INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. (2008)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/joc.1667

Weather patterns in eastern Slovakia 1717–1730, based on records from the Breslau meteorological network

Rudolf Brázdil,[a]* Andrea Kiss,[b] Jürg Luterbacher[c,d] and Hubert Valášek[e]

[a] *Institute of Geography, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*
[b] *Department of Physical Geography and Geoinformatics, University of Szeged, Egyetem u. 2-6, H-6722 Szeged, Hungary*
[c] *Oeschger Centre for Climate Change Research and National Centre of Competence in Research on Climate (NCCR), University of Bern, CH-3012 Bern, Switzerland*
[d] *Institute of Geography, Climatology and Meteorology, University of Bern, CH-3012 Bern, Switzerland*
[e] *Moravian Land Archives, Žerotínovo nám. 3-5, 656 01 Brno, the Czech Republic*

ABSTRACT: The Breslau (Wrocław) physician, Johann Kanold established a network that included direct meteorological measurements and visual weather observations from several places in Europe. The results of the observations were published every quarter of a year for the 1717–1730 period. They included the first meteorological measurements from the Prešov station (1717–1720), made by the physician, Johann Adam Reimann for the recently defined eastern Slovakia (former Upper Hungary), as well as visual weather observations provided up to 1730 in a similar fashion in Kežmarok by George Buchholtz. The quality of the instrumental measurements of pressure and temperature is discussed. Observations from both places have been used to derive weighted temperature and precipitation indices. Three outstanding weather periods have been analysed in detail: a drought spring-autumn in 1718, disastrous floods in 1725 and a severe and snowy winter in 1725–1726. The article is a contribution to the historical climatology of Slovakia and central Europe. Copyright © 2008 Royal Meteorological Society

KEY WORDS Breslau network; early instrumental measurements; visual daily weather records; temperature; pressure; weather extremes; eastern Slovakia

Received 6 August 2007; Revised 29 October 2007; Accepted 16 November 2007

1. Introduction

In western Europe, certain systematic instrumental weather records from individual stations or regions reach back as far as the 17th century, for example a temperature series for central England from 1659 (Manley, 1974), and a precipitation series for Kew, England from 1697 (Wales-Smith, 1971); Paris precipitation from the 1680s onwards (Slonosky, 2002); temperature and pressure series from Paris and London (Legrand and LeGoff, 1992; Pfister and Bareiss, 1994; Slonosky *et al*., 2001). In the early 18th century, these came to be accompanied by observations from other European stations (see, for instance European homogenized daily temperature and pressure series in Moberg *et al*., 2000; Jones, 2001; Bergström and Moberg, 2002; Cocheo and Camuffo, 2002). However, in many cases this activity was associated only with a few individuals who provided such measurements for a variety of reasons. In addition to the astronomers, physicians made important contributions. In the Czech Lands, for example visual daily weather observations were already being taken in the second part of the 16th century, namely by the physician and astronomer, Tadeáš Hájek of Hájek for the period between 1557 and 1558 (Brázdil and Kotyza, 1996) and by the physician, Matyáš Borbonius of Borbenheim during the years 1596–1599 and 1622 (Brázdil and Kotyza, 1999).

A neo-Hippocratic hypothesis concerning the relationships between climate and human health established itself in the awareness of physicians in the 18th century. It had its origin in the 'Father of Medicine', Hippocrates of Kos (born c. 460 – died c. 380–370 B.C., most probably in 377 at Larissa, central Greece, according to the UN), a Greek physician and philosopher, who considered disease as a failure of balance between the organism and its environment, including the weather and climate. Hippocrates' ideas appear in historical times in the work of the English physician, Thomas Sydenham (1624–1689), who believed that atmospheric conditions played an important role in diseases. The impact of the climate on man arose, according to 18th-century physicians, out of the effects of the air that people inhale. Efforts to quantify the effects of meteorological patterns led the physicians to perform meteorological observations (Demarée, 1996, 2004).

The Breslau (Wrocław, Poland) physician, Johann Kanold organized a network of several European correspondents during 1717–1726, and published the results of their meteorological measurements. After his death, this activity was continued by other physicians until 1730.

* Correspondence to: Rudolf Brázdil, Institute of Geography, Masaryk University, Kotlářská 2, 611 37 Brno, the Czech Republic. E-mail: brazdil@sci.muni.cz

Thanks to this 'Breslau network', spatial weather patterns in central Europe could be easily described. The first instrumental records for some countries are preserved in Kanold's volumes. There is, for example a case for the Czech Republic, with three daily observations for Zákupy in northern Bohemia from 21 December, 1719 to 31 March, 1720 (Brázdil and Valášek, 2002). Observations from historical Upper Hungary (now part of Slovakia) were also included in the network, namely for Prešov (see also Konček and Réthly, 1968; Réthly, 1970; Munzar, 1993) and Kežmarok. Analysis of observations made between 1717 and 1730 is the aim of this article.

After the introductory part, the second section of the article gives the basics of the 'Breslau network'. A general description of observations is given in the third section. The following sections deal with the analysis of instrumental and visual observations and their climatological interpretation. Further, selected outstanding weather and climatic patterns, together with their impacts, are discussed.

2. Johann Kanold and the 'Breslau Network' of meteorological stations in Europe

Attempts to obtain and publish meteorological observations from various places in Europe were made long before the establishment of the famous Societas Meteorologica Palatina in 1780 (e.g. Hellmann, 1914; Kington, 1988). The first international meteorological network, known as the Rete Medicea, was formed between 1653 and 1654 with ten European stations. It was established by the Grand Duke of Tuscany and a founder of the Accademia del Cimento (Academy of Experiments) in Florence (1657), Ferdinand II, and his brother Prince Leopold de Medici. The network ceased to function after the Accademia del Cimento was disbanded in 1667 (Camuffo, 2002a). Among other successful efforts was that of the Wrocław (in German Breslau) practical physician, Johann Kanold who, with help of his two colleagues, J. C. Kundmann and J. G. Brunschweig, published 'Sammlung von Natur- und Medicin-, Wie auch hierzu gehörigen Kunst- und Literatur-Geschichten' (Kanold, 1718–1727). Its quarterly published volumes contained the results of meteorological measurements and observations that had been sent to him from various places in Europe.

Johann Kanold was born on 15 December, 1679 in Wrocław. He went to the University of Halle (Germany) in 1701 and graduated as a physician in 1704. He then returned to Wrocław where he began private practice. In 1719, he was elected a member of the Imperial Academy of Natural Curiosities (Academie der Naturae Curiosorum). He died in Wrocław on 15 November, 1729 (Zedler, 1737).

Between 1718 and his death, Kanold published altogether 37 volumes of 'Sammlung' and 4 supplements with meteorological data for the period between the summer of 1717 and the summer of 1726. On the title page of the first volume (Figure 1) he explains its contents: "*(1) Change in thunderstorms from day to day and from time to time. (2) Earth and weather epidemics due to air and weather from month to month. (3) Expansion and fertility of fields, forests, and garden fruits, as well as general animal fertility, observed from one season to another: (4) matters concerning individual natural events in the sky, in the air, above and under the ground, in the water, effects on people and animals: also (5) what was found and learned before the new physical and medical discoveries of this time: and then (6) what has changed in the physical-medical literature*." In order to fulfil these criteria he decided to use "*highly honoured colleges and societies, as well as learned individuals* [...] *because of the period has come when many famous German, English, Dutch, French, Danish, Swiss, Italian and other public and private societies not only record natural history, but they extend knowledge by means of their own experiments and discoveries*." For this reason his aim was "*not to show curiosities and things particularly special, but drawn from the greatest part of general and everyday things*", which might be usefully exposed to the public. Kanold published "*everything from a rich correspondence and other news, as well as, in greater part, from* [his] *own experience*."

Individual quarterly volumes were divided monthwise. In the first section ('Classis I, Artic. I'), daily observations 'in extenso' from some stations were published. Wrocław, Nuremberg, Zurich and Löbau should be mentioned among those with the most complete observations. The second section ('Artic. II') contains weather reports sent from more distant parts of Europe, some of them also including quantitative temperature and precipitation data. In the following chapter, all of the material was worked up into a monthly overview with an attempt to explain the course of the weather. Reports of outstanding events (such as optical phenomena, auroras, thunderstorms, gales and hailstorms) were published in 'Classis IV'.

After Kanold's death, Andreas Elias Büchner, a medical professor in Erfurt (Germany), continued to publish the series. He published volume 38 for the last part of the year 1726 in the year, 1730, and a universal index to all volumes and supplements in 1736. Meteorological data for the period 1727–1730 were then published in 1731–1734 under the title 'Miscellanea Physico-Medico-Mathematica, oder angenehme, curieuse und nützliche Nachrichten von Physical- und Medicinischen, auch dahin gehörigen Kunst- und Literatur-Geschichten' (Büchner, 1731–1734; Zedler, 1737; Lenke, 1964b).

3. Meteorological observations in Slovakia, 1717–1730

The volumes mentioned above also contain the results of meteorological observations in Prešov (known in Hungarian and German as Eperjes) and Kežmarok (in Hungarian Késmárk, in German Käßmarck) in the eastern part of Slovakia (at that time a part of Upper Hungary).

DOI: 10.1002/joc

Sammlung
Von
Natur- und Medicin-
Wie auch
hierzu gehörigen Kunst- und Literatur-.
Geschichten,
So sich
An. 1717. in den 3. Sommer-Monaten
In Schlesien und andern Ländern begeben.
Welcher Gestalt nemlich:
1) Die Veränderung des Gewitters von Tage zu Tage und von Zeit zu Zeit. 2) Land- und Witterungs-Seuchen, von Monat zu Monat, nach dem Einfluß Lufft und Wetters. 3) Zu- und Mißwachs von Feld- Wald- und Garten-Früchten, auch allerhand animalischem Proventu, in allerley Ländern Europens von einer Jahrs-Zeit zur andern bemercket worden: Wie nicht weniger 4) was vor eintzelne eclatante natürliche Begebenheiten am Firmament, in der Lufft, auf und unter der Erde, im Wasser, an Menschen und Vieh: auch 5) was vor neue physicalische und medicinische Erfindungen diese Zeit über hervorgebracht und bekañt worden: und denn 6) was in re literaria Physico-Medica veränderliches vorgefallen.
Alles in ordentlicher Connexion und mit allerley Reflexions
Aus vielfältiger Correspondenz, und andern Relationibus, so wie grossen Theils aus eigener Erfahrung zusammen gelesen;
Und
Als ein Versuch ans Licht gestellet
Von
Einigen Breßlauischen Medicis.
Sommer-Quartal 1717.
Breßlau,
Bey Michael Hubert, M DCC XVIII.

Figure 1. Title page of the first volume in the Kanold series with the results of meteorological observations for the summer quarter of 1717.

3.1. Observations from Prešov

The physician, Johann Adam Reimann was responsible for the observations in Prešov. He was born on 23 April, 1693 and started his education at Košice. After spending some time at an evangelical college in Prešov studying pharmacy ('ars pharmaceutica'), he took to the study of medicine in 1709, first in the universities of Erfurt and then in Leiden (the Netherlands). By November 1712, he passed the necessary exams, and on 16 December he successfully defended his dissertation work 'De praecipuis diversitatis morborum fundamentis et curatione diversa.' Despite interesting offers of employment in Poland he returned to Prešov after his studies. He was elected as town physician in 1713. On 6 December, 1714, he married Sophia Wachsmann, the daughter of doctor in Prešov. They had 7 children born between the years of 1716 and 1729. From 1731 onwards, Reimann owned a pharmacy and in that year he was also accepted as a burgher of Prešov town. He died after a serious illness on 24 April, 1770 (Bartunek, 1990).

Reimann published about 80 scientific articles, mainly relating to medicine. From his very first work, published in Latin in Kanold's volume in 1718, he maintained that epidemics was related to weather patterns. This may be explained by the fact that, during his study in Leiden, he had been deeply influenced by Herman Boerhaave (1668–1739), one of the most important representatives of the neo-Hippocratic hypothesis in 18th-century medicine. A strong belief in the relationship between weather and illness significantly influenced Reimann throughout his working life.

Weather records from Prešov are included with other stations in the part of 'Classis I' entitled 'Von Witterungs-Geschichten' (On Weather Stories). They consist of two parts. From 1 July, 1717 to 30 June, 1720, Reimann measured pressure and temperature three times a day, and described and characterized the weather every day. These

DOI: 10.1002/joc

data were included in 'Tägliche Observation von Wind und Wetter' (Daily Observation of Wind and Weather). From July 1720 onwards, Reimann's observations were published in summary form in the section 'Fragmenta von Wetter-Veränderungen in allerhand Ländern' (Fragments of Weather Changes in All Kinds of Countries).

Reimann used a mercury barometer for pressure measurements "*made according to the practice of Mr. D. Hamberger, a professor in Jena*." Georg Albrecht Hamberger (1662–1716) was a doctor of philosophy and a professor of mathematics and physics at Jena University (Hellmann, 1883), where he published an article on barometry ("De barometris") in 1701. Reimann might well have met him, since he studied medicine in Erfurt from 1709. The scale of the barometer was divided according to the Paris measure in inches ('Grad.') with values of 26, 27 and 28, every inch with 12 lines ('Dig.') and every line with 10 units ('Scrup.').

For temperature measurements, Reimann used a Florentine thermometer in which *F* values denoted "*a degree of cold*" and *C* values "*a degree of warmth*" ("Gradum Caloris"). From the values measured one may assume that this thermometer was divided into 80 'degrees' above and 80 'degrees' below the zero point, as was also the case of the Florentine thermometer used by Johann Carl Rost at Zákupy in northern Bohemia (Brázdil and Valášek, 2002). The weather during the day was described in the usual German terminology with attention to precipitation, clouds, wind and weather phenomena (e.g. fog, thunderstorm). In the case of winds, Reimann determined the wind direction according to the cloud movement, without any further attributes, such as mild or strong.

Reimann was already taking measurements before July 1717, when his reports appeared in Kanold's volume. This follows from the note for December 1717, in which he mentions the highest pressure of the year as being on 22 January ("*27 Gr. 4 Dig. 5 Scrup.*") and the lowest pressure on 6 December ("*26 Grad. 3 Dig. 8 Scrup.*").

The degree of detail varies in Reimann's weather records after June 1720. For some months, events are recorded day by day, for others he limits himself to just listing days with rain or snow, wind and weather phenomena. However, in some months (e.g. August and September, 1722), the reports from Prešov are missing altogether. On the other hand, extreme pressure or temperature values are mentioned for some months, which confirms the continuation of Reimann's instrumental observations after June 1720. Further, he sometimes contributed to other reports, such as a record of a strong thunderstorm on 17 July, 1717, or the state of viticulture. It is not clear whether the short reports about the weather were sent to Kanold in this form or if they were shortened by its editors.

3.2. Observations from Kežmarok

Weather data from Kežmarok appears in Kanold's volumes for the first time to cover October 1717 to April 1718. The author was probably Daniel Fischer, who sent a Kežmarok epidemic report to Kanold. Fischer was born into a merchant family on 9 November, 1695. After early schooling in Kežmarok, he studied medicine at Wittenberg University (Germany) from 1713 to 1718 and graduated as a doctor of medicine. He was among the most famous central European physicians of his time. Fischer was physician for the Liptov district (1719–1725) and from the summer of 1725 onwards he acted as town physician to Kežmarok (see e.g. Magyary-Kossa, 1940). In addition to this position, he was private physician to Bishop Miklós Csáky, who later held the significant post of Archbishop of Esztergom (Hungary). He also established a private medical school in Kežmarok which, like the one in which Karol Moller (who also sent reports to 'Sammlung') was involved in Banská Bystrica, became one of the most well-known and distinguished medical schools in Upper Hungary (Antall *et al.*, 1988). Fischer died suddenly on 16 September, 1746 in Debrecen (Hungary).

From January, 1723 onwards, weather observations from Kežmarok appeared once more in the Kanolds series, originating from George Buchholtz who, from 1722 onwards, sent in monthly weather reports for Vel'ká Palúdza (Nagy-Palugya in Hungarian), a now-defunct village on the River Váh, near Liptovský Mikuláš (Figure 2). Buchholtz was born on 3 November, 1688 into the family of an evangelical priest in Kežmarok, the third of five children. After studies at Rožňava and Kežmarok, he started his university education in 1709 at Gdańsk (Poland) and continued for 2 years with the study of mathematics in Greifswald (Germany) (Zemplén, 1961). In 1710, he defended a dissertation on the conjunction of Mercury and the sun. He then spent an additional 2 years at the universities of Leipzig and Wittenberg (Germany). After graduation, Buchholtz became a rector of the evangelical school in Vel'ká Palúdza and since 1723, a rector of the evangelical school in Kežmarok, one of the five most important, high-prestige evangelist lyceums in Upper Hungary at that time. During his time in Kežmarok, he investigated also the High Tatras and created its first known panoramic illustration with the names of the individual summits (Széchényi Library, Budapest, catalogue no. Tk 2097/a-b). Buchholtz added around 50 different articles to the Kanold series. He married Elisabeth Plathy and had a son, Paul. George Buchholtz died on 3 August, 1737 at Kežmarok (Zemplén, 1964).

Buchholtz's weather records were always qualitative. For some months, they describe the weather day by day, in other months the records are shorter. These observations are an important complement to the records provided for Prešov, especially in months with very brief or absent information from Reimann. Published data for the period 1717–1730 can partly be supplemented by weather records from Buchholtz's voluminous diary (Itinerarium Bucholtziarum), covering the period 1709–1737 (preserved in the Slovak National Library, Martin, catalogue nos. C 24/I and C 24/II). Further to the well-known family interest in the wonders of nature and

DOI: 10.1002/joc

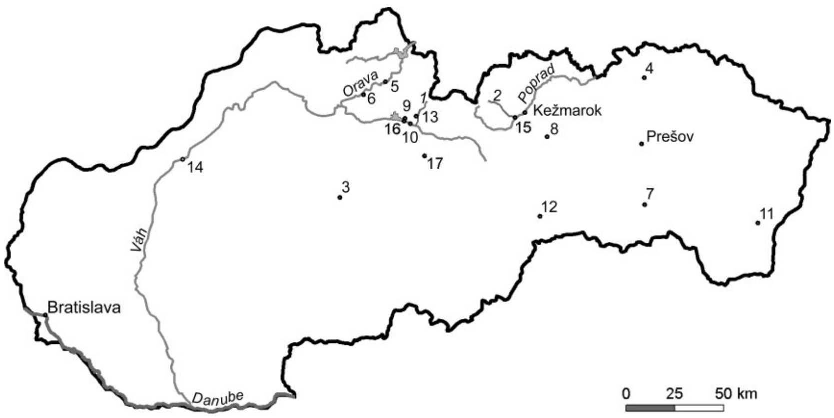

Figure 2. Location of settlements and rivers referred to in Slovakia: 1 – the Smrečianka, 2 – the Studený potok Brook, 3 – Banská Bystrica, 4 – Bardejov, 5 – Dlhá nad Oravou, 6 – Dolný Kubín, 7 – Košice, 8 – Levoča, 9 – Liptovská Ondrašová, 10 – Liptovský Mikuláš, 11 – Pavlovce nad Uhom, 12 – Rožňava, 13 – Smrečany, 14 – Trenčín, 15 – Velká Lomnice, 16 – Vel'ká Palúdza, 17 – Vyšná Boca.

the physical and natural conditions of the Tatra mountains, his father (Georg Buchholtz Senior) and brother (Jakob Buchholtz) were also interested in the weather and climatological patterns of the area, as shown by their family chronicle, started by the father (1643–1724) and completed by Jakob (1696–1758) (see Weber, 1904).

4. Analysis of instrumental pressure and temperature records from Prešov, 1717–1720

Analysis of the instrumental data is always associated with the question of the quality of measurements. In this case, there is no information about the installation of the instruments and their accuracy, about times of the three daily readings (probably morning, noon and evening, but whether the readings were taken at the same time throughout the whole year remains unknown), etc. For these reasons, the monthly pressure and temperature values can be compared only in relation to each other.

For pressure data, only the re-calculation to the present units can be performed (1 Paris inch = 27.07 mm, 1 line = 2.256 mm – see Chvojka and Skála, 1982). It is impossible to reduce the pressure data to 0 °C and sea level without more information about the installation of the barometer and its thermometer readings. Fluctuations of corresponding morning, noon, evening and daily means are shown in Figure 3. The validity of daily pressure readings may be confirmed by comparison with measurements at Zákupy, Bohemia (Figure 4). Consistency between the two series is very good (correlation coefficients 0.88–0.90) and in many cases some delay in the occurrence of typical pressure features due to the prevailing westerly progress of weather systems can be observed.

Analysis of early temperature measurements is fraught with problems similar to those for pressure (see e.g. Lenke, 1964a). Although Reimann mentions a Florentine thermometer, his thermometer 'degree' did not correspond to a degree on any of the better-known scales that were introduced later (such as the Réaumur or Celsius scales). This means that any values measured are again only important in relative terms. Vittori and Mestitz (1981) studied the calibration of small Florentine thermometers (scale from 0 to 50 degrees). They concluded that these thermometers were more useful for obtaining comparable measurements in different places and periods than for measurement of absolute values on a fixed scale. The problems with calibration and instrumental errors in

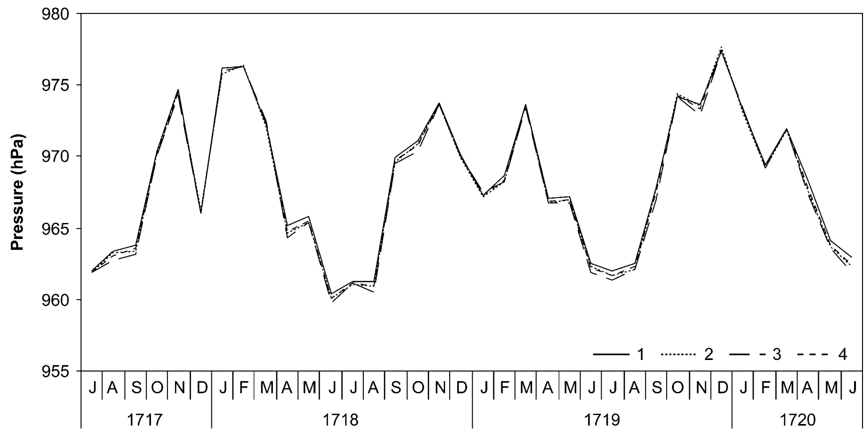

Figure 3. Fluctuation of morning (1), noon (2), evening (3) and daily (4) means of air pressure (hPa) in Prešov for the period July 1717–June 1720 (pressure means are without correction to 0 °C).

DOI: 10.1002/joc

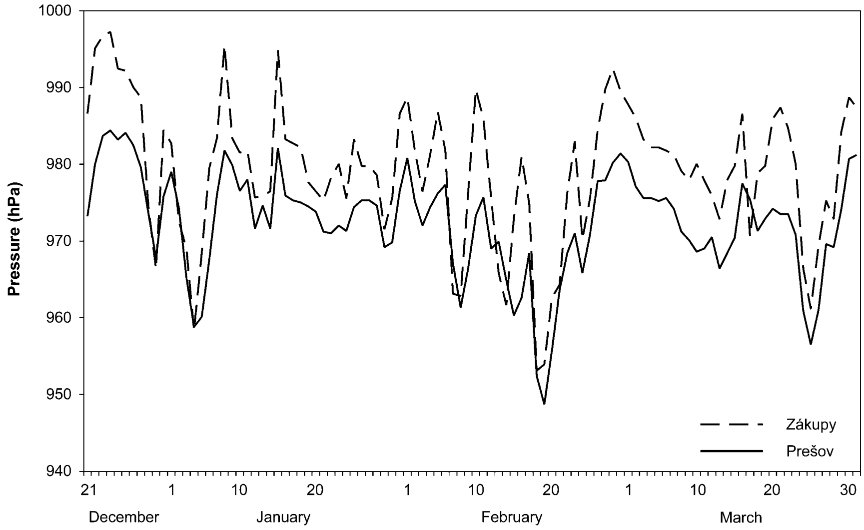

Figure 4. Fluctuation of daily means of air pressure at the Prešov and Zákupy stations for the period 21 December, 1719 to 31 March, 1720.

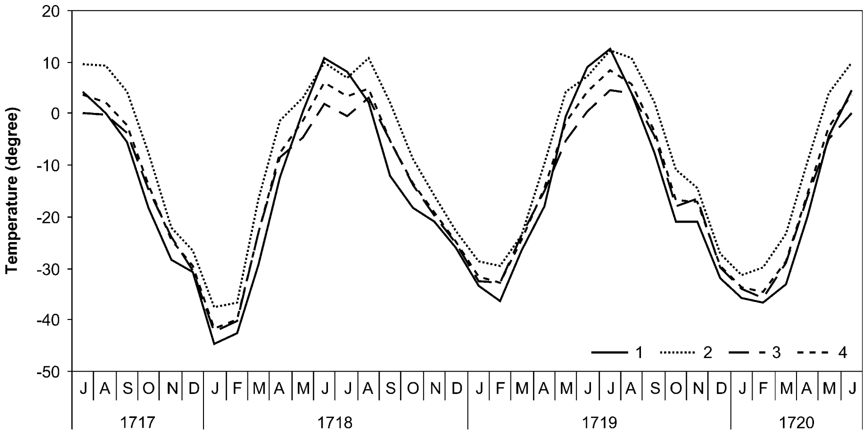

Figure 5. Fluctuation of morning (1), noon (2), evening (3) and daily (4) means of air temperature (degrees of the Florentine thermometer) in Prešov for the period between July, 1717 and June, 1720.

early thermometers have more recently been addressed by Camuffo (2002a,b,c).

Although we do not know the exact time at which the morning and evening temperature readings at Prešov were taken, significantly higher morning values from May to August may bring their quality into doubt. One may assume a direct radiation influence – sunshine on the thermometer – but this effect is not easy to remove from the observations available. The calculated mean monthly temperatures have only comparative importance for temperature patterns from July 1717 to June 1720 (Figure 5). The daily means for Prešov, Zákupy and Wrocław in January–March 1720 (Figure 6) must be viewed in a similar way.

5. Reconstruction of temperature and precipitation patterns in eastern Slovakia, 1717–1730

Although Reimann's observations have been mentioned by some authors, they have not been analysed to date. Only Réthly (1970) published monthly frequencies of days with rain, sleet and snow, thunderstorm and hail for 1717–1726, but without climatological evaluation. However, from instrumental and documentary weather records for Prešov and Kežmarok, it is possible to derive a series of weighted temperature indices for eastern Slovakia in a range from −3 to +3 for every month (−3 extremely cold, −2 very cold, −1 cold, 0 normal, +1 warm, +2 very warm, +3 extremely warm) (Table I). They are based on instrumental measurements, proportions of days with snow in the total number of precipitation days and direct descriptions. For example, January 1726 was characterized as extremely cold (index −3), a degree last experienced in the severe winter of 1708–1709 (see e.g. Lenke, 1964a; Pfister, 1999; Luterbacher *et al.*, 2004 and Science supplementary online information for a review), a season that lodged for considerable time in local memory as an outstanding event. Further, all the recorded precipitation days in January 1726 at Kežmarok took the form of snow.

As in the case of temperatures, the precipitation pattern of every month may be classified with weighted indices in a range from −3 to 3 (−3 extremely dry, −2 very dry, −1 dry, 0 normal, +1 wet, +2 very wet,

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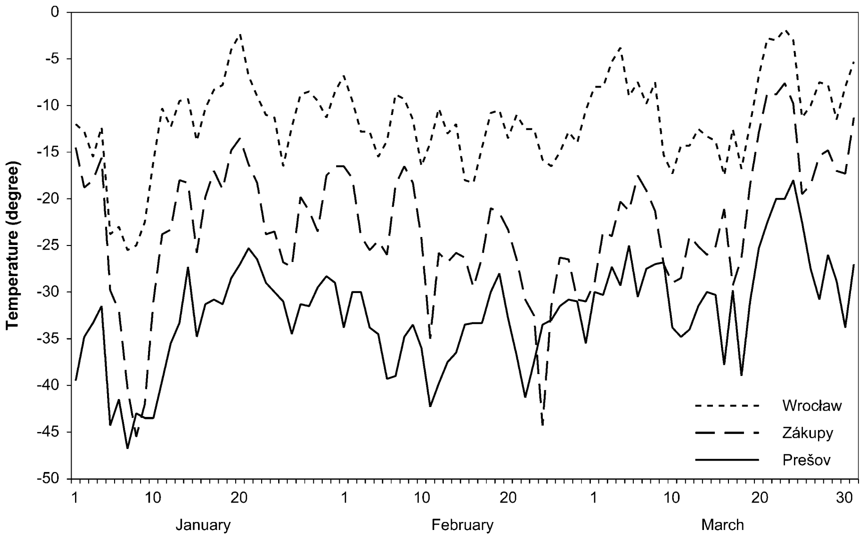

Figure 6. Fluctuation of daily means of air temperature at the Prešov, Zákupy and Wrocław stations for the period 1 January to 31 March, 1720.

Table I. Monthly temperature indices in eastern Slovakia during the period 1717–1730.

Year	J	F	M	A	M	J	J	A	S	O	N	D
1717	–	−1	–	–	–	–	0	0	0	0	−1	0
1718	−2	−2	0	0	0	1	0	1	−1	0	0	1
1719	0	0	0	−1	0	0	1	1	0	−1	0	0
1720	0	0	−1	−1	0	0	1	−1	0	−1	−1	0
1721	1	0	−2	0	−1	−1	−1	−1	0	0	0	0
1722	0	1	1	0	0	−1	−1	0	−1	0	0	1
1723	0	−1	0	0	−1	−1	−1	−1	−1	0	−1	0
1724	1	2	0	0	1	1	0	2	0	0	0	−1
1725	0	−1	0	−1	−1	0	−1	−2	−2	0	0	−1
1726	−3	−1	−2	0	1	2	0	0	1	−1	0	−1
1727	1	1	0	−1	0	0	0	−1	0	−1	0	1
1728	0	−1	1	0	0	2	0	0	−1	−1	0	0
1729	0	−1	−1	1	−1	0	−1	0	0	0	0	1
1730	0	−1	1	0	−1	−1	0	1	0	−1	−1	0

Table II. Monthly precipitation indices in eastern Slovakia during the period 1717–1730.

Year	J	F	M	A	M	J	J	A	S	O	N	D
1717	–	–	–	–	1	–	0	0	0	−1	0	3
1718	0	0	0	0	0	2	0	−2	−3	0	0	0
1719	3	1	2	0	1	0	−1	0	0	0	−1	0
1720	0	0	−1	1	0	2	0	2	0	1	1	−1
1721	3	1	−2	0	1	0	2	0	0	2	−1	1
1722	−2	0	2	0	0	0	1	0	0	0	−1	0
1723	0	0	1	0	0	1	1	2	1	0	0	0
1724	0	2	0	0	0	−2	0	−2	0	−1	1	0
1725	0	−1	0	0	3	0	2	3	3	−1	0	0
1726	1	1	1	0	−1	−1	0	0	−2	1	0	−1
1727	−1	0	1	2	0	2	0	1	0	−1	0	1
1728	0	0	0	0	0	−1	0	−1	1	2	0	0
1729	0	0	0	0	2	0	1	0	0	1	0	0
1730	0	0	0	0	2	0	0	−1	0	−1	−1	−1

+3 extremely wet). In deriving indices, the number of days with precipitation for individual months, together with additional descriptions, may be used (Table II). For example, extremely dry patterns occurred in August and September 1718 (indices −2 and −3, respectively). Although Reimann at Prešov observed six precipitation days in August, he recorded none in September. This is confirmed by other reports referring to hot weather and droughts in August and, later on, to some rivers and lakes drying up. Warm and sunny weather was favourable for ripening grapes and accounting for their higher sugar content, such that records speak about a good wine year. This is consistent with an earlier grape harvest date in Switzerland (Meier *et al.*, 2007) as well as in eastern Austria where very good wine is also mentioned (Strömmer, 2003). On the other hand, 20 precipitation days recorded by Buchholtz at Kežmarok in both August and September 1725, including floods, indicate extremely wet months (index +3).

6. Selected weather and climatic extremes in eastern Slovakia

The description of certain extreme events included in this section is based on reports from Kanold's 'Sammlung' as well as the diary of Georg Buchholtz; only additional sources are further cited.

6.1. Drought in spring–autumn 1718

All spring growth started early in eastern Slovakia during the warm April of 1718. The end of this month was already so hot that Reimann recorded an extraordinarily high temperature ("*16 gradum caloris*") in Prešov, similar to that measured in July 1717. Great heat contributed to significant drying of the soil. According to Buchholtz, there was no rain at all at Vel'ká Palúdza from 17 April until 13 May. By 8 May, prayers for rain were being offered in the church. Only three rainy days occurred in the remainder of May. The uncharacteristically hot,

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dry weather, inhibiting vegetation development, continued to a greater or lesser extent until early June. It was only broken by harmful night frosts on 10, 19, 20 and especially 21 May, when one-inch-thick ice occurred in Prešov. Frosts caused great damage to the cucumber beds and blossoming cherry, sour cherry and plum trees but did not affect the apple and pear trees (they blossom later), which eventually yielded a good harvest. According to the '*Conscriptio*' of the Lednica domain (northwest Slovakia, near Trenčín), frosts led to a bad harvest of millet (National Archives of Hungary, catalogue no. UC 18 : 9).

Although sufficient rain fell in early June, the grass grew thin and sparse, insufficient pasture for cattle. The situation in the Prešov area was more miserable: the harvest was so bad that individual plants, their seeds falling, had to be collected in the rainy weather. Wheat and barley seeds were scorched in the heat. In some areas, the quantity of cereals sowed was greater than that harvested and some severe shortages occurred. There was a better harvest in the area northwest and north of the Prešov region (e.g. Levoča, Bardejov), whereas towards the south, in the Great Hungarian Plain and Transylvania, it was much worse. In the Banská Bystrica area, winter crops were still harvested thanks to the winter moisture, but practically nothing remained of the spring sowing. Moreover, great numbers of mice and hamsters invaded the fields. Three violent hailstorms also occurred. The first one, on 19 June, damaged vineyards mainly in the Tokaj area (northeast Hungary). The second, in the Šariš district, even broke roofs, while large pieces of falling ice killed many rabbits. A note in the diary of the Pálóczi Horváth family from Pavlovce nad Uhom records "*unheard-of hail*" (Szopori Nagy, 1881). The third hailstorm, on 30 July, damaged the whole harvest in the Spiš and Zemplín regions and some wild animals were injured by large hailstones. According to Reimann, people had not seen such great hail damage "*since time immemorial*". The massive hail and extraordinary drought, together with the bad harvest, were also recorded in the accounts of the Regéc domain, to which a great part of the Tokaj area belonged (Bakács, 1930).

In Vel'ká Palúdza, Buchholtz described appropriate rainfall in both June and July, often during thunderstorms with strong winds. He also mentioned snowfalls in the mountains at the turn of June and July, accompanied by horrible winds, and even frost in Vel'ká Palúdza. On 4 July, several horses were injured by hail and snow already extended down to the foot of the mountains. An interruption of the heat by a short, very cold period with heavy snowfalls in the mountains was also reported by Fischer at Kežmarok.

Heat and drought continued through August and lasted until the second half of September in the area of Banská Bystrica and elsewhere. However, it continued to be so dry that many watercourses and some other waters dried up entirely. The level of the Danube at the end of October was lower than at any point in living memory. In the Spiš region, this drought later came to be considered comparable to the memorably dry year of 1585 (Bredetzky, 1807). A great shortage of cereals and hay in the whole of Hungary, but especially in the south-southeast, similar to the conditions brought about by the 1585 drought, was especially striking. A representative summary is given in the diary of the Pálóczi Horváth family: "*In this year* [1718], *there was a horrible drought.*[...] *in the whole country* [Hungary], *both winter and spring crops dried out, so great infertility and need occurred*" (Szopori Nagy, 1881). High cereal prices, moreover, were not only general throughout Hungary in 1718, but continued in 1719, up to the fortunately excellent harvest year of 1720 (Wellmann, 1984).

The extraordinary dry weather had, to modern perceptions, extraordinary social consequences. Outbreaks of the persecution of witches occurred in several places, not only in Upper Hungary but also in other parts of the country, when they were punished for "*creating the dry weather in northern Hungary, but especially in Poland*" (see also Bessenyei, 1997). This was repeated in the Spiš district, where witches were blamed and punished for the drought of the year 1726. Three years later, a massive legal process against weather-altering witches ended in Szeged (Hungary), brought because the accused "*sold off the rain together with the harvest*" (Pócs, 1997, 1999). From the Middle Ages onwards, witches were routinely accused of altering the weather in both western and central Europe (e.g. Flint, 1991; Behringer, 1999; Pfister, 2007).

The period from June to November 1718 was also anomalously warm and dry, as also interpreted by Pfister (1999) for Switzerland. The situation started on 20 May and, with the exception of cold-wet weather in the last third of October, it lasted till the end of November. Similar dry patterns, characterized by water shortage, drying up of watercourses, bad crops, water mills out of operation and high prices, have been recorded in many documentary sources in Moravia and Silesia (Brázdil and Kirchner, 2007). Moreover, very hot and dry summer weather was mentioned by documentary sources from eastern Austria (Strömmer, 2003).

Independent European land temperature reconstructions (Luterbacher *et al.*, 2004, 2007; Xoplaki *et al.*, 2005) are consistent with the findings mentioned above and the derived temperature indices (Table I). The temperature anomalies (with respect to the 1901–1960 reference period) for the area of eastern Slovakia are approximately 1.2 °C for summer 1718 and 0.5 °C for autumn 1718. Also at the European scale, these two seasons were slightly warmer than the 1901–1960 period. The European land-only precipitation reconstructions by Pauling *et al.* (2006) indicate that dry conditions in the summer and autumn of 1718 were a large-scale phenomenon with below-normal rainfall stretching from western to central and eastern Europe and as far as western Russia.

Strong temperature and precipitation anomalies are, to a large extent, determined by the large-scale atmospheric circulation. The large-scale interrelation between the circulation and local to continental scale climate arises

DOI: 10.1002/joc

because they are both associated with change in the quasi-stationary planetary waves and other factors, including the role of advection given by the mean airflow and the planetary waves.

The large-scale sea-level pressure patterns for spring, summer and autumn of 1718 represent departures from the 1901–1960 reference period (Figure 7). Because of missing widespread station pressure series for the period under review, temperature and precipitation information from parts of Europe are included as predictors in the reconstruction exercise (Luterbacher *et al*., 2002). However, no information from this study related to Slovakia has been used. The study area was influenced by anomalously high pressure with a centre of action over the western Mediterranean (in spring), British Isles (in summer) and eastern Europe/western Russia (in autumn). A glance at the monthly sea-level pressure fields (not shown – see http://www.ncdc.noaa.gov/cgi-bin/paleo/lutercont.pl) indicate the eastward extension of high pressure from south-western Europe towards eastern Europe in April and May consistent with the reports of dry and warm conditions in Slovakia. The summer months reveal a similar pressure distribution with strong high-pressure patterns over large parts of Europe (not shown – see Luterbacher *et al*., 2002) that are responsible for the stable warm and dry conditions. The autumn months indicate conditions dominated by high pressure with a changing centre of the activity (not shown – see Luterbacher *et al*., 2002).

6.2. Disastrous floods in 1725

Although floods occurred in eastern Slovakia in other years during the period studied, the most severe events appeared in 1725. From May to July, rainy and cool weather prevailed. Showers and cloudbursts led to a damaging flood around Kežmarok as early as the end of May. According to Reimann, many areas were also inundated because of heavy rain in June.

In August, scarcely a day passed without quantities of rain and it snowed heavily several times in the mountains. During this extraordinary, "*unheard-of*" cold weather in early August, noted with emphasis by Jakob Buchholtz in the family chronicle, even horses, cows and sheep froze to death in their pastures (Weber, 1904). After a heavy storm with continuous rain on 5 August at Kežmarok, the River Poprad suddenly flooded on the following day from midnight until 3 o'clock in the morning. The severity of the flood was largely due to the melting of deep snow in the mountains caused by heavy rain day and night. The water carried away manors, houses, wash-houses, stables and barns in Kežmarok and its surroundings. People took to their roofs and lofts to escape the flood. The damage in terms of livestock was not confined to the smaller beasts: horses, cows and sheep also drowned. The flood overwhelmed and destroyed cornfields, gardens and meadows, flushed the fish from stock-ponds, and destroyed mills and bridges. Such was the power of the water in the mountains that it rolled large boulders. In one place, a great section of the bank was washed away, taking many trees with it. Around a hundred trees fell along the Studený potok Brook flowing into the River Poprad in Velká Lomnica (Weber, 1904).

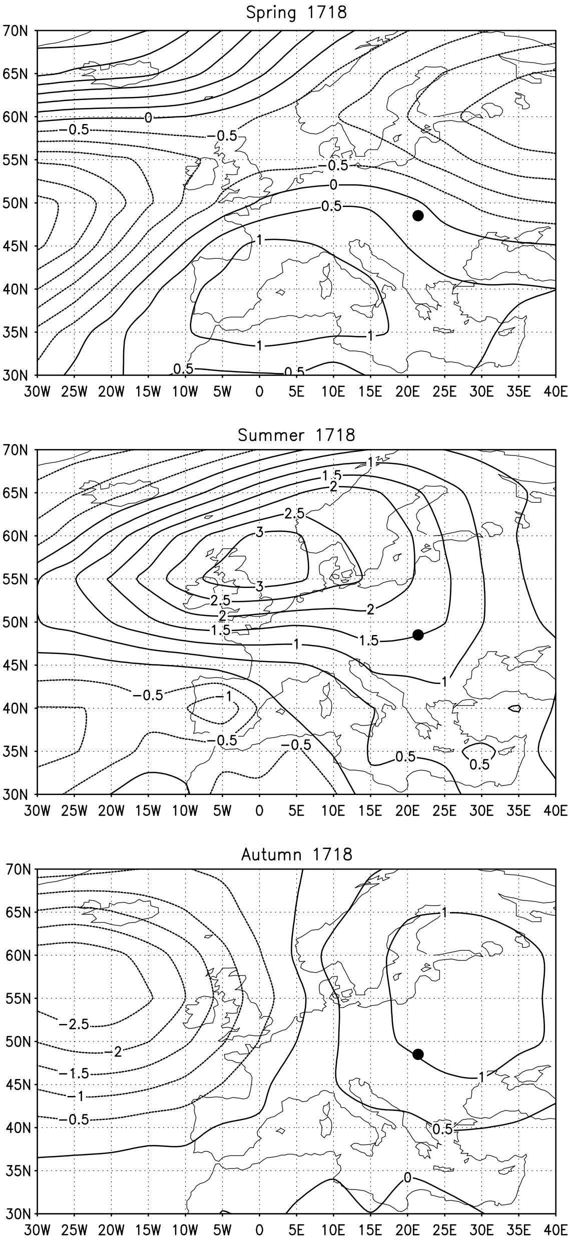

Figure 7. Reconstructed spring (MAM), summer (JJA) and autumn (SON) sea-level pressure anomalies (hPa, the 1901–1960 reference period) for 1718. Negative anomalies are stippled, positive anomalies are indicated with continuous contours (from Luterbacher *et al*., 2002). The black point represents the area of eastern Slovakia.

In the morning of 7 August, the water level fell rapidly, although in some parts of Kežmarok people still could move "*without putting their legs down*". Great damage was recorded around the whole River Poprad, both to buildings and grain. Similarly, a disastrous flash flood occurred in this area on 6 August, 1662, as mentioned for Kežmarok and the Spiš area by Georg Buchholtz Senior in the family chronicle (Weber, 1904), although his son mentioned the year 1660 in both the 'Sammlung' and the diary.

DOI: 10.1002/joc

Reports of an early August flood and damage were related to the River Váh and other watercourses in the northeast, north and northwest Slovakia, also in parts of northeast Hungary. On 6 August, in the village of Liptovská Ondrašová, a flood of the Váh was so severe that it "*tore away houses from their foundations*" (Pongrácz, 1730).

Rains in the mountains of north-central Slovakia were recorded for 4–5 August. On the following day, the violence of the flow in the otherwise small Smrečianka stream became such that people in Smrečany had to leave their houses and the water washed nearly a hundred corpses without coffins out of the cemetery. By the River Orava, the flood swept away farming equipment and tools, while in the market town of Dolný Kubín the water reached the churchyard. As well as people, houses and mills were carried away in the Dlhá nad Oravou area on the River Orava.

Independent European land-only precipitation by Pauling *et al.* (2006) clearly indicates much wetter conditions in the spring and summer of 1725 over large parts of western (in summer) and central (in spring and summer) Europe. Therefore the extreme precipitation mentioned above had a significant contribution to their seasonal totals. In the same seasons temperatures over large parts of central and eastern Europe were more than 1 °C cooler compared to the 1901–1960 reference period (Luterbacher *et al.*, 2004; Xoplaki *et al.*, 2005). This is consistent with the independently derived temperature indices for eastern Slovakia presented in Table I. As mentioned above, the large-scale pressure reconstructions are not entirely independent of temperature and precipitation reconstructions as they share common predictors over the reconstruction period, therefore care should be taken to avoid any circularity in the interpretation. The cool and wet conditions in the spring of 1725 seem however to be connected with a positive pressure anomaly (Figure 8) over north-western Europe (Luterbacher *et al.*, 2002). The Slovakian area is located in the negative anomaly, i.e. a combined influence of anomalous cold and dry air from the northeast and anomalous moist and warm air from the Mediterranean area might have contributed to the observed weather anomalies within that season.

During the summer of 1725, extensive anomalous low-pressure conditions (Figure 8) extending from northern to central Europe might have been connected with the wet and cool conditions over Slovakia.

Cool and rainy weather with frequent snowfalls in the mountains continued until the beginning of September. In early September, after a terrible thunderstorm on 3 September and on the following day, the River Váh again flooded, because the frequent snow in the mountains melted in the rain. Flooding of the Váh was mentioned once more by Georg Buchholtz for 6–8 September. For example, when he was in Vyšná Boca on 7 September, the water there was so vast that the entire plain below was covered by water and appeared as a single river. Water took whole woods from the mountains. The River Poprad also flooded and resulted in significant damage.

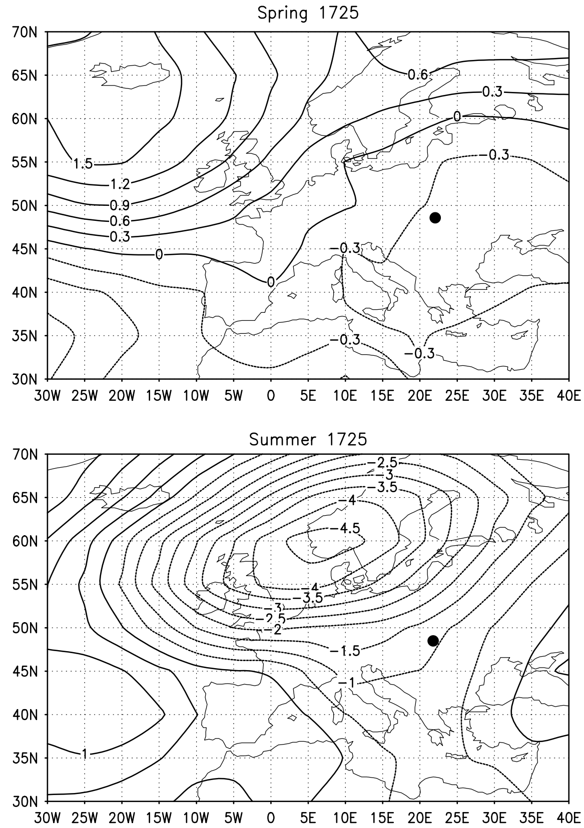

Figure 8. Reconstructed spring (MAM) and summer (JJA) sea-level pressure anomalies (hPa, the 1901–1960 reference period) for 1725. Negative anomalies are stippled, positive anomalies are indicated with continuous contours (from Luterbacher *et al.*, 2002). The black point represents the area of eastern Slovakia.

6.3. Severe and snowy winter, 1725/1726

While the beginning of December 1725 was still rainy, it started snowing on 3 December, and although the snow cover lay and became even thicker throughout the month, strong winds swept snow away from many of the fields. The areas of Kežmarok and Prešov experienced such violent cold in January that it was comparable to the severe event of 1709, when extremely low temperatures culminated throughout Europe (e.g. Lenke, 1964a; Pfister, 1999; Luterbacher *et al.*, 2004 and references in the Science supplementary material). Deep snow covered the ground. Frosty weather occurred in February, and the second half of the month, after a short-melting period, was rich in snow. On the basis of Reimann's reports from Prešov, winter continued till the last week of March, when rapid melting set in. Buchholtz characterized March in Kežmarok as more changeable: the cold and snowy weather was broken by periods of thaw. Winter was exceptionally rich in snow and since it was also cold without significant melting, the snow in the forests reached the height of a man. Hay became extremely expensive and all animals had to be fed.

A similar description is available for the central parts of the Great Hungarian Plain, where several thousand cattle perished in the area of Kecskemét and wild animals could not find fodder in the deep snow; in February and

DOI: 10.1002/joc

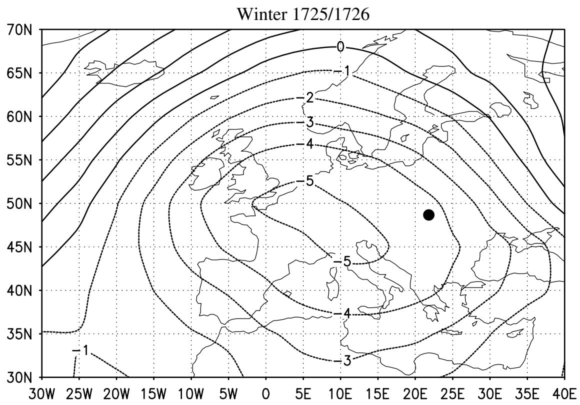

Figure 9. Reconstructed winter (DJF) sea-level pressure anomalies (hPa, the 1901–1960 reference period) for 1725–1726. Negative anomalies are stippled, positive anomalies are indicated with continuous contours (from Luterbacher *et al*., 2002). The black point represents the area of eastern Slovakia.

March, great numbers of deer moved in from the mountains to the lowland areas and entered villages for stored hay. Very cold and snowy winter is further confirmed by reports from eastern Austria (Strömmer, 2003) as well as by daily weather records from the Premonstratensian abbey Hradisko in Olomouc, Czech Republic (Brázdil *et al*., 2008).

The European-scale temperature reconstructions (Luterbacher *et al*., 2004, 2007) for the 1725/1726 winter indicate a strong negative anomaly of the order of 1.5 °C–3 °C stretching from western Europe over central Europe to its eastern part. Slovakia is in the centre of that negative anomaly. This is consistent with the independently derived temperature indices presented for eastern Slovakia (Table 1). In agreement with the above description, large parts of Europe experienced significantly more precipitation during this winter (Pauling *et al*., 2006). The corresponding large-scale sea-level pressure pattern indicates that anomalous cool but wet air over the northern North Atlantic was advected around the low-pressure anomaly towards western, central and eastern Europe (Figure 9).

7. Conclusion

Analysis of early instrumental weather records is a valuable addition to traditional documentary evidence in historical climatology, also helping to address the reconstruction of climatic patterns in the pre-instrumental period. Despite much research activity in historical climatology during recent years (see e.g. Brázdil *et al*., 2005), there still exist spatial and temporal gaps in our knowledge. Although Slovakia has been included in the climatological analysis of early modern Hungary (e.g. Rácz, 1999, 2001), its large potential for historical-climatological research is still not realized; the first articles appeared only in the last decade (e.g. Brázdil and Kiss, 2001). Analysis of Slovak meteorological observations from the 'Breslau network' for 1717–1730 may help in this context, and come to be an important contribution to Slovak climatic history. Other important sources still await systematic historical-climatological research. Reconstruction of temperature and precipitation patterns in Slovakia in the pre-instrumental period is important to bridge existing gaps in the spatial coverage on a central European scale as well as for cross-checking interpretations based on documentary evidence. However, this cannot be done without many detailed analyses, as is the case of this article, which may later become part of a further synthesis.

Acknowledgements

The work of R. Brázdil and A. Kiss on this topic was financially supported by EU project FP-6 no. 017008 European climate of the past millennium (MILLENNIUM). J. Luterbacher was supported by the Swiss NSF through the NCCR Climate. We would like to thank Nora Baráthová (Museum of Kežmarok, Slovakia) for information about Georg Buchholtz, Kateřina Chromá and Jarmila Macková (Masaryk University, Brno) for the preparation of Figures 2–6, Marcel Kuettel (University of Bern) for the assistance with Figures 7–9, Tony Long (Auchrae, Scotland) and Dennis Wheeler (Sunderland, England) for English style corrections. Gaston R. Demarée (Royal Meteorological Institute of Belgium, Brussels) and the second anonymous reviewer are acknowledged for their useful and constructive criticism on the manuscript.

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