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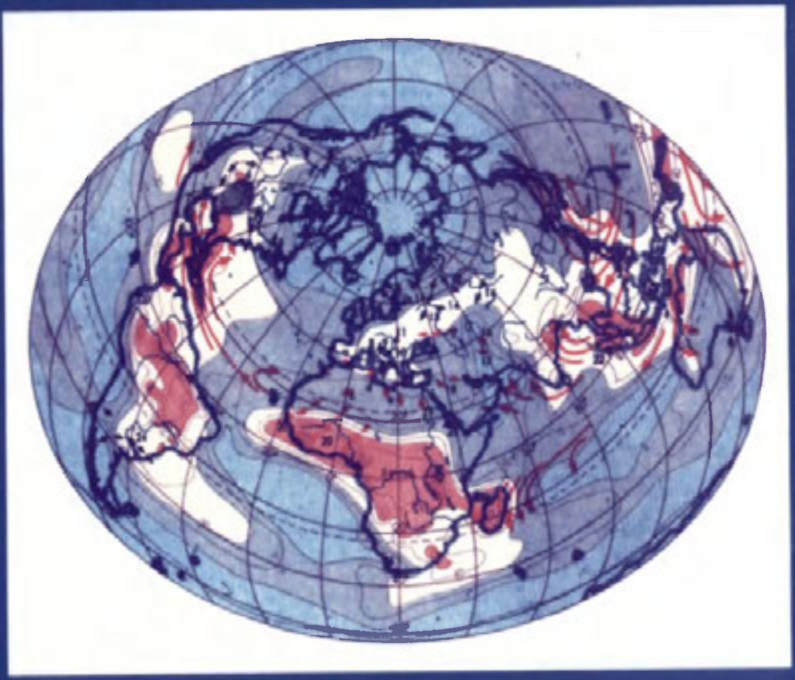
# GEOGRAPHIA POLONICA



POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

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# GEOGRAPHIA POLONICA

PAPERS in GLOBAL CHANGE IGBP, No. 8

Guest Editor:
Barbara Obrębska-Starklowa
Polish National IGBP Committee PAS

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## FOREWORD
## HISTORICAL CLIMATOLOGY
## – A NEW TOOL IN THE STUDIES ON CLIMATIC CHANGES

Recent climatological studies have been dominated by investigations of the climatic changes occurring on different scales from the global via the regional to the local, over periods of varying duration. These investigations comprise studies on climate in the past, the evaluation of the present-day functioning of a climatic system and forecasting of future climate, together with characterisations of transformed living conditions of humankind in the environment. Another task is to determine how human beings perceive climatic changes, how the results of the current studies dealing with the influence of natural factors on climatic changes and characteristics of anthropogenic changes are comprehended by society. Also being examined is the degree to which humankind feels responsible for climatic changes and the protection of the environment, including climate. It is apparent at present, that the climate should be protected at all its levels of functioning in the environment, by introduction of the principle of sustainable development into the management of environmental resources. The costs of activity of this type will be borne by tax payers, who have to be fully aware of the rationale behind the programmes undertaken.

Growing emphasis is being placed on the source materials which serve in examining the history of climate and originate from climatological, geological, paleoecological and paleogeographic investigations and have been obtained by various methods. On account of this the source materials differ as to their accuracy when it comes to identifying and interpreting the changes and variability in climate over the past centuries and millennia.

International research teams (e.g. ADVICE, IMPROVE) are involved in studies devoted to the reconstruction of climate in order to work out unified methods of collecting and elaborating the aforementioned source materials.

The results of the collective studies became the background for the elaboration and dissemination (among researchers and decision makers) of systematic reports on changes of climate and forecasted changes of the Earth's environment. By the end of the 1980s the Intergovernmental Panel on Climate Change (IPCC) had been appointed, while during the so called Earth Summit in Rio de Janeiro in 1992 the UN Framework Convention on Climate Change was made available for signature. In turn, in Kyoto in 1997, the Protocol defining the legal commitment of particular states to the reduction of greenhouse gas emissions was presented. The Protocol and its assumptions became the basis for still ongoing and unresolved discussion between groups of decision makers and politicians.

In the last years of the 20th century a new discipline of science emerged. This is historical climatology and its deals with the evaluation of the results of instrumental studies, and with the analysis of various other materials evidencing climatic changes during the last several hundred years or even over several millennia. Historical climatology focuses on the study of the past and helps to explain the present. It also deals with such climatic changes as the Medieval Warming and the Little Ice Age.

The most important historical data are the sources of information on the frequency and concentration of rare extreme phenomena of high socio-economic significance, such as: strong storms, floods, droughts, etc. Historical climatology also uses calibrated indirect data, e.g. – thermal data calculated on the basics ice cores and lacustrine varves or fluvial and slope deposits left behind by catastrophic events. Such information in the database is mainly used for the reconstruction of global climatic changes over longer geological periods (e.g. the Holocene) using the global circulation models (GCMs).

Among sources of information, other than the early instrumental measurements, one should mention various records in dairies made by farmers, nature lovers and chroniclers, notes in logbooks, lists of wages, reports and notes on the development and thickness of ice cover on lakes and seas (e.g. the Baltic). There is a commonly accepted opinion that such indirect data require particular exactitude during their elaboration. Even if well dated and chronologically ordered at a particular site, such data is likely to give rise to certain errors, when compared with that from other study sits on account of differences in the form of records or different interpretation of events associated with social and economic management. A chance for verification may be sought in conscientious mutual control of indirect data in correspondence with the data from the instrumental measurements and a "cross-check" for any lack of homogeneity and consistency. The results of historical climatology, confirmed by the documentation of climatic phenomena comprising relatively long time series, have become the key issue in the world debate on anthropogenic changes of climate. They serve to determine the influence of particular catastrophic phenomena, their mutual coincidence or temporal shift over whole continents or significant parts of them. In the synthesising of works in the field of historical climatology, use is made of methods allowing for reconstruction of the atmospheric pressure field based on mean monthly values together with the calculation of indicative indices evidencing the variability and changes in climate in Europe based on reconstructed mean monthly air temperature and precipitation. In turn, grid data (defined for network nodes) are used in the evaluation of the variability and changes in indices of atmospheric circulation such as, for example, the NAO (North Atlantic Oscillation) or AO (Arctic Oscillation) which illustrate the spatial differentiation of the climate in Europe.

When tracing indirect evidence of changes in climate the following feedback is assumed: the environment influences the socio-economic system, while society has an impact on the environment, including the climate. It is for this reason that verified and standardised databases are so focused on. The interest in these data is growing steadily due to increasing threats to the environment. New possibilities for international co-operation in the field of the evaluation of environmental changes are emerging. The European Society for Environmental History may serve as an example here. An important problem to be solved in the not so distant future is the determination of those rare phenomena occurring in the climatic system, which should still be treated as "typical", i.e. not exceeding the boundaries of normal reactions of this system to external climatic factors, and which should be referred to as unquestionable changes. Thus, special emphasis is paid to extreme climatic phenomena, characterisations of their frequency of occurrence in various regions and in various periods, and assessment of the severity of the damage caused by these phenomena. There is a concept that the extreme climatic phenomena (droughts, hurricanes, downpours, floods, heat fluctuations), being more frequent and giving more severe effects with far-reaching social consequences, can be one of the results of the present-day changes in the geoecosphere.

Recently in Poland there has been an intensified interest in studies in the filed of historical climatology. In Cracow, the days 20–22 September 2000 saw the convening, by the Institute of Geography and Spatial Management of the Jagiellonian University, the Institute of Meteorology and Water Management and the Polish National IGBP – Global Change PAS Committee of an international millennium conference entitled "Images and Reconstructions of Weather and Climate over the Last Millennium". Participants included experts in the fields of historical instrumental studies, indirect databases, climate modelling, climate-environment interrelationship and extreme climatic conditions. The conference was held under the auspices of the Ministry of Education of the Republic of Poland. It was organised in Cracow – the European City of Culture – during the celebration of the festival "Cracow 2000" and coincided with the 600th Anniversary of Refunding of the Cracow Academy and the 150th Anniversary of the founding at the Jagiellonian University of the first chair in geography in Poland. The conference was attended by 150 participants from 20 countries.

When summarising the results of the Conference, the Scientific Committee, chaired by Prof. Christian Pfister, agreed that it had attested to the headway made in historical climatology over the previous 10 years. There had been a definite shift from the reconstruction of climatic history at particular sites to successful, fully justified and punctilious climate reconstructions on a regional scale with particular local reconstructions being combined and united. Such remarkable progress took place in Central Europe, especially in the Czech Republic and, moreover, in Switzerland, Iceland, on the Iberian Peninsula and in Norway. The study results obtained from the uplands of Bolivia aroused considerable interest. A wider access to the archive data from China, Islamic countries, Japan and Latin America is anticipated. From the summary it is also apparent that the reconstruction of climate in Europe based on monthly data from the 17th century, and on seasonal data in the case of the 15th century, should be the subject of studies. Bearing in mind the above, the necessity of the participation of research groups in the ARCHISS project in collaboration with the WMO, UNESCO and the International Council on Archives has been signalled. This would allow for the seeking of climatic data in the internal archives of various countries. This type of access to data is, for example, very important in the case of Latin America. There is also a hope that the historical climatological databases can combine with application of the dynamic GCMs models to contribute to the three-dimensional reconstruction of the state of the Earth's atmosphere and ocean during various periods.

This volume of "Geographica Polonica" ("Global Change" series) publishes the papers from the Cracow Conference. These present characteristics of climatic conditions based on varied source materials for historical periods of various lengths. They address the nature of the relationship between climate and natural environment and society, as well as possibilities for the utilisation of source material in the reconstruction of climatic changes.

**R. Brázdil** and **P. Dobrovolný** deal with the chronology of catastrophic events in Central Europe from the pre-instrumental period to date. They have elaborated this chronology in relation to the frequency of occurrence of strong winds associated with convection storms and tornadoes. The occurrence of such winds has been reconstructed by reference to forests blown down, the destruction of housing in the Czech Lands and other damage from 1500 to 1999. For the sake of comparison, regularities in the spatial differentiation of strong winds in the given area were assessed using meteorological records from 1961–1990. The paper assumes that quantitative characteristics of extreme meteorological events can be helpful in identifying changes in functioning of the climatological system and in the human-environment relationship. The authors face the fundamental dilemma as to whether the stated extreme meteorological events are the result of global warming or of a higher living standard, and higher social sensitivity to natural hazards which are thus more often noticed. In this respect, the rules for developing uniform databases and attempting explanations of the influence of volcanic eruptions on the development of a wider variability of climate on the regional scale have emerged as very interesting.

The impact of climatic conditions on vegetational development in 1990s Poland is presented in the paper by **K. Kożuchowski** and **E. Żmudzka**, for 5 lowland regions. It is an interesting and methodical attempt to characterise the variability of vegetation conditions in relation to the variability of heat, water and light resources, as defined by the appropriate: thermal, insolation and precipitation indices. The stage of vegetational development was estimated using NOAA satellite images, as normalised differences of vegetation indices. Additionally, the calculations included the elaboration of simple statistical models based on the correlation and multiple regression of the described vegetation index and climatic indices. Another source of information as to the vegetation period's variability concerned the occurrence of fire threat in forests, in relation to the normalised differences in vegetation indices and thermal and precipitation conditions. These relations were described using multiple regression equations. The paper is a contribution to studies on the genetic relations between biotic and abiotic environmental components and allows for identification of periods with differenting climatic variability, which are of importance to the functioning of the environment and the human economy.

The improvement and upgrading of databases through the inclusion of more rarely analysed climatic elements and phenomena has been presented by **D. Matuszko**, with a series of data from the historical station of the Jagiellonian University in Cracow in the period 1772–1999. The homogenous series of quantitative and qualitative records of cloudiness in Cracow during 1906–1999 is of a particular value. In this period of observations there was no change in definitions of cloud genera, the way of determining cloudiness or the recording site. The results are comparable with the other series of records (from Warsaw or Prague). The development in urbanisation in Cracow in the 20th century can be inferred from analysis of the appearance of certain cloud genera (St, Cu, Cb). The influence of natural climatic factors on nephological conditions was examined as the effects of various synoptic situations in a multi-year period on cloudiness and cloud genera. All the above favours the usage of the multi-annual series of cloudiness records in Cracow in the development of models of climate functioning on the local and regional scales.

The next two papers present databases on and characteristics of the variability of climatic elements extreme values on a regional scale, especially in the last decade of the 20th century.

**J. Otterman** et al. characterise the influence of atmospheric circulation (the Tna index) on air temperature at a height 2 m above the ground (the Ts index), at the end of winter and the beginning of spring in Europe in the middle latitudes of 45–60°N. The authors correlated the Ts and Tna indices to determine the role of the direction of marine air advection from the Atlantic Ocean. Inter-annual variations in atmospheric circulation and their influence on thermal extremes at the end of a warm winter followed by an early spring, or at the end of a cold winter followed by a late spring, were examined using daily data from succeeding pentads, in the period 1989/1990–1995/1996, for a few sites in Poland. One of the interesting results concerns the influence of wind speed in the North Atlantic on the air temperature in Europe at the standard height of 2 m above the ground. Another interesting result is the finding of a dependence between the combination of these two elements and the beginning of phenophases, the timing of field works and heating fuel usage in the middle latitudes of 45–60°N.

The longest period – the whole last millennium – has been taken into account by **L. Starkel** in studies on extreme precipitation and floods in Europe. In his paper the author used instrumental data, data from the historical sources and indirect data of a geological and geomorphological nature. On the basis of these the magnitude and types of widespread floods are reconstructed using special procedures, while geological deposits have been dated by a radioisotope method. The author focuses on the climatic phases in Europe over the last millennium, drawing on relations between the frequency of extreme events and fluctuation in the input of solar radiation and volcanic activity. He distinguishes the Medieval warming during the first 300 years, the transitional period into the Little Ice Age (1300–1550), the Little Ice Age (from the 16th century until 1850) and then the warming period from the end of the 19th century which has been accompanied by an increased frequency of floods. The concentration of downpour events over the last decade of the 20th century deserves special attention. The water supply associated with these downpours exceeds the present functional thresholds of the river and slope systems, causing their far-reaching transformation and changes in evolutionary directions. The Little Ice Age has been recorded for the whole of Europe, although its singular events never occurred simultaneously all over the continent. The shift in the timing of the events in various parts of Europe might be assumed to coincide with the predominance of meridional circulation or longitudinal circulation. The downpours of the 1990s are the examples of effect of the latter.

Climatic conditions of the Little Ice Age in southern and western Poland are presented by **M. A. Szumiec** and **D. Augustyn**. The authors elaborated the method of climate change estimation from the end of 16th century to the beginning of the 19th century, for the Upper Silesia region, taking under consideration the number and distribution of fish ponds with carp culture. The paper reveals two aspects of the issue, natural and socio-economic one. Thus first, the deterministic model was constructed to describe quantitative relations between the characteristics of air temperature (which define optimal thermal conditions of the water) and carp culture effectiveness. That part of the project is based on detailed observations of climatic elements and meteorological water balance for the years 1960–1999 at Golysz research station, in Beskid Śląski Mts. The analysis is summarised with discussion on the fluctuations of thermal and hydrological conditions in the Little Ice Age. Final results of the project, according to the tendencies of climatic and bioclimatic changes, were verified also in relation to economic, social and historic conditions. Increased fish consumption due to the religious reasons, economic prosperity, periods of famine and wars were taken into consideration. Analysing the historical sources from the chosen period for Central Europe, the authors found out that the changes of temperature and precipitation in Little Ice Age had regional range. In Silesian region they occurred at the same time as in Saxony.

Dynamic development of the research in historical climatology and emergence of new tasks which the natural sciences have to confront at the turn of the 21st century, induces studies of temporal and spatial aspects of the causes and the state of patterns of particular components of the climatic system. Special attention should be paid to extreme phenomena and long-lasting climatic anomalies. Their complex analysis, based on homogenous material, allows the discussion on the anthropopression and construction of the models or scenarios of environmental changes. It also contributes to the effectiveness of forecasts and predictions for the decision-makers and to an effort to construct the development strategies for environmental structures of different order.

Barbara Obrębska-Starklowa
Guest Editor

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# HISTORY OF STRONG WINDS IN THE CZECH LANDS: CAUSES, FLUCTUATIONS, IMPACTS

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ABSTRACT: Problems of wind speed measurements are analysed. The climatology of strong winds in the Czech Republic during the period 1961–1990 is presented. The main groups of strong winds are characterised according to their origin. The accuracy of historical written reports of strong winds and to their impacts in the pre-instrumental period are discussed. The chronology of strong damaging winds in the Czech lands from A. D. 1500–1929 is presented with a division into gales on the one hand and strong winds connected with convective storms on the other. Cases of gales of the century are described. The impact of strong winds is discussed, with special attention being paid to forest damage.

KEY WORDS: strong wind, gale, tornado, damage, Czech lands.

## INTRODUCTION

Meteorological extremes can be understood as cases either of the exceeding of limit values for meteorological elements or the occurrence of meteorological elements or phenomena with an impact on nature or human society which can often be reflected in loss of human life and great material damage (Brázdil 2000b). As a result of its more complex infrastructure, contemporary society is more vulnerable in terms of the extent of the damage. Extremes of the same intensity cause a higher level of damage today than was the case in the past. For instance, in the years 1990–1999 in comparison with the decade 1950–1959, the number of great natural disasters was 4 times as great and economic losses fourteen times as great (Munich Re 1999). In these statistics windstorms follow immediately behind earthquakes and floods (Munich Re 1990).

Strong winds are among of the most significant meteorological extremes in the Czech Republic. Their occurrence is often accompanied by loss of life and great material damage (such as wind breakage or damage to buildings). Hitherto, papers about strong winds in the Czech Republic have been primarily oriented at the synoptic analysis of individual cases (e.g. Gregor 1955; Kameník 1986; Setvak and Strachota 1986; Sálek 1994; Nekovar and Valter 1998) or at the determination of synoptic situations associated with their occurrence (Stekl 1985, 1997). Study of long-term fluctuations with respect to impacts is almost completely lacking (exceptions are Slaby 1990a, 1990b, 1993; Brazdil 1998; Brazdil, Stekl et al. 1999). Preliminary results of research into strong wind events in the Czech lands from the sixteenth to nineteenth centuries were published by Brazdil and Dobrovolny (2000).

The following general questions concerning meteorological extremes are important for research into strong winds in the Czech Republic (Karl and Easterling 1999):
- if the observed process of global warming is projected on to the frequency and intensity of meteorological extremes;
- whether and to what extent human society is becoming more sensitive to the impacts of meteorological extremes;
- if the perception of meteorological extremes is affected by the media to a greater extent.

## PROBLEMS OF WIND MEASUREMENT

Anemometers or anemographs are used for the measuring of wind speed at meteorological stations. Without these instruments, wind force was assessed according to the 13-point Beaufort scale (Tab. 1). The most exact continuous data about wind speed can be obtained using anemographs that measure wind speeds to a maximum of 50 $ms^{-1}$. However, the quality of such measurements is adversely affected by several factors, including interruptions due the formation of ice deposits, lightning strikes to the sensors or the adjustment or replacement of the instrument. Slaby (1993) thinks that the actual occurrence of gusts and their

Table 1. Characteristics of strong winds according to the Beaufort scale (List 1951) (wind speed in $ms^{-1}$).

| No. | Name of wind | Wind speed | Description |
|---|---|---|---|
| 7 | Moderate gale | 13.9–17.1 | Whole trees in motion, inconvenience felt when walking against wind. |
| 8 | Fresh gale | 17.2–20.7 | Breaks twigs off trees, generally impedes progress. |
| 9 | Strong gale | 20.8–24.4 | Slight structural damage occurs (chimney pots and slates removed). |
| 10 | Whole gale | 24.5–28.4 | Seldom experienced inland, trees uprooted, considerable structural damage occurs. |
| 11 | Storm | 28.5–32.6 | Very rarely experienced, accompanied by widespread damage. |
| 12 | Hurricane | > 32.7 | Destructive damage. |

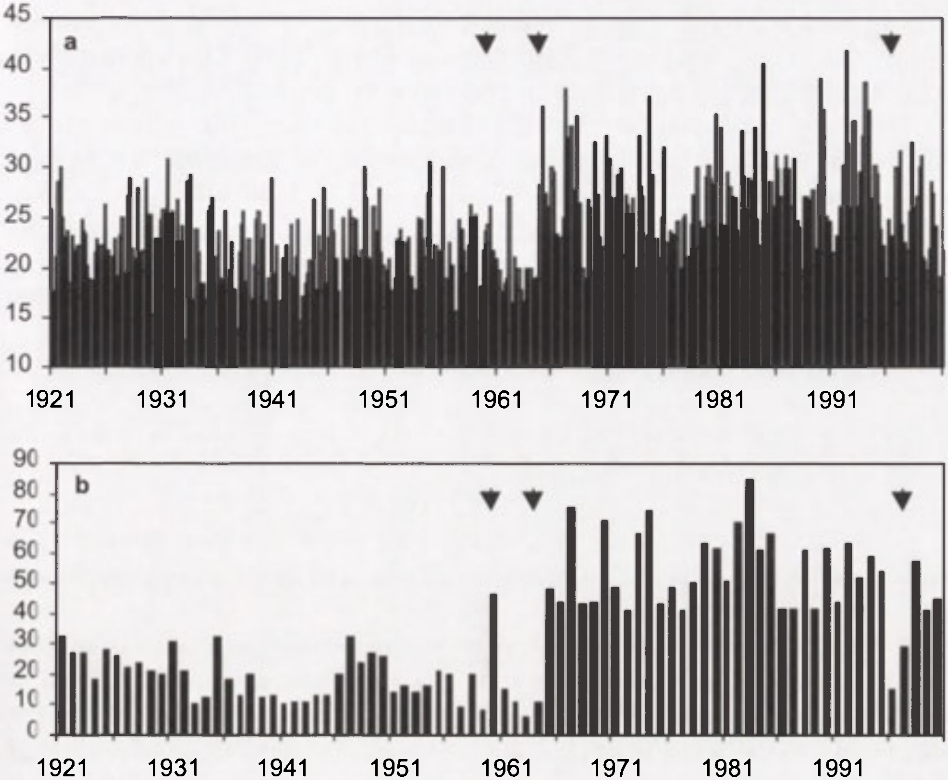


Figure 1. Fluctuations in maximum monthly wind gusts ($ms^{-1}$), a – the annual number of days with wind gusts > 17 $ms^{-1}$, b – at the Prague-Karlov station from 1921–2000 (data in *Ročenky povětrnostních pozorování observatoře Praha-Karlov 1921–2000*). Arrows mark the years in which the anemographs were exchanged.

speed is greater than those shown by the anemograph records. The homogenisation of wind speed series is difficult to carry out, because of their extremity and spatial variability or else because station metadata are incomplete. A document of the effect of instrument exchange on the homogeneity of measurements is proved by data on maximum daily wind speeds and the number of days with daily gusts ≥ 17 $ms^{-1}$ at the Prague-Karlov observatory (Fig. 1). Evidently lesser wind gusts were measured beginning in 1921, with a Dines pressure tube anemograph (Munro, London) being used. In 1960, the instrument was replaced first by a Czech-produced METRA universal anemograph and by a more sensitive version on 30 October 1964. A further replacement by the same type of instrument occurred in 1996. While all these changes are very clearly perceptible in the fluctuations of the two characteristics, their meaningful homogenisation is problematic on account of the great spatial and temporal variability.

Problems with measuring wind speed give rise to a recommendation that, in the study of fluctuations of this characteristic, they can be replaced by long-term surface (or sea-level) pressure measurements and analyses (i.e. by the calculation of the geostrophic wind – see Trenberth and Owen 1999). This approach was used in papers by e.g. Schmith et al. (1998) and Heino et al. (1999).

However, extreme values for individual wind characteristics offer no information on impact, i.e. on the material damage caused or human life lost. In these cases, it is necessary to combine meteorological records with other sources (chronicles, memories, newspapers, etc.). The strong winds occurring in convective storms and confined in their effects to local damage are not necessarily registered at the given station at all. In addition, the series of measured wind gusts employed covers several decades only.

## TYPES OF STRONG-WIND EVENTS AND THEIR SYNOPTIC CAUSES

In central European conditions, strong-wind events manifest themselves in connection with convective storms or in the form of gales along conspicuous horizontal pressure gradients.

The strong winds in the first group are bound to the development of thunder clouds (in severe convective storms, multicell storms, or supercell storms). It conditions their relatively short duration (usually dozens of minutes), their most frequent occurrence in the warm half of the year and the local confinement of damage. As a rule, these winds take the form of a tornado (Snow and Wyatt 1997) or downburst (Fujita 1985). Tornadoes are primarily known from the USA (Schaefer et al. 1993), particularly thanks to destructive effects that are usually characterised according to the Fujita scale (Fujita 1973). Their occurrence in Europe or in the Czech Republic is not, however, uncommon (e.g. Wegener 1917; Pühringer 1973; Munzar 1995; Paul 1999), though their effects here are weaker (Dessens and Snow 1993). A downburst is a strong downdraft which induces an outburst of damaging winds on or near the ground. After Fujita (1985) these can be divided into:

a) macrobursts – outburst winds extending more than 4 km in a horizontal dimension with widespread, tornado-like damage; damaging winds of as much as 60 m $s^{-1}$ lasting 5 to 30 minutes,

b) microbursts – outburst winds extending only 4 km or less; damaging winds of as much as 75 $ms^{-1}$.

Gales, lasting several hours or days and affecting more extensive regions, are associated with considerable horizontal pressure gradients. According to Stekl (1985, 1997), an exception in the Czech Republic are extremely high wind speeds from the directions 10–80°. If the directions are between 190–360°, they are connected with the upper frontal zones in 93% of cases. In more than a half of all cases, they are associated with deep cyclones above Denmark or southern Scandinavia. They are mostly associated with the passage of cold fronts, with the strong winds exhibiting considerable temporal variability. For extremely high wind speeds from the directions 90–180° lasting more than 2–3 days, a conspicuous pressure gradient is valid between coherent pressure formations – between a cyclone over the North Sea, western or central France and an anticyclone over eastern or northeastern Europe (a smaller effect of fronts), and/or a conspicuous pressure gradient at the rear part of an anticyclone with its centre above Ukraine (without the influence of fronts). The intensification of the wind speed can be helped by the deformation of streaming by the Alps and further mountain obstacles in central Europe.

## FLUCTUATIONS OF STRONG WINDS IN THE INSTRUMENTAL PERIOD

Brázdil, Štekl et al. (1999) presented long-term fluctuations to the mean wind speed at the windiest Czech station Mt. Milešovka (837 m above sea level) over the period 1905–1994. However, since the speeds prior to 1955 were obtained by converting from the Beaufort scale only the variation in the mean annual wind speed for the period 1956–2000 is presented in Figure 2. The maximum mean speeds occured in the period 1973–1980, which followed lower speeds in the years 1968–1972. A continuous drop in wind speeds has been observed since 1993. The whole series shows a statistically insignificant, downward linear trend. Within the annual variation, the windiest months are November and December, the lowest mean speeds are in May–July (in the 1961–1990 period). The relation between the mean wind speeds, calculated using the $07^{00}$, $14^{00}$ and $21^{00}$ hours measurements, and maximum speeds is, of course, insignificant.

The occurrence of strong winds can be characterised by reference to the number of days with a wind speed above a certain limit, or the magnitude of wind gusts. Linking up with the papers by Slabý (1990a, 1990b, 1993), the limit value of gusts was taken to be the wind speed of $\geq 17$ ms$^{-1}$, a figure which approximately corresponds to the lower limit of speed stated in the Beaufort scale

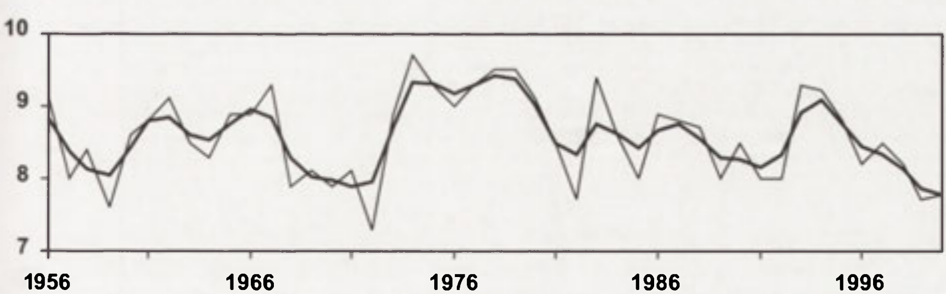


Figure 2. Fluctuations in the mean annual wind speed (at times $07^{00}$, $14^{00}$ and $21^{00}$ hours) at the Mt. Milešovka station in the period 1956–2000. Smoothed by a Gaussian 5-years filter.

for a fresh gale (Tab. 1). Slabý (1993) analysed wind gusts at 40 stations in the Czech Republic which had at least five years of measurement in the period 1961–1987. Thirty of them recorded a maximum gust of $\geq$ 35 ms$^{-1}$, but only five one of $\geq$ 45 ms$^{-1}$. Wind gusts in Bohemia are concentrated in the western quadrant (W and WSW directions). In the Bohemian-Moravian Highlands and western half of Moravia the most frequent gusts are from the W to NW and the S to SE, while the frequency of the latter increases with elevation above sea level. In the north-east of the Czech Republic, there are 2–3 directions for the maximum of gusts. On the whole the great effect of orography, on the speeds and directions of wind gusts is perceptible, above all in the Alpine-Carpathian system and the Moravian Gate (e.g. as a manifestation of the so-called jet effect).

For the twelve professional meteorological stations of the CHMI (Fig. 3), a number of days with wind gusts $\geq$ 17 ms$^{-1}$ were found using anemographs in the period 1961–1990. Unfortunately, at a number of stations an evident impairment of the homogeneity of measurement is perceptible, signalled by a sudden drop or rise in the number of analysed days (e.g. in the period 1967–1969 for Svratouch, 1970–1972 for Brno-airport or 1988–1990 for Holešov). In addition to the large natural spatial variability of wind gusts, these inhomogeneities contribute to low correlation coefficients between the individual stations which only exceptionally exceed the value 0.50 (the maximum is for the stations Pribyslav and Kuchařovice, at 0.70) or are even negative. However, low spatial correlations together with incomplete metadata make it impossible to homogenise these series. In order to partially minimalize the above drawbacks, efforts were made to calculate an average series of days for the Czech Republic on which a gust of $\geq$ 17 ms$^{-1}$ was recorded at least one of the 12 stations (Fig. 4). This characteristic


Figure 3. Meteorological stations used in the analysis of wind gusts in the Czech Republic in the period 1961–1990.

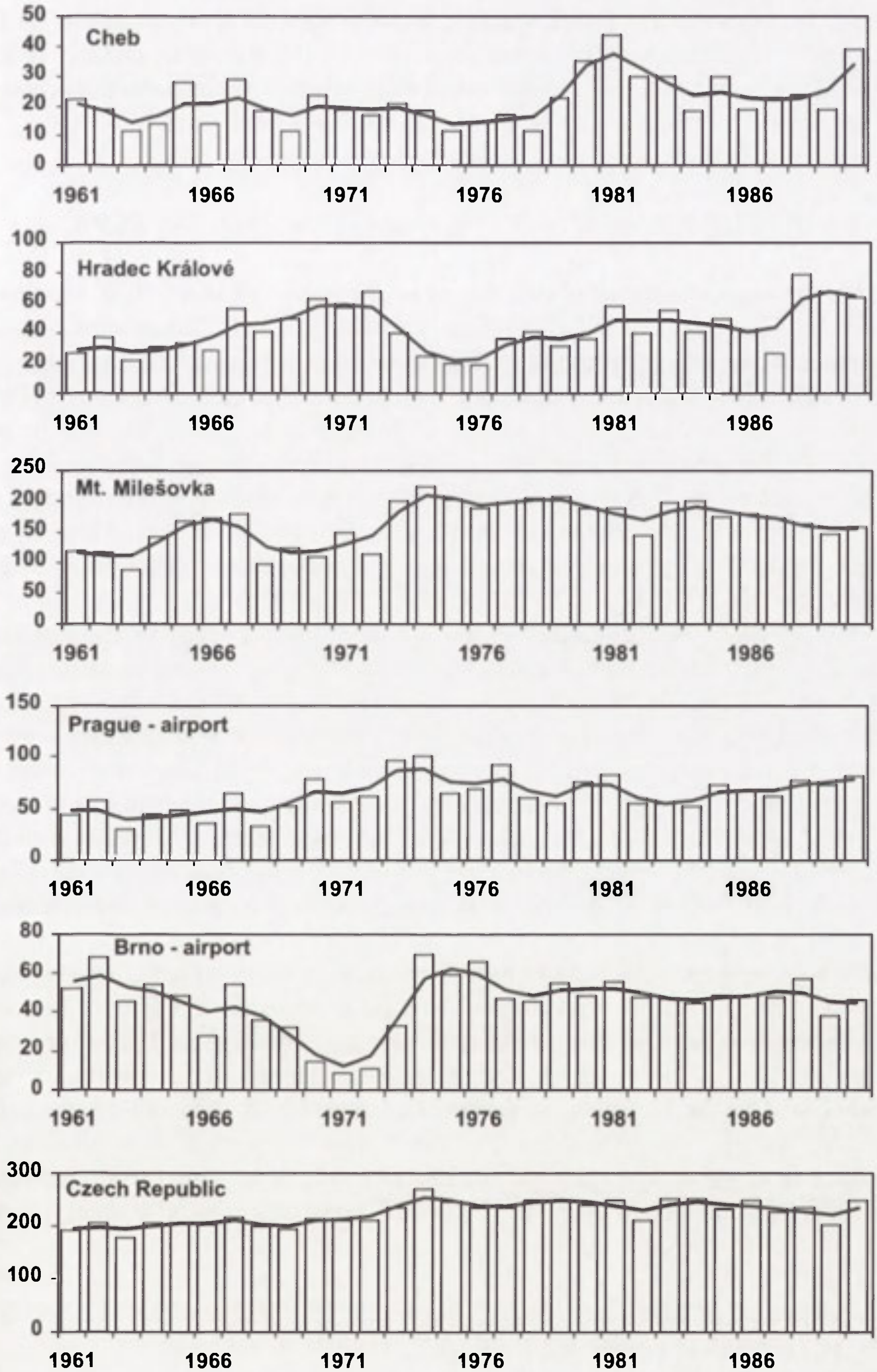


Figure 4. Fluctuations in the annual number of days with wind gusts ≥ 17 $ms^{-1}$ at selected meteorological stations and in the average series for the Czech Republic in the period 1961–1990. Smoothed by a Gaussian 5-years filter.

shows an upward linear trend which is the consequence of lower values in the years 1961–1972 in comparison with the remainder of the 1970s and the 1980s. A similar significant trend can be observed at selected stations (with exception of the Brno-airport station), where it is statistically insignificant.

## DATA ON STRONG WINDS IN THE PRE-INSTRUMENTAL PERIOD

On the basis of the verbal description of the impact of wind (Tab. 1), strong wind can be seen to coincide with Beaufort numbers 8–12. These observations are another possible, hitherto not much utilised, source of data (see e.g. Schiesser et al. 1997). The longest continuous 200-year record of gale frequency (1780–1988) comes from Edinburgh, Scotland (Dawson et al. 1997). For the period before the beginning of systematic wind observations, written weather reports may be used (see e.g. Brázdil 2000a for sources), in which it is possible to find exact dating and a description of the phenomenon and its effects. Thus, in the Czech lands the first credible record of wind is Kosmas's description of the Prague tornado of 30 July 1119 (Bláhová and Fiala 1972):

"On 30 July on Wednesday, when the day was approaching the evening, a rapid wind, even Satan himself in the shape of spiral, striking suddenly from the southern side to the princely palace at the castle of Vyšehrad, uprooted an old and very strong wall, and thus – which is an even stranger phenomenon – while both the front and the rear sides remained whole and undamaged, the centre of the palace was destroyed to the ground and more quickly than a man would break an ear of cereal, the wind gust broke upper and lower beams into pieces with the house itself and threw them about. This gale was so strong that wherever it raged, in this country by its vehemence it uprooted forests, apple trees and whatever stood in its way."

Written records deal for the most part with cases in which a strong wind caused some damage. The more destructive the given extreme, the more frequent the written evidence and the more detailed the list of damage is. The information value of such reports is, as may be understood, variable their density varying markedly with the comprehensiveness, and accessibility of, and previous research into, the source material. Despite certain limitations, it is possible to compile from these data chronologies of strong winds yielding certain information about fluctuations in the period before the beginning of regular observations.

## CHRONOLOGIES OF STRONG WIND EVENTS IN THE CZECH LANDS FROM THE SIXTEENTH TO TWENTIETH CENTURIES

The historical-climatological database of the Department of Geography, Masaryk University, Brno was used as a source from which to select all cases of strong wind events since A.D. 1500 which were included in some of the following groups according to the verbal description as: 1 – tornadoes, 2 – other strong winds during convective storms, 3 – strong winds, 4 – gales (gale, storm, hurricane). In the case of the tornado, the description had to include a report of a typical funnel cloud pointing to the ground and/or its typical effects. As a group convective storms were classified in those cases in which a strong wind was mentioned together with a thunderstorm or hailstorm. Gales included cases wherein a strong wind extended over a considerable territorial range, with damage of varying intensities or reports from narrative sources about a strong wind where damage was not mentioned. If a strong wind was mentioned without any further specifying information in daily weather records, the inclusion of such an event into the category of gales was considered on a case by case basis.

In the fluctuation to the frequency of all strong winds causing damage in the sixteenth to nineteenth centuries in the Czech lands two maxima are apparent (Fig. 5). The first appears in the late sixteenth and early seventeenth centuries,

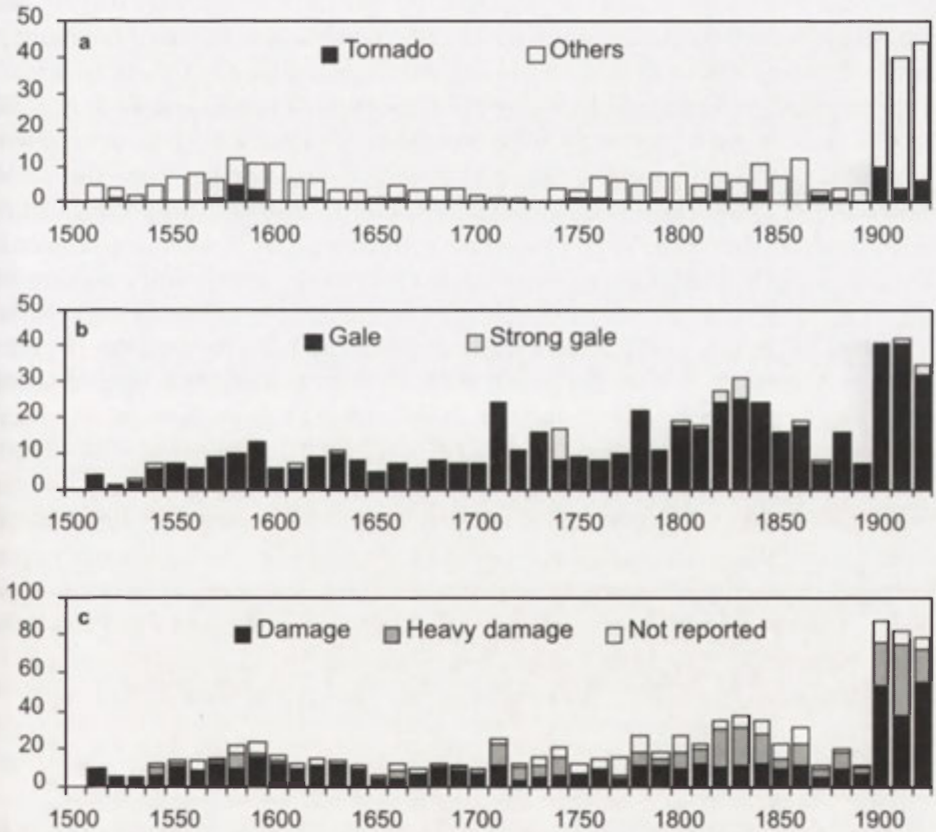


Figure 5. Fluctuations in decadal frequencies of the occurrence of strong winds connected with convective storms (tornadoes and others), a – gales, b – cases of strong winds with damage, c – in the Czech lands over the period A.D. 1500–1929. Years indicate the first year of the respective decade.

the other between 1800 and 1870. A question concerns the extent to which these maxima are conditioned by the density of records in those periods as against the other parts of the four centuries studied. In the case of the frequency of strong winds connected with convective phenomena, the first maximum is better expressed. For the period 1900–1929, cases of strong winds were found systematically using a daily newspaper (*Lidové noviny*). The substantially higher number of cases in these years indicates that the frequencies established for the sixteenth-nineteenth centuries are conspicuously underestimated.

The first paper on the occurrence of tornadoes in the Czech Republic was published by Munzar (1995). In historical reports, their occurrence can be judged by reference to the descriptions of the phenomena, damage and duration. Thus the Memorial Book of Litoměřice (*Pametní kniha Litoměřic*, pp. 298–299) describes the occurrence of a tornado on 19 June 1597 in the following way: "About a great wind on Thursday after St. Guy's Day, which hurried from Píšťany via Radobýl and took stones and poles and there was a great noise like in a battle, and wherever that storm moved, it was as if a wagon were driving and the bushes turned black, the water in the Elbe arose to the height of the highest house, from the Elbe it sped to Prosmyky and along the road as far as Lovosice". The chronicler of Louny, Mikšovic (p. 149) mentions a tornado on 14 July 1598 near Březno: "Also a great wind arose near Březno, so that a big pole came down from the clouds and then a fire was observed, descending from the same cloud...". In many cases it is, however, difficult to distinguish tornadoes from other cases of damaging wind associated with convective storms (e.g. a microburst or squall). Additionally, their local occurrence, many times outside of settled areas, reduces the probability of their being recorded in historical reports. Although the frequencies of tornadoes in our database is higher than the 30 cases given by Munzar (1995) for the period A.D. 1119–1993, the actual occurrence of tornadoes is markedly underestimated. Thus, only 11 cases have so far been recorded for the nineteenth century, and another 20 in the years 1900–1930. Recently, the web pages of the CHMI mention fifteen tornadoes only for the years 1996–2000, of which seven were in 2000. This increase in information during the 1990s is a consequence of the systematic attention which has begun to be paid to this phenomenon by CHMI researchers. Every recorded occurrence of this phenomenon is, however, valuable for further study (see e.g. Paul 1999 for France).

## HUNDRED-YEAR GALES

Irrespective of the varying density of historical records on the weather, it is evident that many of the most destructive wind disasters are expressed in them. Lamb and Frydendahl (1991) studied historic storms of the North Sea, British Isles and Northwest Europe over the past 500 years. Kington (1998) analysed the great storm of 1–2 October 1697 whose synoptic conditions were analogous to those in well-known tragedy of 31 January–1 February 1953. Pfister (1999) characterised the five heaviest winter storms for Switzerland since A.D. 1500 (end of January 1645, 16–18 January 1739, 20 February 1879, 23 February 1967, 27 February 1990). Similarly, hundred-year gales have also been found in the Czech lands.

In the sixteenth century, most records are related to the New Year's Eve of 1556 and to the night of 4 to 5 January 1556 (due to the limited extent of this contribution, complete quotations of the corresponding historical sources will not be provided). In both cases, a thunderstorm, a gale and great damage are mentioned in narrative sources for many places throughout the whole of Bohemia. Probably in both cases, it was the passage of a cold front along a strong horizontal pressure gradient from a westerly-northwesterly direction across Bohemia that was associated with a marked intensification of wind speed.

In further cases, extremely strong winds also coming from a direction of 190–360° were probably associated with large horizontal pressure gradients and the passage of fronts. Such was the case on 28 December 1612, when an exceptionally destructive gale affected Bohemia, the Bohemian-Moravian Highlands and northern Moravia. Besides damage in towns, great wind breakage is also mentioned. According to Mikšovic (pp. 349–351) "in Germany from Most and to Marienberg, forests roads were swept from uprooted woods in many places, carmen almost could not go to Bohemia to buy grain, because they would have had to clear roads with thirty to fifty workers for several days". The extraordinary character of this event is witnessed by the fact that it was reflected in the book of the priest Jakeš Přerovský (1613).

An analogous situation evidently occurred on 20 December 1740, when reports of a so-called "Thomas-wind" appeared from all over the Czech lands (Fig. 6). The gale began in the evening hours and continued through the night into 21 December. The reports speak of great damage to buildings, courts, barns and sheep-cotes. Thus, in Olomouc the storm "damaged all buildings in the town, broke all windows, pulled down roofs and carried them a quarter of a mile further on" (Roubic 1993). Great damage was the result of the extensive windbreakage. Thus, in the region of Poděbrady, 5887 trees were uprooted in the local lords' woods. The uprooted trees were so broken and twisted that they could only be used for firewood (Anonymous 1927). Other actual reports of damage in woods from this gale are given by Berger (1880) and Nožička (1957). According to Czech sources, this gale also affected other countries, such as France, Germany and Austria.

Several exceptionally destructive wind events are also mentioned by sources for the nineteenth century. The greatest of them were on 18 December 1833 (3.7 million m$^3$ of damaged timber – Vicena et al. 1979), 7 December 1868 (6 million m$^3$ of damaged timber, combined with snow damage – Vicena et al. 1979) and the night of 26 to 27 October 1870. These cases are documented for a number of

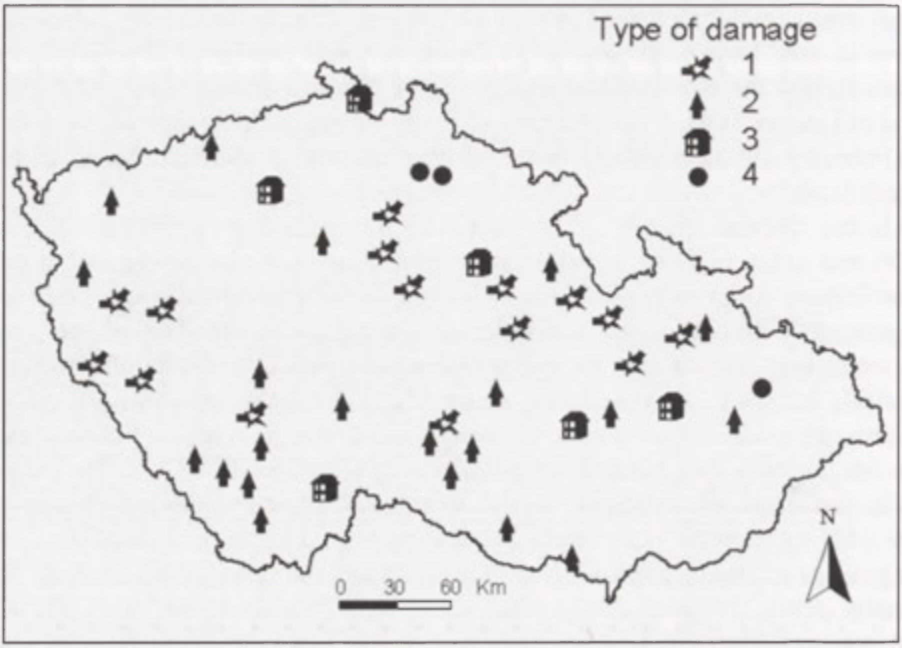


Figure 6. Places in the Czech lands reporting the gale of 20 December 1740: 1 – wind breakage and damage to buildings, 2 – wind breakage, 3 – damage to buildings, 4 – without damage specification.

places all over the Czech lands. In the last case, an area of 3800 ha was almost deforested and 2.29 million $m^3$ of timber were destroyed by the gale in the region of Český Krumlov (Frič 1934). Vicena et al. (1979) estimated the overall losses in the Czech lands and Slovakia at 6 million $m^3$.

In the twentieth century, the strongest wind events are considered to be those of 17 January 1955 (for a description of the synoptic situation see Gregor 1955, with 3.5 million $m^3$ of damaged timber – Vicena et al. 1979), of 2–4 January 1976 (6.8 million $m^3$ of damaged timber – Červený et al. 1984) and of 23–24 November 1984. In the last case wind breakages damaged around 7 million $m^3$ of timber, while 86,400 damage reports were filed with the Czech Insurance Co., with the costs reaching 258 million Czech crowns (for a detailed meteorological analysis, see Setvák and Strachota 1986). The greatest wind disaster of the twentieth century was that of 26 February – 1 March 1990, which damaged 8.4 million $m^3$ of timber (for the meteorological conditions, see Nekovář and Valter 1998). In this period, storms Daria, Herta, Vivian+ and Wiebke caused damage of over 20 billion Swiss francs in Great Britain, Belgium, Denmark, Germany and Switzerland (Munich Re 1990; Pfister 1999).

## IMPACTS OF STRONG WINDS

The action of the wind is given by its force effects on objects, when, in exceeding the limits of their strength or resilience, material damage occurs. The spectrum of damage is very broad. The effects of wind appear on the one hand as direct damage to houses, buildings and other objects (damage to roofs, collapsing walls, falling poles of power lines etc.), on the other hand by secondary damage to objects on the ground due to objects wind transported (e.g. roof cover), or uprooted (e.g. trees) or falling (e.g. crane). Particularly major damage is caused by strong winds in forest stands, as a result of the breaking, bending or uprooting of trees (Vicena 1992). Often, this is associated with loss of life. Thus, during a gale on 21 August 2000, a falling tree at a camp site in Chlumec nad Cidlinou killed a small girl in a tent. In the clearing up following this gale, a fitter was killed in a fall from a high electric line pole in the region of Přelouč. In the same year, two men died from injuries after falling from a roof during a sudden wind gust as they tried to save the roof of a family house during a gale (28 February) at Supíkovice.

The problem is that, as a rule, there are no continuous series documenting the numbers of victims or the amount of damage due to wind. An exception in the Czech Republic is systematic data about wood felling since 1963. It follows from these data, that wind is the most significant abiotic factor, wind breakage being most markedly responsible for salvage felling. Damage due to wind, ice deposits and snow accounted for 43.8% of salvage felling of timber from 1900–1950 (Forst et al. 1985), whereas in the years 1963–1999, their share grew to 75%. The wind's share was 46.3% (Brázdil 2000b). From Figure 7, a rapid increase in felling is clearly perceptible in connection with the destructive gales of 1976, 1984 (with a continuation of salvage timber felling in the subsequent year) and

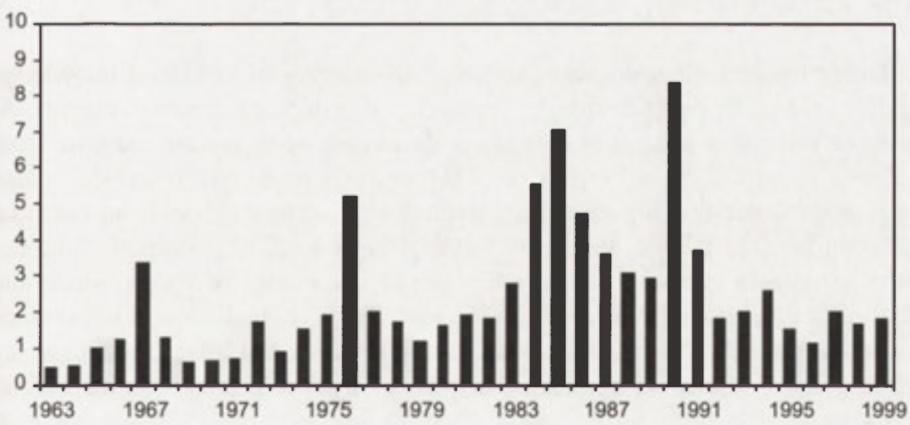


Figure 7. Salvage felling of timber (million $m^3$) in the Czech Republic due to wind in the period 1963–1999.

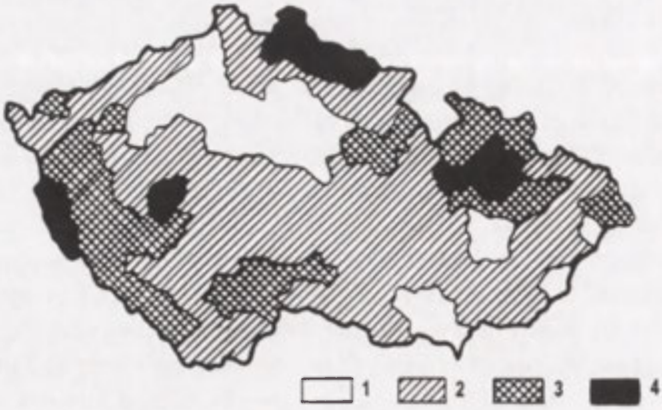


Figure 8. Location of damage due to wind in the Czech Republic over the period 1963–1975 (Vicena et al. 1979). Degree of damage according to the mean amount of salvage felling ($m^3 \cdot ha^{-1}$): 1 – negligible (< 0.10), 2 – slight (0.11–0.50), 3 – moderate (0.51–1.00), 4 – high (> 1.01).

1990. Only in 1969, 1970, 1979 and 1980 was wind damage exceeded by damage due to snow and in 1996 by damage due to ice deposits (Brázdil 1998). From the location of wind breakage in the Czech Republic (Fig. 8) it follows that 9% of the stand area was affected by severe damage (in the Jizerské hory Mts., the Giant Mts., part of the Bohemian Forest Mts., the Brdy Mts. and the Bohemian-Moravian Highlands, the High Jeseník Mts. and the western part of Moravian-Silesian Beskyd Mts.) and 24% by moderate damage (Vicena et al. 1979). The greatest damage is most clearly associated with higher elevations.

## CONCLUSION

To recognise meteorological extremes, it is necessary to extend knowledge about them to the period before the beginning of instrumental measurements. At the same time, it is necessary to register those cases which were extreme from the point of view of their impact on nature and society, something which also holds true for strong winds. Further systematic study in archives is an essential condition for expansion of the corresponding data base. This extremely time-demanding process is also a pathway to a better knowledge of strong winds and their impacts within the Czech lands. The problems studied acquire importance in connection with the current global warming which can affect the frequency and severity of strong winds in a fundamental way. For instance, an increase in the mean wind speed in north-west Europe (in the range of 1–9% over the next 75 years) follows from the Hadley Centre transient response climate model experiment (Murphy 1992). Dorland et al. (1999) showed for the Netherlands that an increase of 2% in wind intensity by the year 2015 could lead to a 50% increase in storm damage to houses and businesses. There is no doubt that even in the Czech Republic a possible increase in the frequency and severity of strong winds could lead to a conspicuous increase in the scale of damage. On the other hand, there is an interesting finding resulting from the 200-year series for gale frequency in Edinburgh (Dawson et al. 1997), which shows three clear peaks in storminess that follow the volcanic eruptions of Tambora (1815), Krakatau (1883) and El Chichon (1982). That points to the necessity for the possible effect of natural forcing on the frequency and severity of strong wind events also being studied.

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# ASSESSMENT OF RELATIONS BETWEEN THE NORMALISED DIFFERENCE VEGETATION INDEX (NDVI), FREQUENCY OF FOREST FIRES, AIR TEMPERATURE, SUNSHINE, PRECIPITATION IN POLAND

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ABSTRACT: Climatic variation in the growing seasons of the 1990s was examined using 10-day values for the normalised difference vegetation index (NDVI) in five regions in Poland. The NDVI values were compared with climatic conditions, by calculating multiple correlation coefficients and regression equations for the 10-day means of NDVI on the one hand, and temperature, precipitation, and sunshine anomalies on the other, in the period between April and September. The frequency of appearance of forest fires was analysed for the same regions. The relationships between the frequency of occurrence of forest fires and NDVI values, air temperature, and precipitation were identified.

KEY WORDS: climate variations, vegetation, normalised difference vegetation index (NDVI), forest fires.

The purpose of the study reported was to define the influence of climatic conditions on the development of vegetation during the growing season in Poland.

The state of development of vegetation was determined on the basis of the normalised difference vegetation index (NDVI) obtained from NOAA satellite imagery, as registered by AVHRR scanners. The NDVI data, encompassing the period between 1992 and 1998 (excluding 1994) were made available by the Institute of Geodesy and Cartography in Warsaw, which collaborates in gathering these data with the Canadian Remote Sensing Centre within the framework of the System of Evaluation of Conditions for Plant Growth in Poland (Bochenek 1999).

The NDVI is defined as the quotient of the streams of radiation registered by the satellite in the visible light range for the band 0.58–0.68 μm and in the near infrared band of 0.72–1.1 μm, or more precisely:

$$\mathrm{NDVI} = \frac{\mathrm{nearIR} - \mathrm{visible}}{\mathrm{nearIR} + \mathrm{visible}}.$$

NDVI was shown to be closely correlated with the leaf area index (LAI), net primary production (NPP), see White et al. (1992), and biomass volume (Struzik 1999).

The 10-day averages for the NDVI on the area of Poland during the growing season attain a maximum in the first ten days of June, a second, somewhat lower, maximum – at the beginning of July, and a third – even less pronounced one – in the middle of August (see Tab. 1). These changes can be supposed to correspond with the course of the fieldwork and periodic changes in the biomass on agricultural land.

Since the development of vegetation is regulated by light, thermal, and humidity conditions, relations were studied between the NDVI and insolation, temperature and precipitation during the growing season. The measure of the actual influence of the meteorological elements on the value of the NDVI is the correlation of the deviations of the values of these variables during particular growing seasons from their average "climatic pattern" as represented by the long-term means. In addition, relations between the development of vegetation and weather conditions change with consecutive phases of the growing season. In order to account for these changes, the growing seasons analysed, encompassing the period between April 21st and September 30th, were divided into phases of approximately 40 days each, namely: April 21st – May 31st (I), June 1st – July 10th (II), July 11th – August 20th (III), and August 21st – September 30th (IV).

With the 10-day averages for NDVI, air temperature (T), insolation (S), and precipitation (R) being available for all phases of the growing season, the highest and lowest values for these variables were determined for the 6-year period considered, and then, as in Bochenek (1999), the following normalised indicators calculated for each phase in the consecutive years.

The indicator of vegetation condition:

$$\mathrm{VCI} = 100\,\frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}.$$

The thermal indicator:

$$\mathrm{TI} = 100\,\frac{T - T_{\mathrm{min}}}{T_{\mathrm{max}} - T_{\mathrm{min}}}.$$

The sunshine indicator:

$$\mathrm{SI} = 100\,\frac{S - S_{\mathrm{min}}}{S_{\mathrm{max}} - S_{\mathrm{min}}}.$$

The precipitation indicator:

$$RI = 100 \frac{R - R_{min}}{R_{max} - R_{min}}.$$

In particular phases of the season from April to September the indicators defined in this manner take the values between 0 and 100.

Multiple regression equations for VCI (TI, RI, SI) were identified separately for each phase of the season (I through IV) and for five selected regions of Poland: the vicinity of Szczecin – representing the North-West (NW) of Poland, Wrocław (SW), Suwałki (NE), Przemyśl (SE), and Łódź (centre) – see Figure 1. Equations were identified on the basis of 24-element samples (four 10-day periods × six years). The regression coefficients obtained and the corresponding correlation coefficients are shown in Table 2.

Coefficients corresponding to the variables RI and TI change their sign depending upon the phase of the growing season, and only the relation between the VCI index and insolation is consistently positive. Precipitation mostly has a positive influence on the value of the VCI index. A temperature increase is associated

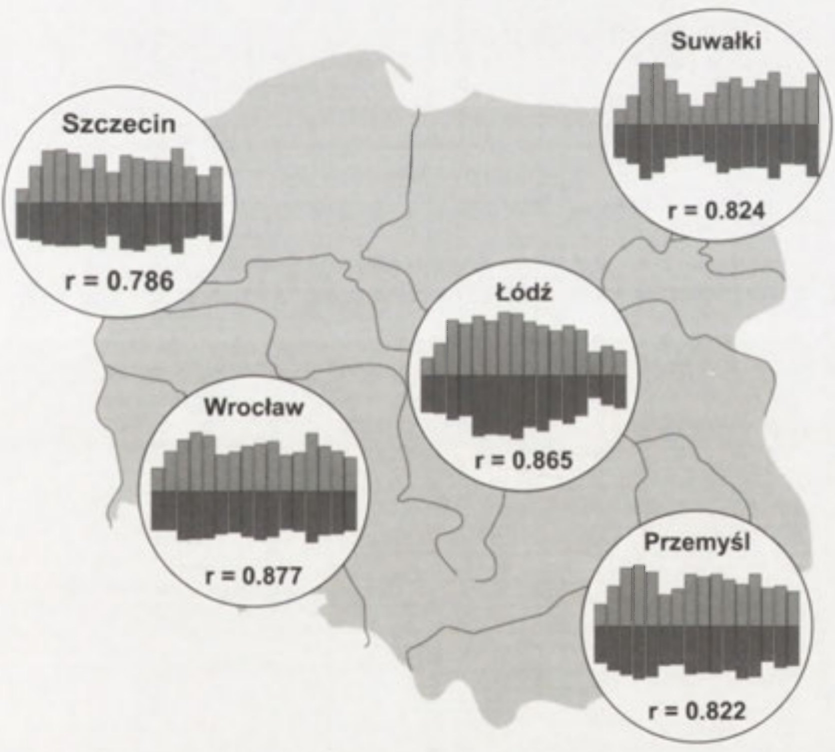


Figure 1. The six-year averages of the observed values for 10-day periods (April 21st – September 30th) of the NDVI index (upper parts of histograms), the values of the NDVI estimated on the basis of sunshine, precipitation, and air temperature (lower part of histograms), as well as their correlation coefficients (r).

Table 1. Ten-day averages of NDVI values in Poland.

| Month | IV | V | | | VI | | | VII | | | VIII | | | IX | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Decade | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| NDVI | 0.324 | 0.414 | 0.500 | 0.507 | 0.557 | 0.519 | 0.540 | 0.549 | 0.471 | 0.465 | 0.438 | 0.444 | 0.422 | 0.368 | 0.363 | 0.368 |

Table 2. Coefficients of the multiple regression equations and correlation coefficients (r) of the VCI index with sunshine (SI), precipitation (RI), and air temperature (TI) in the four phases of the growing season; b – constant (phase I: April 21st – May 31st; phase II: June 1st – July 10th; phase III: July 11th – August 20th; phase IV – August 21st – September 30th) (* – coefficients significant at the level of 0.05).

| Statiions | I | | | | | II | | | | | III | | | | | IV | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SI | RI | TI | b | r | SI | RI | TI | b | r | SI | RI | TI | b | r | SI | RI | TI | b | r |
| Szczecin | 0.86 | 0.31 | –0.21 | 14.84 | 0.49 | 0.77 | –0.02 | –0.70 | 49.73 | 0.57 | 0.76 | 0.15 | –0.64 | 57.60 | 0.64* | 0.84 | –0.08 | –0.23 | 29.01 | 0.61* |
| Suwałki | 0.25 | 0.33 | 0.67 | –8.15 | 0.64* | 0.62 | 0.52 | –0.08 | –10.58 | 0.37 | 0.50 | 0.22 | –0.54 | 53.71 | 0.54 | 0.93 | 0.09 | –0.53 | 49.64 | 0.56 |
| Łódź | 0.24 | 0.19 | 0.25 | 23.82 | 0.39 | 0.16 | 0.29 | 0.03 | 66.69 | 0.27 | 0.53 | 0.35 | –0.48 | 57.50 | 0.57 | 1.20 | 0.33 | –0.59 | 13.62 | 0.64* |
| Wroclaw | 0.78 | 0.46 | –0.21 | 15.13 | 0.54 | 0.41 | 0.22 | –0.10 | 39.56 | 0.31 | 0.35 | 0.43 | –0.47 | 55.63 | 0.63* | 0.58 | 0.12 | –0.04 | 32.49 | 0.43 |
| Przemyśl | 0.26 | 0.44 | 0.32 | 19.40 | 0.54 | 0.76 | 0.36 | –0.02 | 15.08 | 0.66* | 0.49 | 0.17 | –0.28 | 48.30 | 0.43 | 0.63 | –0.11 | –0.12 | 35.47 | 0.71* |

with a decrease in the VCI value in phases III and IV of the season, while in phase I the correlation is positive in the eastern part of the country, and negative in the western part. The strength of the relationship between VCI and meteorological variables increases distinctly in the second half of the season, and so, for instance, for the area of Przemyśl, the correlation coefficient attains a value of 0.71 in phase IV of the season (Tab. 2).

Using the four regression equations for (phases I–IV) one can estimate the value of the VCI index during the whole April – September season. Coefficients for the correlations between the estimated and observed values of VCI range between 0.49 (Wroclaw) and 0.66 (Łódź), and change significantly in different years (Tab. 3). The course of the estimated and observed values of VCI for the region of Łódź, where the correlation emerged as the strongest, is shown in Figure 2.

Table 3. Correlation coefficients (r) between the observed and the estimated values of the VCI in consecutive years and in the whole 6-year period between 1992 and 1998 ($r_6$).

| Stations | r | | | | | |
|---|---|---|---|---|---|---|
| | 1992 | 1993 | 1995 | 1996 | 1997 | 1998 | $r_6$ |
| Szczecin | 0.73 | 0.48 | 0.72 | 0.39 | 0.44 | 0.61 | 0.58 |
| Suwałki | 0.59 | 0.38 | 0.70 | 0.46 | 0.72 | 0.66 | 0.58 |
| Łódź | 0.79 | 0.27 | 0.84 | 0.54 | 0.90 | 0.72 | 0.66 |
| Wroclaw | 0.38 | 0.46 | 0.62 | 0.65 | 0.70 | 0.16 | 0.49 |
| Przemyśl | 0.59 | 0.67 | 0.52 | 0.72 | 0.72 | 0.35 | 0.59 |

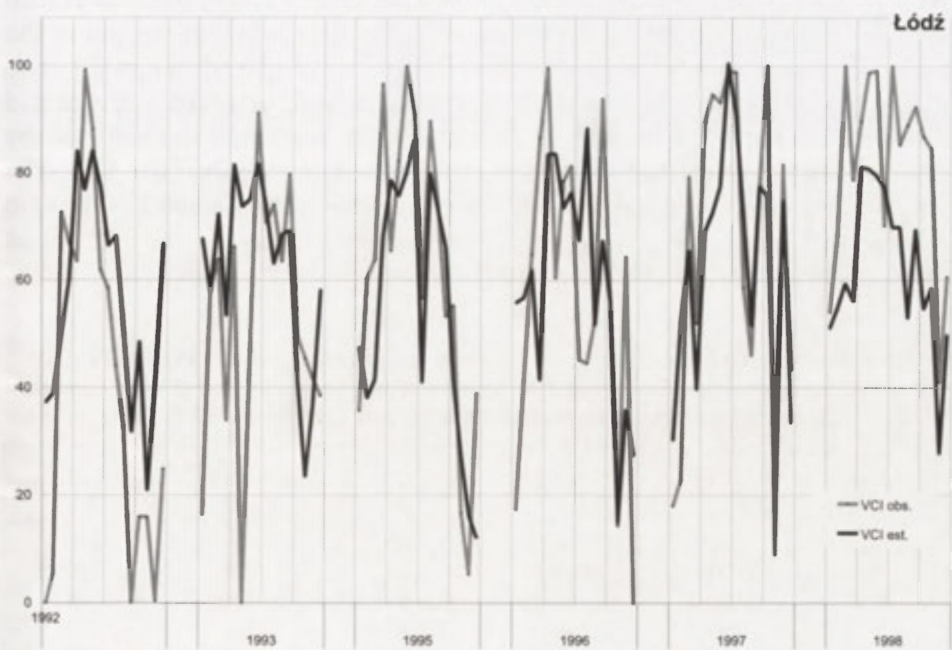


Figure 2. Observed values of the vegetation condition index (VCI obs.), and its estimated values (VCI est.) in the region of Łódź in the years 1992–1998.

In the search for the more precise relationship between the NDVI index and the meteorological elements, coefficients were also calculated for regression equations and for correlation on the basis of deviations of the NDVI, temperature, sunshine, and precipitation, from the average values in the particular 10-day periods. These coefficients are given in Table 4. As can be seen from the example of Łódź the correlation coefficients do not differ significantly from those defined on the basis of deviations (from indices) on the scale of whole phases of the season (i.e. four 10-day periods each).

Table 4. Coefficients of the multiple regression equations and correlation coefficients (r) of the 10-day anomalies of the NDVI index with sunshine (S), precipitation (R), and air temperature (T) in the four phases of the growing season (phases I through IV, see Tab. 2) in the region of Łódź.

| Phase | S | R | T | b | r |
|---|---|---|---|---|---|
| I | 0.110 | –0.001 | –0.006 | 0.000 | 0.40 |
| II | 0.003 | 0.014 | 0.005 | 0.000 | 0.26 |
| III | 0.182 | 0.040 | –0.017 | 0.000 | 0.67 |
| IV | 0.121 | –0.002 | –0.016 | 0.000 | 0.62 |
| I–IV | | | | | 0.53 |

It is interesting to note that the time period analysed has seen a quite systematic change in the difference between observed and estimated values of the NDVI. Thus, in the first two years the measured values of NDVI were lower than the ones estimated on the basis of meteorological data, while at the end of the period they were clearly "too high". The NDVI index displayed an upward trend during the 1990s (Tab. 5). No significant changes were observed in the period considered in either the length – or the dates of the beginning and end – of the growing season, as defined on the basis of the thermal criterion ($T \geq 5^{\circ}C$). The length of the growing season in Łódź varied between 192 days and 227 days (in 1997 and 1996 respectively), while its beginning varied between the 85th day of the year (1992) and the 106th day (1997).

Table 5. Average differences between observed and estimated values of the $\overline{NDVI}$ (Δ), seasonal averages of the $\overline{NDVI}$ value, as well as the beginning (B), end (E) and duration ($L_v$) of the growing season in the region of Łódź in the years 1992–1998.

| Years | Δ | $\overline{NDVI}$ | Growing season | | |
|---|---|---|---|---|---|
| | | | B | E | $L_v$ |
| 1992 | –0.045 | 0.3703 | 85 | 300 | 216 |
| 1993 | –0.017 | 0.3974 | 89 | 298 | 210 |
| 1995 | 0.015 | 0.4304 | 87 | 304 | 218 |
| 1996 | 0.004 | 0.4136 | 94 | 320 | 227 |
| 1997 | 0.006 | 0.4378 | 106 | 297 | 192 |
| 1998 | 0.046 | 0.4826 | 86 | 296 | 211 |

The increase in the NDVI during the 1990s is most probably therefore conditioned by factors not related to weather.

In spite of the observed temperature increase, especially during winter, but also in the summer (Tab. 6), the growing season (corresponding to the persistence of T ≥ 5°C) in the 1990s did not change significantly in comparison with its long-term average characteristics from the years 1951–1990. The average duration of the growing season for Poland is, respectively 217 and 221 days for the corresponding annual average temperatures of 8.0°C and 7.6°C (see Tab. 6).

Table 6. Beginning (B), end (E), and duration ($L_v$) of the growing season, and average air temperature values for the year (I–XII), winter (XII–II), and summer (VI–VIII) in Poland in the years 1992–1998 and 1951–1990 (according to the monthly averages from 51 weather stations).

| Years | Growing season | | | $T_{(I-XII)}$ | $T_{(XII-II)}$ | $T_{(VI-VIII)}$ |
|---|---|---|---|---|---|---|
| | B | E | $L_v$ | | | |
| 1992 | 85 | 302 | 218 | 8.7 | –0.2 | 19.2 |
| 1993 | 80 | 298 | 219 | 8.0 | –0.5 | 15.8 |
| 1994 | 80 | 308 | 229 | 8.8 | 0.5 | 18.2 |
| 1995 | 88 | 304 | 217 | 8.1 | 1.1 | 18.0 |
| 1996 | 95 | 321 | 227 | 6.5 | –5.0 | 16.6 |
| 1997 | 105 | 301 | 197 | 7.8 | –2.6 | 17.5 |
| 1998 | 86 | 298 | 213 | 8.2 | 1.6 | 16.9 |
| 1992–1998 | 88 | 305 | 217 | 8.0 | –0.7 | 17.5 |
| 1951–1990 | 90 | 309 | 221 | 7.6 | –1.7 | 16.8 |

The length of the growing season with temperature ≥ 5°C ($L_v$) displays a weak correlation with the monthly and seasonal averages of air temperature. Correlation coefficients for $L_v$ are only significant – though not too high, either – with the average temperatures of these months, during which the threshold of 5°C is being crossed (Tab. 7). In this context one should treat with caution the formulation of forecasts as to a significant extension of the growing season in conditions of the expected climate warming (Demidowicz et al. 1999).

Climatic conditions existing during the growing season are of definite significance for flammability and the fire hazard in forests. The number of fires breaking out in forests is partly determined by random events, such as lightning strikes, but is most often the result of direct or indirect human activity, depending on the environmental conditions – the stage of development of vegetation, humidity, and the amount of litter accumulated. All of the factors listed feature seasonal variability, including that of human presence in the forest.

On the basis of the statistical data obtained from the Fire Rescue Headquarters in Warsaw, it is possible to establish that more than 7,000 forest fires a year were observed in Poland in the years 1993–1998. The frequencies of these fires displayed a characteristic annual rhythm, and a significant variability from year to year.

Table 7. Coefficients of correlation (r) of the duration of the growing season ($T \geq 5^{o}C$) with the average values of temperature in the region of Łódź in the years 1951–1998 (* – coefficients significant at the level of 0.05).

| Months | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | III–V | VI–VIII | IX–XI | XII–II | I–XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| r | 0.21 | 0.33* | 0.53* | 0.46* | 0.01 | 0.10 | 0.11 | 0.07 | –0.03 | 0.41* | 0.54* | –0.26 | 0.59* | 0.14 | 0.56* | 0.31* | 0.55* |

Table 8. Monthly averages of the frequency for forest fires in Poland (1993–1998).

| Months | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | I–XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of fires | 37 | 75 | 425 | 1902 | 1632 | 914 | 1253 | 1246 | 153 | 95 | 25 | 12 | 7769 |
| Number of fires per 100 sq. km of forests | 0.04 | 0.09 | 0.48 | 2.17 | 1.86 | 1.04 | 1.43 | 1.42 | 0.17 | 0.11 | 0.03 | 0.01 | 8.86 |
| Coefficient of seasonality [%] | 0.5 | 1.0 | 5.5 | 24.5 | 21.0 | 11.8 | 16.1 | 16.0 | 2.0 | 1.2 | 0.3 | 0.2 | 100.0 |

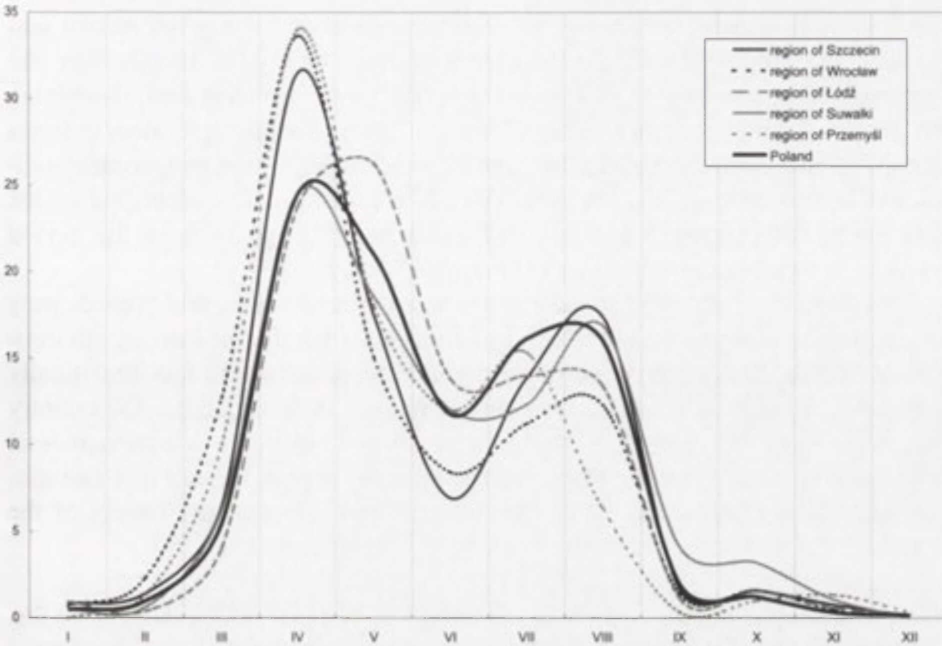


Figure 3. The average annual course of the number of forest fires in Poland in the years 1993–1998.

The annual dynamics to the number of forest fires has two distinct maxima: one in spring (April), and a second in summer (July, August). The minimum frequency of fires occurs in December (Tab. 8). The annual cycle features high stability, i. e. is repeated in consecutive years and can be perceived in all the analysed series from various parts of the country (Fig. 3). However, the spring maximum for fires is seen to be more distinct and takes place somewhat earlier in the West and the South of Poland, i. e. where the spring is warmest, and the humidity of the litter lowest (owing, in particular, to sparse snow cover in winter).

In order to explain the variability in the number of forest fires from year to year we accounted for three environmental factors expected to shape conditions for the appearance of forest fires: the stage of development of vegetation, air temperature, the precipitation. The influence exerted by these factors on the monthly frequencies of forest fires in Poland was assessed using multiple regression equations describing the dependence of the number of fires on deviations from the norm, for a given month, of the vegetation index NDVI, air temperature, and precipitation. As in the study of relations between the vegetation index and elements of climate, these deviations are expressed in percentage indicators, in such a manner that the indicator takes the value of 0 whenever a given variable assumes the monthly minimum for the period considered, and 100 – when it assumes the maximum value for a given month. A similar transformation was applied to the number of fires – the minimum number for a given month was ascribed the value FI = 0, the maximum number FI = 100. In this way the regression equation FI = a(VCI) + b(TI) + c(RI) + d was identified, describing the "excess" of the monthly number of fires, FI, above the average value, in terms of dependence upon the vegetation condition index (VCI), the temperature indicator (TI), and the precipitation index (RI). The equations were identified on the basis of the 30-element sample consisting of monthly values from the period April to September in the years 1993 and 1995–1998.

The limited size of the sample ensures that the results obtained provide only an a generalised depiction of the conditioning of the number of fires by environmental factors. The multiple correlation coefficients are not in fact statistically significant, though in terms of their differentiation in space across the country they seem to be justified (Tab. 9). Least sensitive to changes in environmental conditions turn out to be the forests of the Suwałki region, located in a late-glacial lake district landscape, while the montane and sub-montane forests of the Przemyśl region feature the highest sensitivity (coefficient r = 0.69).

Table 9. Multiple regression coefficients and multiple correlation coefficients (r) of the fire number indicator (FI) with the indicators of vegetation condition (VCI), air temperature (TI), and precipitation (RI), according to the monthly averages from the period April–September of the years 1993 and 1995–1998; d – constant (* – denotes the coefficients differing significantly from zero at p = 0.05).

| Territories | a(VCI) | b(TI) | c(RI) | d | r |
|---|---|---|---|---|---|
| Poland | –0.09 | 0.55* | –0.29 | 26.8 | 0.54 |
| Region of Szczecin | –0.11 | 0.47* | –0.07 | 24.5 | 0.45 |
| Region of Suwałki | –0.02 | 0.28 | –0.02 | 29.7 | 0.28 |
| Region of Łódź | –0.39 | 0.17 | 0.10 | 39.1 | 0.46 |
| Region of Wrocław | 0.09 | 0.38* | –0.19 | 21.9 | 0.46 |
| Region of Przemyśl | –0.51* | 0.57* | –0.45* | 48.0 | 0.69 |

Some of the regression coefficients differ significantly from zero. This is above all true of the coefficients determining the impact of temperature on the number of fires b(TI). The significant role of temperature is seen throughout the country, in the South and in the West (Tab. 9). This result conforms to meteorological conditions shaping the fire hazard (air temperature and humidity, precipitation), as described by Pieślak (1961).

The coefficients c(RI), defining the influence of precipitation, are – with just one exception – negative, but only in the case of the Przemyśl region is the respective value significantly different from zero. Equations confirm the obvious dependence of fires on humidity.

Similarly, negative – with just one exception again – are the coefficients a(VCI), expressing the influence of the stage of vegetation development on the frequency of fires. The "less green", i.e. drier, forests, take on fire more easily.

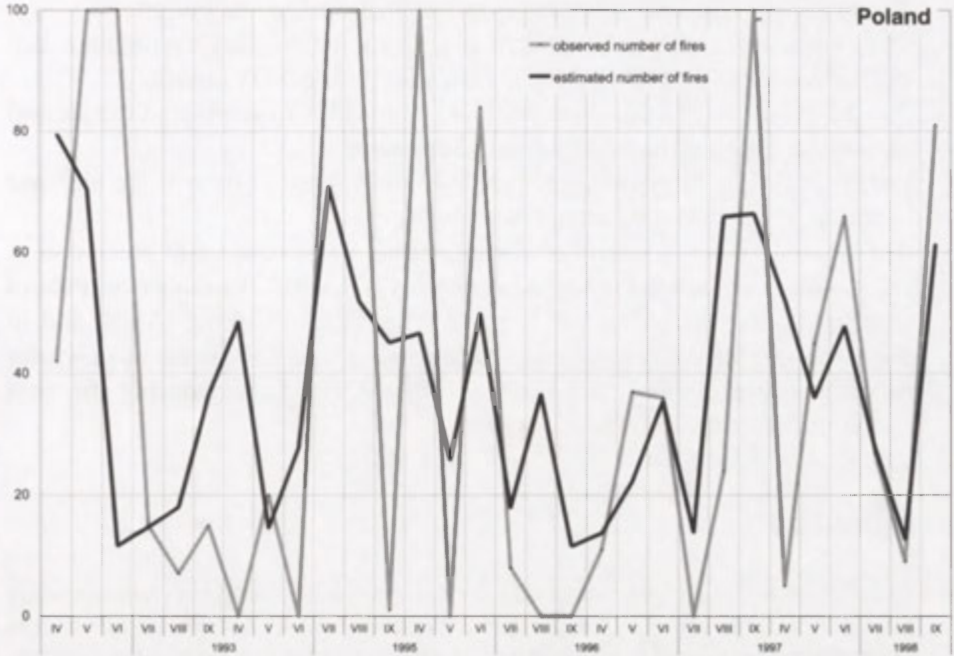


Figure 4. The observed and estimated values of the indicator of forest fire frequency in Poland in the years 1993 and 1995–1998.

As before a significant negative coefficient characterises the forest in Przemyśl region.

We can estimate the indicator of the frequency of forest fires (FI) on the basis of the regression equations identified. An instance of such an estimation is provided in Figure 4. The concordance of the observed and estimated values of the FI indicator is measured by the correlation coefficient, which takes the value of 0.53 for the country-wide series, and ranges for selected regions between 0.29 and 0.62.

In spite of the fact that the factors accounted for – vegetation conditions, air temperature, and precipitation – determine only a small part of the observed variability in numbers of fires (even in Przemyśl region only approximately 38%), attention should be paid to the perhaps non random spatial differentiation to the relation analysed. Climatic factors, along with the state of vegetation, influence the occurrence of fires in the forests of SE Poland most strongly, while this influence is weakest in the region of Suwałki (NE Poland).

In the context of observed and expected climate changes the frequency of forest fires can be expected to feature an upward trend. Alongside the increase in temperature and decreased precipitation of the 1990s, the increase in the fire hazard can certainly also be attributed to the scarce snow cover. The lack of snow during winter may first of all entail the acceleration and amplification of the first, spring culmination of fires.

The major observations resulting from the analyses carried out are:

– that synchronous changes in insolation, precipitation, and temperature can explain some 50% of the observed variability to the NDVI index,
– that the influence of climatic conditions on the NDVI increases in the second part of the growing season (August – September),
– that the length of the growing season has not changed in spite of the increase in annual average temperature in the 1990s,
– that the state of development of vegetation, air temperature, and precipitation explain up to 38% of the observed variability in forest-fire numbers in Poland with forest fires occurring with highest frequencies in spring (April) and in July and warming of climate and the disappearance of snow cover in winter capable of contributing to an increase in the fire hazard during the first maximum of forest fires, i.e. in spring.

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# LONG-TERM OBSERVATIONS OF CLOUD COVER IN CRACOW (1792–1999)

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ABSTRACT: Cracow's series of nephological observations is unique in Europe. Neither the place of observations nor the methods of estimation of the degree of cloud cover nor the definition of cloud genera have changed significantly for about one hundred years. The paper presents therefore the database on cloudiness in Cracow and its possible applications on both the local and global scale.

KEY WORDS: Cracow, cloudiness, cloud genera, nephological conditions.

## INTRODUCTION

Though believed to be of fundamental importance in the formation of climate, cloudiness differs from other meteorological elements like temperature or precipitation, in having been examined rather inadequately. Information on it is provided by the IPCC reports (Climate Change 1992) and numerous papers (Schneider 1972; Wetherald and Manabe 1980; Rossow 1981; Wang et al. 1981; Hughes 1984), wherein the authors emphasise the necessity of nephological studies if climate is to be to understood, modelled and monitored.

The Meteorological Station of the Climatology Department at the Jagiellonian University in Cracow ($\varphi$ = 50°04' N, $\lambda$ = 19°58' E, h = 206 m above sea level) is one of the most unique stations in Europe, which can boast a long and, what is most important, continuous observation of cloud cover. The 'state of the atmosphere' has been recorded since the station's foundation, i.e. from 1792. At first, the report on cloud cover concerned only its size and was irregular. Systematic reports date from 1853, when the 10-grade scale of cloud cover was introduced. The first qualitative records of clouds date from December 1862, but describe only four genera: cumulous H, stratified S, cirrous-stratified FS, and cumulous-stratified HS, which were recorded only at noon. In accordance with the new classification employing Latin names, introduced by Howard, clouds were observed from September 1866, although at first sporadically and only at

14:00 hrs. While clouds were recorded three times a day in the 'year of international observations', i. e. from May 1896 to May 1897, they unfortunately, fell back later to one observation only at noon. Since 1904, clouds have been discerned according to the *International Cloud Atlas*, three times a day. This date marks the beginning of uniform nephological observations in Cracow and since then neither the place itself nor the method of estimation of cloud cover nor the definition of cloud genera have changed significantly.

The aim of this study is therefore to present the database on cloud cover in Cracow and to point to its possible applications on both the local and global scales.

## DATABASE

Daily nephological observations in the years 1792–1999 form the archival material belonging to the Climatology Department at the Institute of Geography and Spatial Management of the Jagiellonian University which is the source of the databank on cloud cover in Cracow. These include:

1. Daily Records of Meteorological Observations, so called Great Books, which contain the results of the observations at given times of day.
2. Lists of Monthly Meteorological Observations, so called Middle Books, which contain the diurnal values.

The records of nephological conditions comprise the proportion of the sky covered by cloud and cloud genera noted as letters. Ten cloud genera have been accounted for, according to the *International Cloud Atlas*: Cirrus Ci, Cirrocumulus Cc, Cirrostratus Cs, Altocumulus Ac, Altostratus As, Stratocumulus Sc, Stratus St, Nimbostratus Ns, Cumulus Cu, and Cumulonimbus Cb.

Cloud genera analysis is a complicated task due to the qualitative character of the phenomenon. None of the presented mean values necessary to show some general relationships, are able to offer a complete reflection of nephological conditions. However, as there is no better method, previous works (Michna 1957, 1959a, 1959b; Warakomski 1961 et al.) have been followed, in that the frequency of particular cloud genera in a month in climatological terms have been calculated. The sum of the values for all months is the annual frequency of the cloud genus, and this can be used to calculate the multi-annual frequency. To obtain a more complete image of the nephological conditions, cloudiness structure was also considered, together with its multi-annual course and annual course in three climatological terms, against the background of the mean values. The mean values are somehow artificial, but present the examined process more explicitly.

Mean cloudiness has been calculated for all cloud genera, using an 11-degree scale (0–10; where 0 represents a cloudless sky, and 10 a sky entirely covered by cloud). The data from the period 1989–1999 have been transformed from a 9-degree to an 11-degree scale.

## POSSIBLE APPLICATIONS OF THE LONG-TERM NEPHOLOGICAL OBSERVATIONS IN CRACOW

‘Metadata’ i.e. information on the history of nephological research in Cracow, is crucial for scientific research. Very few meteorological stations in the world have so long and continuous a series of records with complete observatory documentation. Archive materials from this station therefore serve as a reference for research on changes in the climate of Central Europe, as, according to Obrębska-Starklowa (1993), the climatic variations in Cracow are representative of this region of Europe.

The Cracow database on cloud cover may be applied:

1. To assess the long-term variability in nephological conditions,
2. To study the relation between cloudiness and cloud genera versus circulation and anthropogenic factors,
3. To define the structure of cloud cover of a town situated in an inversion foothill valley.

## EVALUATION OF THE LONG-TERM VARIABILITY IN NEPHOLOGICAL CONDITIONS

On the basis of records from 1859–1999, mean annual cloudiness in Cracow amounts to 67%. However, during the examined period the values changed from year to year. The curve for the mean annual cloudiness (Fig. 1), smoothed by 10-year moving averages, has two clear minimum values of 57%, in 1921 and 1982, and two equal maximum values of 78%, in 1941 and 1952. From 1859 until the turn of the century the course for mean annual cloudiness is steady. An increase in cloudiness is observed from the beginning of the 1940s with the level remaining high for the next 20 years, before decreasing from 1961 onwards. The subsequent increase in cloudiness starts from the beginning of the 1990s.

Almost the opposite pattern is presented by plots for the number of cases of a cloudless sky in particular climatological observation terms (Fig. 2). It was during the most cloudy years (1941–1960) that a cloudless sky was observed most rarely, and during the years with the lowest cloudiness (1961–1995) that it

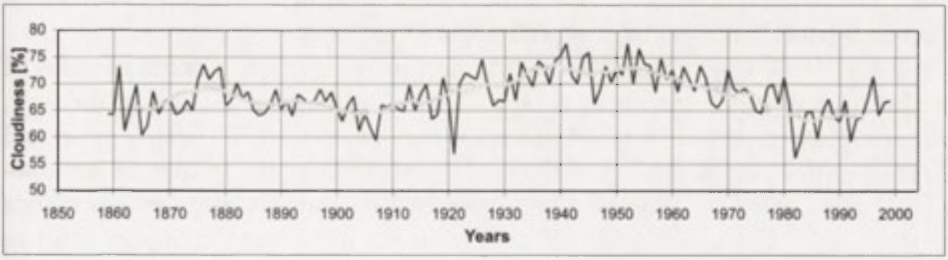



Figure 1. Multi-annual course for cloudiness (in %) in the years 1859–1999 in Cracow.

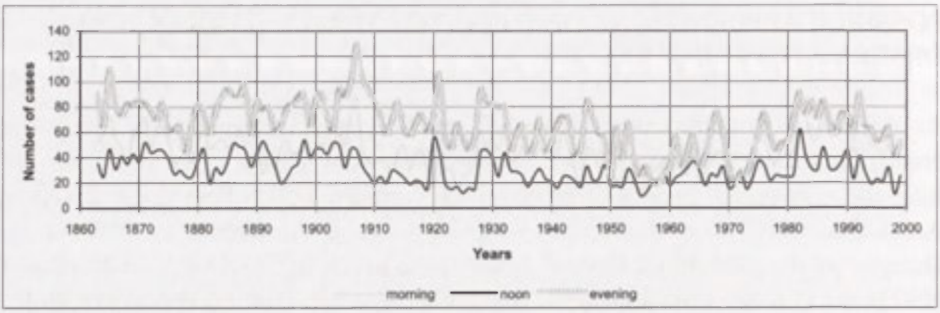



Figure 2. Multi-annual course for frequency of occurrence of a cloudless sky in the different climatological terms in Cracow (1906–1999).

was most frequent. For example, a cloudless sky in the morning and evening occurred twice as often in the years 1981–1985 as between 1951 and 1955. Moreover, in the least cloudy year of the whole examined period (1982), every fourth evening was cloudless. It is interesting that, when comparing with the mean for the period 1906–1995, the greatest elevation in the number of cases of a cloudless sky (by 225) was that which occurred during the last 10-year period in the morning observation term (an increase of 148 cases in the evening observation term). That might be related to the decrease in the frequency of occurrence of St clouds, which appear most often in the morning and which used to predominate in the structure to the cloudiness over Cracow.

The results presented above coincide with those in the papers by Henderson-Sellers (1986) on the changes in cloudiness in Europe. That author has examined the influence of climatic warming on cloud cover and shown that cloudiness in the multi-year period increased during the shift from the cool subperiod (1901–1920) to the warm (1934–1953). She also reports that an increase in cloudiness is denoted in northern and western Europe, while in central Europe (to which Cracow is assigned) there is a decrease which may be caused by the intensified activity of high pressure systems.

The calendar of synoptic situations for the upper Vistula river drainage basin (Niedźwiedź 1988), makes it clear that Cracow has also witnessed an increase in the frequency of occurrence of anticyclonic situations in recent years (after 1975 there is a definite downwards trend for the cyclone index – 142 in 1990) which favour weather without cloud or with slight cloudiness.

It should also be noticed that the greatest increase in the number of cases of a cloudless sky in recent years is characteristic of the cold seasons of the year, i.e. the heating period in which an additional amount of artificially-generated heat is emitted to the atmosphere. This is confirmed by the studies of Kossowska-Cezak (1978) for Warsaw. According to Kossowska-Cezak, stratus clouds can be scattered over a warmer part of a town due to the thermal impact of urban built-up areas. The studies of Kuczmarski (1982) have shown that in Cracow in the period 1951–1975 a downward trend for cloudiness occurred in November, December and January only. Anthropogenic factors have also been emphasised by Morawska-Horawska (1984) in relation to the decrease in the number of days with fog in Cracow in the period 1971–1980. At that time this number, 61 in a year on average, was 41 lower than in the previous 10-year period.

Cracow resembles other regions of the world (London et al. 1991; Nicholls et al. 1996) in that an increased frequency of occurrence of certain cloud genera (Ci, Ac, Sc, Cu and Cb) is observed, along with a decreased frequency of other cloud genera (Cc, Cs, Ns, St and fog).

Among the high clouds, it is Ci clouds which have the largest role in the cloudiness of Cracow (accounting for 7% of cases). Furthermore, unlike in the cases of other clouds of this height, their frequency shows an upward trend (Fig. 3). Until 1937 their frequency of occurrence was low (at 2 cases per month). Subsequently, it increased gradually until 1955 (at 9 cases), before remaining almost steady during the subsequent 20 years (at ca. 5 cases). It then fell (down to 3 cases), up to 1991 before increasing again in recent years. This general tendency in the multi-annual course also refers to particular terms of climatological observations. Over the entire period of studies, Ci cloud occurred most often at noon, while the largest differences in frequency between the other observation terms come in years when the increase in the incidence of Ci cloud is greatest (1937–1955).

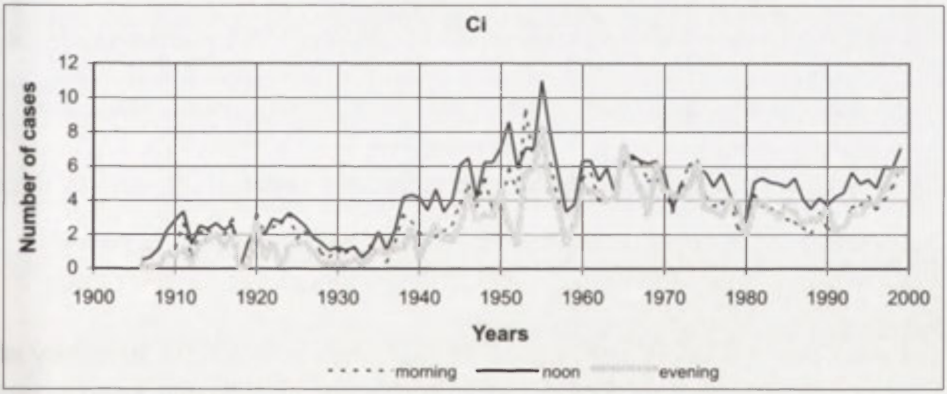



Figure 3. Multi-annual course to the frequency of the Ci cloud genus in Cracow (1906–1999).

Among the high clouds, Cc cloud occurs most rarely (accounting for 3% of the total amount of cloudiness in Cracow), with the frequency of occurrence showing a downward trend in the whole record series (Fig. 4). Until 1920 and in the 1950s, the frequency of Cc cloud took on rather high values for what is the most rarely occuring cloud in the sky (more than 2 cases). However, there are some doubts whether these values reflect the actual state.

The multi-annual course of occurrence of Cs clouds (5% of cases of cloudiness over Cracow) also shows a downward trend (Fig. 5), but the latter is gradual

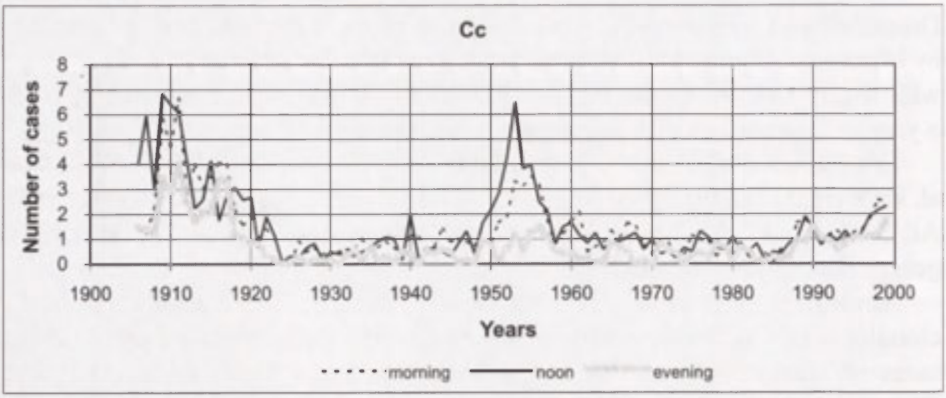



Figure 4. Multi-annual course to the frequency of the Cc cloud genus in Cracow (1906–1999).

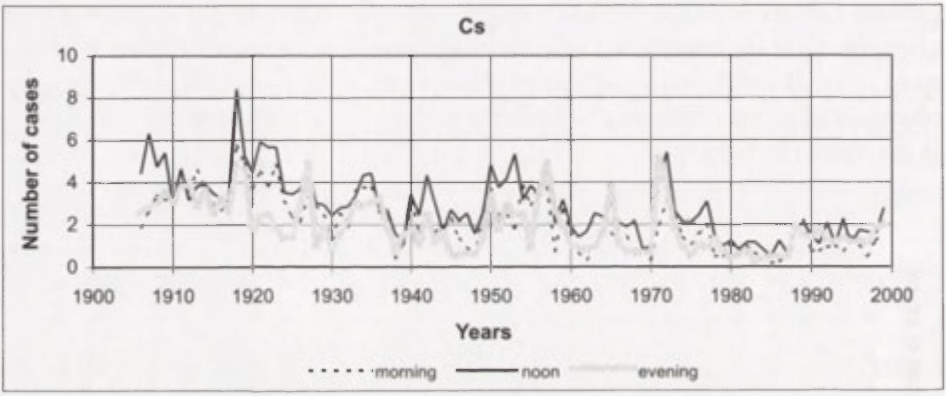



Figure 5. Multi-annual course to the frequency of the Cs cloud genus in Cracow (1906–1999).

and even over the whole multi-annual period. Years in which the frequency of Cs cloud occurrence exceeded 4 cases did happen, though, the average was 2 cases.

The multi-annual course to the occurrence of Ac clouds, the commonest in Cracow apart from Sc clouds (at 15%), shows an upward trend (Fig. 6). A significant increase in the frequency of occurrence of Ac clouds was marked from 1941 until the mid 1960s (ca. 10 cases). Earlier (in the years 1921–1940), Ac clouds used to occur at an almost constant frequency (of 2–4 cases). During the last 15 years, the frequency of occurrence of Ac clouds has remained at a rather steady, high level (of between 8 and 10 cases). Until 1920 Ac cloud occurred most often at noon (ca. 5 cases more than in the other observation terms), while during the next 20-year period the peak came in the morning (2 cases more than in the other observation terms, on average), and until the 1940s the differences

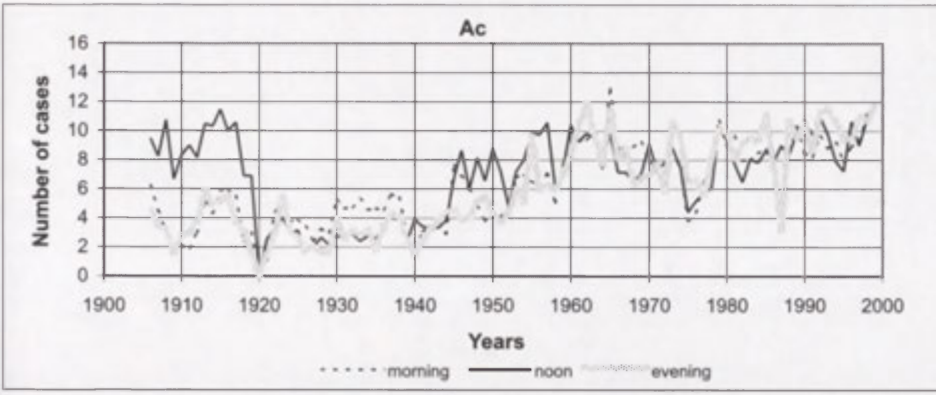



Figure 6. Multi-annual course to the frequency of the Ac cloud genus in Cracow (1906–1999).

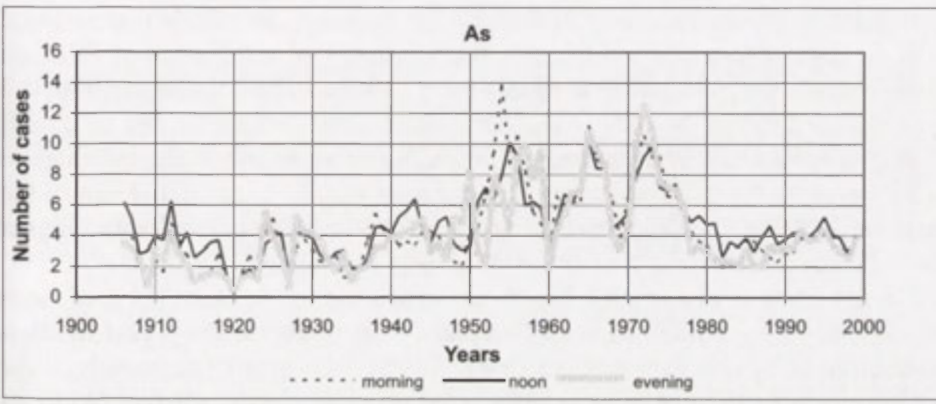



Figure 7. Multi-annual course to the frequency of the As cloud genus in Cracow (1906–1999).

in frequency between the observation terms were insignificant. The subsequent period to the 1960s saw the highest frequency at noon again, and subsequently in the evening.

As cloud (10% of all cases of cloudiness) shows a very interesting multi-annual course for frequency of occurrence (Fig. 7). From 1906 until the mid 1940s and from the 1980s until the end of the examined period the frequency of occurrence of As cloud varied from 1 to 5 cases, while in the middle years of the examined period the frequency was much higher and reached 11 cases per month on average in 1965 and 1972.

The multi-annual course of occurrence of Sc clouds shows an upward trend (Fig. 8), and one which is clearly marked from 1941. The high number of cases of Sc clouds in the initial part of the examined period (until 1920) evokes some doubts. It seems that a high figure above 10 may result from inconsistency in the

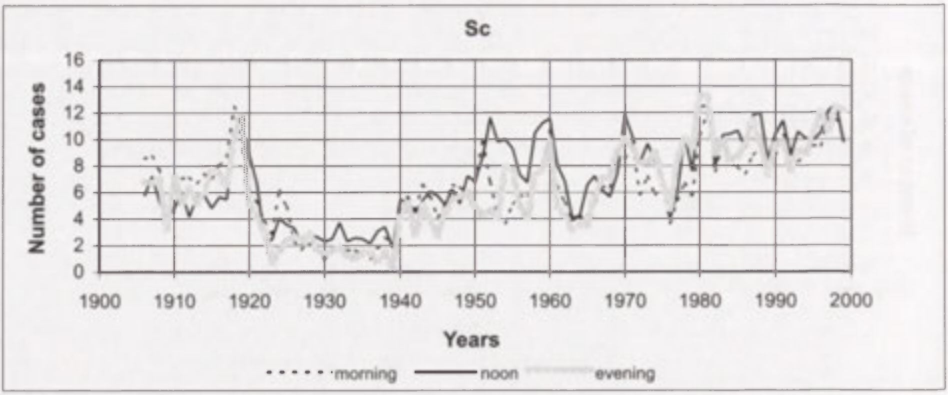



Figure 8. Multi-annual course to the frequency of the Sc cloud genus in Cracow (1906–1999).

methodology of observation and classification of clouds. It is likely that Sc cloud was recorded instead of St cloud, as the frequency of occurrence of St cloud shows very low values just in the years from 1906 to 1920. This supposition can be evidenced by the fact that, only in the aforementioned period, did Sc clouds occurred most often in the morning, prevailing at noon and in the evenings in other years. In the morning observation term, especially in the initial part of the examined period, the proportion of fog and St clouds, which veiled the higher laying clouds, was significant in the cloudiness of Cracow.

In the multi-annual course (Fig. 9) of occurrence for St cloud (12% of cases of cloudiness) some doubts refer to the years 1906–1920, i.e. the period which is characterised by low values (ca. 1 case). As has been mentioned already, these low values are attributed to imprecise recording of Sc clouds, whereas St clouds and fogs in fact occurred. From 1921 the yearly number of cases of St cloud exceeded 8 and was increasing slowly, to reach a peak of 13 cases in 1956. From

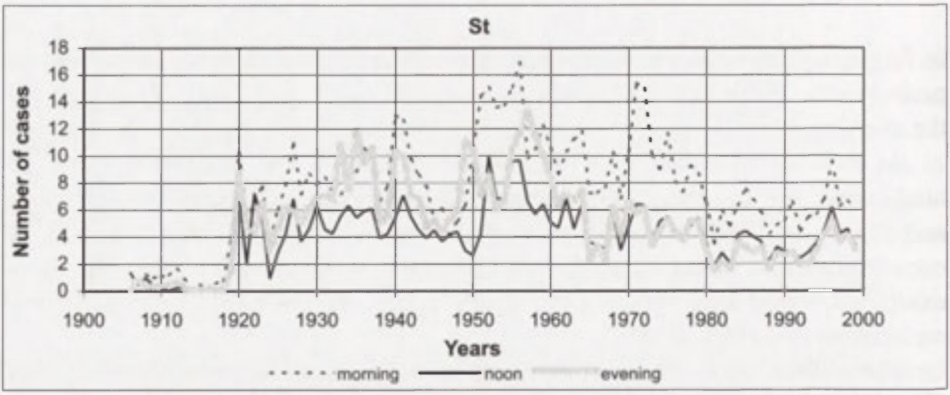



Figure 9. Multi-annual course to the frequency of the St cloud genus in Cracow (1906–1999).

that moment on there is a significant fall in the frequency of occurrence of St cloud, maybe due to the warming and drying of the air over the town as a result of the thermal impact of industrial plants and the building-over of swampy areas in the Vistula valley. St clouds occurred most often in the morning during the whole examined period. While the difference between the morning and evening observation terms was insignificant until the 1960s (to 2 cases), it then increased considerably (to 8). From that moment, the frequencies of occurrence of St clouds in the evening and noon observation terms were similar to each other.

The multi-annual course for the occurrence of Ns clouds (Fig. 10) shows a downward trend. Until the 1920's, the values did not exceed 10 cases per month. A maximum frequency (15 cases) was recorded in 1923, and there was a decisive fall subsequently, as the years 1924–1936 were characterised by lower values (about 6 cases). In the following years, there was another rise in the frequency of occurrence of Ns clouds, but since the 1940's the frequency has again been showing a significant downward trend, and with almost constant low values (of about 2 cases) since the 1960's. It is probable that the frequency was overestimated in the initial years due to the imprecise cloud classification which employed rain cloud Nimbus and was used until 1932 (Matuszko, Bielec 1998). The decrease in the later period was probably related to circulation factors; an increase in the activity of high pressure systems causes a weakening of zonal circulation favourable to Ns cloud formation.

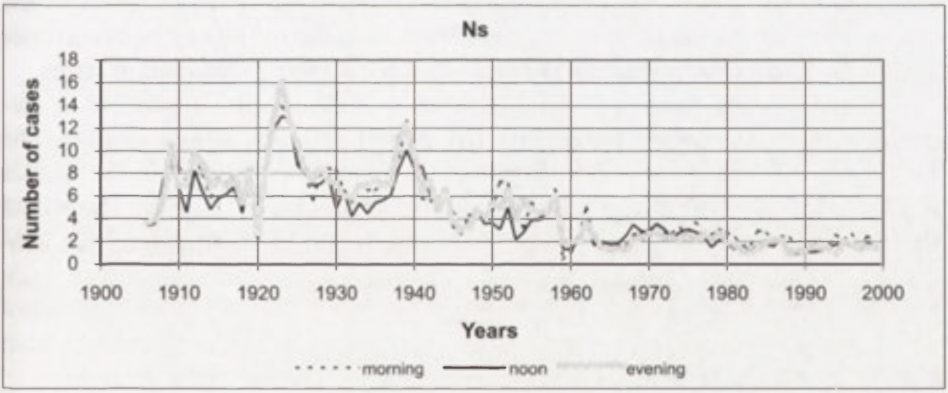



Figure 10. Multi-annual course to the frequency of the Ns cloud genus in Cracow (1906–1999).

The first period of St and Ns cloud observations (1906–1920) is associated with an inhomogeneity most probably due to a rather imprecise cloud classification.

The upward trend to the multi-annual course for the occurrence of Cu cloud (Fig. 11) is probably related to circulation factors, as such tendencies are observed across Europe, as well as to the impact of the surface. The intense urbanisation of Cracow has ensured a steady decrease in green areas and consequent increase in artificial concrete surfaces capable of inducing strong convection.

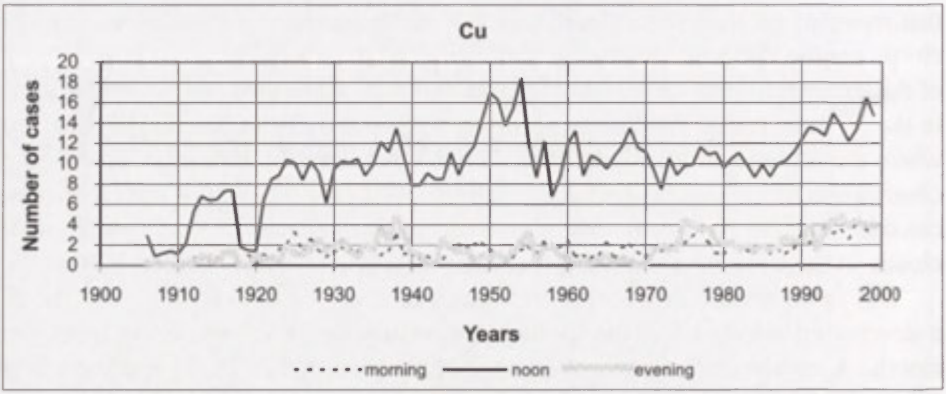



Figure 11. Multi-annual course to the frequency of the Cu cloud genus in Cracow (1906–1999).

Similar effects of the thermal impact of urban architecture on cloud cover have been pointed out by Kossowska-Cezak (1978) for Warsaw. In the multi-annual course to the occurrence of Cu clouds, it is the noon observations which are especially significant, because these clouds reach their maximum frequency of occurrence on account of their convection origin. The highest values for Cu clouds frequency (exceeding 14 cases) fall in the period between 1948 and 1955; while the lowest values (below 2 cases) characterise the first five years of the course. The last ten years, have seen an increase in the frequency of occurrence of Cu cloud, something which has been noted for all three observation terms.

The most rarely-occurring cloud in Cracow – Cb cloud – (with 2% of frequency) shows an upward trend (Fig. 12), including in the winter months. The increase in the frequency of occurrence of Cb cloud is confirmed in the studies by Bielec (1996), which deal with the number of storms in Cracow. The whole multi-annual period of observations of Cb clouds can be divided into two sub-

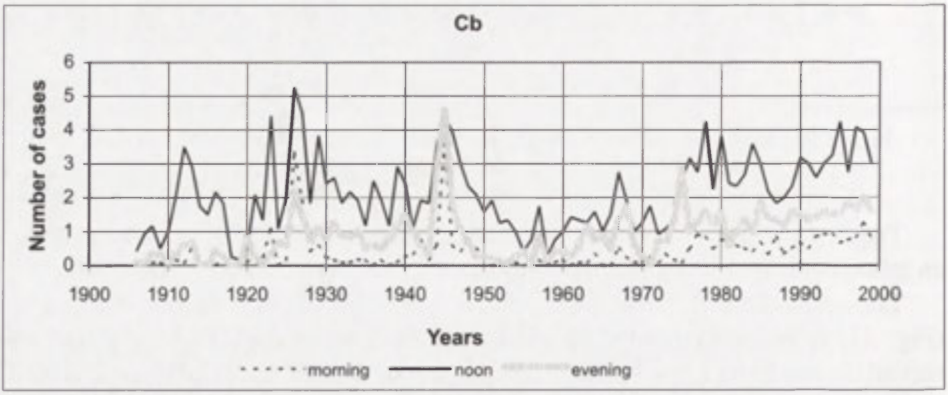



Figure 12. Multi-annual course to the frequency of the the Cb cloud genus in Cracow (1906–1999)

periods before and after 1950. During the first subperiod there were three, distinct, few-year intervals of the higher frequency of occurrence of Cb clouds. In turn during the second, the frequency of occurrence of Cb clouds was increasing gradually. In fact, in the first years (up to 1932), the frequency of Cb clouds was underestimated (Matuszko and Bielec 1998). During that subperiod, there were situations in which thunderstorms occurred but Ns clouds were recorded instead of Cb clouds. The *International Atlas of Clouds* from 1910 – which was followed until 1932 – distinguished a rain-generating Nimbus cloud. This classification might have been the reason for the misidentification of Cb and Ns clouds. Mistakes from observers determining rain clouds are also possible today, as Cb clouds often accompany Ns clouds. According to the *International Atlas of Clouds* (1959) Ns clouds can develop though the spreading of Cb clouds, while Cb cloud can also form as a result of the modification and piling-up of a part of an Ns cloud.

During the whole examined period Cb clouds occurred most often at noon, less so in the evening and most rarely in the morning. The increase in the occurrence of Cb clouds observed from the mid 1970s, is true of all the observation terms.

As regards the variability coefficient (Tab. 1) it is Cc, Cb and Ns clouds that show the highest variability in the multi-annual course. As has been mentioned already, these are the cloud genera whose classification and observation were most doubtful. It cannot be ruled out that their high variability is superficial and results from methodological errors rather than climatic fluctuations.

In summarising one should state that the presented characteristics of the nephological condition in Cracow confirms the multi-annual tendencies to the frequency of occurrence of cloud genera on the global scale. The growing trend towards certain cloud genera like Ci, Ac and Sc in Cracow can be related to circulation factors and changes in Cu and Cb to circulation and anthropogenic factors. On the other hand, the decrease in the occurrence of St clouds is attributable to local factors – mainly the development of the city. The stated downward trend to the occurrence of Ns clouds is most likely a reflection of circulation and methodological factors.

Table 1. Coefficient of variation for the frequency of occurrence of particular cloud genera in Cracow in the years 1906–1999 in the different climatological terms.

| Climatological terms | Genera of clouds | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ci | Cc | Cs | Ac | As | Sc | St | Ns | Cu | Cb | Bch |
| Morning | 59 | 89 | 61 | 44 | 62 | 44 | 54 | 61 | 56 | 147 | 38 |
| Noon | 51 | 100 | 52 | 42 | 45 | 44 | 56 | 64 | 37 | 53 | 40 |
| Evening | 68 | 110 | 64 | 53 | 64 | 52 | 66 | 67 | 78 | 85 | 36 |
| Mean | 56 | 91 | 53 | 41 | 53 | 44 | 54 | 63 | 39 | 64 | 34 |

Bch – cloudless sky.

## EXAMINATION OF THE RELATIONS BETWEEN CLOUDINESS AND CIRCULATION AND ANTHROPOGENIC FACTORS

Cloudiness' dependence on circulation and local factors is a complex problem on account of various feedbacks. Henderson-Sellers (1986) calls this research speculative because of difficulties in defining whether the cloud cover increase resulting from temperature rise (and therefore increased evaporation), is leading to a rise in cloud cover (St clouds) or to an increase in vertical development (Cu clouds), even with a possible decrease in the horizontal range. The existence of an almost one-hundred-year-long series of nephological observations helps in the search for quantitative relations between cloud cover and air circulation, and allows for the creating of a forecast model for cloud genera depending on the synoptic situation. This model makes it possible to define as a percentage the probability of occurrence of particular cloud genera in an arbitrarily-selected (forecasted) synoptic situation (for each month or at the noon term).

Table 2 presents the probability of occurrence of particular cloud genera in relation to the synoptic situation in July at noon. Generally, the summer weather, controlled mainly by the Azores high pressure system, is characterised by the occurrence of convection clouds. The intense heating of the ground by solar rays

Table 2. Probability of occurrence (in %) of particular cloud genera and cloudless weather (Bch) at noon, with various synoptic situations in Cracow (July 1906–1999).

| Type | | Genera of clouds | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ci | Cc | Cs | Ac | As | Ns | Sc | St | Cu | Cb | Bch |
| 1 | Na | 7 | 3 | 3 | 13 | 7 | 4 | 13 | 1 | 39 | 8 | 1 |
| 2 | NEa | 8 | 3 | 4 | 16 | 6 | 4 | 13 | 1 | 34 | 8 | 3 |
| 3 | Ea | 10 | 3 | 12 | 10 | 6 | 4 | 7 | 2 | 38 | 4 | 5 |
| 4 | SEa | 12 | 7 | 18 | 11 | 5 | 5 | 2 | 0 | 32 | 4 | 5 |
| 5 | Sa | 12 | 5 | 8 | 12 | 3 | 1 | 7 | 0 | 37 | 7 | 8 |
| 6 | SWa | 16 | 8 | 6 | 22 | 1 | 0 | 4 | 1 | 34 | 1 | 6 |
| 7 | Wa | 8 | 3 | 5 | 15 | 8 | 4 | 14 | 3 | 33 | 5 | 1 |
| 8 | NWa | 5 | 3 | 2 | 17 | 7 | 6 | 18 | 3 | 31 | 8 | 1 |
| 9 | Ca | 15 | 4 | 9 | 4 | 6 | 1 | 9 | 0 | 37 | 5 | 10 |
| 10 | Ka | 12 | 3 | 7 | 15 | 7 | 2 | 7 | 2 | 36 | 4 | 6 |
| 11 | Nc | 4 | 1 | 1 | 10 | 8 | 19 | 19 | 7 | 24 | 7 | 0 |
| 12 | NEc | 1 | 1 | 2 | 14 | 9 | 12 | 18 | 7 | 25 | 10 | 1 |
| 13 | Ec | 4 | 4 | 4 | 16 | 10 | 1 | 15 | 7 | 28 | 9 | 0 |
| 14 | SEc | 12 | 3 | 9 | 12 | 11 | 11 | 11 | 3 | 26 | 4 | 0 |
| 15 | Sc | 13 | 7 | 4 | 16 | 3 | 7 | 8 | 3 | 31 | 6 | 2 |
| 16 | SWc | 11 | 8 | 10 | 14 | 12 | 2 | 7 | 1 | 28 | 5 | 2 |
| 17 | Wc | 6 | 3 | 5 | 15 | 10 | 9 | 15 | 5 | 26 | 5 | 0 |
| 18 | NWc | 3 | 2 | 3 | 15 | 11 | 15 | 17 | 5 | 22 | 7 | 0 |
| 19 | Cc | 5 | 2 | 8 | 8 | 8 | 13 | 11 | 8 | 22 | 16 | 2 |
| 20 | Bc | 6 | 4 | 6 | 14 | 10 | 10 | 12 | 4 | 27 | 8 | 0 |
| 21 | X | 14 | 9 | 5 | 16 | 5 | 2 | 12 | 2 | 28 | 7 | 0 |

Bch – cloudless sky.

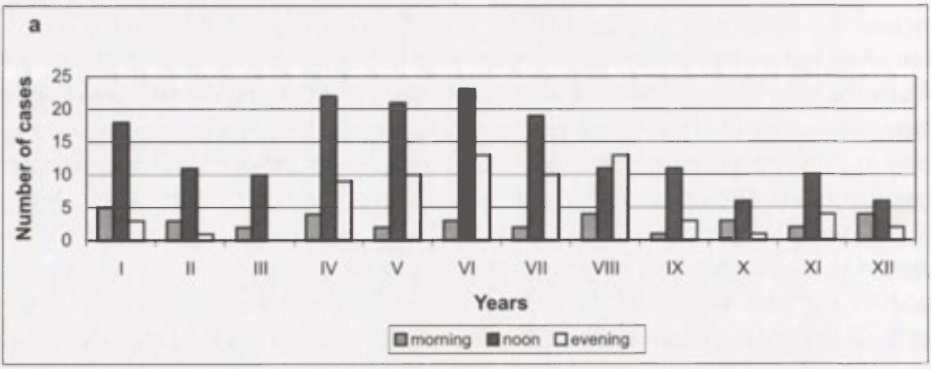
ensures the development of an unstable air layer near the ground, and the formation of strong rising air currents together with the development of vertical clouds. When the convection weakens these clouds disappear from the top. Spreading of these clouds results in a development of Ac clouds, which are very frequent at this time of the year. In July, intensified activity of the Azores high pressure system, makes the advection of air masses form the west (Wc – 11.5, Wa – 10.3%) and high pressure wedge Ka (15.9%) the predominating circulation situations (Matuszko 2000). The above types of circulation are most often accompanied by Cu and Ac clouds. July brings a maximum of air advection from the north (5.6%), which favours the rise of air masses on the Carpathian slopes and the generation of downpours from Ns (23%) and Cb (15%) clouds under conditions of Na and Nc synoptic situations (with the latter causing floods along the Carpathian tributaries of the Vistula river – Niedźwiedź 1988).

The detection of anthropogenic changes makes use of a method of comparing the conditions of the natural climate with one affected by anthropopressure. In practice, it is very difficult to find areas which have a "natural climate". We can only analyse the areas which are under a lesser or greater impact of anthropogenic factors. Bearing the above in mind, the commonly-accepted assumption is that the non-urbanised areas are more similar to the natural conditions. The impact of urbanisation on the quantitative and qualitative variability in cloudiness in Cracow in the multi-annual period may therefore, be defined on the basis of changes in mean annual cloudiness, the frequency of cloudless skies, days without cloud cover and the occurrence of low clouds (assuming the climate of the initial years of the examined period to be the natural one). An attempt was made at the comparison of nephological conditions in the city (Cracow) and out of the urban areas (Balice), especially in the post-war period since this saw the most intensive development of the municipal-industrial agglomeration. The example of Cracow points to a city causing an increase in the occurrence of Cu and Cb (Fig. 13) clouds, probably thanks to the emission of artificial heat into the atmosphere and convection over heated concrete surfaces. One can also observe decrease in the occurrence of low Stratus clouds due to the drying of air over the city, and a consequent decrease in cloud cover.

## STRUCTURE OF THE CLOUDINESS OF A CITY LOCATED IN AN INVERSION FOOTHILL VALLEY

The comparison of nephological conditions in Cracow and other towns (Fig. 14, Tab. 3) may be an attempt to define trends to the structure of cloudiness in the highly-urbanised area of a foothill valley:

- Large cloud cover (as exemplified by Cracow and Prague in the period between 1906 and 1960; on average 10% higher than in other towns), related to the location in a weakly-aired, humid foothill valley with a large river.



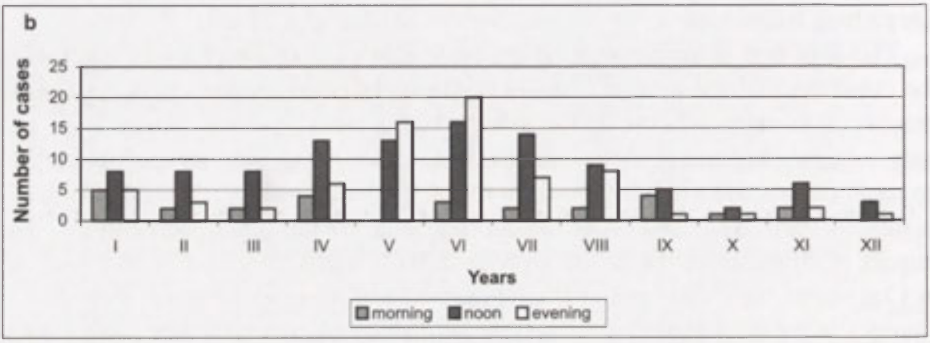




Figure 13. Annual course for Cb cloud frequency in: a – Cracow, b – Balice, and monthly averages for their appearance in the different climatological terms (1981–1985).

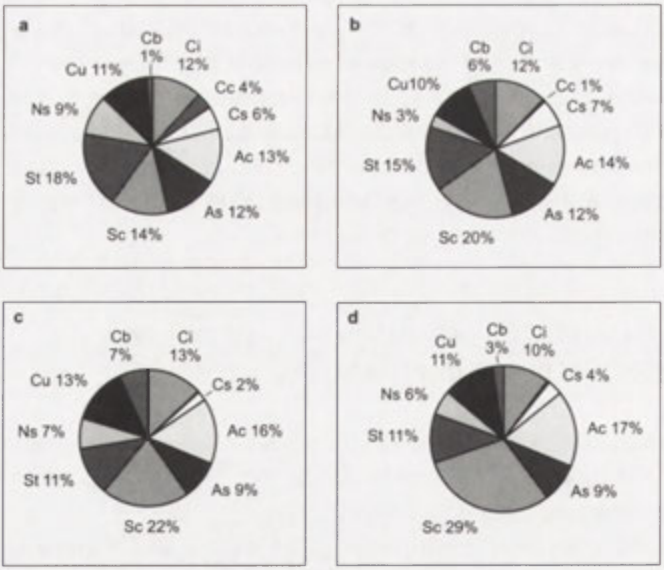



Figure 14. Percentages of cloud genera in: a – Cracow, b – Lublin, c – Przemyśl, d – Rzeszów (1947–1956).

Table 3. Amount of cloudiness (in %) in Cracow, Lublin, Rzeszów, Przemyśl and Prague in the period 1947–1956.

| Stations | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cracow | 82 | 81 | 73 | 69 | 68 | 71 | 65 | 64 | 63 | 70 | 85 | 85 | 73 |
| Lublin | 78 | 73 | 61 | 57 | 53 | 57 | 54 | 52 | 50 | 57 | 78 | 79 | 62 |
| Rzeszów | 74 | 73 | 68 | 61 | 60 | 62 | 57 | 54 | 52 | 59 | 77 | 77 | 65 |
| Przemyśl | 72 | 72 | 66 | 59 | 57 | 60 | 55 | 50 | 50 | 58 | 77 | 75 | 62 |
| Prague | 79 | 76 | 66 | 65 | 62 | 63 | 63 | 59 | 58 | 69 | 81 | 83 | 69 |

It is also caused by a weak air exchange due to stagnation of the inversion layers and a high number of condensation nuclei resulting from air pollution over the city.

- The predominance of St clouds over other cloud genera, as a consequence of radiation cooling processes in a foothill valley, and high humidity over the wetlands therein which are favourable to the formation of fog and low Stratus clouds.
- The increased occurrence of Cu and Cb clouds. The impact of the city via the heating of lower layers of the atmosphere ensures the development of an unstable equilibrium and the formation of convection clouds, unless there is a strong thermal inversion at the given moment.

## CONCLUSIONS

This study sustains the conviction that Cracow's series of cloud observations may form a basis for scientific analyses and comparisons, and may prove helpful in constructing the climatic models, wherein cloud cover is still the lacking element. The application of approaches to the problem that are both quantitative (proportion of the sky covered by clouds) and qualitative (cloud genera) and based on a long and homogenous series of nephological observations conducted from the ground, may help in supplementing the results obtained from modern, satellite research on clouds.

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# EXTREME ANOMALIES OF WINTER AIR TEMPERATURE IN MID-LATITUDE EUROPE

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*As long as the earth remains, seed-time and harvest, and cold and heat, and summer and winter, and day and night, shall not cease*

*Genesis, Chapter VIII, Verse 22*

ABSTRACT. The aim of this paper is to report extreme winter/early-spring air temperature (hereinafter temperature) anomalies in mid-latitude Europe, and to discuss the underlying forcing to these interannual fluctuations. Warm advection from the North Atlantic in late winter controls the surface-air temperature, as indicated by the substantial correlation between the speed of the surface southwesterlies over the eastern North Atlantic (quantified by a specific Index $I_{na}$) and the 2-meter level air temperatures (hereinafter $T_s$) over Europe, 45–60°N, in winter. In mid-March and subsequently, the correlation drops drastically (quite often it is negative). This change in the relationship between $T_s$ and $I_{na}$ marks a transition in the control of the surface-air temperature: absorption of insolation replaces the warm advection as the dominant control. This forcing by maritime-air advection in winter was demonstrated in a previous publication, and is re-examined here in conjunction with extreme fluctuations of temperatures in Europe. We analyze here the interannual variability at its extreme by comparing the warm-winter/early-spring of 1989/90 with the opposite scenario in 1995/96. For these two December-to-March periods the differences in the monthly mean air temperature in Warsaw and Torun, Poland, range above 10°C. Short-term (shorter than a month) fluctuations of air temperature are likewise very strong. We conduct pentad-by-pentad analysis of the surface-maximum air temperature (hereinafter $T_{max}$), in a selected location, examining the dependence on $I_{na}$. The increased cloudiness and larger amounts of total precipitable water, corollary effects to the warm low-level advection in the 1989/90 winter, enhance the positive air temperature anomalies. The analysis of the ocean-surface winds is based on the Special Sensor Microwave/Imager (SSM/I) dataset; ascent rates, and over land wind data are from the European Centre for Medium-Range Weather Forecasts (ECMWF); maps of 2-m air temperature, cloud cover and precipitable water are from the National Centers for Environmental Prediction (NCEP) Reanalysis.

KEY WORDS: anomalies of air temperature in Europe, maritime-air advection, climatic fluctuations.

## INTRODUCTION

The aim of this paper is to analyze the interannual variability which characterizes the late-winter surface air temperature in mid-latitude Europe, 45–60°N. and discuss its causes. Strong variability applies as well to the timing of the end of winter and onset of spring, whether measured by the beginning/end of snow cover, or by phenological events (Wos 1999; Jaagus and Ahas 2000). The fluctuations have profound implications for agriculture, forestry, and indeed for the way of life of the large population living in these regions.

With the winter sun low above the horizon, and low absorptivity (high albedo) of the snow-covered surface, advection from the oceans effectively controls the air temperatures over the adjoining continent, as shown by Rogers and Mosley-Thompson (1995), for instance. The surface of the North Atlantic is much warmer than that of the mid-latitude Europe, whereas the Arctic is colder, such that the air temperature in Europe fluctuate with the wind direction. It is widely recognized that circulation patterns over the North Atlantic and Europe fluctuate with the North Atlantic Oscillation (NAO), the stage of which is quantified by an Index (Rogers 1997). Recently, a specific index quantifying the low-level flow from the North Atlantic into Europe has been developed by measuring the strength of the ocean-surface southwesterlies over the eastern North Atlantic. Apparently, this index, $I_{na}$, is a more directly relevant measure of the maritime-air advection into France and into mid-latitude strips through Europe, from France to Russia (Otterman et al. 1999).

We analyze here the interannual variability at its extreme by comparing the warm-winter/early-spring of 1989/90 with the opposite scenario in 1995/96. Short-term (shorter than a month) fluctuations of the air temperature are likewise very strong, so for these two December-to-March periods we conduct pentad-by-pentad analysis of the $T_{max}$ in a selected location and our Index $I_{na}$.

## SSM/I, ECMWF, NCEP DATASETS

A large dataset of surface wind speeds over the global oceans has been derived from the SSM/I aboard the Defense Meteorological Satellite Program (DMSP) satellites. Variational analysis method was selected to derive the wind-vector data. In this method, the SSM/I retrievals (that is, the measurements of speed) are combined with independent wind observations to produce consistent fields of wind speed and direction. The resulting global ocean-surface dataset is appropriate for climate analysis (Atlas et al. 1996).

The ECMWF dataset is part of the Basic Level III-A analysis product with the ECMWF/World Climate Research Programme (WCRP) Global Atmospheric Data Archive. In our study, we use data interpolated horizontally to the standard

Goddard Laboratory for Atmospheres grid of 2.0° in latitude and 2.5° in longitude, from the ECMWF data archived on a 2.5° by 2.5° latitude/longitude grid.

Significant parts of our study are based on the NCEP Reanalysis dataset, described in detail by Kalnay et al. (1996), which extends from January 1948 essentially to the present. Improvements to the numerical weather prediction operational systems were introduced when satellite measurements become available (see Kalnay et al. 1996, for a documentation of the changes). The intent in reprocessing was to produce a consistent dataset. Still, some discontinuity was apparently introduced starting with 1979, relative to the earlier (1948–1978) period when no satellite observations were available. This uncertainty, crucially important to the evaluation of trends, is addressed in a recent report on the Reanalysis project (Kistler et al. 2001).

## NORTH-ATLANTIC WINDS AS THE PRIMARY CONTROL OF THE SURFACE-AIR TEMPERATURE IN EUROPE

In this section we examine the influence of maritime-air advection in raising the winter air temperature in Europe. The strength of the warm advection is quantified by a specific Index, $I_{na}$, of the ocean-surface southwesterlies over the eastern North Atlantic. From the SSM/I dataset (Atlas et al. 1996), we evaluate at 45°N; 20°W pentad-averages of the wind speed from all the measurements which report the direction from the quadrant 180°–270°. When the direction is not southwesterly, the speed is counted to the average as a zero speed. The Index $I_{na}$ derived by this approach is plotted in Figure 1 for the winters 1989/90 and 1995/96, that is for the 24 pentads from December 2–6 to March 27–31.

Alongside $I_{na}$ we plotted in Figure 1 the pentad-averaged $T_{max}$ of daily maximum air temperature in Brussels, Belgium. We selected this Royal Meteorological Institute meteorological station, since its very long record establishes this dataset as suitable for the evaluation of trends (Demarée et al. 2001). We note very large differences between the air temperature $T_{max}$ in 1989/90 and those in 1995/96, amounting to about 10°C for much of the winter. Based on detailed correlation analysis (Otterman et al. 1999), this difference in $T_{max}$ can be attributed to the difference in the warm advection, quantified by $I_{na}$, the strength of the southwesterlies at the "gateway" to Europe. We note here that $I_{na}$ exceeds 10 $ms^{-1}$ for much of the warm 1989/90 period, but assumes low values, generally below 4 $ms^{-1}$, for most of the cold winter 1995/96. The differences in the warm advection affect the surface-air temperature over vast areas, as can be seen from Figure 2, where we compare February 1990 with February 1996. The observed sensitivity of the surface-air temperature to the low-level maritime-air advection in winter is directly due to the large air temperature difference prevailing then between the North Atlantic and the European continent (Otterman et al. 2000). The warming of the near-surface layer tends to produce a steeper lapse rate, that

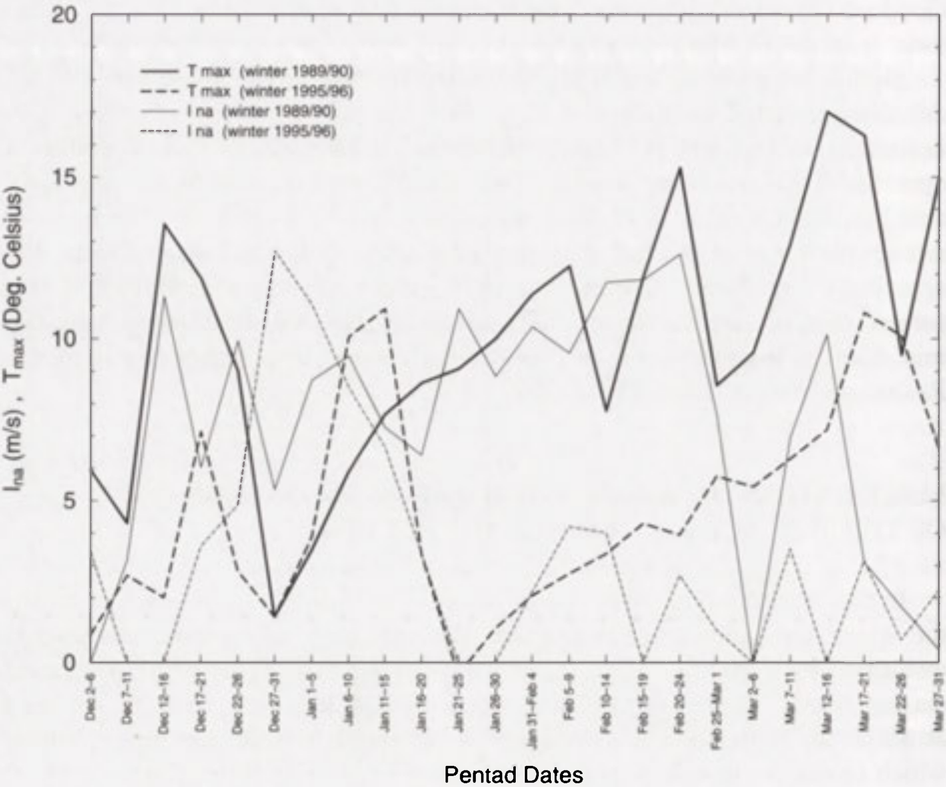


Figure 1. Maximum daily air temperature ($T_{max}$) in Brussels, and the Index of the southwesterlies ($I_{na}$), pentad-averages for the December-to-March periods in 1989/90 and 1995/96.

is, to destabilize the atmospheric conditions. These effects are analyzed in the next section.

## COROLLARY EFFECTS OF WARM AND MOIST LOW-LEVEL ADVECTION

The winters of 1989/90 and 1995/96 are well representative of opposite extremes in the NAO index. Sea level pressure gradients across 25°W longitude between latitudes 45 and 55°N were approximately twice as strong in 1990 as in 1996. Some of the largest sea level pressure differences between the two NAO states occur typically around the Bay of Biscay (Rogers 1997). During periods such as early 1990, when storms migrate far northeastward of Iceland, they can advect warm air and cloud cover as far east as central Siberia (Rogers and Mosley-Thompson 1995).

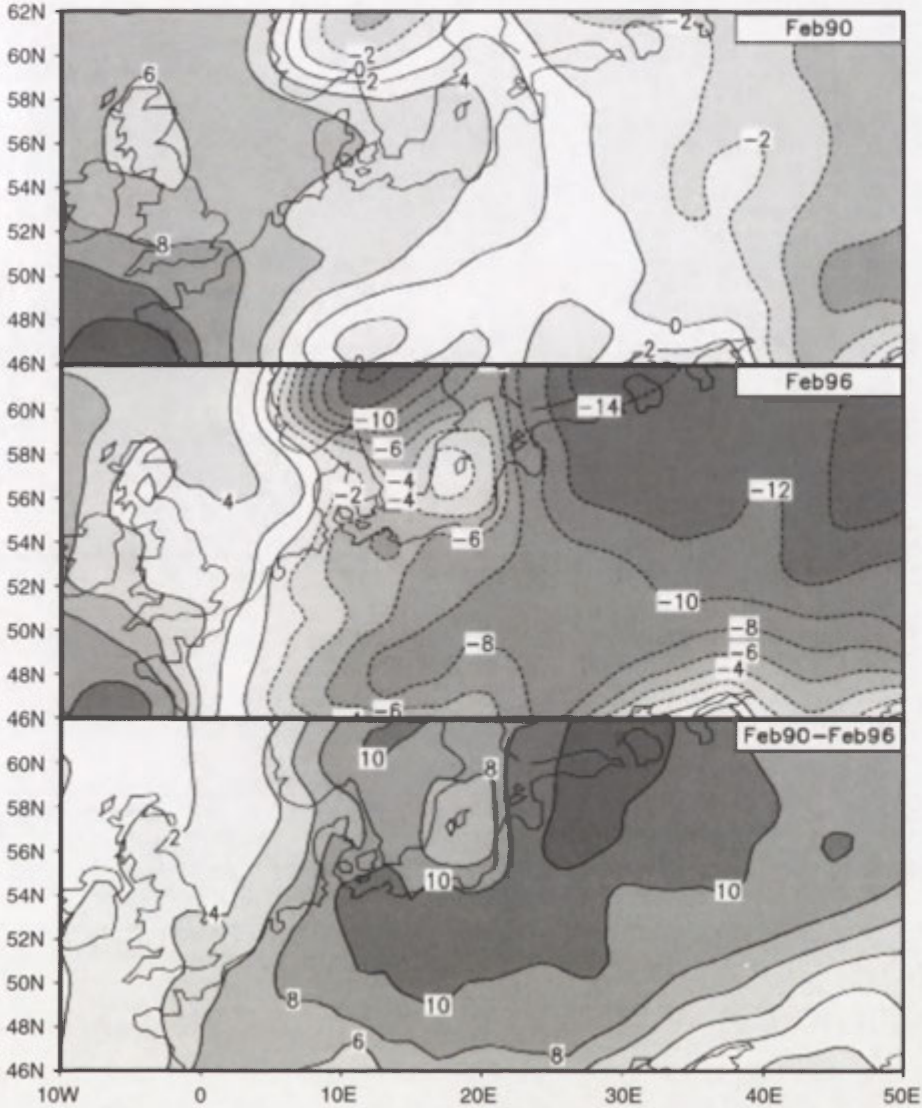


Figure 2. Surface air temperature ($T_S$ in $^0$C) over the eastern North Atlantic and mid-latitude Europe (46°N to 60°N; 10°W to 50°E), February 1990 at the top, February 1996 in the middle, their difference in the lowest figure.

While only monthly (or seasonal) data are relevant in climate studies, insight into the phenomenology can be gained from a "single-moment" scenario. We illustrate the winter 1990 conditions in Figure 3 presenting surface winds (from SSM/I and ECMWF) for February 1, 1990, 00Z. We note a "STREAK" of southwesterlies directed toward France and England, where the wind speed exceeds 10 $ms^{-1}$.

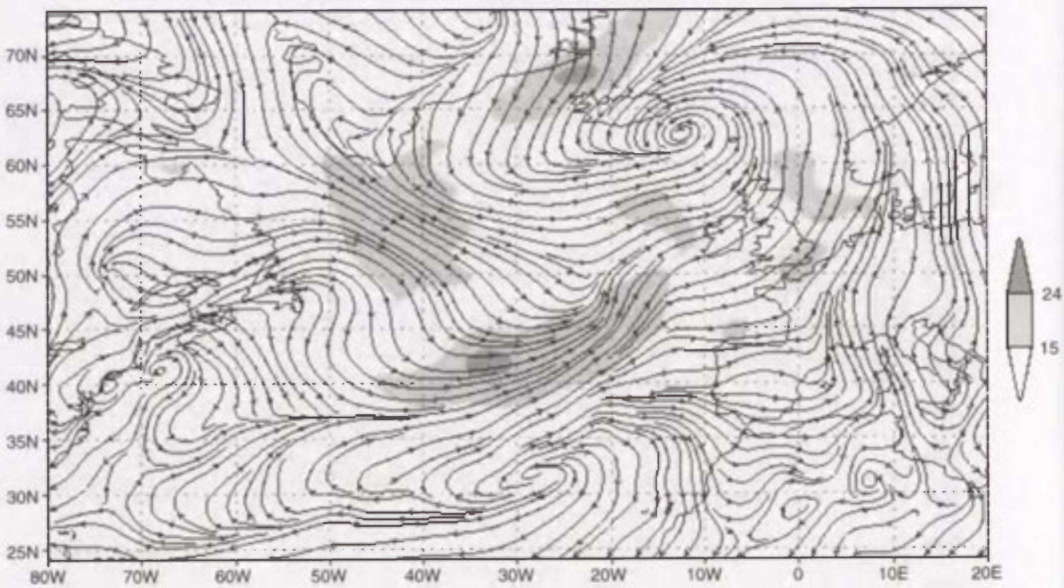


Figure 3. Surface winds ($ms^{-1}$) over the North Atlantic and Europe, February 1, 1990, 00Z (from SSM/I and ECMWF).

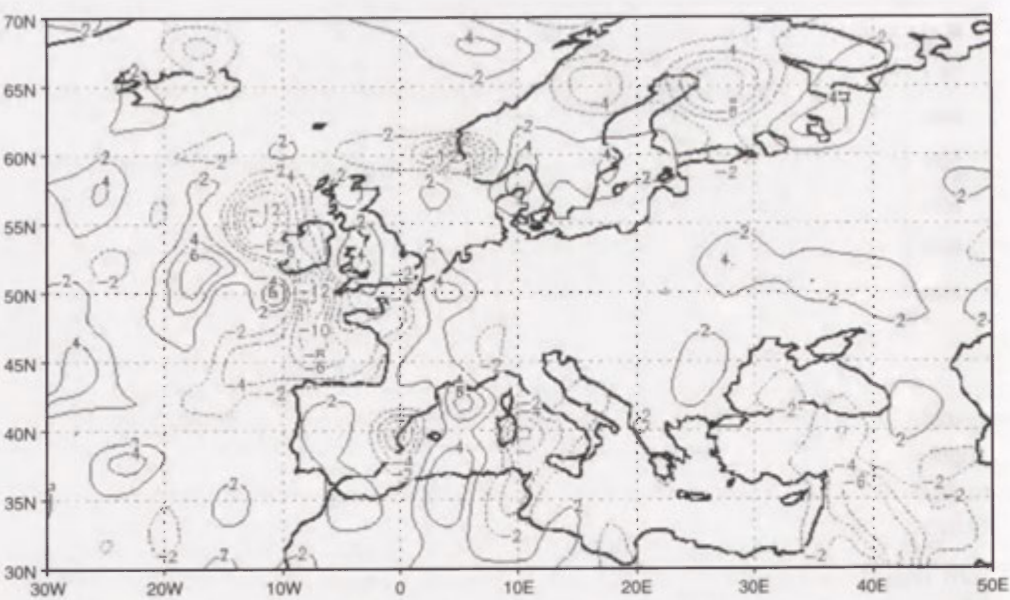


Figure 4. Ascent rates at the 700 mb level (10 Pa $s^{-1}$), February 1, 1990, 12Z (from ECMWF).

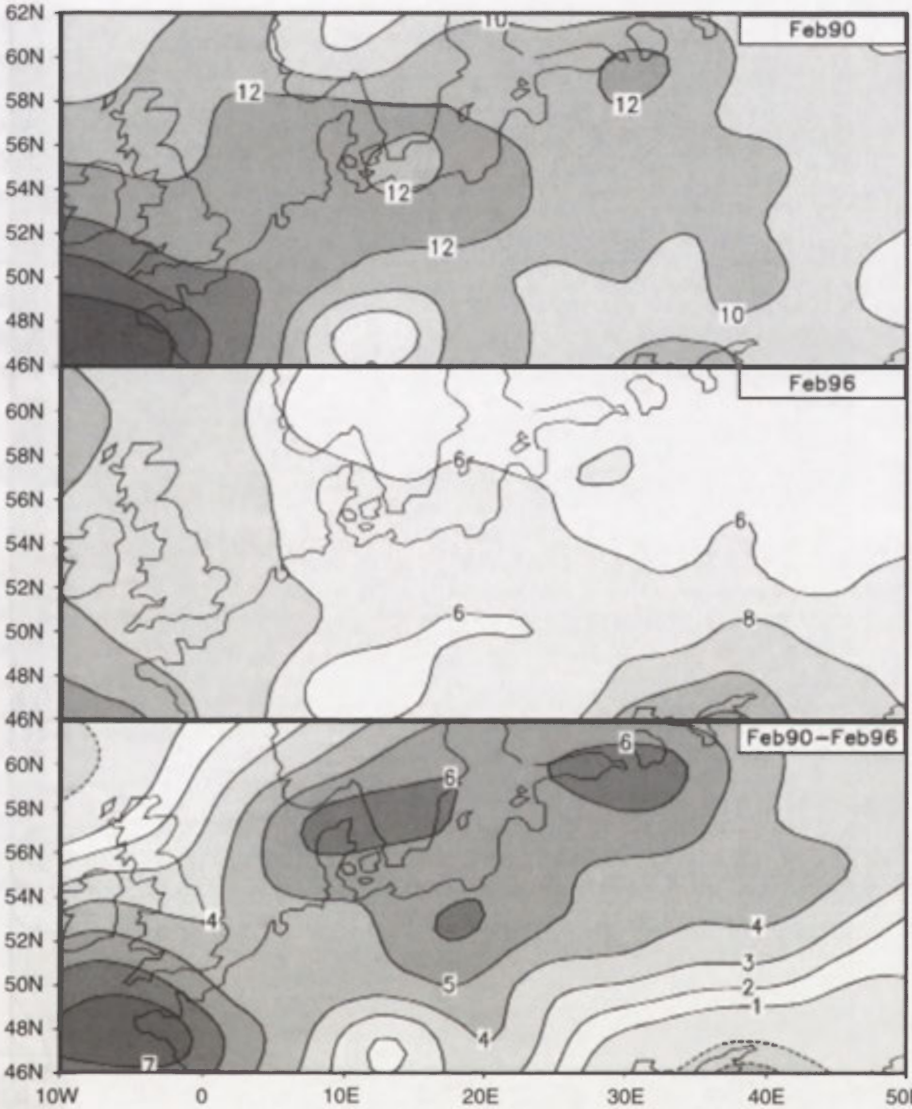


Figure 5. As Figure 2, for the water vapor in the vertical column (kg/m$^2$).

The low-level warm advection in 1990 produced strong updrafts: ascent rates of up to –0.4 Pa s$^{-1}$ were observed in monthly averages at 700 mb, which were especially strong over the ocean just to the west of Scandinavia. Such high monthly-average ascent rates persisted for more than a month. By comparison, in 1996, the monthly-average ascent rates at that level were reported generally as zero, with only occasional –0.1 Pa s$^{-1}$ readings.

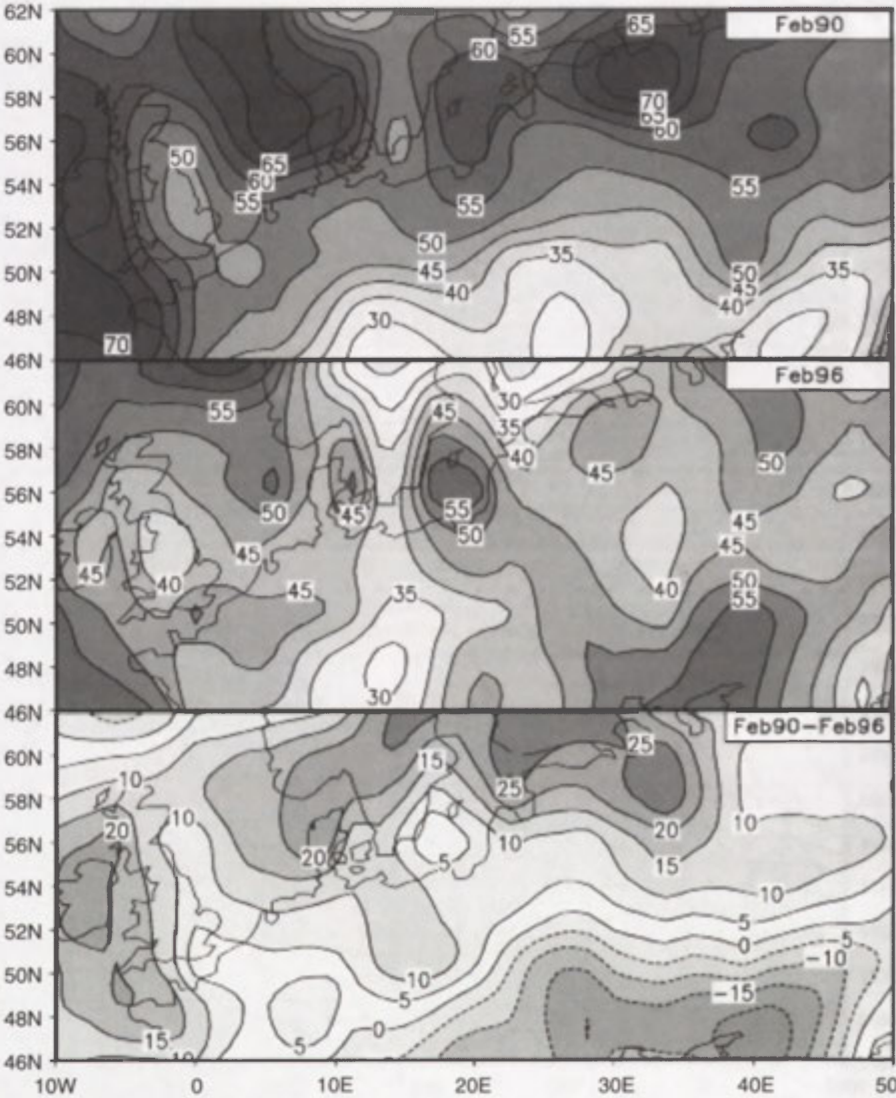


Figure 6. As Figure 2, for the total cloud cover (percent).

The way in which the strong warm advection illustrated in Figure 3 is affecting the state of the atmosphere 12 hours later, that is on February 1, 1990, 12Z is shown in Figure 4. We observe at 700 mb large cells of high ascent rates in a 270° "ring" around central Europe. In the strongest cells, one to the northwest of Ireland and the other centered on the southern coast of Scandinavia, the ascent rate tops $-1.2$ Pa $s^{-1}$. In cells over Finland, Spain and western Mediterranean, the ascent rates top $-0.9$ Pa $s^{-1}$.

The warm air masses advected in the 1989/90 winter are certainly moist, as we illustrate in Figure 5: in central Europe at latitudes 52-to-60°N the total precipitable water is some 5 kg m $^{-2}$ higher in February 1990 than in February 1996. Higher moisture levels and a steeper lapse rate combine to increase cloudiness: the total cloud cover reaches 60 to 70% for February 1990 as compared to 45 to 55% in 1996 (Fig. 6). In February the sun is low over the horizon in Europe, and the absorptivity (co-albedo) of the snow-covered surface is low, and thus absorption of insolation is hardly an important consideration for the surface temperature. Enhanced cloud cover and precipitable water vapour levels reduce heat loss to space. These corollary effects, by enhancing the greenhouse factor, reinforce the underline near-surface warming by the low-level warm advection from the North Atlantic.

## DISCUSSION AND CONCLUSIONS

Characterizing climatic conditions for a region involves specifying average values of the key climatic parameters, combined with their variability, that is, the statistics of departures from the averages. Poleward of 35°, the key climate parameter for agriculture and forestry (and for heating-fuel demand) is the surface temperature (both of skin and the surface air, which are closely related). Surface air temperatures dictate the beginning of planting and seeding at the end of winter, and the harvesting of crops before the next winter sets in. The winter/early-spring differences between 1989/90 and 1995/1996 that we discuss here, persisting at the level of 10°C for more than a week at a time for Brussels (see Fig. 1), are extremely large. This reported variability is entirely consistent with the variations in the February means characterizing central Poland (see

Table 1. Air temperature (°C) in Warsaw, 1990 and 1996.

| Monthly average air temperature (Lorenc 2000) | | |
|---|---|---|
| Months | 1990 | 1996 |
| December, previous year | 1.1 | –4.8 |
| January | 1.9 | –5.7 |
| February | 5.1 | –5.3 |
| March | 6.7 | –1.1 |
| Monthly average maximum air temperature (absolute maximum air temperature in brackets) (Niedźwiedź and Ustrnul 1994) | | |
| Months | 1990 | 1996 |
| December, previous year | 3.7 (14.2) | –2.5 (7.7) |
| January | 4.1 (10.7) | –3.2 (5.3) |
| February | 9.1 (17.2) | –2.3 (5.3) |
| March | 11.5 (20.5) | 1.4 (6.4) |

Table 2. Air temperature (°C) in Toruń, 1990 and 1996.

| Monthly average air temperature (highest and lowest mean daily air temperature in brackets) | | |
|---|---|---|
| Months | 1990 | 1996 |
| December, previous year | 1.2 (9.5/–5.7) | –5.0 (3.5/–14.1) |
| January | 2.4 (7.8/–5.5) | –5.7 (2.1/–16.0) |
| February | 5.3 (11.5/–0.1) | –5.7 (1.6/–15.6) |
| March | 6.7 (11.7/0.4) | –1.0 (3.4/–4.9) |
| Monthly average maximum air temperature (absolute maximum air temperature in brackets) | | |
| Months | 1990 | 1996 |
| December, previous year | 3.7 (13.0) | –2.2 (6.5) |
| January | 4.6 (12.0) | –3.3 (5.2) |
| February | 9.3 (17.1) | –2.4 (4.8) |
| March | 11.2 (21.5) | 2.1 (7.8) |

Table 1 or Table 4.1, for Warsaw p. 78, in Woś 1999). The fluctuations reported for Toruń, amount to 11.0°C and 11.7°C in the case of average monthly $T_s$ and $T_{max}$, respectively (see Table 2). The above-described large temperature differences occurred over almost the whole continental mid-latitude Europe (see Fig. 2).

Our study indicates that the underlying cause of the winter air temperature fluctuations in Europe is the variability of the surface winds over the North Atlantic. This dependence constitutes an important teleconnection similar to that examined by Hurrell (1996) and Otterman et al. (2000). The dependence of temperature, specifically in Poland, on the circulation patterns was discussed by Niedźwiedź and Ustrnul (1994). The strong winter temperature trends at northern latitudes in Eurasia reported by Ross et al. (1996) maybe the result of intensified adrection from the North Atlantic. A more quantitative assessment of the sensitivity of the air temperatures in various European locations to the advection effects should be attempted.

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# EXTREME RAINFALLS AND RIVER FLOODS IN EUROPE DURING THE LAST MILLENNIUM

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ABSTRACT: Information on extreme rains and floods during the last millennium is gathered on the basis of various records stretching back from modern direct instrumental records to historical written sources, and also including proxy data based on sediments, organic remains and relef features. Among these extremes it is possible to distinguish heavy downpours, continuous rains, rainy seasons, rapid snowmelts and combinations of all of them. On this basis itis in tern possible to describe phases with higher and lower frequencies of extreme rains and floods in Europe during the last millennium in a regionally-differentiated manner. The phase of the Little Ice Age is well expressed throughout Europe, although its particular events were never simultaneous. In the final discussion the author connect the causes of these variabilities in space and time with fluctuations in solar radiation and volcanic activity.

KEY WORDS: extreme rains, floods, Europe, last millennium.

## INTRODUCTION

Mediaeval deforestation, soil cultivation and overgrazing have combined with populaion growth and the developing of cities, and later industrialisation and the final onset of organised water management in creating scenery for the study of the role ofheavy rains and floods in the environmental and economic transformation of the las millennium. The frequency of heavy rains has varied through time, while accelented runoff has facilitated the crossing of thresholds in various natural systems. Clusterings of events have also played a critical role in these transformations.

## THE TYPOLOGY OF EXTREME RAINS AND FLOODS

The longitudinal and latitudinal extent of the European continent create a great variety of extreme rainfalls and snowmelts causing floods.

In the climatic conditions of Europe several types of extreme events can be distinguished. Depending on climatic fluctuations these may 'migrate' in W-E or S-N directions. Each may be expressed more or less precisely in written sources, as well as in deposits and land forms. In relation to this we may in tern draw conclusions as to the spatial and temporal extend of events (Starkel 1976, 1996).

Heavy downpours are restricted to areas of several or several tens of $km^2$. Rainfall totals fluctuate between 20 and 150 mm, but intensity exceeds 1–3 mm $min^{-1}$. In deforested areas such rains create an intensive overland flow and wash over slopes and condition the emergence of debris flows and flash floods (Starkel 1998).

Continuous rains embrace extensive areas of many thousands of $km^2$. Thought of low intensity, their long duration and hence high overall totals (up to 300–600 mm) facilitate infiltration in the ground, subsurface runoff with piping, landsliding and finally the formation of flood peaks in larger catchments. The infamous 1997 flood in the Oder and surrounding basins may serve as an example (Dubicki et al. 1999). The greatest damage is noted when heavy downpours are superimposed on the continuous rain, in such a way that there is simultaneous crossing of thresholds for slope and river channel runoff, as well as the sediment load allowing for mass movements (cf. Froehlich and Starkel 1995).

The opposite extremes (in relation to downpours) are the rainy seasons in which groundwater storage is close to 100% during several rainy months, while additional intensive rainfall or snowmelt may cause the passing of threshold and reactivation of landslides and flooding (Gil and Starkel 1979; Starkel 1997).

Features specific to the more eastern and northern parts of Europe (as well as the mountain areas) are rapid snowmelt floods, frequently accelerated by simultaneous rain and/or the fact that they follow cold weather leaning still-frozen ground (Lvovitch 1971; Starkel 1976). In river valleys flowing northwards these floods are combined with the formation of ice jams of a kind also recorded from more western and southern regions during the Little Ice Age (cf. Glazer and Hagedorn 1990).

## SOURCES OF INFORMATION

The last millennium offers a great variety of records of different degrees of qualitative recognition, quantitative precision and definite pinpointing in space and time. Three main groups should be distinguished among them (cf. Brázdil 2000):

*1. Direct instrumental records*

These include instrumental records of precipitation rarely starting before the 19th century, measurements of water stages on larger rivers, markers of peak high flood levels on buildings by rivers and maps and photos showing the extend of flooded areas or damage incurred by floods (cf. Brázdil et al. 1999).

*2. Indirect records*

These data are less quantitative as well less precise in space or time. Among them are various written sources on heavy downpours, continuous rains, ice jams and floods related to a river valley, region or sometime a single town or village. There are also drawings and pictures describing flood events as well as, from the 17th century onwards, plans or maps of river channels and river banks surveyed after extreme events (cf. Brázdil et al. 1999; Glaser and Hagedorn 1990; Lossaco 1967).

*3. Proxy data*

A very extensive group of data includes different geological and geomorphological records wherein the use of retradiction procedure makes it possible to reconstruct (sometimes very precisely) the type and extend of a single flood, the course of erosion or deposition and at least the phases with various flood frequency. Of special importance are the sediments of facies that may be: alluvial (among them channel, levee, crevasse backswamp and other sediments), colluvial, proluvial (fan deposits), deluvial (slope wash) etc., including organic remains; as well as the relief features connected with them and created during heavy rains and floods, like gullies, landslides, debris flows, undercut scarps, abandoned river channels, etc. All of these may be dated more or less precisely using $^{14}C$, $^{210}Pb$, $^{137}Cs$ and other radionuclides or, by way of various archaeological methods usually 'antequem'or 'postquem' in relation to organic beds or cultural horizons (cf. Starkel et al. 1991). The phases with a higher frequency of extreme events may be well identified by reference to clusterings of subfossil oak trunks (Becker 1982; Krąpiec 1992). Rainy years with frequent heavy rains can also be recognised by the higher attendant rates of peat growth and by rising lake water levels (Ralska-Jasiewiczowa, Starkel 1988).

## REGIONAL DIFERENTIATION OVER EUROPE

Studies on the frequency and extend of heavy rain and flood events are mainly restricted to western-central Europe or mountain areas (Lamb 1977).

On the European scale, we observe a great variety of climate from the Mediterranean to subarctic areas, and from the oceanic climate in the west to the continental one in the east (Pardé 1955; Sundborg and Jansson 1991). Along the S-N transect the winter rainy and snow-melt floods of the Mediterranean tend to give way in the Central European mountain basins to more frequent summer rainy floods, although even there the spring mixed flood prevail in the lowland basins. In the north, the reducing effect of the postglacial transfluent lakes makes floods rare and restricted to the spring breaking of ice. The western edge of Europe is exposed to humid air masses, and here continuous winter rains are the leading factors. In contrast East-European plains with seasonally-frozen ground and continuous snow cover and rapid melting give rise to the spring flooding combined with ice-jams (Lvovich 1971). This brief description of regional differentiation does not mean that there are sharp boundaries. This fact is especially visible in the transition zone of Central Europe with its great variety of winter and summer seasons and vertical diversity of precipitation. In fact we can expect various types of floods there, as with the last spring flood in 2000 in Transylvania and Hungary caused by a rapid snowmelt combined with heavy rains.

## COURSE OF EXTREME RAINS AND FLOODS DURING THE LAST MILLENNIUM

The characterization of extremes events over Europe during the last millennium is based on a very unequal set of data which is more detailed for selected catchments in the SW and NW, as well as in Central Europe (cf. Bradley and Jones 1992; Brázdil et al. 1999). The information from countries further to the east is not so widely propagated (Schwetz 1978; Maruszczak 1988; Kliege 1990, etc.). The last millennium may be recognised to have experienced several longer or shorter episodes with a higher frequency of different extreme events well identified by their clusterings (cf. Starkel 1998), (Fig. 1). These episodes may have a more regional character or may be restricted to some catchments (cf. Benito et al. 1996). The variations in question are usually considered the effect of general fluctuations in temperature and humidity (Lamb 1977; Grove 1988; Pfister et al. 1998). Due to extensive forest clearance and cultivation the sedimentological records indicate an acceleration of soil erosion and sediment loading that was especially well expressed during the Little Ice Age (cf. Grove 1988; Starkel 1995).

The first three centuries of the last millennium are usually presented as the Mediaeval warming (Lamb 1977), but the 11th century at least was humid. This was noted not only in Britain, where the growth rate of the Bolton Fell Moss increased (Lamb 1984). After Pfister et al. (1998) a distinct drop in temperature was recorded between 1090 and 1180 AD. At several localities in Central Europe the organic horizons or cultural layers of the 10th and early 11th centuries are buried under thick alluvial or proluvial loams (Radwański 1972; Havlicek 1983; Niedzialkowska et al. 1985; Starkel 1995), and there are also buried oak trunks with distinct clusters at around 1020–1030 AD and 1075–1100 AD (Krąpiec 1992; Starkel et al. 1996). In loess areas, new gully erosion was noted in the late 11th century (Jersak et al. 1992). The next two centuries (12–13th) were drier in Britain and Germany, due to the blocking of western zonal flow (Lamb 1984), while higher discharges were recorded in the Dnieper valley from 1100–1250 AD (Schwetz 1978). It was also wetter in Mediterranean zone: in W-Spain floods were frequent between 1150 and 1290 AD (Benito et al. 1996) and in central Italy, lake water levels rised (Dragoni 1998).

The transition to the main Little Ice Age (1300–1550 AD – following Flohn

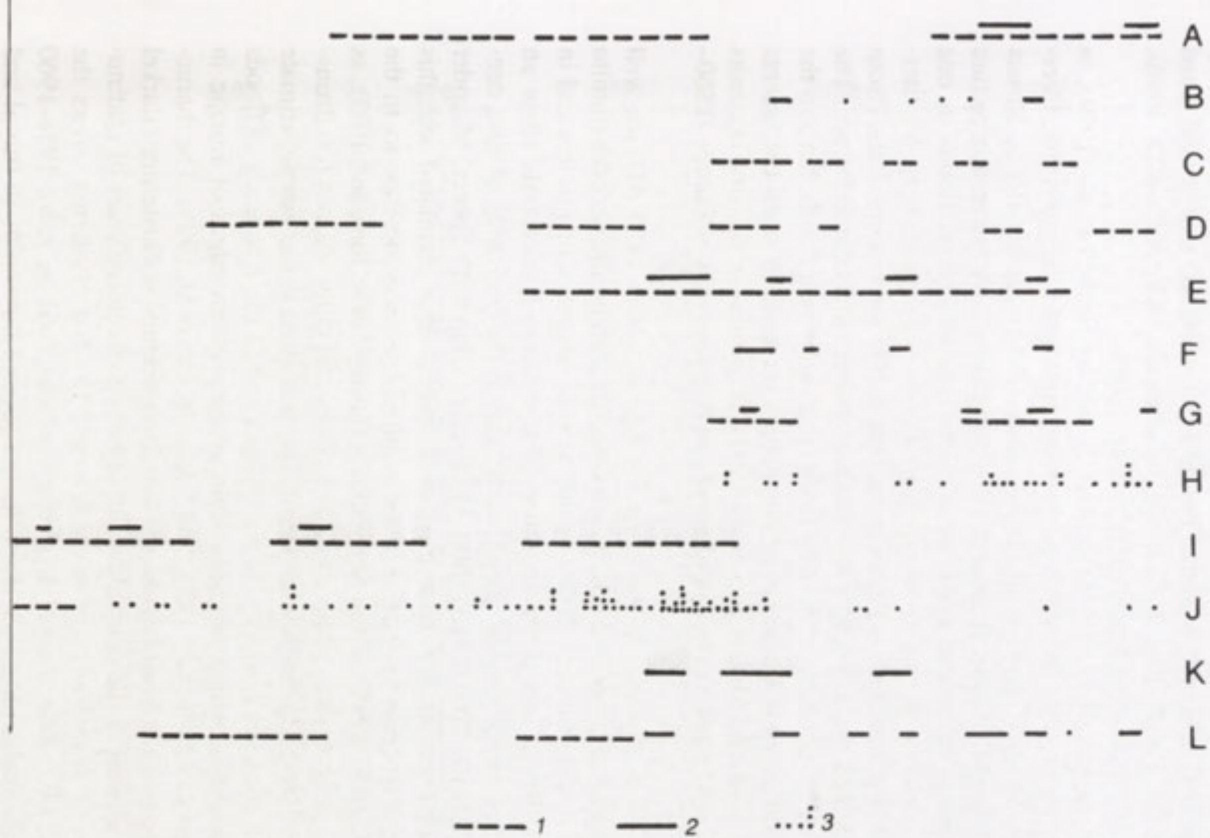


Figure 1. Heavy-rain flood records in selected parts of Europe (based on chronicles, sediments and other data), mainly starting from the 15th or 16th century. Signs: 1 – phases of floods, 2 – clusterings of floods or heavy rains, 3 – years of extreme rains and floods (in 5-year intervals). A – English rivers (Rumsby and Macklin 1996); B – French rivers – extreme floods (Bravard and Bethemont 1989); C – Southern France rainy years (Guiot 1987); D – Spanish rivers (Benito et al. 1996); E – Tiber river (Camuffo and Enzi 1995); F – Switzerland – extreme rains (Pflster 1992); G – Czech Republic – rainy years (Brazdil and Dobrovolny 1992); H – Rains and floods in the W-Sudetes (Czerwiński 1991); I – Vistula valley (after dendrochronologically dated subfossil oaks – Krąpiec 1992, 1997; Starkel et al. 1996); J – Vistula valley (floods recorded in chronicles – after Strupczewski and Girguś 1965); K – Russia – moist years (Lyakhov 1988); L – Dnieper river – high discharges (Schwetz ).

1978) again shows some rise in flood frequency in the 15th century, as reported from Spain (Benito et al. 1996), Italy (Pavese et al. 1992) and Ukraine (Schwetz 1978). In Britain a reactivation in the transformation of river channels is explained by higher activity in that transitional phase to the Little Ice Age (Rumsby and Macklin 1996). It is also with that period 1250–1400 AD that several dated landslides in the Polish Flysch Carpathians coincide (Alexandrowicz 1996), thereby probably indicating long-lasting rainy seasons.

The monographic study of 16th century floods by Brázdil et al. (1999), as supplemented by records from Poland (Strupczewski and Girguś 1965; Czerwiński 1991), Spain (Benito et al. 1996), Italy (Pavese et al. 1992), Russia (Lyakhov 1988) and Ukraine (Schwetz 1978) supplies a very interesting picture (Fig. 2). In every catchment there were clusterings of several floods in one decade, separated by phases with less frequent floods 1–3 decades long. Mediterranean Europe is dominated by floods in the first half of the century. Later (from 1560) the flood belt extends across the whole of western and central Europe. The floods involved are not only large rainy floods and snow-melt floods, but also the local floods connected with the heavy downpours recorded in small catchments of the Western Sudetic Mts. (Czerwiński 1991). In particular, the first accounts of the Little Ice Age seem to be simultaneous in many regions of Europe (1560–1570 AD).

The successive centuries of the Little Ice Age (to about 1850 AD) are well marked out in various flood records, which coincide with humid decades (Benito et al. 1996; Brazdil, Bukacek 2000) visible also in advances of glaciers and in tree rings (cf. Briffa and Schweingruber 1992). These last records show an interesting repetition of clusterings of heavy rains at the beginning of each century (ca 1590–1610, 1705–1715, 1800–1815) coinciding with Spörer, Maunder and Dalton solar minima (cf. Chambers et al. 1999). Also correlated with this phase is a high frequency of debris flows caused by heavy downpours in the Tatra Mts. (Kotarba 1995) and in Scandinavia (Grove 1988; Jonasson 1993), as well as landslides connected with continuous rains and rainy seasons (cf. Brunsden and Ibsen 1997; Alexandrowicz 1996). The transition to the warmer climate at the close of the 19th century is linked with a rise in the frequency of floods (cf. Bielański 1984), which is also visible at the western edges of Europe in Britain (Rumsby and Macklin 1996) and Spain (Benito et al. 1996). The characteristic feature of heavy rainfalls in the last 20th century is clustering (Starkel 1996, 1998), as well as the coincidence in several consecutive years of continuous rains, heavy downpours and rainy seasons. The last clustering covers the years 1996–2000, while the previous one was observed in years 1958–1960 (Ziętara 1968). Such clusterings cause the passing of thresholds in fluvial and slope systems, provoking long-lasting transformation and even a change in the tendency of evolution (Starkel 1996, 1998).

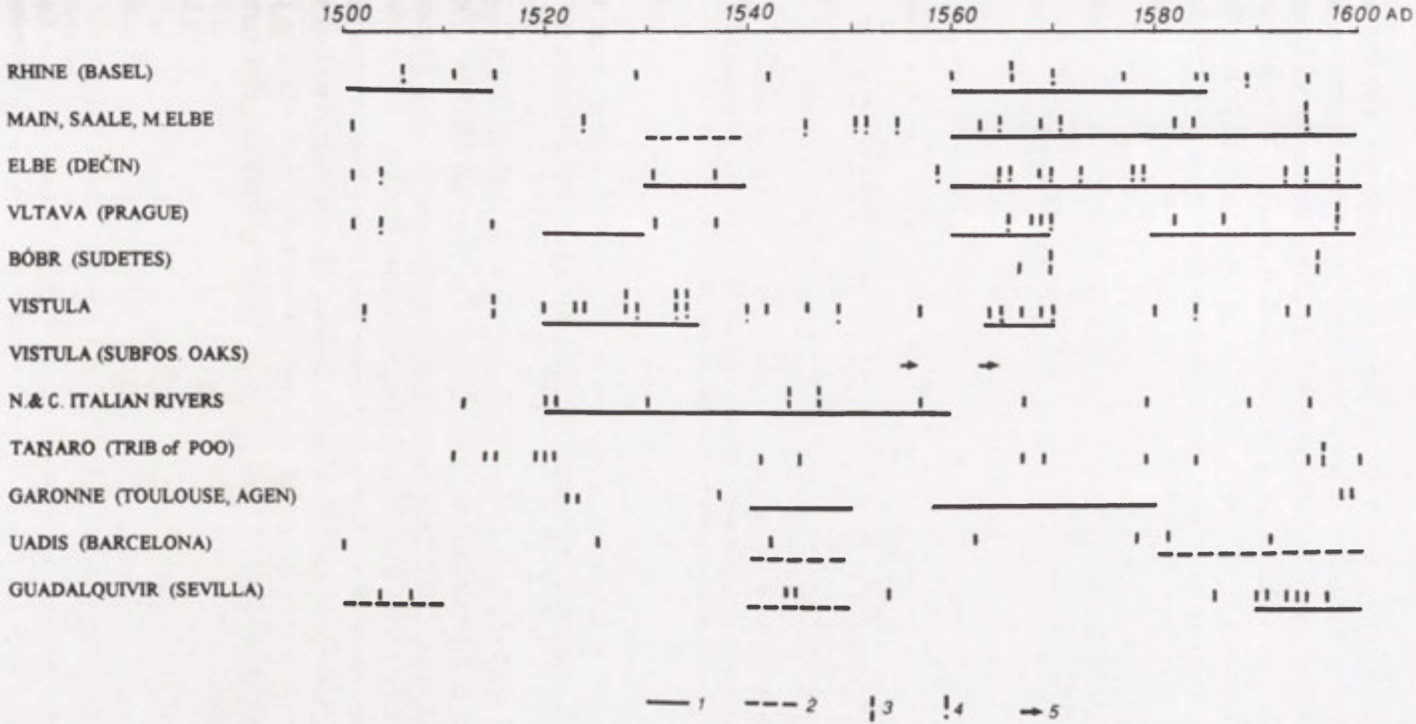


Figure 2. Floods in the 16th century in selected river valleys – based on records collected in paper by Brázdil et al. (1999), supplemented by records from Polish rivers (Strupczewski and Girguś 1965; Czerwiński 1991, Krąpiec in: Starkel et al. 1996) and Tanaro river in N-Italy (Pavese et al. 1992).

Signs: 1 – main phases of frequent floods, 2 – less distinct phases, 3 – floods in single years, 4 – snowmelt flood, 5 – subfossil oaks found in alluvia.

## CONCLUDING REMARKS

The data presented above reveal the existence of longer phases with various frequencies of extreme events as well as of their clustering in several consecutive years. The longer phases of a high frequency of extremes during the Holocene seem to coincide with reduced solar activity and increased $^{14}C$ production (Magny 1993; Chambers et al. 1999). But it is just during these phases that frequent volcanic eruptions are superimposed (Bryson and Bryson 1998; Starkel 1998).

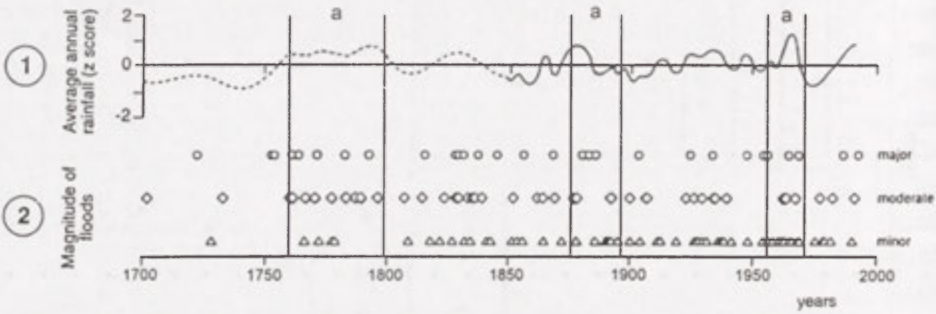


Figure 3. Precipitation, flood frequency and magnitude in the Tyne basin, northern England 1700–1900 AD (after Rumsby and Macklin 1996); a – periods of enhanced meridional circulation (after Lamb 1977).

Also the solar minima starting from Oort in the late 11th century seem to explain the rises in frequency of extreme rainfalls during the last millennium.

The shift in the timing of wetter and drier decades over Europe may also coincide with the dominance of either a latitudinal or a meriodional circulation; the latter seeming to effect frequent extremes (cf. Rumsby and Macklin 1996, Fig. 3). The last decade of this millennium provides examples of such frequent disturbances connected with a meridional circulation over Europe.

The alternating phases of the higher and lower frequency of heavy rains and floods in the last millennium (as registered so distinctly in sediments and later in written records) give a very important message for our better understanding of the present-day acceleration to various processes in the hydrosphere that transform geoecosystems.

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# CARP CULTURE – AN INDICATOR OF CLIMATE FLUCTUATIONS

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ABSTRACT: The paper attempts an evaluation of such climate fluctuations, as those of the Little Ice Age, from the point of view of historical data on carp culture. In the climate of Central Europe, carp growth is limited by temperature, especially in periods of unfavourable thermal conditions, and by water – in periods of drought. A tracing of the history of carp culture in the southern and western parts of Poland, where hydrological, climatic and geological conditions have been suitable for the development of fish farms, has made it possible to trace climate fluctuations since the Middle Ages onwards.

KEY WORDS: ponds, carp growth, temperature, water balance.

## INTRODUCTION

The history of fishponds began in the early stages of human development. However, Europe's written sources pointed to the greatest development of fish farms in the Middle Ages. They were constructed in the south and west part of Poland, as well as in adjacent countries, where soil, climate, and the dense river net, as well as the extensive area of wetlands were all suitable for fishpond culture. In Silesia the fish farms of big landowners and peasants arose at the end of the Middle Ages (Nyrek 1966; Szczygielski 1967). Ponds were constructed as the response to the overexploitation of fish stock in rivers, along with an increasing demand for fish during frequent and restrictive fasts, reaching half of the days of a year. Development of the great fishpond centres in the Middle Ages followed the introduction of carp culture. It increased the profit from ponds considerably. As a result of this income from the fishpond culture, for example, in the Oświęcim principality, reached 50% of the entire income in the 16th century (Rybarski 1931). An important role in the development of the fishpond culture was played by the proximity of fast-developing towns like Wrocław and the capital of Poland – Kraków – where increasing numbers of citizens stimulated high demand for fish. In Kraków, this demand was also enhanced by the king's

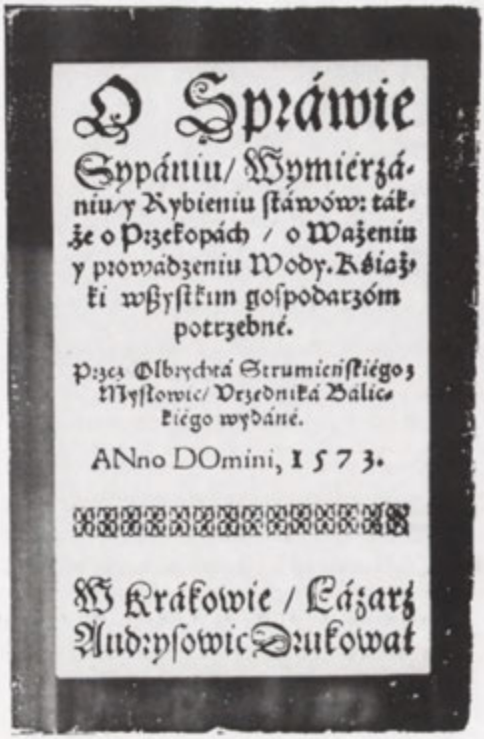

O Sprawie
Sypániu/ Wymierzániu/ y Rybieniu ſtáwów: tákże o Przekopách / o Ważeniu y prowadzeniu Wody. Kśiążki wßyſtkim goſpodarzóm potrzebné.
Przez Olbrychtá Strumienſkiégo z Myſłowic/ Urzędniká Bálickiégo wydáné.
ANno DOmini, 1573.
W Krákowie / Łázarz Andrzyſowic Drukował

Figure 1. Cover of the book “On Pond Management, Construction and Stocking, Also On Digging, Water Levelling and Conducting, a Book Useful for Every Farmer” by O. Strumieński, 1573.

court, while fish delivery to the capital was facilitated by transport along the Vistula River. The importance of fishpond culture in that time finds expression in the publishing of the first technical book in Polish on pond management (Fig. 1, Kwaśniewska-Mzyk 1987).

The early role of ponds was hydrological, since they were built as drainage objects in the lowest-lying parts of marshy terrain, mainly in wet mid-forest cleanings. The first to bring fish to these ponds were probably birds. In the second half of the 16th century the deforestation of the country, caused by the surface mining, the increasing population and pastoral farming (Nyrek 1992), forced the construction of large ponds along the rivers, thus increasing the retention of waters and protecting people from the floods. These ponds were built by landowners with serfs available and enough funds to hire professional builders. Small farmers’ ponds were chiefly built using natural wet depressions, which dried during long periods of drought. In such ponds, fish stocks were reared using labour-consuming methods, and sold to commercial fish farms (Nyrek 1992). Water from the big ponds also served agriculture during long persisting droughts.

The paper aims to point out the association between fish-culture decline in

Upper Silesia from the late 17th to early 19th centuries and the appearance of the Little Ice Age (Semkowicz 1923; Zubek 1979; Brázdil et al. 1996). To present the fluctuations in the thermal and hydrological conditions in these centuries models quantifying the relationship between temperature and carp growth, and survival, were applied (Szumiec 1995, 1998).

## STUDY AREA AND METHODS

The ponds of Upper Silesia were considered in the paper. They are supplied by water from the Vistula river and its tributaries. The source of the river lies in the Beskid Silesian Mountain Range, a part of the Western Carpathians.

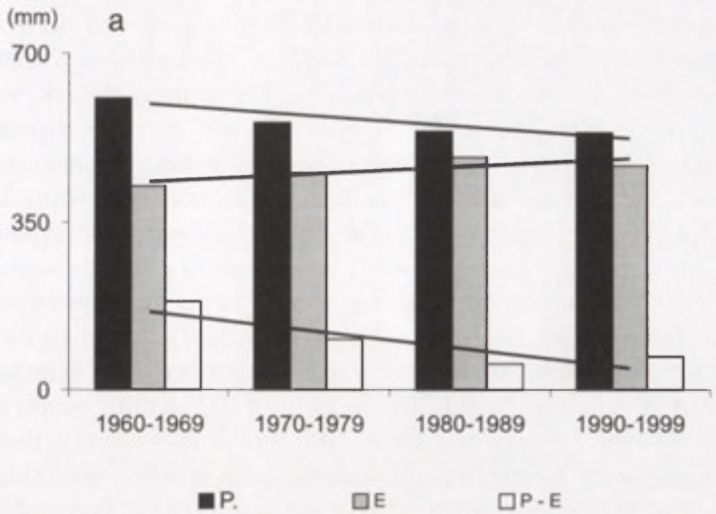
Changes in pond surface area and carp production from the late 17th to 19th centuries are discussed on the basis of results presented by the economic historians of Upper Silesia and neighbouring territories (Matejek 1957; Smerda 1959, Berka 1985; Hartstock 2000a, 2000b). To point to past hydrological events, the results of contemporary (1960–1999) monitoring of precipitation, evaporation and the meteorological water balance at the Golysz Institute were employed. The trend to the variation in air temperature from the end of the 17th century to the beginning of the 19th was evaluated from the yield of table carp in Pszczyna principality (Dynastia Plesnensis), and the deterministic models devised using contemporary results (Szumiec 1995, 1998). As warm-water fish, carp body mass grows proportionally with the sum of the effective water temperature above 14°C. In the climate of Central Europe the effective water temperature in ponds is limited to only 150–160 days/year. Carp juvenile survival in ponds could also be limited by the pronounced water temperature decreases observed in the period of their development, i.e. in May and June.

## RESULTS AND DISCUSSION

In Upper Silesia, the number of ponds was reduced by 60% at the turn of the 18th century, and by a further 10–15% early in the 19th century (Nyrek 1966). Schlenger's map from the second half of the 18th century shows numerous dykes remaining after ponds were drained in Pszczyna principality (Fig. 2). The reduced number and area of ponds are usually attributed to the decreasing level of groundwaters resulting from mining, and to the decline in fishpond culture. Nevertheless, they might also have been caused by the drought (Inglot 1968) evoked by the meteorological water deficit occurring over a long period. Results obtained at the Golysz Institute in 1960–1999, in the seasons of carp growth, i.e. from May to September, showed that a tendency for reduced precipitation waters and increased water-layer evaporated from ponds is also appearing at the present time (Fig. 3a). In seasons with precipitation total lower than 500 mm,




Figure 2. Map of the region of Dynastia Plesnensis in the second half of the 17th century drawn up by Schlenger and Janiak (according to Nyrek & Wiatrowski 1961).



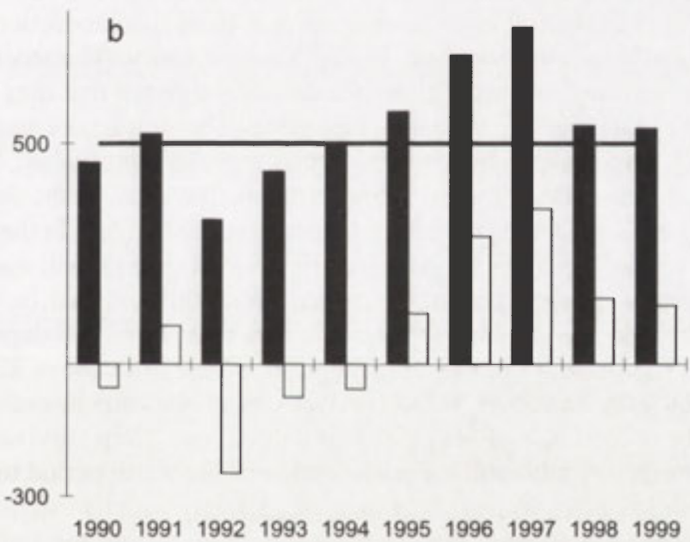




Figure 3. a – Average ten-year seasonal (May–September) sums of precipitation – P, water evaporated from the pond surface – E, meteorological water balance – (P-E), and their trends at the Golysz Institute of Ichthyobiology and Aquaculture PAS; b – Seasonal sums of precipitation (black columns) and meteorological water balance (white columns).

losses of evaporated water exceeded the water income from precipitation (Fig. 3b). This creates the threat of a water deficit lowering considerably the water supply to ponds and the production of fish.

The decrease in pond culture in the first half of the 17th century is attributed to unfavourable changes in social and economic conditions and the devastation brought about by the Thirty-Year War (1618–1648) and the war between Poland and Sweden (Kraków was occupied in 1655). It might also have resulted from the more profitable production of cereals in the 17th century (Nyrek, Wiatrowski 1961; Nyrek 1966; Szczygielski 1967). However, this decrease, especially from the end of the 17th century, seems also to have been the consequence of a lack of carp stock and the low rate of growth in body mass, both being limited by unfavourable thermal conditions. Some Polish historians (Semkowicz 1923; Zubek 1979; Nyrek 1992) have pointed to the onset of climate cooling towards the end of the 16th century. This cooling, as well as the prolonged unfavourable thermal conditions to the beginning of the 19th century, found confirmation in the declining carp output of the Pszczyna principality. The number of carp stocked in the principality's ponds decreased from 10,514 three-scores in the year 1536 to 9,653 in the entire period 1691–1700. In the 18th century, thus after the aforementioned wars, the trend for decreasing carp numbers sold (Fig. 4a) and increasing carp prices (Fig. 4b) confirms the prolonged unfavourable thermal conditions. The total income from fishpond production decreased from 69% of the whole agricultural income in the period 1661–1670 to 3% in 1801–1810 (Nyrek 1966). A considerable decrease in income from fish production between 1553 and 1850 was also observed in the Saxon country (Hartstock 2000a). Searching for reasons for this decline, the author suggested that they might be caused by the unfavourable climatic fluctuation. The drastic decrease in carp production occurred despite the owners' efforts to make it profitable.

The role of thermal conditions in carp culture is illustrated by the dependence of their body mass growth on the effective temperature (Fig. 5a). In the cold year 1978, when sum of the water temperature effective for carp growth was equal to about 500 degrees, production only reached about 50% of that in the warm season 1993, when the effective temperature sum was above 900 degrees (Szumiec 1990). The decrease in the temperature in ponds from above 20 to about 14°C also causes a limitation in the survival rate of the carp juveniles usually stocked in the second half of May and first half of June. Carp survival rate was found to rise significantly with the prolongation of the warm period to about 10 days after fish stocking, while it only increases slightly with its extension above 20 days (Szumiec 2000, Fig. 5b). In the considered climate the unfavourable thermal conditions in spring are more frequent. The appearance of the spring cooling as well as the low sum for the effective temperature in a consecutive year lowered the carp yield considerably.

## CONCLUSIONS

A decrease in the number of small fishponds at the turn of the 17th century might be attributed to the decreasing level of ground waters, resulting from mining, but might also indicate the domination of years with the negative meteor-

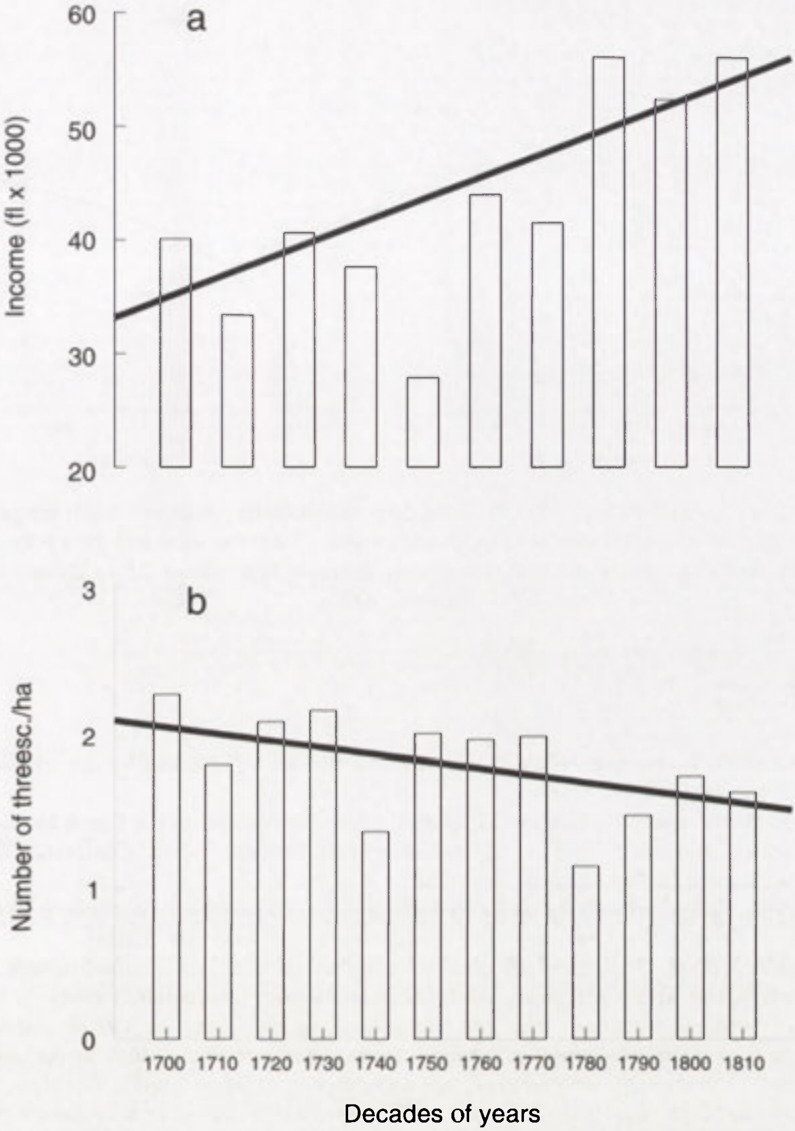



Figure 4. a – 10-year-average income from the fish sold from ponds;
b – 10-year-average number of three-scores of carp fished from ponds of the Dynastia Plesnensis, and the trends for them.

ological water balance. The decline in income from carp production and the increase in their prices, illustrating the high demand for this food, might have resulted not only from unfavourable changes in political, social and economical conditions, but also be indicative of the unfavourable thermal conditions from the late 17th to early 19th centuries. Up-to-date results clearly point to the limiting role of low temperature on the carp growth and survival rates.

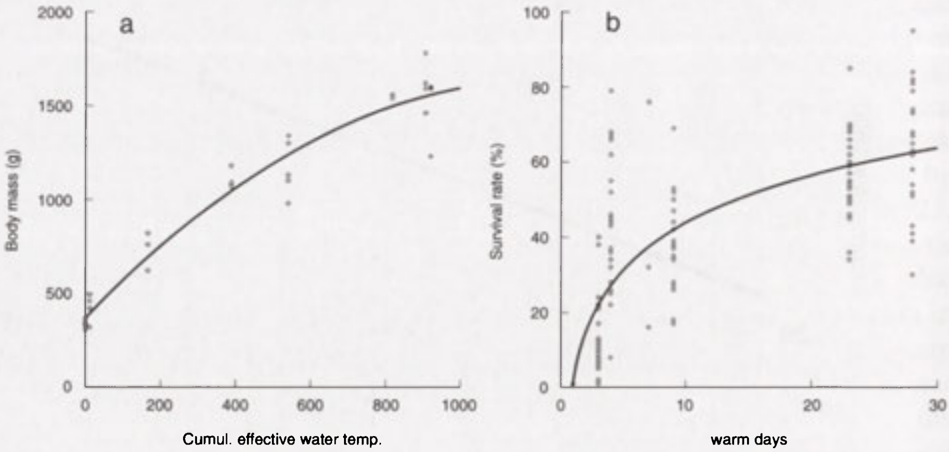



Figure 5. a – Growth rate of three-year-old carp vs cumulative effective water temperature in ponds; b – Survival rate of carp juvenile forms vs number of warm days between stocking fish in ponds and first temperature decrease from above 20$^{o}$ to about 14$^{o}$C (Szumiec 2000).

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# BOOK REVIEV

*Environmental Change in Mountains and Uplands* by M. Beniston, 172 pp., Arnold, London, 2000.

The issue of environmental change is currently one of the most popular among geoscientists and given its breadth and interdisciplinary nature, it is not surprising that geographers have taken the lead in both research and the stimulating of public awareness of the subject. This interest is clearly reflected in the new book series launched by Arnold and managed by J. A. Matthews (Swansea, UK), entitled 'Key Issues in Environmental Change'. The editor announces at least 10 forthcoming titles covering different aspects of environmental change and emphasises in the series preface, that 'It is essential, therefore, to view current and future environmental changes, like global warming, in the context of the broader perspective of the past. This linking theme provides the distinctive focus of the series'.

Likewise, it has become fashionable to work on mountains. There have recently been numerous conferences on various aspects of mountain environments, more are planned, and the year 2002 is declared by UNESCO the 'International Year of the Mountains'. Mountains are, rightly, considered among the most fragile environments on Earth, and equally among the most sensitive to global environmental changes. They are most important for maintaining biodiversity and ensuring the availability of water resources. It is thus no wonder that the first volume in the Arnold series is one about environmental change in mountains. The author, Martin Beniston, is a Professor of Geography at the Fribourg University in Switzerland.

The book consists of eight chapters, including introductory remarks and final comments. Successive chapters include characterisations of mountains and uplands, reviews of past environmental change and modelling approaches and discussions on possible future changes in mountain environments, their impact on natural systems and the socio-economic sphere. There are two principal driving forces of change; natural, related to climatic change and volcanism, and human-related, induced by demographic and economic factors and resulting in pollution and land-use changes. The impact is likely to be experienced in mountain hydrology, the cryosphere, the frequency of extreme events, ecosystem patterns, agriculture, health, tourism, and hydro-power. Some of the topics are illustrated by case studies, usually borrowed from the Alps, such as various policies towards trans-Alpine transport, debris-flow-hazard mitigation, or Holocene glacier retreat.

Promising as the list of contents may be, I could not help a strong feeling of superficiality in the coverage of the subject, after reading this book. To a certain extent, this is probably the effect of a limit imposed by the editors, but the omissions are too many. In the characterising of mountain environments, the neglect of distinctive geomorphic systems of mountains is striking, as it is the topography which is responsible for many of the hydrological features, and for the distribution of glaciers, avalanches and soils. The discussion of the possible impact of future change suffers from this neglect too, as it lacks a coherent framework to analyse the mutual relationships between hydrological, geomorphic, cryospheric and biological components. Another source of disappointment is the chapter about past environmental changes, especially its part about pre-Last Glacial history. I was also very surprised not to see John Gerrard's 'Mountain Environments' in the list of references, and the omission of Carl Troll, the pioneer of mountain geoecology, is even more difficult to understand. On the other hand, there are very useful sections on recent glacier decay, limits and ranges of application of models, various human-induced pressures on mountains, human health issues and tourism. In general, the sections on the human dimension of environmental change in the mountains are much stronger than those about physical systems, except for climate, its change and modelling. This perhaps reflects the expertise of the author.

Another drawback is the very poor illustration, especially frustrating considering the beauty of mountain landscapes. Line diagrams are not too many, and often too simplistic; some case stories are not illustrated at all. It is sad that the principle of one picture saying more than a thousand words was not followed when the book was produced.

Finally, the Polish reader may be interested in whether the mountains in Poland are referred to. Yes, they are featured twice, but both examples are not very fortunate. Catastrophic forest dieback is mentioned, but it would be fair if this information was accompanied by a statement about the successful combating of the disaster and current forest regeneration. Then, the Polish Carpathians are certainly not an appropriate example of mountains 'developed under the planned economy of socialism'.

In summary, this is a timely book which undoubtedly contains a lot of useful material, but does not quite meet expectations and fails to provide a comprehensive analysis of mountain environments, especially their physical side. Hopefully, the forthcoming volumes will have more in-depth coverage, a more balanced approach, and be better illustrated.

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*Hands-on meteorology, Stories, Theories and Simple Experiments*, 1996, Norman (Oklahoma), by Zbigniew Sorbjan, Polish Edition, 2001, Prószyński i S-ka, Warszawa.

*Hands-on meteorology* by Zbigniew Sorbjan represents an unusual achievement for Polish researchers. The author is a Polish meteorologist and geophysicist working for several years at various American universities. The first edition of his book was published in the United States and only now, after 5 years has it been translated into Polish.

Meteorology (which is a branch of geophysics) and climatology (a branch of geography) are in fact closely related research disciplines. They have the same object of study, the atmosphere. Meteorologists investigate temporal states of the atmosphere and physical processes ongoing within it, while climatologists are occupied with long-series data from meteorological observations, seeking time regularities and prognoses regarding climate change. Thus, like climatologists we need to improve our knowledge of meteorological phenomena and meteorological processes.

Z. Sorbjan's book is very useful in this regard. It is dedicated to a wide range of readers: students, engineers, architects, constructors, pilots, sailors, biologists, geologists, geographers and all those interested in observing nature around them. Both structure and content constitute the author's way of arousing readers' interest in meteorology. His principal idea has been to distinguish several parts of the book in order to give readers the chance to choose for themselves the chapters in which they are most interested and to waive the parts which seem obvious.

The book is divided into 8 chapters entitled: principles, air, pressure, heat, light, moisture, forces and movement. The chronological table and glossary of principal meteorological terms constitute very useful appendices. Every chapter leads the reader into the main issues of meteorology. The author presents the history of the fundamental milestones in the exploration of the atmosphere.

*Hands-on meteorology* is an unusual handbook. It does not provide readers with a regular exposition of meteorology. We cannot find here very sophisticated presentations of the main meteorological theories (the nature of the air, heat and moisture transfer, light phenomena, circulation etc.). Special attention is paid to the understanding of the atmosphere and to raising awareness as to humanity's way of coming to know its rules and laws.

For present-day readers of this piece, some terms like heat, pressure, clouds, wind, light and others are so common that we do not need to define them. However, the first definitions there of originated as the results of several experiments and observations. The author describes very evocatively the first experiments carried out by Gallileo Gallilei (the weight of the air), E. Torricelli and B. Pascal (air pressure), B. Thompson (heat production), Ch. Huygens and I. Newton (the nature of light), B. Franklin (atmospheric electricity) and a number of other researchers.

Generally, Z. Sorbjan initiates the readers in the principal meteorological processes and terms by the experimental method. He not only describes the first research experiments but also proposes various ones which can be performed at home (e.g. the discovery of air gases and air pressure, the measuring of heat and moisture, heat transfer etc.). My teaching experience at the university in a "general meteorology and climatology" course tells me that students have a lot of problems with understanding the principal meteorological phenomena and processes. The experiments proposed by Z. Sorbjan can be very useful in educational practice, on the primary, secondary and tertiary levels.

Relatively poor is the chapter dedicated to light. The author concentrates on the visible range of the solar spectrum and only mentions the ultraviolet and infrared ranges. The positive point is that he describe very clearly the formation of such fascinating optical phenomena, as the rainbow, mirage, gloriole and after-image.

The chapter devoted to circulation is very interesting. We can understand the principles of general circulation, the forces playing a role in air motion (e.g. Coriolis force, friction), the theory of fronts, the formation of tornadoes and hurricanes. However, there is no mention of air masses and local circulation. At the end of the chapter we can find essential information about weather forecasts made by both traditional methods, as well as with the use of satellite data and numerical methods.

All the information given by the author and all the descriptions of experiments are very well illustrated. The illustrations were prepared Z. Sorbjan himself on the basis of materials from the History of Science Collection of the Library at Oklahoma University in Norman. They are very demonstrative and helpful where the understanding of the problems discussed are concerned. The text is also supplied with 27 short biographical notes of people involved, marking their contribution to progress in meteorology. However, it does sometimes seem that the list of personalities is a little random.

The chronology points out the milestones in meteorological research. It starts from 500 BC when Parmenides made the first climate classification. The first meteorological achievement is Aristotle's *Meteorology* (350 BC). The instrumental period starts in 1450, when Cardinal Nicholas of Cuse constructed the first weighting hygrometer. The century richest in meteorological discoveries was the 19th century, from 1800 and Herschel's discovery of infrared radiation, up to 1899 when de Bort firstly studied the upper atmosphere. The last milestone pointed out by the author is first of Doppler radar network used by the US meteorological service.

Generally speaking *Hands-on meteorology* by Zbigniew Sorbjan is a kind of guide leading the reader to a better understanding of atmospheric processes and phenomena. While it can not replace the academic handbook on meteorology and climatology, it should be a valuable supplement to any geographical library while also proving valuable in educational practice on the secondary and tertiary levels.

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The manuscripts should be arranged in the following order. First sheet: title, full name of author(s), affiliation, full postal address, e-mail address (if possessed). Second sheet: abstract of no more (no less) than 100 words, key words (3–10) at the end of the abstract. Subsequent sheets: the main text of about 20–25 pages double-spaced (in A4 format). Then on separate sheets: acknowledgements (if desired), notes, references, tables, illustrations, captions to illustrations.

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