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SPATIAL ANALYSIS OF DAMAGE CAUSED BY STRONG WINDS AND GALES IN THE CZECH LANDS SINCE AD 1500

P. Dobrovolný, K. Keprtová: *Spatial analysis of damage caused by strong winds and gales in the Czech lands since ad 1500.* – Geografie–Sborník ČGS, 111, 1, pp. 51–69 (2006). – The aim of this article is an analysis of the spatial distribution of places with damage done by gales and windstorms in Czechia in the course of the last 500 years. Descriptive documentary data derived from historical climatology are used for this analysis and the specific features contained within these data are mentioned. Using ArcGIS tools, thematic maps of the locations damaged by gales for each century are presented and the spatial distribution of the places is characterized. This spatial distribution is connected to a large degree with the quantity and quality of available historical sources. However, spatial analysis enables the characterization of the most affected localities and also the most significant cases, "the windstorms of the century".
KEY WORDS: spatial analysis – documentary evidence – windstorm – damage – the Czech Republic.

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Introduction

Meteorological extremes are a perennial cause of substantial material damage and loss of human life. An increase in the frequency and intensity of extreme weather events has often been considered one of the possible consequences of contemporary climate change (Houghton et al. 2001). Precise data about these phenomena from the instrumental period are very limited. An alternative source of information for the temporal and spatial variability of extreme weather conditions from pre instrumental period may be found in written historical records. This field of scientific study, known as historical climatology, deals with the reconstruction of climate based on data of anthropogenic and natural origin, the clarification of causes of climate changes in the past and the evaluation of the impacts they have had on human life and the environment before regular instrumental observation came into practical use (Brázdil 2000). For Central Europe, written records appear to be one of the richest sources of information about the weather and climate in the past. These include reports of personal origin (annals, chronicles, memoirs), visual daily weather records, diaries, personal correspondence, documents relating to contemporaneous economic matters, original newspaper reports and others. These data, as they extend back over a period of up to a thousand years, can be used for the reconstruction of climate (Brázdil and Kotyza 1995a). In the region of the Czech Republic, the number and reliability of weather reports have been of better quality especially since the 16th century. One of the characteristics of these data is the greater attention given to extreme weather events. Chronicles, newspaper reports and personal correspondence are particularly rich in mentions of weather that diverges from the ordinary.

Although historical weather reports have tended to be analysed in terms of aspects of time in recent years, they also have a great potential for the study of spatial variability of extreme weather events. The quality and quantity of historical records led naturally to time changes being prioritised in the early development of methods in historical climatology. Considering the growing number of historical sources, it is now possible to include a spatial differentiation of the phenomena in their interpretation. Studies emphasizing the space differentiation of meteorological or climatic conditions derived from documentary sources can be divided into two groups. The first group includes papers describing the spatial patterns of individual cases of extreme weather events (Dobrovolný and Brázdil 2003a). The other group is based on contributions consisting of descriptions of prevailing circulation patterns. Once information about meteorological conditions from several locations in West and Central Europe becomes available, it is possible to reconstruct the prevailing circulation or the position of the main air pressure systems. Reconstructions of prevailed circulation patterns based on the interpretation of documentary sources have been carried out by, for example, Lamb (1986) or Kington (1988). The growing reliability of reports coming from a rising number of locations has even enabled, in addition to the subjective circulation classifications mentioned, the use of the objective methods of multivariate statistics (Luterbacher et al. 2002; Jacobeit et al. 2003). However, the potential for reconstructing the circulation pattern of a particular past extreme weather event eventually encounters a time resolution barrier. The quality and quantity of historical climatology data enable reconstructions to be carried out at present only at the level of monthly, seasonal or annual averages.

Comparison between present and historical extreme weather events can assist our overall understanding of such extremes. One of the largely unexplored aspects of the current global warming is the role played by the human society. One of the reasons for searching out an alternative source of information in the past is the possibility to characterize natural climatic variability in pre-industrial times and, consequently, to comprehend the influence of anthropogenic factor on the climate. Furthermore, cases of historical extremes contribute to a better definition of potentially threatened areas. One of the most important aspects of these records is detailed description of their progress. However, most cases record only the impacts of these events.

The aim of this article is to describe the spatial variability derived from historical records concerning the damage done by gales and windstorms in Czechia in the course of the last 500 years. The detailed climatological analyses were carried out by Brázdil et al. (2004). First of all, the fundamental characteristics of the data are given, together with their specific features. Methods useful for the analyses of spatial variability based on spatial autocorrelation are described in the third part. The fourth part includes the basic characteristics of the spatial analyses of the records with the help of the methods mentioned. It also presents some thematic maps of the locations damaged by gales for each century, produced in ArcGIS. The spatial distribution of each category is compared with the theoretical distribution, and the specific features of the places are discussed. The character of the damage caused by windstorms is described in the fifth chapter.

The database of historical climatology

The fundamental material consists of records of the occurrence of strong winds and gales on the territory of the Czech Republic over the last 500 years. These can be found in the database of historical climatology compiled at the Institute of Geography, Masaryk University in Brno, over recent decades. The database for the Czech Republic is in parallel with data for other regions – for example, the HISKLID database in Germany, or EURO-CLIMHIST, which includes almost the whole area of Europe (Schüle and Pfister, 1994). The examples mentioned, apart the other things, support the production of simple schemes and maps that concentrate upon the spatial aspect of historical reports. In other parts of the world for example Mikami (1992) made an evaluation of daily records of the weather taken from personal diaries and transformed them into historical synoptic maps of Japan.

Individual records can differ widely in quantity, quality and accuracy of time evaluation, depending on the origin of data or even the personality of the author. For example, descriptions of the consequences of historical windstorms, those that did a great deal of damage, are often highly detailed and extensive when recorded in chronicles or newspaper reports. On the other hand, notes of daily observations may include concise descriptions of weather, written in the specific style of the author. In spite of such a wide range of various sources in the historical record, five fundamental attributes may be often derived for each of them: the date of the event, the place of occurrence, a concise description of the type of event, the actual text and the original source. These five attributes may be further extended during the interpretation process.

The degree of accuracy in dating specific events differs in many ways. However, it is possible to distinguish four levels: year, season, month and day. Quite a large number of the records are dated to around a reasonably specific period of time, for example religious feast-days (Easter, Christmas, etc) or annual events (harvests, carnivals etc.). Therefore special attention needs to be paid to sorting out events, especially those related to the winter period. It has often been possible, from further documents or other similar records, to allocate a year to the given record. There was quite a large set of reports whose proper time specification needed individual approach and often was based on a comparison of several records. This is the case of all reports dated only by religious holidays (for example records 'before Easter'). An examination of the records in their wider context is nearly always required.

To be able to map the events it is important to deal with their spatial aspect. In many cases, the records mention some settlement or at least a part of it. If the report mentions a location that no longer exists or, in some cases, a minor location that has become part of a vast settlement, the matter needs an individual approach. Quite a large number of records, especially older ones, are not related to individual places. They describe such larger areas as mountains, forest regions, districts or whole lands (Bohemia, Moravia, and Silesia – Fig. 1). In the same way, cases in which locations are known by the same name need to be treated individually. Reports from surrounding countries also play an important role in the process of interpretation.

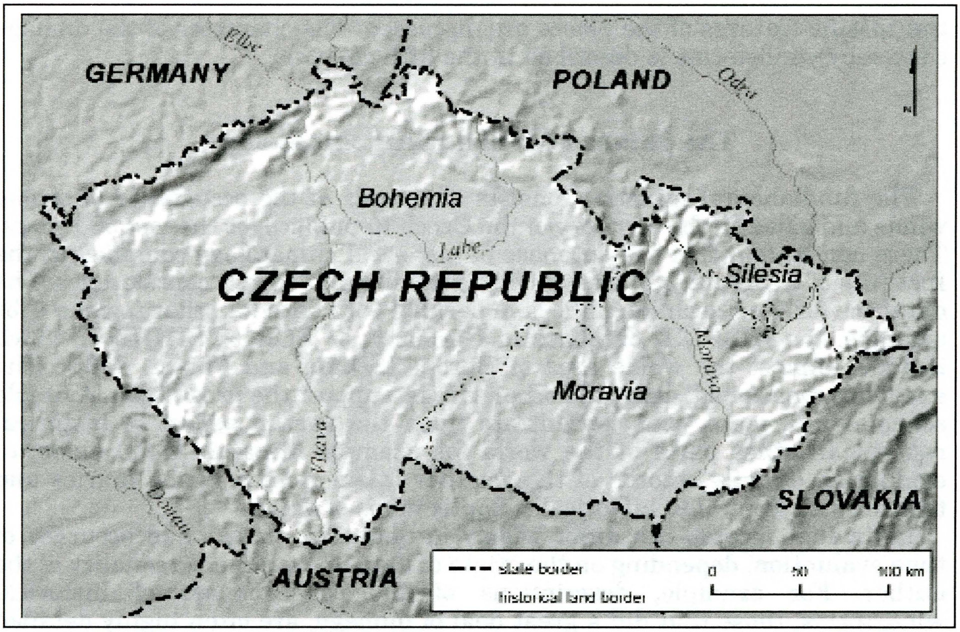
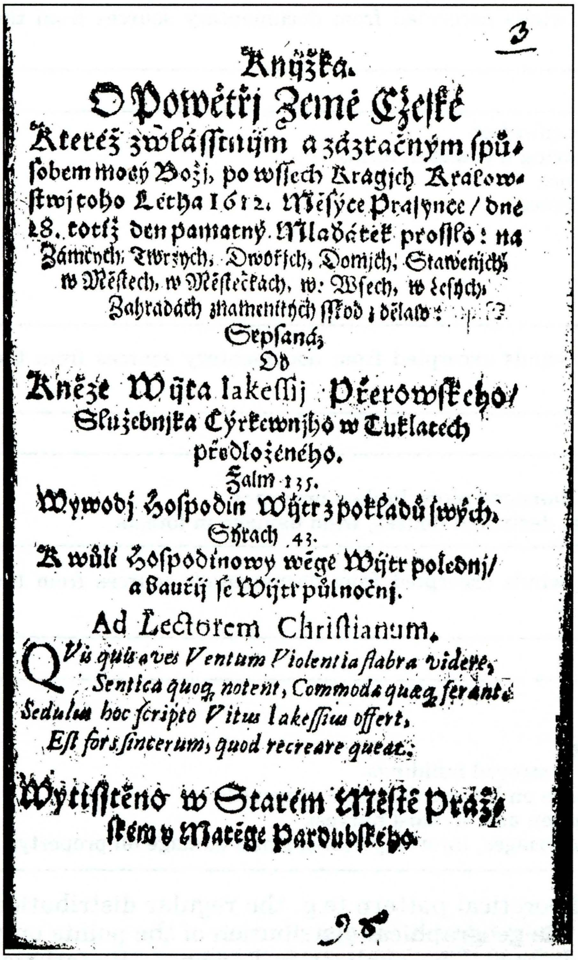


Fig. 1 – The territory of Czech Republic with the names of its historical lands

The third substantial step is to classify the events into individual types. Verbal descriptions of weather conditions and related phenomena can vary considerably from case to case. They may be represented by only a few words or several pages (Fig. 2). Especially in the sixteenth and seventeenth centuries, reports of the occurrence of extreme meteorological events may often be hidden within a colourful depiction of unusual phenomena in the atmosphere connected with stormy activity, perceived as a "miracle" in which people sought various missions or revelations. The description of a gale during a storm recorded on 14 March 1576 at Čestín in central Bohemia is one such example (Paprocký, 1602): "... When the storm broke out ..., people saw evil spirits in it, as if riding three stalls and, having passed the mansion, they turned to the sheep-pen, lifting it up and toppling it, so that where it had stood an empty place remained." The character of these reports and the explanation of the phenomena observed was, of course, a reflection of very limited knowledge of atmospheric processes and their physical nature. Furthermore, in many cases the consequences of event are described rather than the phenomenon itself. Nevertheless, from such accounts it is then possible to evaluate the intensity of the phenomenon and its impacts on society at the time.

Methods of mapping and the study of spatial distribution

The file of historical weather reports corresponds to a large degree with the quantity and quality of available sources. It is clear that many events have remained hidden from the eyes of chroniclers or, in other cases, have not, for various reasons, been excerpted yet. The facts may often be fragmentary and may not contain comprehensive data of the spatial extent of the event or the



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Knjžka.

O Powětřj Země Cžeské

Kterěž zwlásstnijm a zázračným spů-
sobem mocý Božj, po wssech Kragjch Králow-
stwj toho Létha 1612. Měsýce Prasynce / dne
28. totiž den památný Mláďátek prosslo: na
Zámcých, Twrzých, Dworsých, Domjch, Stawenjch
w Městech, w Městečkách, w Wsech, w Lesých,
Zahradách znamenitých sskod i dělalo:

Sepsaná

Od

Kněze Wjta Jakessj Přerowského/
Služebnjka Cýrkewnjho w Tuklatech
předloženého.

Žalm 135.

Wywodj Hospodin Wjtr z pokladů swých.

Sirach 43.

K wůli Hospodinowy wěge Wjtr polednj/
a Baučj se Wjtr půlnočnj.

Ad Lectorem Christianum.

Qui quis aves Ventum Violentia flabra videre,
Sentica quoq; notent, Commoda quaeq; ferant:
Sedulus hoc scripto Vitus Iakessius offert,
Est fors sincerum, quod recreare queat.

Wytisstěno w Starém Městě Pražs-
kém v Matěge Pardubského.

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Fig. 2 – The title page of a moral tract by the priest Vít Jakeš Přerovský, written in reaction to a disastrous windstorm in the Czech Lands on 28 December 1612 (Brázdil et al. 2004a)

damage done by it. Despite of the missing parts of the puzzle, it is possible to define the damage from the viewpoint of spatial distribution and also to specify the main affected areas for individual kinds of damage.

Dobrovolný and Fukátko (2003) describe the process of transforming historical data from an original analogue database into detailed digital form. A set of tools for this process has been developed with the support of ArcView GIS. This enables a step-by-step separation of the original historical data for individual locations and the addition of other descriptive attributes. These tools are capable of storing such additional information as, for example, the accuracy of data, the intensity of the event, and characteristics of the damage. Their main contribution is to the selection of certain types of events and to their presentation in the form of thematic maps. In the case of windstorms, individual cases have been examined to define the basic types (Table 1) and the extent and character of damage (Tables 2 and 3).

The cartographic presentation of events plays an important role in the description of spatial configuration. This can be done in either point or area form. Considering the problems mentioned above with the fullness of historical reports, the damage has been related to the places mentioned in the report. These places have been presented as points for the subsequent analysis of spatial variability. As Lee and Wong (2001) point out, the study of a particular spatial configuration (in our case locations with damage from strong wind) may be compared with the theoretical configuration. There are three types of theoretical configuration: clustered, regular, and random. Two of the methods applicable are discussed at a later point.

Nearest neighbour analysis is an easy method, useful for the description of spatial configuration of points (Lee and Wong 2001). The method is based on a comparison of two variables – an observed average distance between the two nearest locations within the investigated area and the average distance of the

Table 1 – Classification of strong winds excerpted from documentary sources from the viewpoint of the recorded event

Code	The type of event
T0	wind without detailed specification
T1	squall (i.e., gusty wind during a thunderstorm)
T2	tornado – proved occurrence
T22	tornado – probable occurrence
T222	dust devil
T3	strong wind, blizzard
T4	gale
T5	violent windstorm

Table 2 – Classification of strong winds excerpted from documentary sources from the viewpoint of the extent of damage

Code	Extent of damage
E0	damage not mentioned
E1	damage of lesser extent, damaged roofs, broken branches
E2	areally extensive damage, destroyed houses, wind damage in forests

Table 3 – Classification of strong winds excerpted from documentary sources from the viewpoint of the character of damage

Code	Character of damage
DO	casualties (lost lives)
DL	wind damage in forests
DP	small damage on buildings
DB	considerably damaged or destroyed buildings
DS	uprooted fruit trees, damage on hop-gardens and vineyards
DU	damage on field crops, garden and orchard harvest
DJ	other damage (upturned carriages, injured persons, small damage on property)

two nearest locations of the theoretical pattern (e.g. the regular distribution of points in space). In reality, the geographical distribution of the points only exceptionally forms an even pattern. The application known as R-statistics may be used for testing whether a definite distribution of the points in the area studied has a certain pattern. It is determined as the proportion between the observed and the expected average separation distance of the nearest neighbours in a certain area:

$$R = \frac{r_{obs}}{r_{exp}}$$

The figure r_{obs} can be determined when the distance between the given point and all its neighbours is given. Then the shortest distance has to be found – the nearest neighbour. This process is repeated for all the points. The average figure is calculated from all of the shortest distances. To work out the average distance of the nearest neighbour for a theoretical random distribution the following expression is used:

$$r_{exp} = \frac{1}{2\sqrt{(n/A)}}$$

where A is area of the study region and n is number of points. Spatial distribution of points approaches a cluster distribution for all cases with

$R < 1$ ($r_{obs} < r_{exp}$). On the other hand, the distribution approaches the regular one if $R > 1$ ($r_{obs} > r_{exp}$).

This method works only with the position of points in space. It does not consider the value of their attributes – in our case the number of the recorded cases of windstorms causing some damage in the location or the number of individual types of damage. Both parameters, the position and attributes, are evaluated by methods based on the concept of spatial autocorrelation. It is assumed that most processes change in space more or less continually. The near points would have similar values of the examined phenomenon and vice versa. Moran's Index (Moran's I) is among the most frequently used coefficients of spatial autocorrelation (Lee and Wong 2001). The following notation is used in the equations presented:

x_i – value of the studied attribute at point i

c_{ij} – measure of similarity of attribute at points i and j

w_{ij} – measure of similarity of distance between points i and j; $w_{ii} = 0$ for all the points

n – number of points in the study area

s^2 – variance of all x values.

In Moran's I, the similarity of values of the attribute at points i and j is given as follows:

$$c_{ij} = (x_i - \bar{x}) \,.\, (x_j - \bar{x})$$

Moran's I is then set as:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \cdot w_{ij}}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \cdot (x_i - \bar{x}) \cdot (x_j - \bar{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

The measure of positional similarity of points i and j (w_{ij}) is generally considered as the inverse value of the distance between these points. Therefore the more distant points are of less importance and the less distant points of more importance:

$$w_{ij} = 1/d_{ij}$$

The interpretation of Moran's I is based on the comparison of the value calculated for a specific set of points with an expected value. The equation for the expected value calculation of Moran's I has been introduced by, for example, Lee and Wong (2001). The value of the Moran's I is often expressed in the form of a standardized value (Z-score), which is a measure of the distance in standard deviations of a sample from the mean. If the achieved value of the Z-score is outside the interval (–1.96;+1.96) then the studied spatial distribution of points differs significantly from the random one at a level of $\alpha = 0.05$.

Analysis of spatial distribution of places with damage done by wind

As mentioned above, the character of description of strong wind events in documentary sources, their temporal and spatial extent has changed

Table 4 – Numbers of strong winds in the territory of Czechia during the last millennium determined according to documentary sources

Period	Number of cases
before 1500	47
1500–1599	249
1600–1699	298
1700–1799	344
1800–1899	698
1900–1999	787

significantly over recent centuries. This will, of course, also be reflected in the spatial analysis of damage from strong winds in Czechia. The overall number of cases for individual centuries is given in Table 4. The low frequency of data on strong winds up to the year 1500 does not permit their serious evaluation (Brázdil and Kotyza 1995a). A marked increase in the number of reports on strong winds begins in the 16th century. Figure 3 presents the spatial distribution of places reporting wind damage during the 16th century. Within this "older" period we can assume that a number of cases of windstorms cannot be found in the historical records, especially those concerning areas of borderland mountains with lower populations. If the database includes 47 cases of windstorms from the period before 1500 AD, then in the 1500 to 1599 period, 249 cases are related to 112 locations. Most cases for the 16th century are derived from reliable records kept in larger settlements.

The highest number of reports is related to Prague (42 cases), where records of strong winds are represented relatively regularly for the whole 16th century. Altogether, 30 cases of strong winds are documented from the region of south-eastern Moravia, based on daily records kept by Jan of Kunovice (Brázdil and Kotyza 1996). Next, according to the number of records, follows Litoměřice (29 cases), for which the main sources have been records from the Memorial Book of Litoměřice, 1570–1607. Also frequently represented are Náměšť nad Oslavou

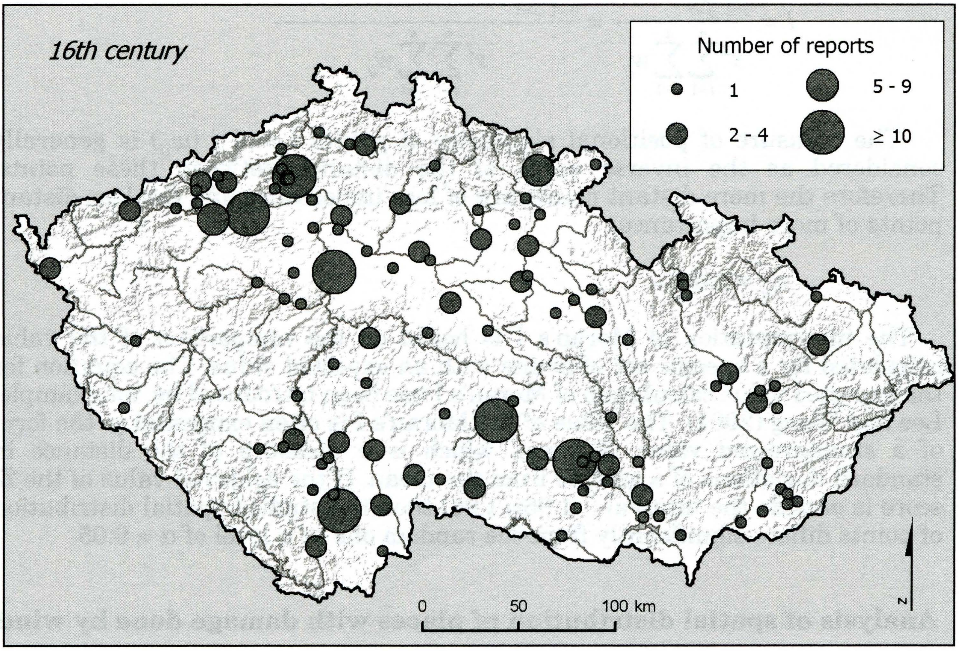

Fig. 3 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 16th century

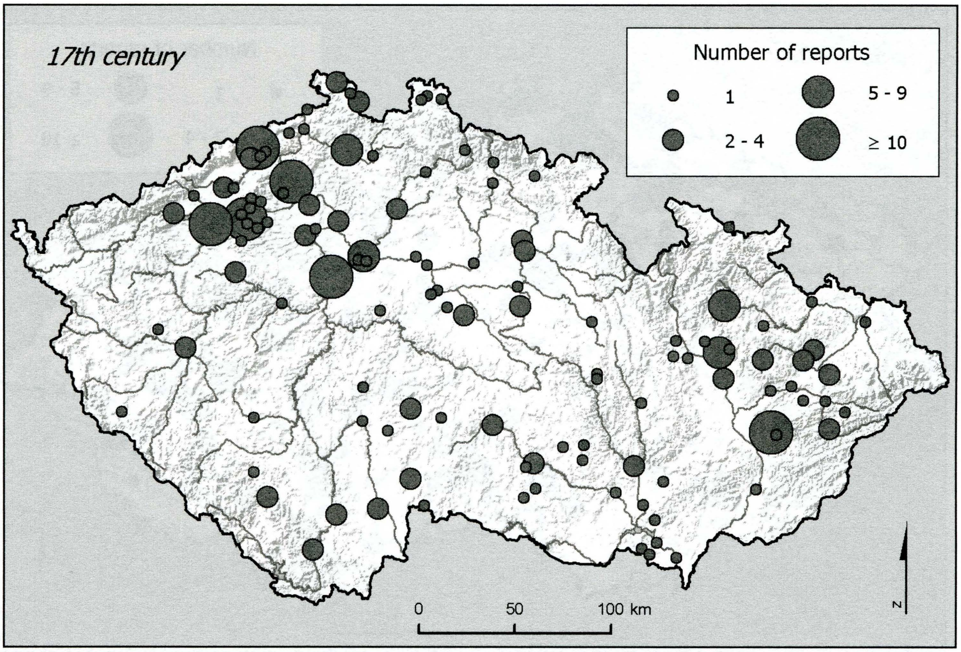

Fig. 4 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 17th century

(24 cases), thanks to the daily records kept by Karel Starší of Žerotín (Brázdil and Kotyza 1995b), followed by České Budějovice (21 cases), Louny (18 cases) and Jihlava (14 cases). The given locality in these records also reflects the place, which the author lived in, as it may be in some cases different from the place of occurrence of a windstorm mentioned. This is a further reason for the higher number of reports for the above towns. A more frequent localization of places in central and north-western Bohemia is evident from spatial distribution, while the lowest number of places is related to western Bohemia and to Silesia. Of 15 reports that do not mention an actual place and have a rather general character, 13 are related to Bohemia and 2 to Silesia.

For the 17th century, 298 cases of strong winds have so far been established. Overall, reports of strong winds are related to 121 actual places in the territory of Czechia (Fig. 4). As in the case of the 16th century, these localities often express where the author of the report lived. The highest number of strong winds was recorded in Prague (47 cases) again, next at Krupka in the north-western Bohemia region (31 cases), Louny (18 cases), Litoměřice and Žatec (both 11 cases). The high number of records from Krupka is linked with the memorial book kept by Michel Stüeler (Brázdil et al. 2004b). In Moravia, the highest frequency information (11 cases) appears in the Chronicle of Holešov (Fialová 1967). In comparison with the preceding century, more reports appear for central Moravia and Silesia, whereas the minimum of places in western Bohemia is joined by a lower number of places in the southern half of Czechia. Among the larger territorial units, 82 cases of strong winds concern central Bohemia.

For the 18th century, 344 cases of the occurrence of strong winds have been established in the territory of Czechia. A greater number of authors

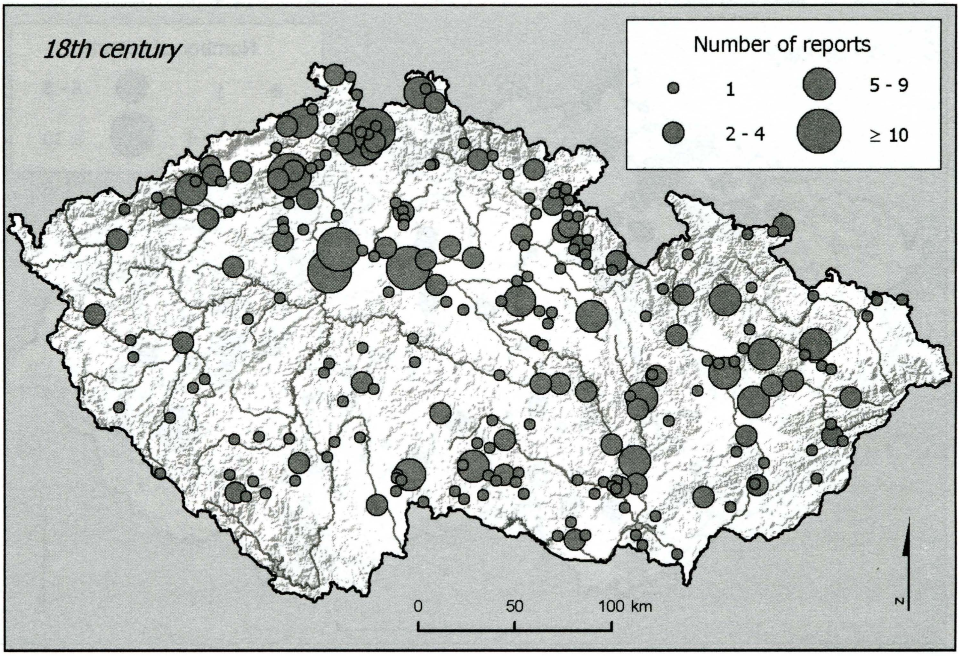

Fig. 5 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 18th century

describe windstorms of particularly large areal extent compared with the previous period. The character of sources and source material also changes in the course of the 18th century. New sources appear (e.g. newspapers) and it becomes possible to more utilize community and family chronicles or personal diaries with regular daily records. At the same time, the number of records of an economic character also increases, above all from forestry management. Reports of winds relate to a total of 236 places in Czechia (Fig. 5).

Similar to the preceding centuries, a high number of reports again comes from Prague (86 cases), central and north-western Bohemia. However, the number of documented gales from the region of the Bohemian-Moravian Highland, the Nízký Jeseník (Highland), central Moravia and from higher-situated border places increases conspicuously. With the increase in the number of reports, locations with natural presumption for the occurrence of strong winds (places exposed to the prevailing airflow, places in higher altitudes, etc.) start to be reflected in their spatial distribution. A lower number of wind calamities was observed in the 18th century in the region of western Bohemia, the Bohemian part of the Bohemian-Moravian Highland and also around Ostrava. As well as these, 35 events are related to larger regions with respect to the place of occurrence.

The chronology of strong winds in the 19th century includes 698 cases. As the density of the records grows, the number of events documented rises, both in terms of more sources and a higher number of places. Particularly for the latter half of the 19th century, the daily press becomes a very important source of data. The material collected relates to 402 places (Fig. 6) and in another 38 cases the reports concern extensive regions.

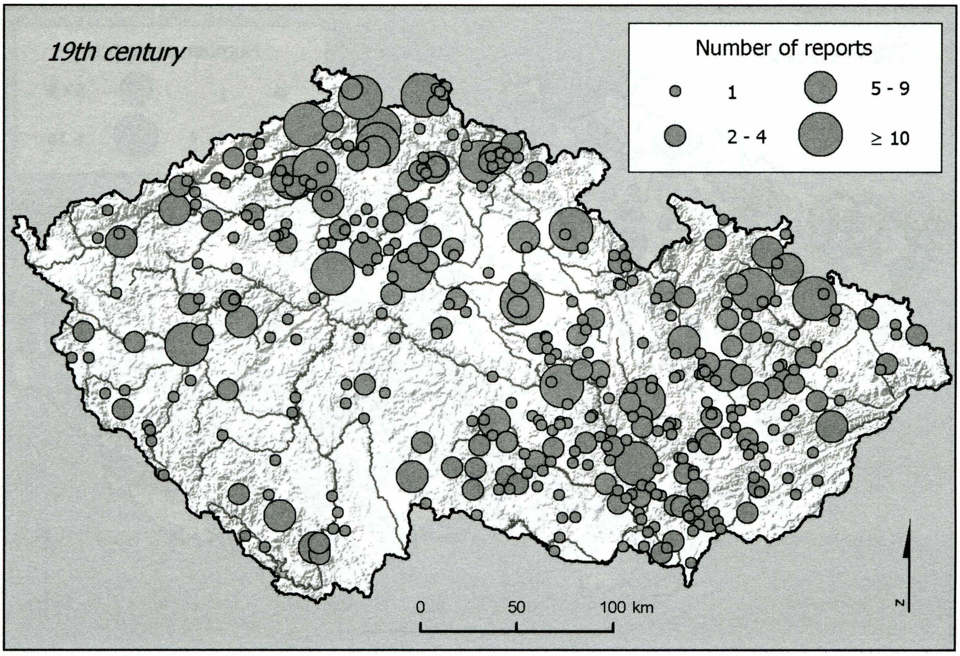

Fig. 6 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 19th century

A higher density of reports for Moravia is evident from Fig. 6. In Bohemia, north-western, north and north-eastern regions of country are the most markedly represented. Essentially fewer strong winds in the 19th century were established in the region of western Bohemia and also in the Bohemian part of the Bohemian-Moravian Highland. Frequent reports come from Jablonné v Podještědí (182 cases), Noviny pod Ralskem (119 cases), Litoměřice (67 events), Děčín (24 events), Brno and Frýdlant (22 events each).

As may be expected, the 20th century is represented by the highest number of cases in the database of strong winds – almost 800 records. This markedly higher number of reports is above all the result of systematic excerption of sources that, for the earlier period, have not so far been fully utilised (newspapers) or are not available. At the same time, this number of records indicates to what extent so far collected documentary evidence for the 16th-19th centuries underestimate the actual numbers of strong winds.

Regardless that both the character of the input material and the nature of the reports themselves change in the 20th century, from the point of view of comparability the same criteria have been used for the inclusion of individual strong winds into groups, considering both the types, and the extent and character of the damage done. Reports about wind calamities relate to 780 places altogether (Fig. 7). A relatively notable number of reports do not mention a particular place; wind damage is related to a broader region, from the whole of the Czech Republic down to individual border mountains, parts of districts, etc. Most reports about strong winds are associated with large towns: Brno (116), Prague (86), Ostrava (45), Jihlava (35), Olomouc (32) and Plzeň (23). Since the Moravian editions of individual newspapers have started to be excerpted, the numbers of gales for Moravian districts are higher than

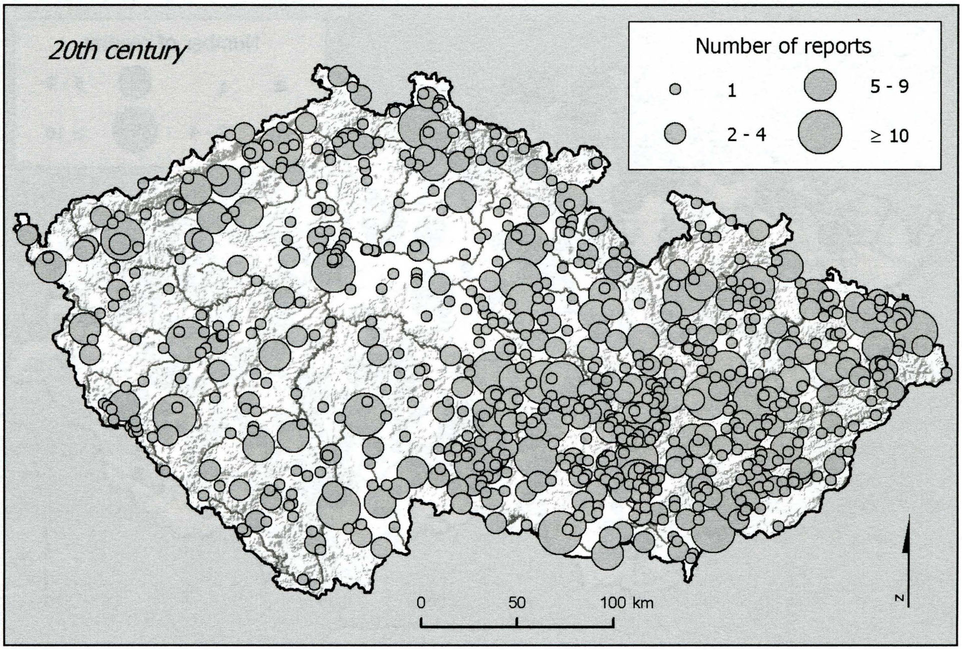

Fig. 7 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 20th century

for districts in Bohemia. This holds above all for the region of the Bohemian-Moravian Highland, the Jeseníky (Mountains) and partly for south-eastern Moravia. Central Bohemia appears to be a region with a lower number of settlements affected by wind calamities. This is probably linked to the fact that primary attention is paid to Prague when wind disaster strikes. Furthermore, a total of 490 strong winds have been quoted for large territorial units such as the border mountain regions.

The spatial distribution of frequency of windstorm records in the territory of the Czech Republic for individual centuries has been also evaluated with the aid of nearest-neighbour analysis and the method of spatial autocorrelation based on calculation of Moran's Index. The results are shown in Table 5.

The distribution of locations for the records of wind damage for the 16th, 17th and 20th century can be characterized as random when evaluated in Moran's I values, whereas the distribution from the 18th and 19th centuries can be classified as clustered. The reason for this lies rather in the quantity and credibility of the data evaluated than in meteorological causes or the physical-geographical predispositions of individual regions within Czechia. The clustered character in the distribution of places with the wind damage is due to a high number of reports from the locations from which the visual daily observations were excerpted. This is the case of observations made by Joseph Dominik Freisler in Jablonné v Podještědí or records made by Anton Lehmann in Noviny pod Ralskem during the first third of the 19th century. Short reports about strong winds prevail in both sources. Due to the specific utterance and subjective evaluations of weather events of authors such type of reports sometimes considerably overestimates the real number of windstorms.

Table 5 – Spatial statistics of places with the strong wind events in Czechia for individual centuries. Statistically significant values for the level of $\alpha = 0.05$ are in bold types.

Period	Nearest neighbour analysis				Moran's I		
	observed	expected	R statistic	Z – score	observed	expected	Z – score
1500–1599	12 971.2	13 874.2	0.9349	–1.3178	–0.0312	–0.0090	–1.1635
1600–1699	11 992.5	14 069.5	0.8524	**–3.1065**	–0.0164	–0.0083	–0.5395
1700–1799	8 871.3	10 602.0	0.8368	**–4.7361**	0.0101	–0.0044	**2.2160**
1800–1899	6 796.5	8 333.6	0.8156	**–6.9596**	0.0256	–0.0026	**6.1184**
1900–1999	5 324.4	6597.4	0.8071	**–9.9595**	–0.0052	–0.0014	–1.4048

The final results of the nearest neighbour method indicate a clustered character in all except the 16th century. The ability of this method to evaluate the spatial distribution of point patterns is, however, less significant comparing to Moran's I values. The nearest neighbour method does not address the numbers of reports from individual locations but only their mutual distancing. Lower number of documentary evidence about strong winds and gales for 16th century can be the cause of this different evaluation comparing to 17th – 20th centuries.

Characteristics of damage done by gales and windstorms

It is often possible to derive the extent and nature of damage from a great number of reports on historical windstorms. However, the proportion of reports that enable interpretation of such information varies over time. Moreover, it depends largely on changes inherent in certain types of reports and also on individual authors.

In the 18th century, for example, František Jan Vavák from the central Bohemian village of Milčice, mentioned 30 cases of strong winds for the period from 1774 to the end of the 18th century and for a half of them he also gave an account of actual damage. Further, in the memoirs of Jiří Václav Paroubek of Líbeznice (Třebízský 1884-1885), a village north-east of Prague, 21 notes of strong winds for the period 1740-1770 may be found; actual damage to property is mentioned in only seven cases. Further, the highest number of cases for the first third of the 19th century was documented by Joseph Dominik Freisler in his records from Jablonné v Podještědí (182 cases) and by Anton Lehmann for Noviny pod Ralskem (119 cases). In both sources, short reports about strong winds in the 19th century prevail, lacking notes about damage. In general, it can be said that the percentage of reports including data about actual damage caused by winds has grown progressively. This proportion is rather low in cases of daily records from the 19th century and indicates, in particular, an over-estimated number of windstorms.

Figure 8 presents the nature of damage done by strong winds in the 16th century. The nature of individual records may be influenced by the prevailing economic and social situation. In general, damage of various degrees to buildings dominates within the larger settlements in Bohemia. Minor damage to roofs is typical of more solid urban dwellings; cases of total destruction tend to be confined to rural dwellings of lighter structure. A vast number of reports that do not specify the types of damage in southern Moravia is associated with the daily records of Karel Starší of Žerotín.

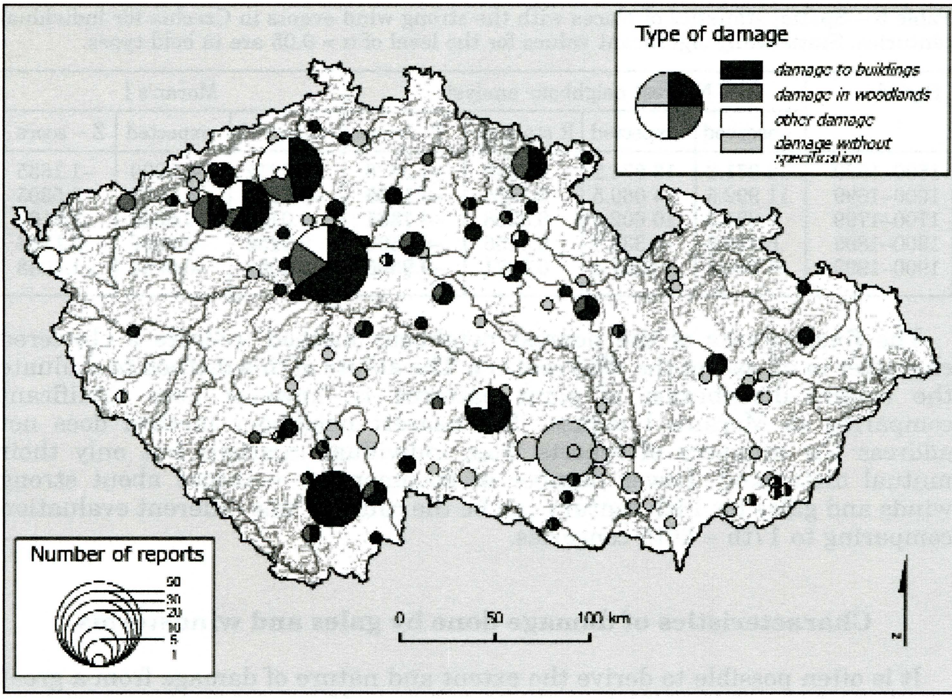

Fig. 8 – The main types of damage caused by strong winds and gales during the 16th century

In more distant periods of the past, records of damage to woodlands and the rural landscape are somewhat rare. This can be deduced from the number of forest calamities (Fig. 9). They are less frequent during the 16th and 17th centuries. According to Vicena et al. (1979), human pressure on forests began in earnest at the beginning of the 18th century. The increased number of historical records mentioning forest calamities in the 18th and 19th centuries might be connected with improved registers of forest management, with the planting of the same-age monocultures and also with the shift of tree species planted in non-indigenous altitudinal environments. Málek (1985) gives a number of reports on the occurrence of the forest calamities resulting from wind in the territory of the Bohemian-Moravian Highland from the 19th and 20th centuries. In a similar way, the historical-climatological database includes information about the damage done by gales and strong winds in the forests surrounding Děčín (North Bohemia) from the first half of the 19th century (Nožička 1962). All these gales fall in the period 1813-1845 and are characterized as spatially extensive windstorms with great damage that certainly affected other places as well.

As can be seen from Figure 9, the increased frequency of wind calamities in forests, with especial reference to the 19th and 20th centuries, is associated with the areas of borderland mountains and also with the area of the Bohemian-Moravian Highland. The greater number of these cases in Moravia when compared with Bohemia is especially due to the quality and amount of excerpted material. In the same way, reports of forest wind calamities in the 19th century may be more common in the middle altitudes of the highlands

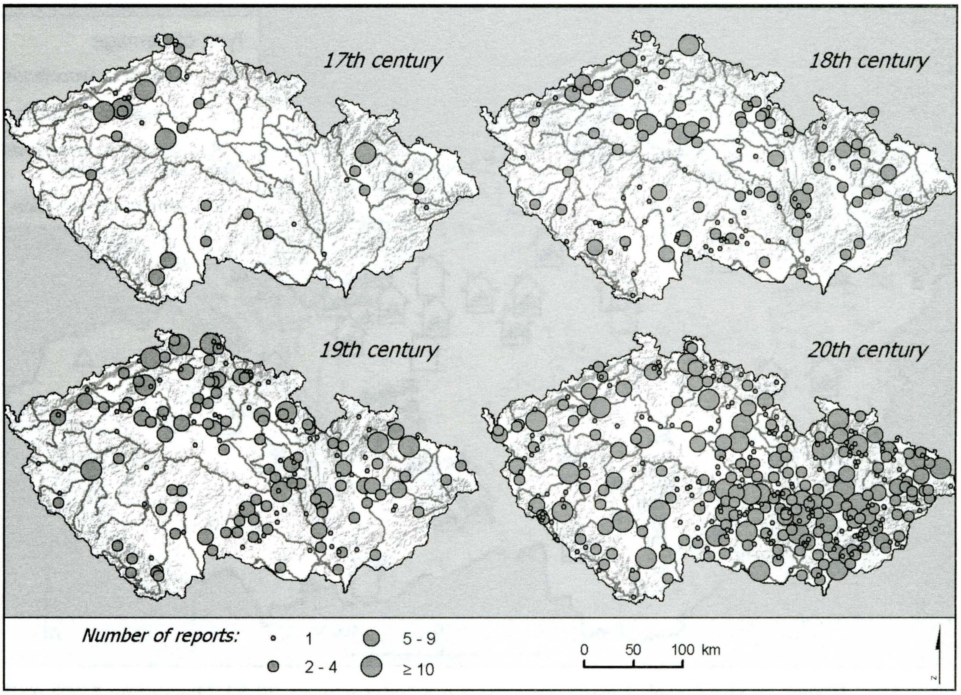

Fig. 9 – Number of reports on wind damage in forests recorded for individual places in the territory of Czechia, 17th – 20th centuries

than in borderland mountains. The lowest number of reports comes from the area of western Bohemia.

Using the database compiled, it is now possible to define the extent and character of damage done by the most significant windstorms, which may be defined as 'the windstorms of the century' (Brázdil and Dobrovolný 2001). In most cases they are winter-type windstorms affecting a great number of locations. These types of storms are often mentioned in records from surrounding countries. One example is a windstorm that affected the territory of the Czech Lands on 20-21 December 1740 (Fig. 10). With respect to both the quantity of records and the number of affected areas this is the best-recorded historical windstorm in the Czech Lands before 1900 AD. The storm was also reported in France, Austria, Germany and Spain. The records state that the windstorm came to the area of Czechia from the north-west. The first gusts were observed in south-west Bohemia in the early-evening hours. It reached central Moravia at around 8.00 pm. The storm lasted the whole night until the following day and caused considerable material damage. As far as can be ascertained, the most affected areas were north-east Bohemia, the Bohemian-Moravian Highland and the Drahanská vrchovina (Highland), but also southern Bohemia and the area of the Jeseníky (Mountains) in North Moravia. Forest areas in particular suffered considerable damage. According to the records of the Šebesta family from Klatovy (Hostaš 1895) 'hrozný vítr … třetí díl lesů v české zemi zporážel' (i.e., a terrible wind … uprooted a third part of the forests in the Czech Lands). Brázdil et al. (2004a) list all the affected locations and sources, mentioning the damage during this windstorm. Unfortunately, the sources enable only a small fraction of the data to be found

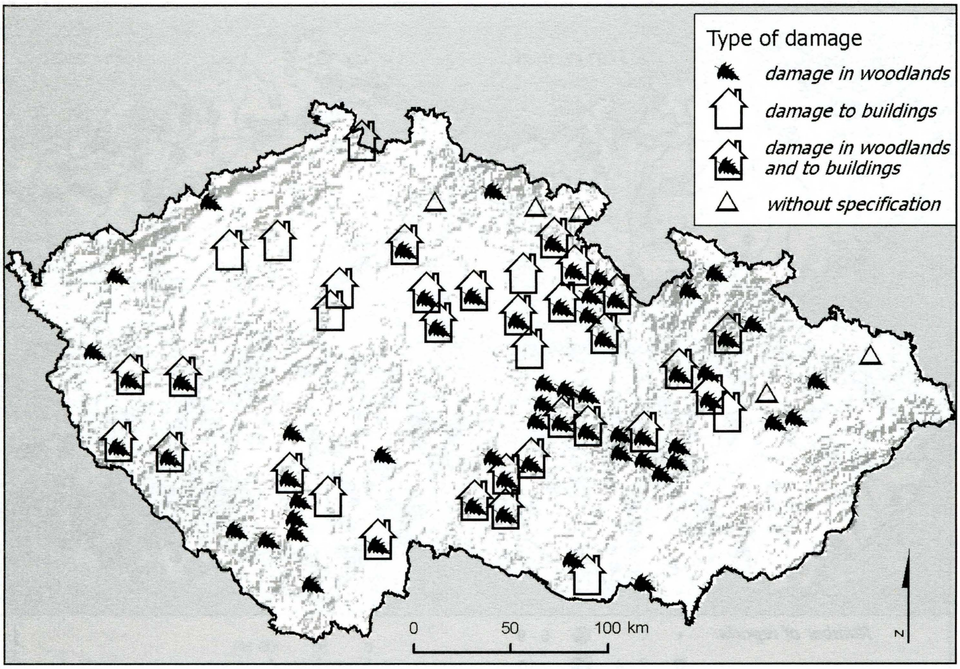

Fig. 10 – Places in the Czech Lands reporting a windstorm on 20-21 December 1740 with the main types of damage

that could help to analyse the meteorological parameters of the windstorm. Luterbacher et al. (2002) carried out a reconstruction of the mean sea level pressure (MSLP) field based on historical climatology data, but only at the monthly level. They define December 1740 as a month with an excessively expressed zonal circulation. This type of circulation is often connected with the occurrence of windstorms in the area of Central Europe (Dobrovolný and Brázdil 2003b). However, for a detailed analysis, the daily MSLP values would be far more valuable than a monthly average. The occurrence of such a gale is far more likely to be connected with a changeover of circulation patterns than with average MSLP conditions. However, a reconstruction of the daily MSLP fields and the position of the main circulation centres derived from the data of historical climatology are not available at present.

Conclusion

The effort that is being put today into the expansion and improvement of the database of historical climatology offers new opportunities for analyses and presentations. The analysis of data in their spatial context often enables, apart from their verification through cross-referencing, their more convenient interpretation. Especially in cases of remarkable extreme weather events it is possible to find data from a great number of locations. When compared with the present instrumental data, the written record sources, in particular, describe the impact of these events together with the extent and nature of the damage. The spatial analysis of wind damage enables the characterization of the most affected localities. However, in most cases, it depends on the reliability of the source material. The spatial analysis of the most significant cases of gales offers the most valuable data. These can assist as analogues for current extreme weather events, towards a better understanding of their origin and also for more effective prevention.

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Shrnutí

PROSTOROVÁ ANALÝZA ŠKOD ZPŮSOBENÝCH SILNÝM VĚTREM A VICHŘICEMI V ČESKÝCH ZEMÍCH OD ROKU 1500

Meteorologické extrémy způsobují každoročně značné materiální škody i ztráty na lidských životech. Právě zvýšený výskyt extrémních projevů počasí se uvádí jako jeden z možných důsledků globální změny klimatu (Houghton et al. 2001). Protože data o meteorologických extrémech z instrumentálního období jsou z časového hlediska omezena, je třeba hledat alternativní zdroje informací o těchto jevech. K takovýmto zdrojům pro před instrumentální období patří mimo jiné údaje z dokumentárních pramenů. Patří sem zápisy v análech, kronikách, pamětech, dále vizuální denní pozorování počasí, záznamy ekonomické povahy, zprávy v novinách, osobní korespondence apod. Sběrem, analýzou a interpretací těchto tzv. proxy–dat se zabývá historická klimatologie.

Jestliže zpočátku byl v historické klimatologii akcentován především časový aspekt zpráv a byly sestavovány různé chronologie, rostoucí množství a kvalita shromážděných údajů umožňuje v současné době analyzovat i vlastnosti prostorového rozsahu zaznamenaných zpráv.

Předložený příspěvek se zabývá prostorovou analýzou zpráv o škodách způsobených silným větrem a vichřicemi v českých zemích od r. 1500. Vstupním materiálem jsou údaje z databáze historické klimatologie Geografického ústavu přírodovědecké fakulty Masarykovy Univerzity v Brně. Zprávy o výskytu vichřic obsahují vedle vlastního popisu události také více či méně přesné údaje o době výskytu, postižených lokalitách či o charakteru způsobených škod. Podle těchto prvotních údajů byl každý záznam v databázi dále kategorizován z hlediska typu události (tab. 1), rozsahu (tab. 2) a charakteru způsobených škod (tab. 3). Při vlastní interpretaci zpráv je nutné zohledňovat jejich popisný (kvalitativní) charakter či značnou míru subjektivismu autora zprávy, který se ve většině případů věnoval více popisu následků vichřic než jevu samotnému.

Přes naznačené problémy byl sestaven rozsáhlý soubor, který umožňuje hodnotit mimo jiné prostorové rozložení postižených lokalit. K tomuto hodnocení byly využity nástroje ArcGIS, za pomoci kterých byly sestaveny kartodiagramy a kterými bylo také charakterizováno prostorové rozložení míst se škodami způsobenými vichřicemi. K tomuto účelu bylo využito dvou metod – metody nejbližšího souseda a metody výpočtu Moranova indexu prostorové autokorelace (Lee a Wong 2001). Jestliže první metoda hodnotí pouze vzdálenost bodů,

druhá metoda uvažuje v každém analyzovaném bodě i počet zjištěných událostí (případů škod větrem). Obě metody umožňují porovnat konkrétní rozložení lokalit s určitým druhem události s teoretickými typy rozložení. Tato teoretická rozložení bodů v prostoru jsou definována jako rozložení pravidelné, náhodné či shlukové.

Vlastní analýza prostorového rozložení postižených lokalit byla provedena pro jednotlivá století (obr. 3 až 7) a tabulka 4 shrnuje počty zjištěných případů vichřic. Z analýzy je patrné, že především pro starší období se v sestavených mapách odráží spíše množství a kvalita zpráv než predispozice míst vůči škodám větrem. Lokality často odrážejí působiště autora zprávy. Proto se zvýšené počty zpráv vztahují k velkým městům a nebo k lokalitám, ze kterých byly k dispozici vizuální denní záznamy o počasí.

Prostorové rozložení lokalit postižených škodami silným větrem hodnocené Moranovým indexem je charakterizováno jako náhodné pro 16., 17. a 20. století, zbývající dvě století jsou charakterizována spíše rozložením shlukovým. Metodou nejbližšího souseda jsou rozložení pro všechna století s výjimkou 16. charakterizována jako shluková.

Ze sestavených map je patrný postupně se měnící charakter zpráv o škodách způsobených větrem. Zprávy o větrných lesních kalamitách jsou poměrně málo četné pro 16. a 17. století, výrazněji se začínají objevovat až v 18. století. To může souviset například se zlepšujícími se způsoby evidence v lesním hospodářství na jednotlivých panstvích či s vysazováním stejnověkých monokultur náchylnějších větrným kalamitám.

Především pro největší vichřice, které postihly území českých zemí v posledních 500 letech, lze nalézt v historických pramenech velké množství informací z mnoha lokalit. Dokumentární prameny tak často umožňují charakterizovat rozsah a charakter způsobených škod, ale i průběh vlastní události. Případem vichřice, která je nejhojněji popsána v historických zprávách, je ta z 20. a 21. prosince 1740 (obr. 10). Uvedená vichřice byla zaznamenána i v okolních zemích a podle některých zpráv zničila celou jednu třetinu lesů v českých zemích.

Úsilí vložené do rozšiřování a zkvalitňování databáze historicko–klimatologických údajů v současné době přináší nové možnosti analýzy i prezentace dat. Prostorová analýza míst se škodami větrem sice dovoluje charakterizovat oblasti zvýšeného výskytu, ve většině případů však souvisí s kvalitou vstupního materiálu. Velmi cenné informace přináší prostorová analýza největších případů vichřic. Ty mohou sloužit jako analogony pro současné případy extrémních projevů počasí, pro lepší porozumění příčin jejich vzniku a též k efektivnější ochraně před jejich následky.

Obr. 1 – Území České republiky s označením historických zemí
Obr. 2 – Titulní strana moralistického spisu kněze Víta Jakeše Přerovského sepsaného jako reakce na ničivou vichřici, která postihla české země 28. prosince 1612 (Brázdil et al. 2004a)
Obr. 3 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 16. století
Obr. 4 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 17. století
Obr. 5 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 18. století
Obr. 6 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 19. století
Obr. 7 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 20. století
Obr. 8 – Hlavní typy škod způsobené silnými větry a vichřicemi v průběhu 16. století. Hlavní typy: škody na budovách, lesích, ostatní, bez specifikace.
Obr. 9 – Počty zpráv zaznamenávajících škody větrem v lesích pro jednotlivé lokality v českých zemích v průběhu 17. až 20. století
Obr. 10 – Místa v Česku zaznamenávající škody větrem při vichřici z 20.–21. prosince 1740 s hlavními typy škod

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