since 1500. Science 303:1499–1503. doi:10.1126/science.1093877

Lüdecke C (1997) The monastery of Andechs as station in early meteorological networks. Meteorol Z N F 6:242–248

Macdonald N, Jones CA, Davies S, Charnell-White C (2009) Developing a historical climatology of Wales from English and Welsh language sources. Weather 64, in press

Macdonald N (2006) An underutilized resource: historical flood chronologies a valuable resource in determining periods of hydrogeomorphic change. In: Rowan JS, Duck RW, Werritty A (eds) IAHS/ICCE International Symposium on Sediment Dynamics and the Hydromorphology of Fluvial Systems [IAHS Red Book]. IAHS Publ 306:120–127

Macdonald N (2007) Epigraphic records: a valuable resource in reassessing flood risk and long-term climate variability. Environ Hist 12:136–140

Macdonald N, Black AR, Werritty A, McEwen LJ (2006) Historical and pooled flood frequency analysis for the River Tay at Perth, Scotland. Area 38:34–46. doi:10.1111/j.1475-4762.2006.00673.x

Marsh TJ (2007) A hydrological overview of the summer 2007 floods in England and Wales. Weather 63:274–279. doi:10.1002/wea.305

Marsh TJ, Hannaford J (2007) The summer 2007 floods in England and Wales—a hydrological appraisal. Centre for Ecology & Hydrology, Wallingford, p 32

Matějíček J, Hladný J (1999) Povodňová katastrofa 20. století na území České republiky (The Flood Disaster of the 20th Century on the Territory of the Czech Republic). Ministerstvo životního prostředí, Praha, p 60

Matthews JA, Briffa KR (2005) The ‘Little Ice Age’: re-evaluation of an evolving concept. Geogr Ann A 87:17–36. doi:10.1111/j.0435-3676.2005.00242.x

May W, Voss R, Roeckner E (2002) Changes in the mean and extremes of the hydrological cycle in Europe under enhanced greenhouse gas conditions in a global time-slice experiment. In: Beniston M (ed) Climatic change: implications for the hydrological cycle and for water management. Kluwer Academic, Dordrecht, pp 1–29

McCloy ST (1941) Flood relief and control in eighteenth-century France. J Mod Hist 13:1–18. doi:10.1086/243917

Merz A (1784) Rede über die Pflicht wegen der von der Stadt Augsburg abgewendeten schädlichen Ueberschwemmung Gott im Geiste und in der Wahrheit zu danken, … Am dritten Sonntage in der Fasten gehalten von Aloys Merz, der Gottesgelehrtheit Doktor, und Prediger in der hohen Domstifftskirche. Neueste Sammlung jener Schriften, die von einigen Jahren her über verschiedene wichtigste Gegenstände zur Steuer der Wahrheit im Drucke erschienen sind. Joseph-Wolfischen Buchhandlung, Augsburg, p 40

Militzer S, Börngen M, Tetzlaff G (1999) Das Oderhochwasser von 1736. Ein Analogon zum Jahrhunderthochwasser 1997. Geoökodynamik 20:309–322

Milly PCD, Wetherald RT, Dunne KA, Delworth TL (2002) Increasing risk of great floods in a changing climate. Nature 415:514–517. doi:10.1038/415514a

Mudelsee M, Börngen M, Tetzlaff G, Grünewald U (2003) No upward trends in the occurrence of extreme floods in central Europe. Nature 425:166–169. doi:10.1038/nature01928

Mudelsee M, Deutsch M, Börngen M, Tetzlaff G (2006) Trends in flood risk of the River Werra (Germany) over the past 500 years. Hydrol Sci J 51:818–833. doi:10.1623/hysj.51.5.818

Munzar J, Elleder L, Deutsch M (2005) The catastrophic flood in February/March 1784—a natural disaster of European scope. Morav Geograph Rep 13:8–24

Munzar J, Deutsch M, Elleder L, Ondráček S, Kallabová E, Hrádek M (2006) Historical floods in Central Europe and their documentation by means of floodmarks and other epigraphical monuments. Morav Geograph Rep 14:26–44

Nonne HR (ed) (1784) Kalte Winter, Eisstöße, Ueberschwemmungen und Wasserverheerungen in den ersten 3 Monaten des Jahres 1784. In: Unterhaltendes Schauspiel nach den neuesten Begebenheiten des Staats, der Kirche, der gelehrten Welt und des Naturreiches vorgestellt. Achter Aufzug. H. R. Nonne, Erfurt, pp 482–501

Novotný J (1963) Dvě stoleté hydrologické řady průtokové na českých řekách (Two hundred-year discharge series on the Czech rivers). Sborník prací Hydrometeorologického ústavu Československé socialistické republiky 2. Hydrometeorologický ústav, Praha, p 116

Oman L, Robock A, Stenchikov GL, Thordarson T, Koch D, Shindell DT, Gao C (2006) Modeling the distribution of the volcanic aerosol cloud from the 1783–1784 Laki eruption. J Geophys Res 111:D12209. doi:10.1029/2005JD006899

Parker DE, Legg TP, Folland CK (1992) A new daily Central England Temperature series, 1772–1991. Int J Climatol 12:317–342. doi:10.1002/joc.3370120402

Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) (2008) Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge, p 986

Pauling A, Luterbacher J, Casty C, Wanner H (2006) 500 years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Clim Dynam 26:387–405. doi:10.1007/s00382-005-0090-8

Pfister C (1999) Wetternachhersage: 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995). Verlag Paul Haupt, Bern, p 304

Pinto JG, Brücher T, Fink AH, Krüger A (2007) Extraordinary snow accumulations over parts of central Europe during the winter of 2005/06 and weather-related hazards. Weather 62:16–21. doi:10.1002/wea.19

Poliwoda GN (2007) Aus Katastrophen lernen. Sachsen im Kampf gegen die Fluten der Elbe 1784 bis 1845. Böhlau, Köln, p 295

Pötzsch CG (1784) Chronologische Geschichte der großen Wasserfluthen des Elbstroms seit tausend und mehr Jahren [...]. Walther, Dresden, p 232

PPS 25 (Planning Policy Statement 25) (2006) Development and flood risk. Communities and local government. HMSO, Norwich, p 50

Rohr C (2006) Measuring the frequency and intensity of floods of the Traun River (Upper Austria), 1441–1574. Hydrol Sci J 51:834–847. doi:10.1623/hysj.51.5.834

Sadler JP, Grattan JP (1999) Volcanoes as agents of past environmental change. Glob Planet Change 21:181–196. doi:10.1016/S0921-8181(99)00014-4

Schirmer W (2008) Die Stadt Gera, die Weiße Elster und die Hochwässer von 1617 bis 1981 (unpublished manuscript). Town Archives Gera, p 22

Schmidt M (2000) Hochwasser und Hochwasserschutz in Deutschland vor 1850. Eine Auswertung alter Quellen und Karten. Kommissionsverlag Oldenbourg Industrieverlag, München, p 330

Schmutz C, Arpagaus M, Clementi L, Frei C, Fukutome S, Germann U, Liniger M, Schacher F (2008) Ereignisanalyse Hochwasser 8. bis 9. August 2007–Beitrag der MeteoSchweiz. Arbeitsberichte der MeteoSchweiz 222. MeteoSchweiz, Zurich, p 30

Schönburg-Hartenstein J, Zedinger R (2004) Jean-Baptiste Brequin (1712–1785). Ein Wissenschaftler aus Lothringen im Dienst des Wiener Hofes. Forschungen und Beiträge zur Wiener Stadtgeschichte 42. Deuticke, Wien, p 124

Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor MMB, LeRoy Miller H, Chen Z (eds) (2007) Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi, p 996

Steinthorsson S (1992) Annus mirabilis: 1783 í erlendum heimildum (Annus mirabilis: the year 1783 according to contemporary accounts outside of Iceland). Skírnir 166:133–159

Stevenson DS, Johnson CE, Highwood EJ, Gauci V, Collins WJ, Derwent RG (2003) Atmospheric impact of the 1783–1784 Laki eruption: part I chemistry modelling. Atmos Chem Phys 3:487–507

Stothers RB (1996) The great dry fog of 1783. Clim Change 32:79–89. doi:10.1007/BF00141279

Strömmer E (2003) Klima-Geschichte. Methoden der Rekonstruktion und historische Perspektive. Ostösterreich 1700 bis 1830. Forschungen und Beiträge zur Wiener Stadtgeschichte 39. Deuticke, Wien, p 325

Sturm K, Glaser R, Jacobeit J, Deutsch M, Brázdil R, Pfister C, Luterbacher J, Wanner H (2001) Hochwasser in Mitteleuropa seit 1500 und ihre Beziehung zur atmosphärischen Zirkulation. Petermann Geogr Mitt 145:14–23

Szlávik L (ed) (2003a) Az 1998. évi árvíz (Flood of the year 1998). Vízügyi Közlemények 85(1: Special Issue), p 216

Szlávik L (ed) (2003b) A 2001. évi árvíz (Flood of the year 2001). Vízügyi Közlemények 85(3: Special Issue), p 144

Szlávik L (ed) (2003c) Elemző és módszertani tanulmányok az 1998-2001. évi ár- és belvizekről (Analytic and methodological studies on the floods and inland waters of the years 1998–2001). Vízügyi Közlemények 85(4: Special Issue), p 336

Tetzlaff G, Börngen M, Raabe A (2001) Das Jahrtausendhochwasser von 1342 und seine meteorologischen Ursachen. In: Hochwasser—Niedrigwasser—Risiken (Nürnberger Wasserwirtschaftstage). Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., München, pp 5–22

Thelen JL (1784) Ausführliche Nachricht von dem erschrecklichen Eisgange, und den Überschwemmungen des Rheines, welche im Jahre 1784 die Stadt Köln, und die umliegenden Gegenden getroffen. H. J. Haas, Köln am Rheine, p 96

Thiele CC (1785) Gedanken bey der großen Eisfahrt und Elbueberschwemmung in der Stadt Meißen den 29. Februar und 1. Mart. Meißen, p 6

Thordarson T, Self S, Oskarsson N, Hulsebosch T (1996) Sulfur, chlorine, and fluorine degassing and atmospheric loading by the 1783–1784 AD Laki (Skaftar fires) eruption in Iceland. Bull Volcanol 58:205–225. doi:10.1007/s004450050136

Thorndycraft VR, Barriendos M, Benito G, Rico M, Casas A (2006) The catastrophic floods of AD 1617 in Catalonia (northeast Spain) and their climatic context. Hydrol Sci J 51:899–912. doi:10.1623/hysj.51.5.899

Tol RSJ, Langen A (2000) A concise history of Dutch river floods. Clim Change 46:357–369. doi:10.1023/A:1005655412478

Traumüller F (1885) Die Mannheimer meteorologische Gesellschaft (1780–1795). Ein Beitrag zur Geschichte der Meteorologie. Dürrsche Buchhandlung, Leipzig, p 48

Truchlivá novina o letošním pamětihodném povodni, které mezi 27. a 28. dnem měsíce února v Čechách a nejvíce v Pražských městech se přitrefilo (The sad news about this year's memorable flood which happened between 27th and 28th day of February in Bohemia and mostly in the Prague towns). Vytištěná na Malé Straně, p 8, 1784

Ulbrich U, Brücher T, Fink AH, Leckebusch GC, Krüger A, Pinto JG (2003a) The central European floods of August 2002: part 1—rainfall periods and flood development. Weather 58:371–377. doi:10.1256/wea.61.03A

Ulbrich U, Brücher T, Fink AH, Leckebusch GC, Krüger A, Pinto JG (2003b) The central European floods of August 2002: part 2—synoptic causes and considerations with respect to climatic change. Weather 58:434–441. doi:10.1256/wea.61.03B

Ursinus JF (1784) Etwas zur Geschichte der großen Eisfahrten und Elbüberschwemmungen in der Stadt Meißen. Dreßdnische Gelehrte Anzeigen auf das Jahr 1784, 14:140–152

von Berger JW (1784) Beschreibung der schrecklichen Ueberschwemmung und Eisfahrt, wodurch den 27 und 28sten Februar 1784 ein großer Theil von Mülheim am Rhein verwüstet worden ist, verfasset von einem, der selbst vieles mit gesehen, gehöret und empfunden hat. Johann Fiedrich Hutmacher, Mülheim am Rhein, p 69

Wanner H, Beck C, Brázdil R, Casty C, Deutsch M, Glaser R, Jacobeit J, Luterbacher J, Pfister C, Pohl S, Sturm K, Werner PC, Xoplaki E (2004) Dynamic and socioeconomic aspects of historical floods in central Europe. Erdkunde 58:1–16

Weichselgartner J (2000) Hochwasser als soziales Ereignis. Gesellschaftliche Faktoren einer Naturgefahr. Hydrol Wasserbewirtsch 44:122–131

Weigl A (2003) Frühneuzeitliches Bevölkerungswachstum. In: Csendes P, Opll F (eds) Wien. Geschichte einer Stadt, Vol. 2: Die frühneuzeitliche Residenz (16. bis 18. Jahrhundert). Böhlau, Wien, pp 109–131

Weikinn C (2000) Quellentexte zur Witterungsgeschichte Europas von der Zeitwende bis zum Jahr 1850. Hydrographie—Teil 5 (1751–1800), Börngen M, Tetzlaff G (eds). Gebrüder Borntraeger, Berlin, Stuttgart, p 674

Weißenborn B (1933) Rundes Chronik der Stadt Halle 1750–1785. Thüringisch-Sächsischer Geschichtsverein, Halle/S., p 858

Will GA (1784) Von der neulichen größten Ueberschwemmung und Wassersnoth, welche die Stadt Nürnberg erlitten. Eine historische Nachricht auf Verlangen ertheilet von Georg Andreas Will, Nürnberg, p 79

Xoplaki E, Luterbacher J, Paeth H, Dietrich D, Steiner N, Grosjean M, Wanner H (2005) European spring and autumn temperature variability and change of extremes over the last half millennium. Geophys Res Lett 32:L15713. doi:10.1029/2005GL023424

Archival sources

Archives of the Canal du Midi, Toulouse, liasse 663

Archives Municipales de Lyon, 1G211

Archives Municipales de Poitiers, 5 MI 1052-15

Bibliothèque Nationale de France, Paris, Ms 6680-6677

Departmental archives of the Pyrénées-Orientales, Perpignan, 1 J 163/2

District-Archive Sömmerda, Gebesee A, No. 888

Dreßdnische Gelehrte Anzeigen

Eötvös Loránd University Library, Budapest, Collection of Old Books and Manuscripts, No. E 40, *Klapka, C. J.: Observationes Thermometricae et Barometricae a 1a Septembris 1780 usque ultimam Decembris 1803. Temesvarini factae*

Fejér County Archives, Székesfehérvár, IV-A-73: F 51 No. 172, 501/1784, *Conscriptio Damnorum per exundationem in Oppido Érd Causatorum*, 1784

Gazette de France

Hungarian National Archives, Budapest, A 101. *Protocollum Commissionis Banaticae*, 1784, Vol. 1, 18v–51r; Vol. 2. 42r–124v

Hungarian National Archives, Budapest, C 127, *Directio Navigationis*, 1777–1788, Vol. 2, p 60

Journal de Paris

Library and Archives of the Franciscan Order in Hungary, Budapest, VI. 5. Documents of the Franciscan Friary of Gyöngyös, *Historia Domus Gyöngyösiensis*, 1512–1814

Library of Nancy, Ms 1310–1323

London Chronicle

Magyar Hírmondó

Municipal Archive of Wels, *Accounts of the bridge master*, 1782–1787

Museum of the City of Prague, catalogue no. 1.324

Pressburger Zeitung

Prespůrské Noviny

Public Advertiser

Szabó Ervin Library, Budapest, Budapest Collection, B614/1/1789.2.11, *An die Menschenfreunde in Pest, zum Besten der durch die Ueberschwemmung bedrängten Armen*, 1789.

Town Archives Bad Langensalza, library, no. 14

Wiener Zeitung