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HISTORICAL CLIMATOLOGY: DEFINITION, DATA, METHODS, RESULTS

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The development of historical climatology is presented and different approaches to its delimitation as a branch of science are discussed. Basic groups of data sets divided into man-made and natural sources are characterised. The general method of the historical-climatological analysis documented on the example of the reconstruction of winter air temperatures according to data about cutting ice at Louny is described. Main results obtained of historical climatology are mentioned and the present state and prospects of historical-climatological research are discussed.

Key words: historical climatology, documentary evidence, natural sources, historical-climatological research, Little Ice Age

1 INTRODUCTION

The present global warming of the Earth usually ascribed to the anthropogenically conditioned intensification of the greenhouse effect (Houghton et al. eds. 1996) can have serious consequences for both the further development of the climate proper and its impacts on nature and the human society. In this connection not only the value of the assumed warming is hinted at, but also the rate of this process having no analogy in the last 10,000 years. The source of information for the estimate of future

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changes is, besides the climate modelling, also the study of climatic fluctuations and their impacts in the history of the Earth.

Instrumental meteorological measurements permit to analyse only a small part of the history of the Earth's climate covering the time interval of the order of 10^2 years. The longest continuous temperature series of central England begins in 1659 (Manley 1974, Parker et al. 1992) and the precipitation series of Kew since 1697 (Wales-Smith 1971, 1980), whereas the measurements of further meteorological elements and at further stations are essentially shorter. In the 18th century continuous observation series of air temperature and pressure begin on a larger scale. In the Czech Republic temperature measurements from 1752 are preserved from the Prague Klementinum (Pejml 1975), but continuous observations are available only since 1775 in the case of air temperature, since 1781 in air pressure (with the interruption in 1787-1788) and since 1804 in precipitation (Jírovský 1976).

The study of climatic fluctuations on the scale of 10^3 years and longer belongs to palaeoclimatology, most frequently connected with the climate in the geological history of the Earth. That is based above all on the employment of the proxy (indirect) data. They are data of natural character in which the information about the climate is encoded in a certain way. The analysis of these data is then based on the application of the principle of relevance when it is assumed in a simplified way that the effect of climatic patterns on nature and processes taking place in it were the same in the past as they are at present. According to Bryson (1997) the proxy data, dependent on the local microclimate, may not reflect the true macroclimate.

The space between palaeoclimatology and climatology of the instrumental period is overlaid by the so-called historical climatology. The objective of the present contribution is to clarify the essence of this branch of science, to characterise the employed data and methods of investigation and to outline the possibilities of this branch in the present study of the climate. For a better instructivity of this topic numerous examples from the Czech Republic are presented.

2 HISTORICAL CLIMATOLOGY AS A BRANCH OF SCIENCE

According to Ingram et al. (1978) historical climatology emerged as a discipline in the late 19th and early 20th centuries, the first major work of synthesis being by Brooks (1926). In the following decades a number of further climatologists contributed to a further development of historical climatology (such as G. Manley, H. Flohn, H. Lenke). Worth mentioning is particularly the monograph of the French historian Le Roy Ladurie (1967) devoted to the climate of the last millennium and its impacts which, however, in the following years, but for exceptions (Le Roy Ladurie and Baulant 1980, Le Roy Ladurie 1998) did not find support in his research activity. No doubt the most significant development of historical climatology was due to the papers by H. H. Lamb, P. Alexandre and C. Pfister.

The British climatologist Hubert H. Lamb (1913-1997) in his voluminous work (see e.g. Lamb 1965, 1977, 1982, 1984, 1987) described the climate fluctuation of the last millennium with the basic delimitation and characteristic of the key periods - the Medieval Warm Epoch, the subsequent deterioration of the climate and the Little Ice Age including the impacts of the climate on nature and human society. He introduced the use of series of indices and compiled the first weather charts for the pre-instrumental period. His papers affected in a fundamental way the further development of historical-climatological research and understanding of the climate of the last millennium.

The Belgian historian Pierre Alexandre stressed the use of only historically credible sources for the reconstruction of past climates (this problem was drawn attention to by e.g. Bell and Ogilvie 1978 in connection with the existing compilations of weather reports), which he applied in his analysis of climatic fluctuation in Europe in 1000-1425 with the publication of an abridged version of the starting sources (Alexandre 1987).

With the Swiss historian and climatologist Christian Pfister the development of historical climatology is closely connected in the 1980s and 1990s. His analysis of temperature and precipitation patterns of Switzerland since 1525 expressed in the form of series of temperature and precipitation indices, subsequently quantified (Pfister 1984, 1988) has become a model for a number of further studies. Not less important were his activities linked up with the establishment of international cooperation (see the data base of historical-climatological data from Europe EURO-CLIMHIST - see e.g. Schüle 1994) which resulted in the study of the climate of the so-called Maunder minimum (Frenzel et al. eds. 1994) and the analysis of the 16th century climate and its impacts in Europe (Pfister et al. eds. 1999). The subsequent output of this cooperation was the reconstruction of average circulation patterns of the period 1675-1704 in the European-Atlantic region (Wanner et al. 1994, 1995). Another contribution of Pfister consists in the accentuation of climatic impacts on man and the society (see Pfister et al. eds. 1999) and in the utilisation of proxy data for the study of climatic and hydrometeorological anomalies (Pfister 1999).

Recent decades are a document of the upsurge of historical climatology, which is reflected by both an expressive increase in the number of individual papers, proceedings and monographs (see e.g. Grove 1988, Bradley and Jones eds. 1992, Mikami ed. 1992, Hughes and Diaz eds. 1994, Jones et al. eds. 1996, Wishman et al. eds. 1998, Pfister et al. eds. 1999) and the number of specialists and teams going in for the research of this topic in many countries.

In connection with the described development of historical climatology it is impossible to neglect the contributory papers by K. Pejml of the 1960s and 1970s in the then Czechoslovakia (Pejml 1965, 1966, 1968, 1974) which did not get a major response abroad mainly because they were published in only the Czech language.

Despite a great number of historical-climatological studies there are only few papers devoted to the definition of historical climatology as a branch of science. According to Ingram et al. (1978) historical climatology "is concerned with the study and climate interpretation of descriptive documentary evidence." This definition accentuates above all the meaning of the word "historical" connected with the period for which written records exist. The limitation of historical climatology only to the work with descriptive documentary evidence is, however, too narrow (see part 3). Analogously Munzar (1993) defines historical climatology as "a part of climatology dealing with the study of the climate in the historical period, above all from the point of view of the fluctuation of climate," stating further a list of data employed.

Fairbridge (1987) defines historical climatology "as the study of climate through the time-range of civilized *Homo sapiens*, during the period in which humans have developed the arts of writing and the construction of permanent dwellings and other structures relating to their maintenance and culture. That time-range varies from region to region. With respect to the world's continually inhabited town Jericho in the Jordan valley, which was established 10,000 years ago, the Holocene epoch become, however, the logical and ultimate time frame of historical climatology." This limitation of the studied period to the whole Holocene seems to interfere in the palaeoclimatology proper.

Hagedorn and Glaser (1990), of course, speak instead of historical climatology about "historical" palaeoclimatology "which comprises that period for which direct and/or indirect written climatic information is available." Later, however, Glaser (1993, 1996) again returns to the term historical climatology, but he leaves open its position towards palaeoclimatology. The concept historical climatology is used neither by Bradley and Jones (1992) who include documentary records to the other palaeoclimatic data. It is not used by Neumann (1996) in the Encyclopedia of Climate and Weather, although he himself worked with documentary evidence in the analysis of great historical events significantly affected by weather.

The present shift in understanding historical climatology is characterised as "an approach which at present aims at reconstructing weather and climate, natural disasters and large-scale synoptic situations on the basis of man-made data and natural data for the period prior to the creation of networks run by national weather services" (Pfister et al. 1999). This perception of historical climatology does not delimit it so strictly with respect to palaeoclimatology as the definition of Fairbridge (1987), its time specification with respect to the climatology of the instrumental period depends on the development in this or that region. As against Ingram et al. (1978), this perception correctly does not limit itself to only descriptive documentary evidence. On the other hand, this branch should study rather hydrometeorological than natural disasters.

From the view of the above defined historical climatology it is quite confusing to use the concepts "historical climatology" and/or "historical data" which have appeared recently for series of instrumental measurements obtained in some period in the past (e.g. Vose et al. 1992). This also holds for the employment of the concept historical climatology as the synonym for time-series analysis (see e.g. Kaas et al. 1996).

3 DATA BASE OF HISTORICAL-CLIMATOLOGICAL RESEARCH

As follows from the preceding part, historical climatology works on the one hand with direct data about weather and climate (i.e. the datum includes direct information about the weather), on the other hand with proxy data. According to their origin it is possible to speak of man-made and natural sources. The group of man-made sources includes data that are directly the result of man's activity. They are early instrumental records, written or picture records and archaeological finds.

The group of early instrumental records can include instrumental meteorological measurements appearing in Europe in the 17th-18th centuries before the beginning of systematic measurements. Most frequently they concerned the measurement of air pressure and temperature, wind direction and the observation of cloudiness and/or further meteorological phenomena. Such information can be a valuable source of knowledge for the study of the climate fluctuation of the given place (e.g. the records of L. Morin in Paris in 1675-1715 - see Pfister and Bareiss 1994), characterisation of climatic anomalies (e.g. extremely hard winter of 1708/09 - Lenke 1964) or spatial climatic variability (measurements at several central European stations of 1718-1726 published in Wroclaw - see Pfister 1988). Although the employment of these data evokes a number of problems, the early instrumental records represent the most objective source of information.

An exceptionally rich source of information, loaded with a major or minor rate of subjectivity, are written and picture records (also descriptive documentary evidence - see Pfister et al. 1999). A more detailed division and the discussion of these materials can be found e.g. in the papers by Ingram et al. (1981), Pfister (1984, 1988), Brázdil and Kotyza (1995). In the Czech Lands they are above all the following types of data:

a) narrative sources

They are reports of weather and weather dependent phenomena and events included above all in annals and chronicles (in Europe already since the 8th century - see e.g. Yan et al. 1997, Pfister et al. 1998). As a rule, they concern the extreme course of weather and/or hydrometeorological extremes and their impacts.

b) daily weather records

They are more or less regular daily visual weather observations recorded by their authors into the ephemerids (Fig. 1), calendars or personal diaries. In the Czech Lands the earliest daily records come from the years 1533-1545 by John of Kunovice from the region of southeast Moravia (for detail see e.g. Brázdil and Kotyza 1996, 1999a).

c) correspondence

In personal correspondence there is information about the weather and hydrometeorological phenomena to complete the communication of personal character. A special case are written communications of farmstead managers about the management to their owners.

d) early journalism

Descriptions of extreme hydrometeorological phenomena and their impacts were the subject of occasionally published leaflet papers (such as about the flood in Prague on 9 March, 1581, in which a raft capsized and about 150 persons were drowned), later in regularly issued newspapers.

e) records of economic character

It is information of economic character about facts affected by weather. Important are records of the beginning of vintage, the size of the harvest, prices of agricultural crops, petition for the delay of taxes due to damage caused by hydrometeorological extremes, etc. An example can be the municipal books of accounts keeping at Louny in which payments for municipal and agricultural works performed in the preceding week were recorded on Saturdays (Brázdil and Kotyza 1999b).

f) epigraphic records

They are marks engraved or drawn into rocks, stones or structures, denoting as a rule the level of high or low waters, but also memorials reminding of some event. An example can be levels of floods on the Elbe engraved at the castle rock at Děčín (Fig. 2) or the hunger stone on the Elbe in the same place. In Prague the level of the Vltava

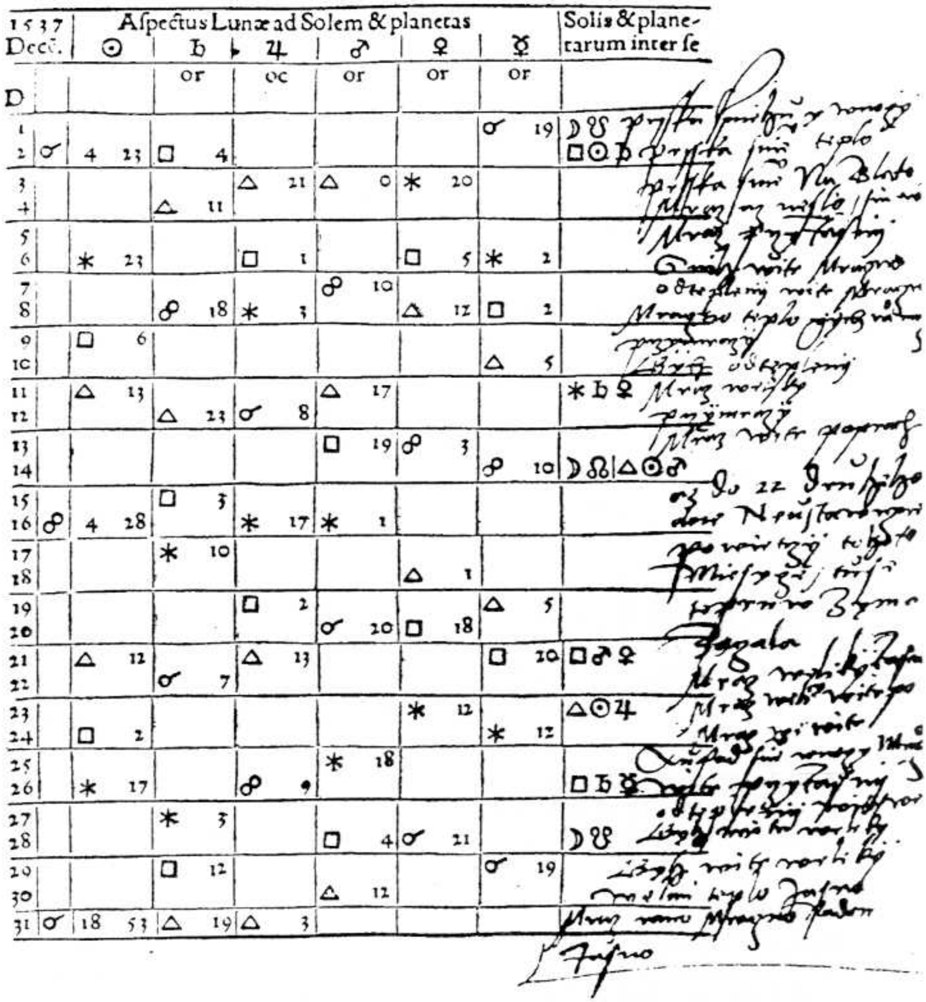

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Fig. 1. A specimen of daily weather records in Stoeffler's ephemerids by John of Kunovice (Brázdil and Kotyza 1996).

floods in the pre-instrumental period was characterised according to a stone head of the so-called Bradáč (i.e. bearded man) transferred in 1840 from Judith bridge to a newly built embankment wall (Kotyza et al. 1995).

From the archaeological sources the most important are the data about the settlement of the flood plain, extinction and leaving the settlements (e.g. Kotyza 1990), building adaptations oriented at the protection of the dwelling, etc. The found information must, however, be understood as a result of a long-term integrated effect of the climate and/or climatic extremes, the connection to the climate not being always unambiguous (for detail see Brázdil and Kotyza 1995).

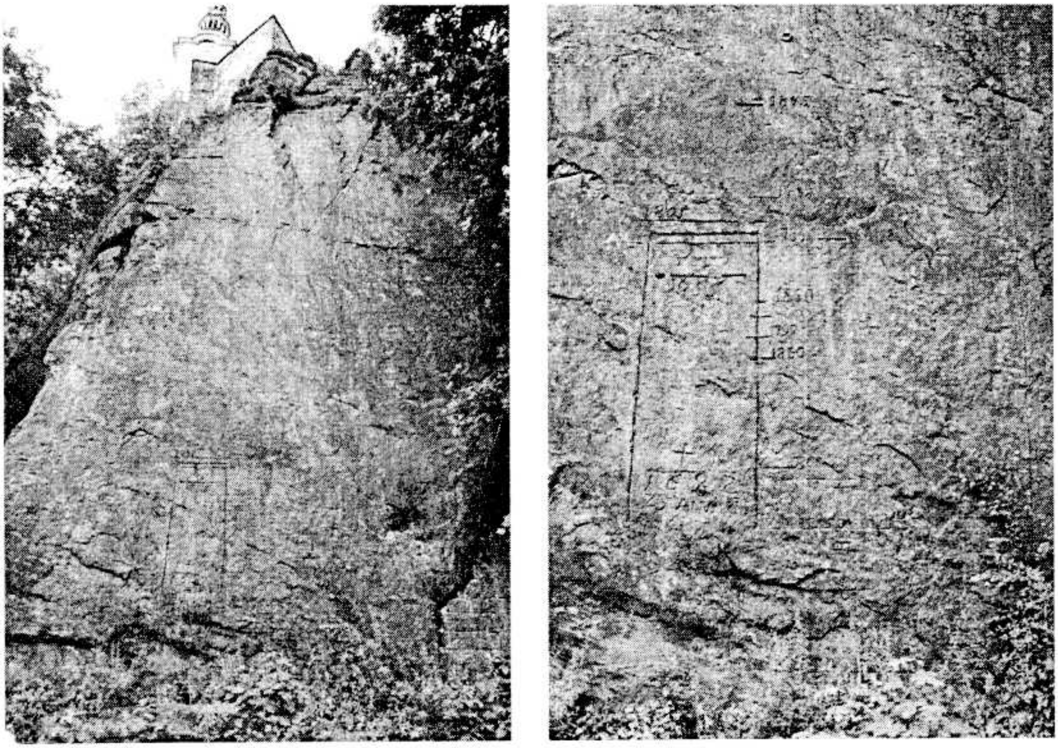

Fig. 2. Marks of the highest water levels on the castle rock above the right bank of the Elbe River at Děčín (District Museum Děčín, catalogue number N 12284/1,2).

The information about natural sources (also "field evidence" according to Ingram et al. 1981), having exclusively the character of proxy data, can be summed up in the following groups (Brázdil and Kotyza 1995):

a) glaciers

Starting from the dependence of the formation of ice on the temperature and precipitation regimes changes in the extent of mountain glaciers are studied. On glaciers with prevailing accumulation (Antarctica, Greenland, selected mountain glaciers) an analysis of ice cores obtained from drilling is carried out (see e.g. Neftel 1991).

b) tree-rings

The widths of tree-rings and the latewood density of trees growing under extreme conditions (such as the northern or upper limit of the forest) reflects the effect of air temperature fluctuation, in drier regions again of precipitation (Schweingruber 1987). The existing dendrochronologies can then be used for the reconstruction of air temperatures (see e.g. Brázdil et al. 1997) and precipitation.

c) palaeobotany

It is the reconstruction of the vegetation cover, reflecting the dependence on climatic patterns. It is based above all on analyses of pollen spectra obtained from peat bog stratigraphy (see e.g. Jankovská 1997), but also the analysis of macro- and microremnants of plants from sumps (e.g. Opravil 1976, 1985).

d) soil sediments

This group includes data of sedimentary fillings of erosion furrows (Bork 1988, Bork et al. 1998) and the formation of annually laminated sediments in lakes (varves) which reflect the signs of the precipitation regime and/or the occurrence of floods.

e) geothermics

The analysis of borehole temperature logs (geotherm) permits, on the basis of the knowledge of the spreading of thermal energy in the given rock environment, to assess the ground surface temperature history (Čermák, 1994). The result is a strongly smoothed variation of annual temperatures (see e.g. Bodri and Čermák 1997).

The above overview does by far not exhaust all groups of data. In some cases it appears that the data obtained need not necessarily belong into only one of the delimited groups. Since descriptive documentary evidence represents the data base for most historical-climatological studies, it is necessary to further mention above all the advantages and limitations of those data. In comparison with natural proxy data the following belong above all among their advantages (Pfister et al. 1999):

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

On the other hand, among their drawbacks belong (Pfister et al. 1999):

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

4 METHODS OF THE HISTORICAL-CLIMATOLOGICAL RESEARCH

The basic pattern of the historical-climatological research (Fig. 3) should include the criticism and interpretation of data including the setup of proxy chronology, calibration, verification and the reconstruction proper. Evidently best is this method elaborated as part of dendroclimatology (see e.g. Brázdil et al. 1997), whereas in the work with descriptive documentary evidence it has not yet been fully considered.

4.1 Criticism and interpretation of data

Each of the groups of data included in part 3 has certain advantages and drawbacks following from their character. They are reflected in a different resolution power, sensitivity to different climatic characteristics, geographical limitation, etc.

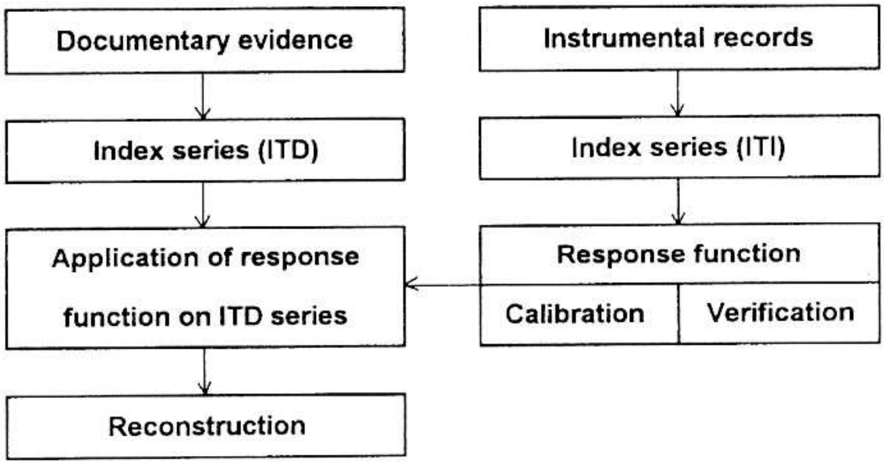

Fig. 3. The diagram of historical-climatological analysis.

The formation of corresponding chronologies of proxy data should take into consideration these limitations and aim at the formation of homogeneous series, with the elimination of disturbing factors (such as the influence of man). An important means of increasing the credibility of data is their cross-checking, both spatial (i.e. the weather phenomena have a certain territorial extent) and factual (i.e. expressions of the same phenomenon by different sorts of data).

Descriptive documentary evidence has a prevailingly qualitative character. A means for the quantification of those data is setting up series of indices expressing the temperature and precipitation patterns of the individual months, seasons and the year. Depending on the character of data an interpretation of the temperature and precipitation patterns can be carried out by means of simple monthly indices (air temperature: 1 - warm, 0 - normal, -1 - cold; precipitation: 1 - wet, 0 - normal, -1 - dry) or weighted monthly indices (such as seven-degree ones with the scale from -3 to 3). Seasonal or annual indices can then be obtained by a simple addition of monthly values. Thus, in simple indices the seasonal values can fluctuate from -3 to 3, in weighted ones (seven-degree scale) from -9 to 9.

4.2 Calibration and verification of data

The objective of the calibration of data is finding the relation (response function) between the given proxy characteristic and the meteorological element for the calibration period in which both values of the given proxy characteristic and the measured values of the meteorological element are available.

The obtained relation is applied to the so-called verification period for which, on the basis of the given proxy characteristic, are calculated the values of the given meteorological element which in turn are compared to the actually measured values. For comparing the measured and the reconstructed values it is possible to use diffe-

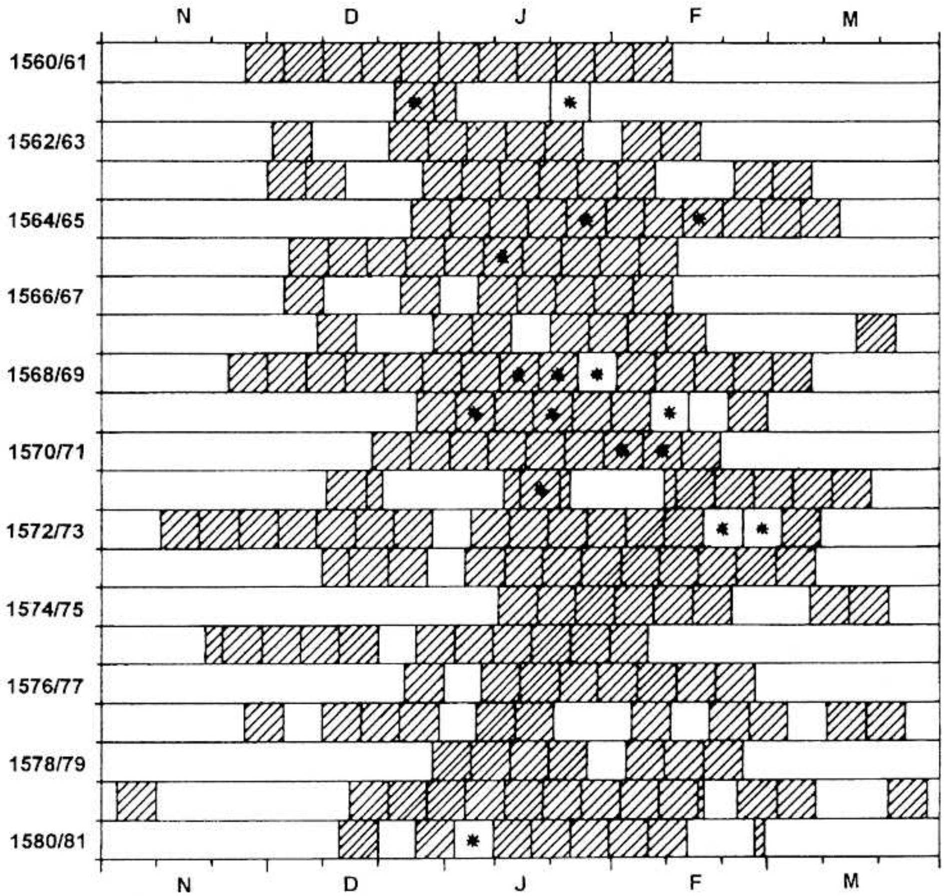

Fig. 4. The time of cutting ice at the mills of Louny (shaded) according to paid Saturday wages (the asterisk means the payment of the wages for clearing the snow) in the period 1561-1581: N - November, D - December, J - January, F - February, M - March.

rent statistical characteristics (such as the correlation coefficient, the root-mean-square error, the t-test for the paired values). At the same time it is necessary to evaluate what part of the variability of the given series can be expressed by the given response function. With respect to the as a rule shorter length of the calibration and the verification periods it is suitable to exchange them in the next step and to repeat the whole procedure.

4.3 Reconstruction

In case the found response function expresses the variability of the given series of the meteorological element with satisfactory precision, it can be used for the reconstruction on the basis of chronology of the given proxy characteristic. This approach assumes that the given response function has its validity for the whole time of the reconstruction, which, of course, need not correspond to reality (e.g. changes in phenological data in dependence of new varieties, agrotechnology, etc.).

4.4 Example of the reconstruction of winter air temperatures

The exercise of the described approach can be documented on the example of the reconstruction of winter air temperatures for Prague-Klementinum (for detail see Brázdil and Kotyza 1999b together with references). For the town of Louny in northwest Bohemia books of accounts have been preserved for some time sectors of the period 1450-1632 about wages for community work, regularly paid on Saturdays for work in the preceding week. They also contain wages for work connected with cutting ice at three mills of Louny (Fig. 4), from which it can be judged at the temperature pattern of the winter months. These data were used for making series of temperature indices (ITD) for every winter month in the seven-step scale from -3 (extremely cold) to +3 (extremely warm), further data from the Czech Lands being also taken into consideration.

The determination of the response function of the individual winter months was based on temperature anomalies δt of the station Prague-Klementinum (reference period 1901-1960) corrected by the intensification effect of the urban heat island (Brázdil and Budíková 1999). From them values of temperature indices (ITI) were determined also in the seven-step scale for the period 1901-1960. In another step the response function was determined in the form of an equation of linear regression of the type $\delta t = a + b$ ITI (a, b are regression coefficients), by means of which reconstructed temperature anomalies were calculated. From their comparison with the measured temperature anomalies there followed that this kind underestimates more conspicuously extremely cold winters (Fig. 5). That is why another approach was chosen, when the reconstructed temperature anomaly corresponded to the mean of measured temperature anomalies belonging to the given value of the ITI index. The suitability of the reconstruction by means of the two approaches was verified for the periods 1886-1900 and 1961-1975 by means of the root-mean-square error and maximal positive and negative deviations of the measured and reconstructed temperature anomalies.

The second approach based on the averaging of measured temperature anomalies always for the given value of the ITI index proved to be better and was further used for the reconstruction proper. Each monthly value of the ITD index from the Louny series was co-ordinated the mean temperature anomaly from Prague-Klementinum, by which the temperature anomaly of the given month was obtained with respect to the reference period 1901-1960. The temperature anomaly for the whole winter was calculated by averaging the temperature anomalies of December, January and February (Fig. 6).

5 RESULTS, POSSIBILITIES AND PROSPECTS OF THE HISTORICAL-CLIMATOLOGICAL RESEARCH

By the exercise of historical-climatological information a broadly used pattern of climate division of the last millennium was formed to the Medieval Warm Epoch (MWE), the period of climate deterioration and the Little Ice Age (LIA) linked up with the present warming (since about the 1880s - see Houghton et al. eds. 1996).

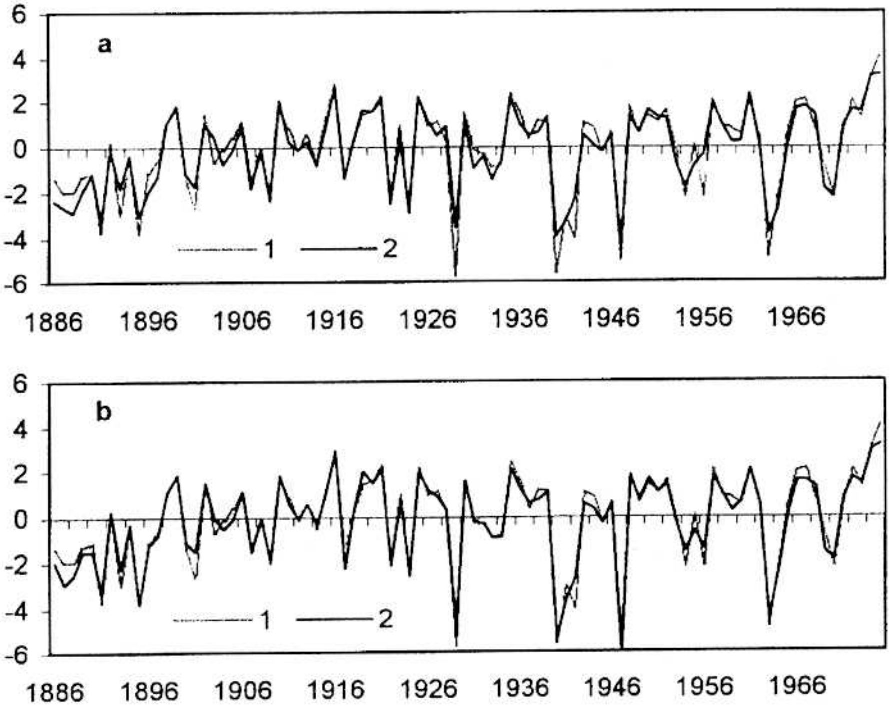

Fig. 5. The comparison of the measured (1) and reconstructed (2) winter air temperature anomalies (°C) at Prague-Klementinum (reference period 1901-1960) by the method of linear regression (a) and by averaging temperature deviations (b).

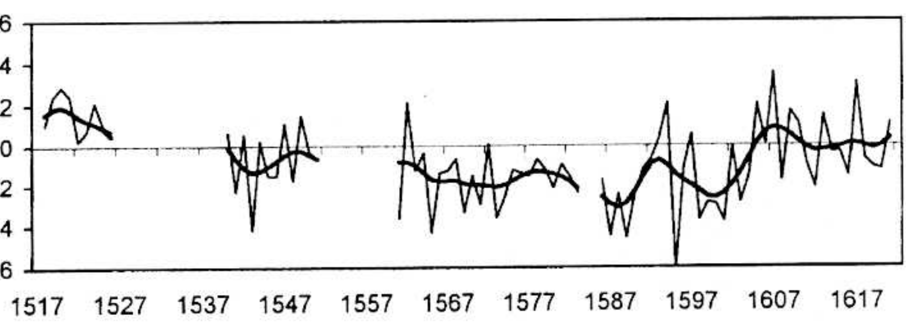

Fig. 6. Fluctuation of winter air temperatures (expressed in the form of temperature anomalies (°C) from the reference period 1901-1960) at Prague-Klementinum in the period 1518-1621. Smoothed by the Gauss filter for 10 years.

Considerable problems arise, however, in their detailed time delimitation, the same as in characterising the corresponding climatic patterns. Today it is possible to consider as classic Lamb's delimitation of MWE by the years 950-1200 (in the greater part of Europe 1150-1300) and LIA by the years 1550-1850 (the main phase 1550-1700) (Lamb 1977). On the example of LIA it is, of course, possible to document the complexity of this problem.

The concept of "Little Ice Age" comes from F. Matthes who states that "We are living in an epoch of renewed but moderate glaciation - a "little ice age" that already has lasted about 4,000 years" (Matthes 1939). In another paper he specifies "... glacier oscillations of the last few centuries have been among the greatest that have occurred during the 4,000 year period ... the greatest since the end of the Pleistocene ice age" (Matthes 1940). Whereas Lamb (1977) states the beginning of LIA in the mid-16th century, according to Porter (1986) it was already around AD 1250 (on the basis of the study of glaciers on the Northern Hemisphere) and according to Pfister et al. (1996, 1999) in central Europe shortly after 1300 (due to the pronounced drop in winter temperatures). From the reconstruction of the climate of the Czech Lands (Brázdil and Kotyza 1995) it follows, of course, that the 1340s-1380s can be considered temperature optimum, when out of the total number of temperature extreme months 60 % were warm. On the contrary, Grove (1988) in her comprehensive treatise of LIA left its time delimitation open on account of the distribution of data then available, even though later she was convinced that LIA was under way on a global scale by about AD 1250-1300 (see Pfister and Brázdil 1999). The essence of the problem seems to be expressed to a considerable extent by the conclusions of Jones and Bradley (1992):

1) The last 500 years have not experienced a monotonously cold Little Ice Age; certain intervals have been colder than others.
2) The coldest periods in one region are often not coincident with those in other regions. There is geographical variability in climatic anomalies.
3) Different seasons may show different anomaly patterns over time.

A similar situation also exists with the delimitation of MWE (Hughes and Diaz 1994), where the situation is substantially complicated by a lower amount of documentary evidence. A possible solution of this complex situation is to take into consideration more proxy data and by their combination try to set up comprehensive series with a broader geographic coverage. Thus, Guiot (1992) reconstructed European temperature patterns at selected grid points during the last millennium by using both documentary and tree-ring data. Bradley and Jones (1993) compiled a series of summer temperatures from the 15th century onwards for all of Europe, combining documentary evidence, tree-ring and glacial data.

Historical climatology also offers significant possibilities in the study of conspicuous climatological anomalies. This revealing approach is documented at the level of monthly temperatures and precipitation by Pfister (1999) for Switzerland. His division of anomalous months is based on the categories warm, cold, dry and wet and from their mutual combination. For the period 1560-1895, overlapping for the most part with LIA, in 71 % of anomalous months there prevail cold months (cold ones 40 %, cold-dry 17 %, cold-wet 14 %). In the warm 20th century (1896-1988) the share of anomalously cold months dropped to 56 % (warm ones 44 %), and in the period 1988-1997 cold anomalies disappeared altogether. That corresponds well with the observed temperature trend (Houghton et al. eds. 1996).

The fact that historical climatology expresses with a great time resolution the climate fluctuation in the period before the beginning of instrumental measurements shows a possibility of utilising these series for the study of the effect of natural climate-forming factors before the effect of man's activity on the climate passed from local and regional scale to the global one. The traditional approach is based on the analysis of climatological series, such as in the paper by Pfister and Brázdil (1999), where the relationships of the central European temperature and precipitation series of the 16th century to the solar factor, volcanic activity and ENSO (El Niño/Southern Oscillation) were looked for. A substantially broader space for the analysis of climate forcing over the past centuries is offered by the employment of General Circulation Models (GCMs) (see e.g. Rind and Overpeck 1994, Rind 1996, Mann et al. 1998) which shows the significant role of the solar factor, volcanic activity and internal variation in the ocean-atmosphere system. According to Hunt (1998), of course, climatic anomalies associated with MWE and LIA can be attributed only to internal mechanisms of the climatic system (according to the 500-year run of GCM). The results of the model do not exclude the possible contribution of external forcing agents which, however, would enhance existing naturally-induced climatic features rather than initiate them. For the verification of GCM historical-climatological data are of essential importance.

Descriptive documentary evidence includes a lot of information about hydrometeorological extremes with the description of their causes and often with a very detailed description of their impacts. Since the series of extremes in the period of continuous observations are often limited to a relatively short time, the obtained information can be significantly completed by historical data. Thus, the 16th century floods on selected European streams were analysed from the point of view of causes, seasonality and impacts (Brázdil et al. 1999), a chronology of extreme floods since the 14th century for the Elbe at Děčín and for the Vltava in Prague being elaborated (Kotyza et al. 1995, Brázdil 1998). Similar chronologies can also be obtained for further meteorological extremes (gales, hailstorms, heavy thunderstorms, etc.), although the fluctuating density of documentary evidence can be a source of inhomogeneity of such series. Also systematic records of the impacts of extremes can be used for the compilation of their chronologies. Thus, de Kraker (1999) utilised the data in dikes accounts (dikes protected a polder region) in the northern part of Flanders for the analysis of storminess (high tides, storms, storm surges) in 1488-1609.

The spreading of the data base in Europe also allows the reconstruction of circulation conditions in the form of mean monthly sea-level pressure charts for the individual months and/or the individual weather extremes (Wanner et al. 1994, 1995, Jacobeit 1997, Jacobeit et al. 1999). The methodology of making those maps was further elaborated by means of canonical correlation analysis (Luterbacher et al. 1999). By means of reconstructed maps it is possible to clarify not only the main features of the fluctuation of reconstructed temperature and precipitation series, but also the differences of the climatic regime in different parts of Europe (Fig. 7). On the other hand, in regions where temperatures and precipitation react sensitively to changes in circulation parameters a possibility is offered for the reconstruction of series of circulation indices, such as NAOI (North Atlantic Oscillation Index - see e.g. Hurrell 1995).

Human activities are markedly affected by sudden disastrous phenomena and events, linked up e.g. with hydrometeorological extremes or considerable climatic anomalies or their frequent occurrence in certain seasons. The precisioning of climatological knowledge of the last millennium can significantly contribute to the clarifi-

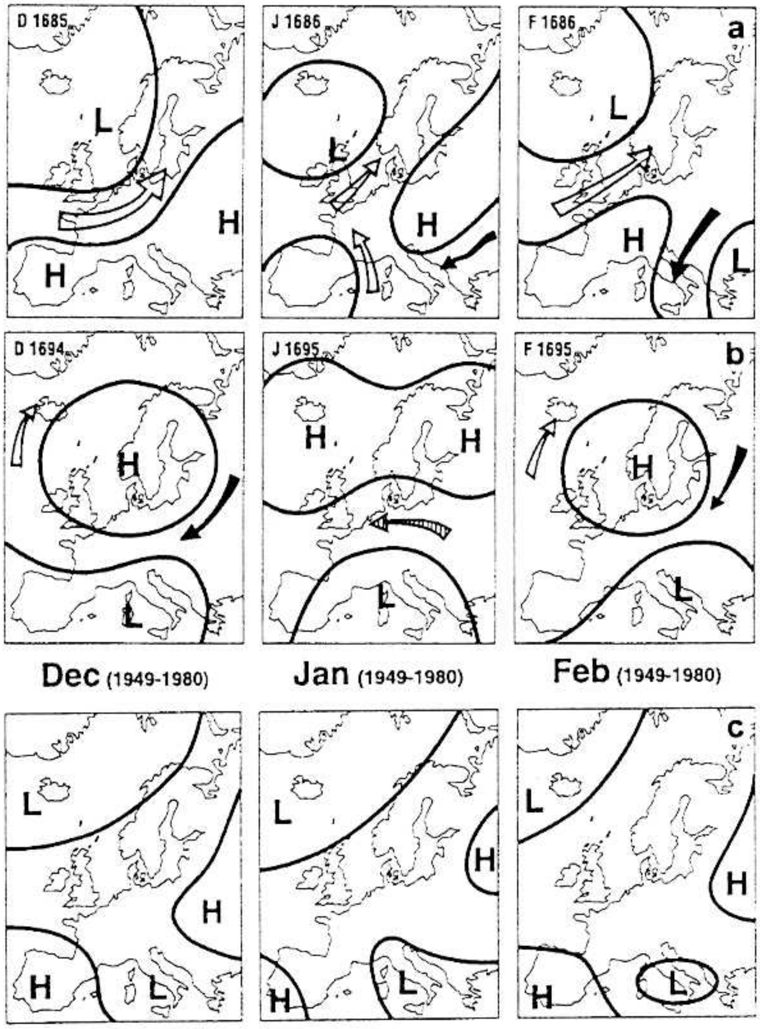

Fig. 7. Monthly mean sea-level pressure maps for winter months: a) mild winter 1685/86, b) severe winter 1694/95, c) average patterns 1949-1980. Arrows: white - warm air advection, hatched - moderate air advection, black - cold air advection. Parts a) and b) according to Wanner et al. (1994), part c) simplified according to Brázdil and Štekl (1986).

cation of some historical events. Well known is e.g. the link of the prices of agricultural crops to the size of the harvest, affected besides other factors also by meteorological conditions (see e.g. Abel 1974, Bauernfeind and Woitek 1999). In the Czech Lands a dramatic rise in grain prices was recorded in the hungry years 1770-1772 caused by big bad harvests due to cold and rainy weather (Anonymous 1859).

Landsteiner (1999) studied the production of wine in four selected regions of the southern part of central Europe in the period 1550-1630. He showed the crop failures from mid-1580s, which continued until the late 1590s or the early 1600s. As wine growing was an important activity and important source of income, such harvest failures had far-reaching consequences. For example, in Lower Austria the collapse of wine production motivated the public to switch from wine to beer consumption.

The sensitivity of the society to meteorological shocks was pointed to by Behringer (1999) who studied the connection between large-scale witch-hunting and the distinctly worsening weather in central Europe between the 15th and the late 17th centuries (e.g. dramatic increase in witch burnings after the early 1560s). Most witches were burned for weather-making which was perceived as having caused crop failures, floods and cattle diseases relate to "unnatural weather," i.e. to weather sequences or single extremes that nobody had known or experienced before.

An assumption for further impact studies is on the one hand the increase in the accessibility of high-resolution climatic data for different geographical regions, calibrated for the conditions of contemporary climate, as well as the change in the hitherto one-sided understanding of historical processes not admitting their affection by the climate and meteorological extremes.

6 CONCLUSION

In 1978 Ingram et al. presented the state of historical climatology as a branch of science. With the gap of more than 20 years the present paper tries to give the characteristic of the present state of historical climatology and the evaluation of historical-climatological research. Historical climatology is defined as a branch of science dealing, on the basis of man-made and natural documentary evidence, with the reconstruction of climate and hydrometeorological extremes, their causal clarification and their impacts on man and nature in the period before the beginning of continuous instrumental observations. Thus it contributes to the knowledge of the state and behaviour of the climatic system in the period of the prevailing effect of natural climate-forming factors at the time when the activity of man on the climate reached only local to regional scale. With respect to palaeoclimatology historical climatology is delimited by the earliest man-made documentary evidence, with respect to instrumental climatology by the beginning of systematic meteorological observations. The time delimitation of historical climatology is thus geographically much heterogeneous. The 1990s can be considered to be the period of the renaissance of historical climatology, which is documented by the extension of historical-climatological research into a number of further countries, by a great rise in the number of papers from this region and a broad international co-operation. Further historical-climatological research should, among others, be oriented at:

a) the extension of existing historical-climatological data bases, their unification and the production of synthetized temperature and precipitation series of a larger geographical extent calibrated to the contemporary climate with the objective of studying past climates,

b) the reconstruction of circulation patterns and the analysis of climate forcing in the pre-instrumental period with a broader utilisation of GCM outputs,

c) the reconstruction of series of climatic and hydrometeorological extremes with special respect to their impacts for the human society (case impact studies).

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HISTORICKÁ KLIMATOLOGIE: DEFINICE, DATA, METODY, VÝSLEDKY

Práce se pokouší charakterizovat současné postavení historické klimatologie a zhodnotit dosavadní historicko-klimatologický výzkum. Historickou klimatologii lze definovat jako vědní disciplínu, zabývající se na základě přírodních a antropogenních údajů rekonstrukcí klimatu a hydrometeorologických extrémů, jejich příčinným objasněním a jejich dopady na člověka a přírodu v období před začátkem souvislých meteorologických pozorování. Přispívá tak k poznání stavu a chování klimatického systému v období převažujícího vlivu přírodních klimatotvorných faktorů v době, kdy působení člověka na klima dosahovalo jen lokálního až regionálního měřítka. Vzhledem k paleoklimatologii je historická klimatologie vymezena nejstaršími údaji antropogenní povahy, vzhledem ke klimatologii období přístrojových měření počátkem soustavných meteorologických pozorování. Časové vymezení historické klimatologie je tak geograficky velmi různorodé. Devadesátá léta našeho století lze považovat za období renesance historické klimatologie, což je dokumentováno rozšířením historicko-klimatologického výzkumu do řady dalších zemí, velkým nárůstem počtu prací z této oblasti a širokou mezinárodní spoluprací. Další historicko-klimatologický výzkum by se měl orientovat zejména na:

a) rozšíření existujících historicko-klimatologických databází, jejich unifikaci a produkci teplotních a srážkových řad většího geografického dosahu kalibrovaných na současné klima s cílem studia minulých klimat

b) rekonstrukci cirkulačních poměrů a analýzu klimatotvorných faktorů v období před začátkem pravidelných přístrojových měření se širším využitím výstupů z obecných cirkulačních modelů (GCM)

c) rekonstrukci řad klimatických a hydrometeorologických extrémů se zvláštním zřetelem na jejich dopady pro lidskou společnost (případové impaktní studie).

Obr. 1. Ukázka denních zápisů počasí ve Stoefflerových efemeridech od Jana z Kunovic (Brázdil a Kotyza 1996).

Obr. 2. Značky nejvyšších vod vytesané na zámecké skále na pravém břehu řeky Labe v Děčíně (Okresní muzeum Děčín, sign. N 12284/1,2).

Obr. 3. Schéma historicko-klimatologické analýzy.

Obr. 4. Doba vysekávání ledu u lounských mlýnů (šrafovaně) podle vyplácených sobotních mezd (hvězdička značí výplatu mzdy za odklízení sněhu) v období 1561-1581: N - listopad, D - prosinec, J - leden, F - únor, M - březen.

Obr. 5. Porovnání měřených (1) a rekonstruovaných (2) zimních anomálií teploty vzduchu (°C) metodou lineární regrese (a) a průměrováním teplotních odchylek (b) pro Prahu-Klementinum (referenční období 1901-1960).

Obr. 6. Kolísání zimních anomálií teploty vzduchu (°C, referenční období 1901-1960) v Praze-Klementinu v období 1518-1621. Shlazeno Gaussovým filtrem pro 10 let.

Obr. 7. Průměrné mapy přízemního tlaku vzduchu pro zimní měsíce: a) mírná zima 1685/86, b) tuhá zima 1694/95, c) průměr období 1949-1980. Šipky: bílé - teplá advekce, šrafované - průměrná advekce, černé - studená advekce. Části a) a b) podle Wannera et al. (1994), část c) zjednodušena podle Brázdila a Štekla (1986).

Translated by Bořivoj H e r z l í k