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Historical climatology in Hungary: Role of documentary evidence in the study of past climates and hydrometeorological extremes

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Abstract—In the present paper, an overview of studies and investigations, related to the field of historical climatology and impact of hydrometeorological extremes based on documentary evidence, is presented. In addition to this, earlier investigations as well as the present stage of historical climatology in Hungary are discussed, based on research studies of climatologists, meteorologists, historians, and geographers. Besides compilations and analyses on long-term climate change, case studies on weather-related extreme events and anomalies of the last thousand years (such as droughts and floods) are also included. As regards climate variability and change, an overview is provided on the research based on lake water-level changes.

Key-words: historical climatology, climate reconstructions, extreme weather events, hydrometeorological extremes, climate anomalies, impact studies

1. Introduction

In the last decade, recent climate change issues and global warming have elicited deeper investigation of not only short, but also long-term changes and variability of climate, with special attention paid to extreme weather events and their consequences. In this respect, studying the climate variability of the last thousand years, historical climatology has begun to play a more important role, not only in other parts of Europe (*Brázdil*, 2000, 2003; *Pfister*, 2001; for the latest overview of European literature, see *Brázdil et al.*, 2005b and *Brázdil*, 2009), but also in Hungary. While there is an obvious general interest, especially among historians, related to environmental history and climatic changes in historical periods, and also a growing demand for a better understanding of the environment where human interactions took place, the climate and climate variability of the last thousand years are still relatively underinvestigated in the

Carpathian Basin and Hungary as well. In 1986, historical climatology was already listed as a separate field of higher education (*Draskóczy*, 1986); nowadays, it is treated among historians as a part of historical ecology and environmental history (*R. Várkonyi*, 2001). Nevertheless, while in the 1980s the actual research on historical climatology related topics played a somewhat marginal role in Hungary, attention was soon drawn towards this field as a result of conference presentations and publications of L. Rácz in Hungarian and international scientific journals and textbooks (*Rácz*, 1987, 1988, 1989, 1994, 1995, 1998, 1999a, 2001a, 2003a, 2003b, 2007 etc.).

Investigations that have some connection with historical climatology and topics are quite dependent on the databases and/or source collections available. The usual practice among scientists analyzing historical evidence is to take an existing database, regardless of the source quality, translation, or copying mistakes; as such, source criticism is still of marginal importance. In fact, due to these problems, most scientists do not dare to 'touch' historical databases at all. Since the building process of a database for detecting long-term changes may take decades and bring forth less attractive results in the period in between, historians usually concentrate on a specific event or series of events, with a special emphasis on the effects of extreme events or anomalies on human society. Another area of research, mainly carried out by motivated climatologists and meteorologists, is database enlargement. Among these databases the Réthly-collection, with its four volumes (*Réthly*, 1962, 1970, 1998, 1999), doubtlessly contains the most useful information.

2. Antal Réthly and beyond: Compilations, data publishing, and reporting findings

2.1. The role of scientific journals

The positivistic 19th century was the heyday of heroic collectors, whereas in the scientific literature of the 20th century, most of the historical data-collection efforts were carried out by climatologists and meteorologists. In the quarterly journal of the Hungarian Meteorological Service (IDŐJÁRÁS), from the beginning of the 20th century up to the 1970s, there was a separate section entitled "*Régi magyar megfigyelések*" (Early Hungarian observations), intended for publishing texts on historical weather events, early meteorological observations, and measurements. Though it was mainly *Antal Réthly* who published his concrete findings, there were other authors such as *Barna* (1960) with his Sárospatak observations, and early instrumental measurements from the mid-19th century and the Slovak climatologist, *Konček* (1972) on early instrumental measurements taken in late 18th century in Bratislava. Most of the evidence was extracted from the original sources; while in many cases Latin or German texts were published in Hungarian in translated excerpts; in some cases transcriptions in the original language (e.g., in Latin) were provided as well (e.g., *Csíkmadarasi Bogáts*, 1943).

From 1952 onwards, there was another journal, called *Légkör* (Atmosphere), which published reviews and descriptions on historical weather observations that were source related, and even if most of those reports were mainly of a short, descriptive nature, they succeeded in drawing attention to the topic and the field (*Csomor*, 1988, 1991, 1992; *Justyák*, 1991, 1992; *Ambrózy*, 1995; *Simon*, 1999). Much less in quantity and better in source-quality, local historians occasionally published sources for further climatological investigation. From these efforts, the importance of the Sopron archives and publication series in the local history journal of the *Soproni Szemle*, amongst others, should be mentioned, where contemporary sources were published, mainly (*Hegyi*, 1966; *Tirnitz*, 1974) or partly for the purpose of further climatological investigations (*Csatkai*, 1940; *Heimler*, 1942).

Besides the publishing works of journals and the Réthly-series, another compilation for the Kecskemét area was published as well. Although the Kecskemét-compilation of *Szilágyi* (1993, 1999) in part contains data taken from the Réthly-series, several additional, local history pieces of evidence were also included. Concerning criticism of historical sources, *Szilágyi* followed the Réthly-style; thus, including both contemporary and non-contemporary evidence in his compilation.

2.2. Role of the Réthly-collection in climate history analysis

Early weather reports, descriptions, observations, and measurements mostly mentioned in the IDŐJÁRÁS were later included in the four volumes of Antal Réthly's well-known compilation on weather events, extremes, and natural disasters of historical Hungary, for periods before 1900 (*Réthly*, 1962, 1970, 1998, 1999). This work, without any doubt, is of the utmost importance and provides a firm basis for further studies. Although Réthly as a meteorologist clearly did ask for the help of archivists and historians for collection, transcription, and translation works in several cases, data selection was clearly his own personal choice throughout the long and fruitful decades of his life. It is a notable fact that his selection criteria, source-quality judgements primarily formed, and provided the basis of evaluation for the existing Hungarian long-term climate reconstructions, descriptions, and most of the short-term surveys as well. As a motivated meteorologist and climatologist, Antal Réthly collected and included in his series all sorts of written information concerning the weather prior to 1900, regardless of the quality of these written materials as a historical source. Thus, contemporary, non-contemporary, and secondary-literature references were all included without much source criticism and validation. As he said in the Introduction of the first volume (*Réthly*, 1962, p. 13): "I included all the old weather data collected…"

Although in some particularly problematic cases and with clear contradictions, he did give his opinion, and thus, criticized some of the sources included in his series from the viewpoint of dating mistakes or general credibility of points, the vast majority of non-contemporary evidence as well as secondary literature references were included in exactly the same way as primary sources. Furthermore, we need to make distinction between the various volumes. While the first three books mainly contain texts or text-summaries taken from contemporary and non-contemporary sources as well as from secondary literature, originally written either in Latin, German, or Hungarian (or occasionally in other languages), in the fourth volume chiefly direct transcriptions of contemporary daily weather observations and early instrumental measurements of the 19th century, originally written in Hungarian, were gathered (*Réthly*, 1999). As such, there is a source-quality difference compared to the earlier, translated extracts, which in many cases were based on non-contemporary evidence. Unfortunately, in this last volume of 19th century daily observations, no clear reference on the availability of original sources are provided for each case, which makes proper investigations in some cases quite difficult.

In conclusion, when making use of the Réthly-series in any climatological analysis, we should enumerate the following sets of problems, which largely affect and concern the complete database included in the first three volumes of the Réthly-compilation:

(1) Up to the late 18th century, significant part of evidence included in the Réthly-collection is non-contemporary, which makes the Réthly-based analysis of the period rather problematic, due to the fact that non-contemporary evidence often contains the wrong dating of events, doubling or tripling events, etc. At the level of data analysis, another crucial problem is that while filtering out the non-contemporary evidence, in periods prior to the 17th century a significant part needs to be removed, and the same goes for some of the 18th century sources. This is especially true for the Middle Ages, whose part of the first volume contains information of acceptable source quality only in exceptional cases. For example, secondary literature without source references (*Bagi*, 1896; *Szentkláray*, 1880–1882; *Tőry*, 1952, etc.), as well as foreign source compilations like the one by *Hennig* (1904) or those by *Weikinn* (1958–1963), and texts of popular journals, newspapers (*Hasznos Mulatságok*) about curiosities which happened hundreds of years earlier, were included as well. In this respect, volumes of the Réthly-collection show clear similarities to other European compilations: none of them can be properly utilized without prior source validation (*Bell* and *Ogilvie*, 1978).

(2) Regarding the majority of the 16th–18th centuries and a part of the 19th century, sources (both contemporary and non-contemporary) were originally written not in Hungarian, but mainly in Latin or German, and rarely in other languages such as Turkish. Hungarian texts are mainly well extracted and

German texts were usually well translated and well extracted too. In some cases, however, there are clear problems (misinterpretations, gaps), for example, with texts taken from Latin, which without the help of other corresponding material can affect some of the index values (e.g., monthly reports taken from the volumes of *Sydenham*, 1769; or texts taken from the Jesuit diary of Levoča (in Hungarian: Lőcse), see Hungarian National Archives p. 478).

(3) In many cases, there are clear contradictions between the intervals provided by Réthly at the beginning of the actual source entry and the duration of a period mentioned in the actual text (e.g., an unknown length of time before a wine harvest is imprecisely recorded as the whole of October); similarly, some of the often equivalent events are misdated (problems of dating winter weather; or the huge amount of misdated materials, taken from secondary literature or from recent, unpublished private compilations or text collections, such the one by Florián Holovics or Gottlieb Bruckner – without mentioning original sources).

(4) Another dating problem especially of the late 16th century is that, although in the introduction Réthly draws attention to the question of proper dating due to the switch between Julian and Gregorian calendars occurring in different years in various parts of the Carpathian Basin, he clearly did not take it into consideration when providing the dates of events or periods in the actual text entries (see parts before and around late 16th – early 17th centuries in *Réthly*, 1962).

(5) Contemporary evidence is very much scattered in space, type, and time: observations or descriptions are rarely available from one place or even one region for a period of at least several decades, and even in these cases it is rare that one type of evidence (e.g., a family diary) contains a lot of detailed (monthly level) data for longer periods (for several decades at least). Hence the available data may be quite patchy; that is, it may have a low level of homogeneity.

(6) Parallel observations and descriptions would be of special importance to specify and check the credibility and quality of indices provided. Since in the majority of cases no parallel observation of appropriate quality on monthly or seasonal level is available in the Réthly-volumes, and contemporary indirect evidence, where it exists, often does not provide enough additional information, in many cases it is not possible to provide good-quality indices. Thus, the sources allow us to provide indices (i.e., the stage of deviations from normal values) only with some uncertainty in relatively clear cases without using further control evidence (independent, reliable sources).

As regards the temperature and precipitation indices of monthly or seasonal level, a great deal of evidence included in the Réthly collection is non-contemporary. Since non-contemporary evidence cannot form the main basis of analysis for further investigations, just the contemporary evidence entries should be used. These circumstances lead us to conclude that large portions of the materials should be excluded from a primary analysis. The remaining contemporary documentary evidence, on the other hand, does not provide a source that is large and detailed enough to draw long-term conclusions in appropriate quality and detail.

In summary, based on the above-mentioned main points, the Réthly-collection by itself cannot form the basis of an adequate long-term historical climatological reconstruction of the past 500 years, or longer. Therefore, significant and systematic database enlargement based on contemporary evidence, not only for the Middle Ages and early modern times but for the 19th century as well, is required.

3. Long-term reconstructions of historical climate

3.1. Index-based climate reconstructions of the last 500 –1000 years

Apart from his studies in collecting weather and weather-related data, Antal Réthly carried out some basic analyses of selected evidence, such as the series of daily observations combined with early instrumental measurements, later published in the 18th century volume of his compilations (*Réthly*, 1970). Despite this, Réthly did not provide any further, long-term analysis based on his compiled database. Instead, somewhat earlier *Berkes* (1940) carried out some investigations on the long-term fluctuations of climate, first based on instrumental measurements, and then on the early-spring temperature-related evidence of the Kőszeg Book of Vinesprouts (*Berkes*, 1942). On a local scale, for the Kecskemét area in the central part of the Great Hungarian Plain, *Szilágyi* (1987, 1988a, 1988b, 1988c), besides his catalogue of weather events, mainly described extremes and anomalies reported from 1600 to 1873, highlighting winter temperature extremes as well as extremely dry periods.

The first and still most widely known and applied (7-scale) index-based temperature and precipitation reconstruction along with a description of weather conditions, for the past five hundred years, focusing on the regions of the former Hungarian kingdom, were published and analyzed by *Rácz* (1999b). In addition to the revised indices and historical investigations, in the extended textual analysis a clear attempt towards separating major regions can be seen (see also *Rácz*, 2001a, 2003c). Another concise statistical analysis of long-term temperature and precipitation conditions as well as of the frequency of strong winds were carried out for a thousand-year period, based on the documentary data included in the Réthly-compilation by *Bartholy et al.* (2004).

In the case of both existing long-term reconstructions and investigations of written weather records, the text data of the Réthly-series formed the basis of further research. Nevertheless, while Lajos Rácz did not include the analysis of medieval parts due to the strikingly low source quality of non-contemporary evidence, in the second reconstruction the complete Réthly-database of weather events, namely documentary evidence of the entire last millennium, was included. Although authors of the second reconstruction (*Bartholy et al.*, 2004) did distinguish between quality value classes of information (based on quantity-analysis), they only provided data for 50-year intervals: in this sense they concluded that the data for the entire 16th century and partly for the first half of the 17th century was of low quality; while from the quantity aspect, only the period of 1700 –1850 was regarded as highly reliable (*Bartholy et al.*, 2003, 2004).

In essence, these reconstructions were carried out for historical Hungary, hence, practically, for the entire Carpathian Basin. In the last decade, however, there has been an increasing demand for high-resolution long-term temperature and precipitation information, divided on a (sub)regional basis, in fields such as landscape research or geomorphology (e.g., *Stankoviansky*, 2003; *Kovács* and *Rakonczai*, 2003; *Kovács*, 2004; *Kiss et al.*, 2006a), and this has a potential use in other well-established or emerging research fields, in the Carpathian Basin, like borehole climatology, dendroclimatology, speleology (*Bodri* and *Dövényi*, 2004; *Kern et al.*, 2004, 2009; *Siklósy et al.*, 2006, 2009; *Popa* and *Kern*, 2009), or fields of historical science that apply the results of historical climatology (e.g., *Laszlovszky*, 1994; *Kiss* and *Paszternák*, 2000; *R. Várkonyi*, 2001; *Szabados*, 2004). Furthermore, some interest from a climatology aspect can be seen as well, which can provide a climatological background to historical climate investigations (e.g., *Mika et al.*, 2000; *Mika* and *Lakatos*, 2008).

In Romania, *Cernovodeanu* and *Binder* (1993) provided a description of historical evidence taken from the Middle Ages onwards, based partly on source materials mentioned in the Réthly-series and partly on other, mainly contemporary written evidence related to the eastern parts of historical Hungary, namely Transylvania and the historical Partium (which today make up the western Romanian lowlands). In their investigations, the historical Romanian principalities (Walachia and Moldova) were also included. In the most westerly areas of the Carpathian Basin, a historical analysis of weather-related evidence was performed by *Strömmer* (2003) for the period of 1700 –1830 for eastern Austria. In his recent investigations, *Rohr* (2007) provided a detailed account and a concise historical analysis of high and late medieval as well as early modern extremes that occurred in the eastern regions of the Alps.

Climate reconstructions of shorter periods are also available in Hungary, mostly in the form of case studies. From a climatological aspect, as early as in 1918, Antal Réthly carried out some statistical analyses, for example, on the early instrumental measurements and daily weather observations of Timişoara (in Hungarian: Temesvár) for the period of 1780 –1803. Tables of results of this study were later included in his compilation (*Réthly*, 1970), together with a basic statistical analysis of other observations and early instrumental measurements of the same type (e.g., for Miskolc and Kežmarok (in Hungarian: Késmárk). This work, together with the digitalization process of the complete Timişoara-manuscript, was continued by *Csernus-Molnár* and *Kiss* (2008). A detailed historical and climatological analysis of well-documented periods, based on daily observations and early instrumental measurements was carried out in certain selected cases, in the present eastern parts of Slovakia, for some periods of the late 17th and early 18th centuries (*Brázdil* and *Kiss*, 2001; *Brázdil et al.*, 2008).

3.2. Phenological evidence and harvest results: The role of indirect information

As regards documentary sources containing regular observations of phenological data of a longer duration, up to now in Hungary the information content of the Kőszeg Book of vinesprouts has without doubt gained much interest. Looking for long-term evidence of climate fluctuation and change, *Berkes* (1942) was the first who investigated the connection between early spring temperature values and the length of vinesprouts illustrated each year on April 24. His evaluation was extended by *Péczely* (1982), who also raised an awareness of the connection between the quality of wine as another possible temperature indicator. Their works on Kőszeg vinesprouts were continued and a temperature reconstruction model, based on the length of vinesprouts, was developed by *Střeštík* and *Verő* (2000). Studying 20th-century data series, the connection between wine quality, quantity and climate is the topic of a recent investigation referring to the Tokaj wine region (*Makra et al.*, 2009).

By the early 1970s, *Bendefy* (1972a) in a conference report pointed out the possible reconstruction potential of wine harvest data series in town council protocols such as those in Kőszeg, Sopron, Szombathely, and Kecskemét. In a preliminary report he considered a 36-year periodicity in Hungarian vintage dates (*Bendefy*, 1972a); no information is, however, available for a continuation of this investigation. While some dates of Kecskemét vintages from the late 17th to the early 19th centuries were already published by that time (*Szabó*, 1934), the Kőszeg vintage dates, for the period of 1649 –1820 (with gaps), were published a few decades later (*Szövényi*, 1965). Nevertheless, in both cases the actual series of dates formed a relatively less-important, additional part of two local history investigations. As a result, both sets of data have never been analyzed from a climatological point of view, or the later remarks on their significance. Moreover, in both cases it can be seen that they often provide not the date of beginning but a date 2–3 days after, or only one date during the wine harvest in general; thus, they did not concentrate on providing data for the beginning of an event. Following these early investigations, based on the original sources, a new interpretation of vine- and grain-related historical evidence (see *Fig. 1*) has been initiated within the framework of the EU project called Millennium (*Kiss*, 2008; *Kiss* and *Wilson*, 2009).

By looking for possible causes of economic wealth, crises, or periods of decline, economic historians can play an important role in identifying weather extremes or climate anomalies. Based on grain tithe accounts, for the bad harvest years of the late 16th century in the Žitný ostrov (in Hungarian: Csallóköz) area, the principal causes of a rainy period and Danube floods as well as wars were highlighted by *Zimányi* (1984). Using tithe series, *Landsteiner* (1999) studied vine harvest results of selected Central European towns, including Sopron, at the end of the 16th and the beginning of the 17th centuries and demonstrated, that similarly to other wine producing areas of Central Europe, the Sopron area had to face a decline in wine production in the late 16th century, mainly caused by adverse weather conditions.

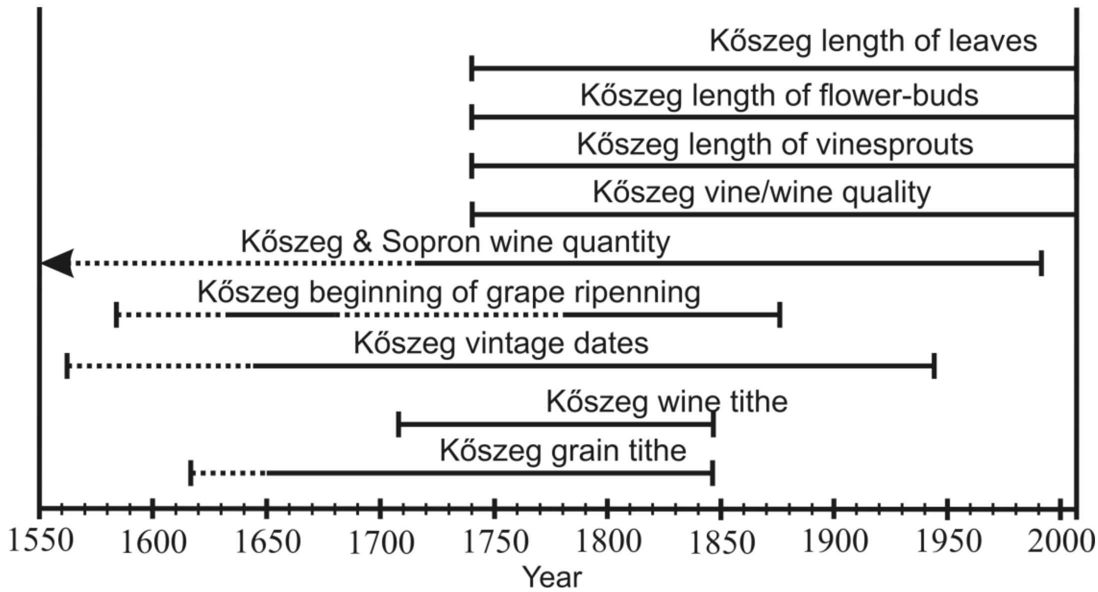

Fig. 1. Temporal coverage of recently available historical phenology evidence in Kőszeg (*Kiss,* 2008).

In the recent years, great interest has been shown in the possible agricultural consequences of climate change: based on evidence obtained from the Réthly-compilation, an analysis of phenological dates was done and phenophases information was examined (*Surányi*, 2006). However, owing to the quality and frequency of the data available in the Réthly-collection it is rather difficult to draw firm conclusions on this topic.

4. Analysis of hydrometeorological extremes

4.1. Causes and consequences: Impact studies based on extreme events

Series and combinations of extreme events and their consequences on the agriculture sector have, in some cases, gained more interest among agrarian and local historians. Some of the local history monographs, published in the period of the Austro-Hungarian Empire, contain particularly detailed accounts of natural disasters, induced by climate anomalies and weather extremes and their impact on local societies. Among others, a good example is the early monograph series by *Reizner* (1899–1900) about the local history of Szeged, where the great flood events of the Tisza in the Szeged area are described in an unusually detailed form, similar to the famine years, caused by a severe, prolonged drought of the late 1710s and 1720s. For instance in 1728, when the spring was particularly dry, and later this weather was combined with a great hailstorm over the plain, this caused the famous Szeged accusation case of witches. This witch-hunt, together with the historical background, was elaborated on in the first volume, together with primary sources (for a Central European context of witchcraft and weather, e.g., *Behringer*, 1999). This is of special importance, since the later monograph series of Szeged paid less attention to such issues (*Kristó*, 1985).

Droughts combined with extremely wet or cold periods caused the series of appealingly bad harvests in the Great Hungarian Plain, Transylvania, as well as in the Romanian principalities, which resulted in the great famine years of 1814–1817 in Bihar county (today, in Hungary and Romania), discussed by *Hodgyai* (1991). Also, the occurrence of the Maunder Minimum anomaly (1675–1715), as well as the cool summers of the 1830s and their adverse consequences on society in historical Hungary were discussed by *Rácz* (1994, 2001b). According to the author, as a consequence of cool summers there were bad harvests: these unfavorable conditions had an indirect influence on the decision-making policies of the contemporary Hungarian reform parliaments.

4.2. Droughts

In the central and eastern parts of the Carpathian Basin, especially in its lowland parts, mainly in the short-term but sometimes even in the long-term, severe droughts or a series of dry years probably had the most marked effects on the economy. Therefore, due to the well-known drought sensitivity of the semi-arid Great Hungarian Plain, droughts, said to be responsible for 22 known famines between 1790 and 1863 (*Érkövy*, 1863), have become a focal point of research. In historical research, the fields of local history and historical ethnography took a principal role in the study, description, and analysis of the effects of droughts on society, social relationships, economy, activities, and campaigns by the state and local authorities in finding solutions for crises which arose as a result of long dry spells. Since droughts had the greatest impact (greater than any flood event) in the aridification-endangered Great Hungarian Plain, studies usually concentrated on the most significant famines and mass extinction of cattle related to prolonged droughts of the late 18th and 19th centuries (*Györffy*, 1978; *Bellon*, 1996), but in some cases attention has also turned to the 1710s and 1720s (*Reizner*, 1899–1900).

Whereas floods caused problems in the previous decades but especially in the 1770s, the 1790s was without doubt the decade of droughts: investigating the great droughts of 1790 and 1794 (whose droughts also touched Moravia and Silesia – see *Brázdil et al.*, 2007), followed by famines, *Szabó* (1991) emphasized the significance of defence mechanisms developed by the society in 1791–1795 at both the local and regional levels in the north-central part of the Great Hungarian Plain, namely in Greater Cumania. Apart from the overwhelming importance of local history and historical ethnography research, looking for historical parallels of present drought events, to some extent environmental scientists also turned their attention towards this question (*Pálfai*, 1994). Nonetheless, without doubt great interest arose in the most influential drought of 1863, which is believed to have been primarily responsible for the fundamental and irreversible structural changes of Hungarian agriculture and as such, was widely discussed at both the regional and local level (*Reizner*, 1899; *Györffy*, 1978; *Bellon*, 1996; *Sipos*, 2001). In recent years, the possible connection between drought and the early 18th-century rise of witch accusations also became a topic of discussion among social historians (see, e.g., *Tóth*, 2008).

In two studies, mostly investigating the occurrence of famines in historical Hungary, the economic background, social consequences of droughts, and the response of the state are topics of discussion (*Gunst*, 1984a, 1984b). In his first article, the author suggests that due to the relatively low importance of crop production and consumption, and also due to the relatively low population density of the Carpathian Basin, droughts did not cause severe famines prior to the 18th century. Still, the number of famines caused by droughts increased from the early 18th century, when a great number of new settlers arrived in the country (*Gunst*, 1984a). Similar conclusions were reached in historical ethnography and local history studies, and he concluded that droughts of the Great Hungarian Plain and Transylvania in the 1850s and 1860s, and especially the well-known drought event of 1863 had probably the greatest impact on the long-term development and changes in agriculture, agricultural management, and economic development in Hungary. Moreover, this great drought event acted as a catalyst for the establishment of an independent Hungarian meteorological institute (*Gunst*, 1984b).

4.3. Floods

In Hungary another direction of historical research, which is also quite important in Central European investigations (e.g., *Brázdil et al.*, 2005a, 2007; *Glaser* and *Stangl*, 2004; concerning the Danube in Austria with emphasis on human response – see *Rohr*, 2005, 2007), focused on destructive historical floods: similar to well-known droughts, some of the especially destructive flood events were of especial interest and, as such, historians, hydrologists, as well as meteorologists studied them in great detail (in a European context, it is also reflected in the definition of historical hydrology – see *Brázdil et al.*, 2006). One of the early investigations was carried out by *Zawadovski* (1891). Apart from a detailed catalogue of data on water regulation, he listed the most destructive flood events that took place on larger rivers of the Carpathian Basin, especially from 1732 onwards, and sometimes he even gave a short overview on selected early modern floods as well. Although in most cases he did not provide clear evidence of his sources, in several cases he did refer to contemporary archival evidence. In addition, the author discussed some consequences (especially of material damage) of the greatest Danube floods in the late 18th and 19th century in the twin-town of Pest-Buda and Pest-Pilis-Solt County, like those of 1768, 1775, 1838, and 1876. Divided into small chapters, the author provided statistical information about damage in tabular form. Even if it is not completely free of errors, owing to the fact that no other comprehensive study of larger historical floods (Vol. 1) of the Carpathian Basin was carried out, this work became especially influential. Later investigations of hydrologists, usually including the obligatory short passages of a historical introduction, were largely based on the Zawadowski-catalogue.

Among the studies on individual flood events, most of the early studies were carried out on the 1838 ice flood at Pest-Buda (*Németh*, 1938; *Lászlóffy*, 1955), and the 1879 great Tisza flood at Szeged (for a concise overview of an early bibliography, see *Dégen et al.*, 1969; for a recent overview, see *Tóth*, 2009). These two events, together with their other consequences gained and still gain attention, and thus, separate chapters on several concise urban local history series, both old and new ones of Budapest and Szeged are usually devoted to the floods of great importance from the viewpoint of later urban development (*Gerevich*, 1975; *Kristó*, 1985). Furthermore, separate issues of the *Hidrológiai Közlöny* (*Hydrological Bulletin*) (1979: 59/6, 1988: 68/2) were published for the anniversaries of the great Pest-Buda and Szeged floods. In the past few decades, a new wave of analyses from both historians and environmental scientists were published for probably the most destructive flood event, namely the great 1838 Danube ice flood (*Faragó*, 1988; *Boldvay*, 1988; *Létay*, 1991 etc.), which practically destroyed the towns of Pest and Óbuda together with their suburbs. In this latter case, the meteorological conditions were also studied in detail (*Bodolainé Jakus*, 1988).

Based on data obtained from the Réthly-collection and the Zawadowski-catalogue, the connection between hard winters, ice cover, and ice floods of the Danube over a thousand year period are topics of discussion in the article by *Déri* (1989): due to the plentiful information available mostly for the period after 1820 and the impact of water regulations on ice cover, they were analyzed in more detail. Déri also emphasized the fact that, while significant efforts of water regulation works markedly reduced the chance of a looming destructive ice flood, still the danger was not over and, in the case of a hard winter, ice floods could cause significant damage even today. Mostly relying on the Zawadowski-catalogue, *P. Károlyi* (1970) studied the main periods and major consequences of significant flood events from the 18th century onwards of the Tisza valley from a hydrological viewpoint, with special emphasis on their impact on the later regulation works.

Other case studies on flood events are available in several individual articles, mainly done by local historians. Historical flood marks in Budapest were, for example, systematically described and investigated by *Rajna* (1979). Based on contemporary local history evidence, the most destructive flash floods and their impact on urban development were discussed in several local history articles (*Boronkai*, 1965; *Dobrossy* and *Veress*, 1978). In other studies, flood events of the River Maros (in Romanian: Mureş) in the 18th century (*Pálfai*, 1997; *Kiss et al.*, 2006b, 2008), those of the Drava river in the 16th–18th centuries (*Petrić*, 2007), and the main ice floods of the Danube between 1768 and 1799 together with related problems in the late 18th century development of Pest suburbs were discussed (*Kiss*, 2007). In a recent case study, the European aspects of great flood events in the winter and spring of 1784, including the Carpathian Basin, were also examined (*Brázdil et al.*, 2009).

5. *Lake water-level changes: An interdisciplinary topic applying documentary evidence*

As regards the lake-level variations related to climate variability, the investigations for Lake Balaton and Lake Fertő (in German: Neusiedlersee) should be emphasized.

By studying the water-level fluctuations of Lake Balaton, a great advantage can be detected in its shallowness as well as in the small, well-defined catchment situated at the west-central part of the Transdanubia in Hungary. In a book by *Bendefy* and *V. Nagy* (1969) on the water-level changes of Lake Balaton on a millennial scale, there is a clear attempt to apply contemporary medieval, early modern and modern documentary evidence. Although the book is still widely-accepted and used by scientists, the authors' interpretation of historical, cartographic, and archaeological evidence is often problematic and conclusions drawn are sometimes conceptual, and mostly related to the possible importance of human activity versus climate variability. As in some cases their results clearly contradict the other existing reconstruction, better accepted amongst historians and archaeologists (*Sági*, 1968; see also *Fig. 2*), a well-known, long-lasting debate (the so-called Balaton-debate), concerning medieval and early modern water levels, developed in the early 1970s (*Sági*, 1970; *Bendefy*, 1972b; *Sági* and *Füzes*, 1973). Another important difference was that, while in the case of the first water-level reconstruction human influence played an important role in the medieval and early-modern periods (*Bendefy* and *V. Nagy*, 1969; *Bendefy*, 1973), the other reconstruction viewed climate fluctuation as the factor primarily responsible for the historical water levels of Lake Balaton (*Sági*, 1968; *Sági* and *Füzes*, 1973).

On the other hand, in both papers there was a consensus on the fact that the average water-level of the Balaton underwent a slow rise in the high and later

Middle Ages, then this increase speeded up from the 16th century onwards. The changing human impact on the only natural outflow of the lake by itself, however, cannot be blamed for this significant increase, since the 14th century up to the mid-15th century contemporary sources show a survival of earlier utilization and management practices (mainly mills) of the waterflow (Fok/Sár river), even if in the 16th century, only the mills of the lower river sections (Sár river) were documented (*Kiss*, 2009). In the past few years, a multidisciplinary study, which included historical documentary evidence, was carried out by *Sümegi et al.* (2009a), and a comparison between the above-mentioned first water-level reconstruction and the available tree-ring evidence, connected to the 19th and 20th centuries, was published by *Kern* (2009).

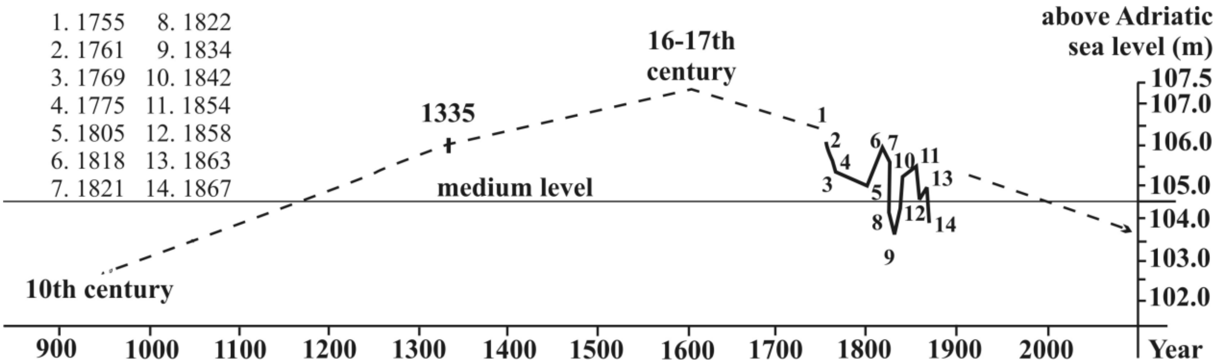

Fig. 2. The water-level changes of Lake Balaton in the past millennium, given by *Sági* and *Füzes* (1973).

Allegedly based on written evidence, the historical water-level changes of another lake, the Fertő (Neusiedlersee), which is even more sensitive to climate variability, was published by *Kopf* (1963). His extended reconstruction (*Fig. 3*), presumably based on documentary evidence, was widely accepted in the Hungarian scientific literature (*Zorkóczy*, 1975). Application possibilities are, however, strongly limited by the fact that Kopf made no mention at all of the sources used in the reconstruction (*Kiss*, 2004a).

In a similar way, although there was great interest and dozens of previous and later studies were carried out concerning the historical water-level changes of Lake Fertő (Neusiedlersee) and the Hanság (in German: Wasen) wetlands, most of the data was presented with no direct source-reference (*Nagy*, 1869; *Kövér*, 1930; *Haller*, 1941; *Károlyi*, 1955). They referred to earlier studies where, likewise, no reference concerning the source of information was provided (*Balsay et al.*, 1975; *Kováts*, 1982). As such, it is rarely possible to trace back all the original sources, based on literature entries. Other problems may occur when taking indirect written evidence into account: reconstruction attempts concerning medieval and early modern conditions often have interpretation problems of contemporary terminology (*Kiss*, 2004b). Quite similar problems have arisen in the scientific literature (*Bendefy* and *V. Nagy*, 1969) for the only natural outflow of Lake Balaton; namely the medieval Fok or Sár river (*Kiss*, 2009).

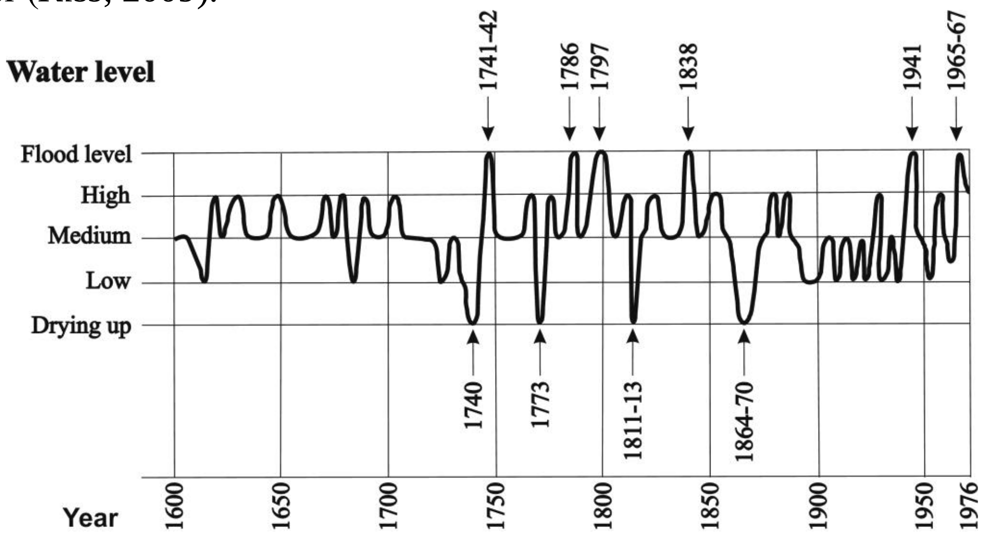

Fig. 3. Water-level changes of Lake Fertő (Neusiedlersee) in the last 400 years, elaborated by *Kopf* (1963), extended by *Zorkóczy* (1975).

6. *Medieval weather and climate: Sources and analysis*

From both medievalists and archaeologists, a growing interest could be seen to some extent from the 1960s (*Sági*, 1968), but especially from the 1990s onwards, with a particular emphasis on the Medieval Warm Epoch and the Little Ice Age transition (e.g., *Fügedi*, 1992; *Györffy* and *Zólyomi*, 1994, 1996; *Laszlovszky*, 1994; *Bálint*, 2003).

For the early Middle Ages, rather questionable attempts were made to relate the very scarce and problematic documentary evidence to a probable drought anomaly in the 8th century (*Györffy* and *Zólyomi*, 1994, 1996). Conversely, recent paleoenvironmental investigations suggest that droughts were more severe in the 13th century than in the 8th century (*Sümegi et al.*, 2009a; referring to 13th century conditions, see also *Sümegi et al.*, 2009b, 2009c). Concerning written sources, even much later, in the 11th –12th centuries only sporadic evidence is available (e.g., the battle of Ménfő: *Négyesi*, 1994), and these rarely provide the opportunity to draw some conclusions (*Kiss*, 2000a). Due to the growing amount of evidence, a few more detailed case studies have been occasionally carried out for particular, well-documented events of the 13th century like the hard winter conditions during the great or first Mongol invasion (*Kiss*, 2000b, 2003).

With the increasing amount of accurately dated 14th century legal evidence, in certain cases such as the 1340s, some great floods and presumed higher flood frequencies may be observed (*Kiss*, 1999). Concerning long-term changes, primarily based on archaeological and partly documentary evidence of the Visegrád royal palace and settlement, an interesting, early case study suggests that a significant increase of the average water level of the Danube began in the late medieval-early modern period (*Héjj*, 1988).

As regards the great subsistent crisis of 1315–1322 in Western Europe (*Kershaw*, 1973; *Jordan*, 1996), *Szántó* (2005, 2007) concluded that no contemporary evidence suggests that the crisis would have reached and had a significant impact in medieval Hungary. A recent investigation based on contemporary documents indicated that the European crisis of the mid-1310s reached and caused some problems in Hungary (*Vadas*, 2008).

Owing to the generally increasing amount of available medieval evidence, a review article was recently published on the medieval climate of Hungary (*Rácz*, 2007). Since very few studies have been published that directly analyze medieval weather and climate, it is a difficult task to provide any reliable conclusions on this subject. Therefore, database extension is of primary importance; up to now even key periods, like the 15th century with the most potential, have clearly been underinvestigated. Moreover, some contemporary legal documents (charters) suggest that not only direct but some indirect, landscape and hydrological evidence, for example the water-level conditions of larger lakes such as the Fertő (Neusiedlersee) in certain years, can also provide more useful information (*Kiss*, 2001; *Kiss* and *Piti*, 2005).

7. Conclusions and outlook

As we have seen, in Hungary climatologists and historians turned towards the study of climatic fluctuations and weather-related natural extremes at a relatively early period in history. This was partly due to the excellent potential arising from the immense amount of documentary evidence, largely available in present-day Hungary, but for historical reasons, for almost all of the Carpathian Basin as well. In this respect, it is clearly a positive point that the area of historical Hungary, meaning mainly Hungary, Slovakia, western Romania, northern Serbia, and the Transcarpathian region in Ukraine, is one of the areas in Central Europe with relatively early long-term historical climate reconstructions for the early-modern period (*Rácz*, 1999b, 2001a).

As a comparison, long-term (500-year or 1000-year) reconstructions on a monthly, seasonal basis (temperature, precipitation) are available in such areas of Central Europe as Switzerland (*Pfister*, 1988), the Czech Lands (*Brázdil* and *Kotyza*, 1995; *Dobrovolný et al.*, 2009a), and Germany (*Glaser*, 2001, 2008; *Glaser* and *Riemann*, 2009). A joint 500-year Central European seasonal temperature reconstruction, including the Czech Lands, Germany, and Switzerland, was recently carried out within the framework of the EU project called Millennium (*Dobrovolný et al.*, 2009b). Thus, an important future task will be to provide new index-based reconstructions, both for temperature and precipitation, based on an enlarged database of contemporary source evidence and a critical evaluation of sources.

Another promising direction for obtaining other long-term (mainly temperature-related) reconstructions is related to historical phenology evidence and other data series concerning agricultural activities (e.g., harvested amounts). Vine and grain phenology-based investigations, covering 500 years or more, have already been carried out in Central Europe (*Meier et al.*, 2007), which may eventually provide a good methodological background for the analysis of evidence either belonging to Hungary or other areas of the Carpathian Basin.

In spite of the good potential of contemporary documentary evidence, covering not just the early-modern period, but also the Middle Ages, in Hungary relatively little has been done on the systematic analysis of hydrometeorological extremes. This is especially true for flood evidence; even if dozens of more or less detailed case studies are available on one or another destructive drought or flood event, no systematic investigations have been carried out, unlike some other parts of Central Europe (see references in sub-chapter 4.3). Hence, another possible future direction of research is the systematic collection and analysis (e.g., frequency, classification, seasonality, causes, impact) of hydro-meteorological extremes. Short- and long-term effects of extremes and anomalies on society had a further importance and have gained increasing interest in the past decade: impact studies and the role of human response have become a significant issue for environmental historians in Central Europe (e.g., *Behringer et al.*, 2005; *Pfister*, 1999, 2002; *Pfister* and *Brázdil*, 2006). As we saw earlier, in the form of individual events, in Hungary historical ethnographers and local historians played an important role in analyses, especially on droughts, and also on other hydrometeorological events like floods. As regards other types of impact, studies on the relationship between climatic fluctuations, frequency of extremes and landscape development might also be an interesting direction of further research (for Central European parallels, see, e.g., *Bork et al.*, 1998).

While no systematic collection and analysis of events have been carried out yet, after the source validation process the vast amount of contemporary evidence included in the Réthly-compilation could form a good starting point for systematic investigations covering a period of four hundred years or more. In this respect, the Middle Ages need to be treated differently: a completely new documentary source collection process has to be launched.

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