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# Hydrosynoptic approaches for identification of flood mechanisms

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## Abstract

The paper discusses possibilities and problems related to application of hydrosynoptic approaches for flood protection in the Czech Republic. The examples presented are based on data from sub-basins of the Czech Elbe River. The mechanism of genesis of extreme floods is analysed within a framework of an integral complex system of: (1) circulation conditions of the atmosphere, (2) dynamics and areal distribution of induced precipitation fields, and (3) the relevant runoff response. The physical-geographic variability of the selected river basins is a reason for their varying sensibility to various types of circulation pattern, that are able to generate a flood. By this, physically realistic possibilities also vary in terms of the lead-time of flood warning across the basins. It can be confirmed also by the results of seasonal analysis of occurrence of floods and their peak discharges in the selected river basins. In the conclusions, a hydrosynoptic categorisation of flood waves in relation to the generating atmospheric factors is presented.

**Key words**: hydrosynoptics, floods, seasonality, categorisation of flood waves

## Introduction

Annual flood damage in the Czech Republic ranges, in the average, between 500 million and 1 billion CZK. In cases of large floods it may, as demonstrated by situation in 1997, be even bigger. It is estimated that, for example, 100-year flood on the Vltava River would bring damage reaching some billions CZK, only in Prague (Reidinger 1995).

Ideas on sustainable development lead subsequently to a conclusion that in the current conditions it will be necessary to develop more systematically than before non-structural approaches in flood protection, i.e. to improve alert, warning and flood forecasting systems. A range of strategic questions is closely related to these requirements, such as "What are physical possibilities for lead-time advance in real time for flood protection measures across the Czech Republic?", "Are the flood situations resulting from similar meteorological conditions also similar to each other?", "What meteorological symptoms in the atmosphere indicate formation of a flood situation in a given river basin?" etc.

It is clear that answers to these problems are to be based on knowledge of mechanisms of formation and development of floods and cannot be resolved without hydrometeorological analysis of historic events. As an appropriate tool for this purpose a databank of observed flood situations could serve, based on recording their characteristic components. It has to be stressed, however, that extreme flood situation is always a result of inter-relationship of a number of exceptional factors not only in the atmosphere, but also in the river basin. Therefore it is necessary to consider their combination both in view of regime and dynamics and view them as a single complex system of events in the atmosphere including process of the discharge in the closing site of the river basin.

The article discusses some of the common aspects and possibilities for such approaches and also summarises practical experience with preparation of background data for suggested hydrosynoptic analysis of historical flood situations. The applications are based on data observed in a number of sub-basins of the Elbe River.

#### Development of hydrosynoptic analysis in the Czech Republic and abroad

Since the times of its originator Augustin (1891), the hydrosynoptic analysis in the Czech Republic was promoted by a number of successors, of which the following from the past decade can be mentioned Brádka (1967, 1972), Barbořík, Hladný (1967, 1971), Buchtele (1972), Kakos (1974, 1983), Panenka (1979), Koblihová (1989), Vavruška (1989), Křížková (1998) and others.

One of the detailed studies of the causes of floods with application of hydrosynoptic methods in the river basins of the Vltava River cascade was presented by Buchtele (1972) at the beginning of seventies. He pointed out to a relationship between a particular type of the synoptic-meteorological situation, location of the precipitation cell and the subsequent occurrence of the flood wave. He showed that a majority of extreme floods on larger Czech river basins was caused by the appearance of the situation Cyclone above the Central Europe, or Trough of low pressure.

Hydrometeorologic analysis and subsequent estimation of flood situation was studied in detail by Kakos (1974) at the beginning of seventies. By comparing prediction methods available in meteorology (extrapolation, statistical, application of analogues, numerical modelling and other techniques) he concluded that regarding possibilities for increasing the lead-time of warning in the physical-geographical conditions of the Czech Republic, the method of analogues could be useful, although it is less accurate for quantitative forecasts. In certain modifications the method is being studied by a number of authors until now, with the aim of explaining more deeply occurrence of floods through definition and verification of a complex of meteorological parameters (symptoms) representing circulation conditions of the relevant meteorological situation across the study area (standardisation of distribution of ground and upper thermobaric and moisture field, characteristics of layering of the atmosphere, frontal lines of air masses, driving circulation, wind shear etc.).

The same author (1983) demonstrated two-day lead-time of meteorological causes by analysis of summer flood events on the Vltava River in Prague in the period of 1873 and 1982, while identifying as significant the symptom of negative thermal deviation from climatological normal.

The relation between circulation processes and precipitation was studied in great detail by Brázdil and Štekl (1986) when stressing the necessity of certain generalisation in any categorisation of historic data.

Vavruška (1989) analysed in detail meteorological causes of floods on the Otava and Lužnice Rivers in the period 1950–1988 and oriented his study mainly on identification of causing types of synoptic situations of these floods.

Vlasák (2000) analysed hydrometeorological causes of occurrence of winter floods on the Otava River and derived types of flood waves corresponding to the given circulation conditions.

Similarly, the results of studies presented by the latest foreign references point out to relevance of the subject nowadays. Bárdossy and Plate (1992) developed a multidimensional stochastic model for time-space distribution of precipitation with parameters dependent on composition of atmospheric circulation. The authors applied for this purpose classification system of the German meteorological service. The results for the Ruhr River basin in the period 1977–1990 were tested using data from 44 precipitation stations.

Duckstein, Bardossy and Bogardi (1993) investigated floods in five river basins of central Arizona and studied the relation to the type of daily atmospheric circulation in macro-synoptic scale. They identified one to three day lead-time dependent on the season and size of the river basin.

Llasat and Puigcerver (1994) described the main meteorological symptoms of extremely strong precipitation with subsequent disastrous floods in Catalania between 1939 and 1989. They analysed in detail ground and upper synoptic data including meso-meteorological conditions and effects of orography of Pyrenees and defined three basic causes of disastrous floods: geographic, seasonal and meteorological (ground convection perpendicular to the shore during 12 to 24 hours, appearance of subsidence inversion, unstable layering implicating occurrence of strong convective systems and other parameters).

Kunkel, Changon and Angel (1994) investigated meteorological and climatological aspects of extreme floods on the Upper Mississippi in summer 1993, when large, medium to strong precipitation (at many places the 24-hour precipitation depths were more than 150 mm) were directed along the basins of main rivers and at the same time there was excessive soil moisture and low evaporation. The authors also pointed out in this respect to an important role by massive meso-scale convective systems ($MCS_s$) and even larger meso-scale convective complexes ($MCC_s$) as sources of extremely strong and extensive precipitation in the central parts of the USA in summer season.

Doswell (1996) aimed at definition of physical basis for understanding of the mechanisms of occurrence of strong precipitation causing floods. The extreme observed depths were, according to his theory, related to fast rise of air containing water vapour and to intensive development of precipitation. Duration of the situation affecting directly precipitation depths is given by size, speed and direction of movement of the precipitation system across the river basin under study. Equally as Kunkel, Changon and Angel, he pointed out to the role of $MCS_s$

a $MCC_s$ in occurrence of extreme precipitation and presented classification of these systems.

Currently, knowledge on general circulation of the atmosphere including mezo-meteorological aspects greatly improved by fast development of top computer technology, instruments, automation of measurements and transfer of large data sets, as well as by the use of satellite and radar measurements together with development of numerical forecasting models.

The existing atmospheric models are not, however, able to describe reliably individual phases of crucial physical processes at small scales and the results often correspond to simplified assumptions (Panenka 1985).

Meteorological situations with the long duration of regional precipitation have all characteristic signs of composition of pressure masses at ground and in the upper atmosphere and are possible to be observed by classical synoptic methods. Their predictability is therefore better than predictability of local storms evolving from unstable air masses. Because more than 80% of precipitation on the territory of the Czech Republic, mainly on the large rivers, relate to atmospheric fronts, it will be always necessary to base the estimate of occurrence and development of floods on hydrosynoptic analyses of necessary macroscopic circulation conditions in the atmosphere. Difficulties arise during transformation of the large-scale processes to river basin of much smaller order of scale. For this purpose the "downscaling" methods are being recently developed (Stehlík 2000).

For floods appearing due to snowmelt, the main generating factor – air temperature – has usually higher level of predictability in comparison with precipitation. Also, its change is usually slow, because even very fast snowmelt appears to be corresponding to intensity of only moderate rain. An exception is represented by snow floods caused by intrusion of warm air over the river basin with parallel raining. If the flood is accompanied by ice shove, the forecasts are affected by increased "noise" and predictability is decreased.

From the review of references it follows that for the modern hydrosynoptic analysis the following range of parameters are needed:

1. generating meteorological conditions (synoptic analysis of circulation processes in the scale of the European continent),
2. precipitation impulses or induced precipitation fields respectively (diagrams of time snaps of the field topography of induced precipitation related to each of the flood events, or heat fluxes, including location of their cells at the river basin),
3. runoff response (a set of synchronised diagrams of discharge of induced flood waves in the observed sites of the given river network allowing to analyse travel time of flow as well as transformation of flood waves and subsequently phased introduction of the river basin into the flood stage).

Such hydrosynoptic studies should allow:

- comparative analyses using the most similar historical flood events with the aim to identify dominant features (symptoms) of generating meteorological situation,

- evaluation of sensitivity of physical-geographic environment to the given type of generating circulation patterns,
- improvement of knowledge on mechanism of occurrence and development of flood situations in the given river basin,
- identification of conditions for extension of the lead-time for warning and improvement of predictability of floods,
- acquiring background material for improvement of meteorological forecasting models of the LAM (Local Area Model) type.

### Categorisation of generating atmospheric circulation patterns

For the territory of the Czech Republic the categorisation developed by Brádka et al. (1961) is being used in meteorology, intended, at least at the time of introduction, for short and medium-time forecasts. It is based on distribution of the main pressure bodies and frontal zones above Europe and near zones of the Atlantic ocean, however, it does not take into account detailed synoptic features – at a mezo β scale and smaller (Brázdil, Štekl 1986). Therefore, its application for characterisation of weather in small regions leads to significantly wider range of results than if using the second categorisation applied according to Konček and Rein (1971). It found its application mainly in climatology, for which it was developed, but the calendar of its categories exists only for the period 1950–1971. A new categorisation of circulation patterns would appear appropriate which includes meso scale, but there is not available the calendar of types for longer period.

Current numerous research activities of mezo-scale atmospheric processes and modelling of pressure bodies might improve a lot. Through automated optimisation procedure based on principles of fuzzy logic a new classification of circulation patterns was developed. Input was represented by daily values of geopotential 500 hPa level and local precipitation depths. As a criteria for definition of separate types was the extremity of precipitation for a given type. By this, significantly "dry" and "wet" types of meteorological situations arose (Bárdossy, Stehlík 1999). Using the proposed downscaling this categorisation was applied for the Otava River basin (Stehlík 2000).

The majority of existing hydrometeorological studies on development of floods on the territory of the Czech Republic was, however, based on an assumption that often simplified procedures for complex processes can bring valuable, although only approximate information. Usually the sequence starting from simple to complex methods is applied. From this viewpoint it is necessary to evaluate so far predominant application of the Brádka's categorisation. Its Catalogue cover the period from 1946 until now and is annually updated (additions are published in the Meteorological Journal). The statistical assessment of generating circulation patterns given below is also based on this categorisation.

If this categorisation of guiding masses in the atmosphere is linked to the relevant historic flood events at a given river site, it is possible to use such a set as a key for explanation of a number of questions related to detection of factors causing development of flood situations. Usually the basic problem is: what circulation atmospheric conditions generated the flood and with what lead-time it is possible to identify these in relation to the river basin under study.

#### Lead-time of the generating atmospheric circulation patterns

Investigation of circulation patterns having flood features brought knowledge that their occurrence is accompanied by certain physical symptoms that precede in time the induced flood. If it is therefore possible to identify them, they could indicate probable occurrence of flood situation with certain advance yet in this step without necessarily quantifying the extremity and the size of the flood. The time of advance is usually longer than the lead-time of the forecasts from observed precipitation. It is estimated to be approximately one to five days in relation to:

1. type of generating meteorological situation,
2. season of its occurrence,
3. characteristics of the river basin represented mainly by the size of its area, orography and direction of the main watercourse in relation to dynamics of circulation processes.

Demonstration of results of such an analysis is given in diagrams, see Fig. 1–6 (the categories applied and their acronyms are taken from the Brádka's Catalogue). The diagrams show number of days of occurrence of the generating synoptic situation before culmination of the flood at the selected site of the river basin under study. For each of the synoptic types and within the range of eight days before culmination a statistical value $n$ was calculated for historic flood events. It is a proportion between the frequency of occurrence of the generating meteorological type and the total

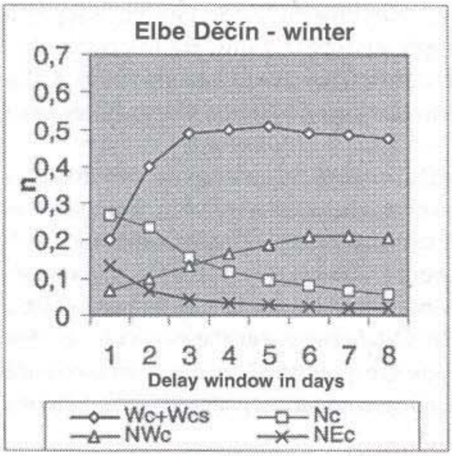


*Fig. 1* Lead-time of synoptic situations Wc, Nc, NWc and NEc in the Elbe basin at Děčín in winter period (XII–II)

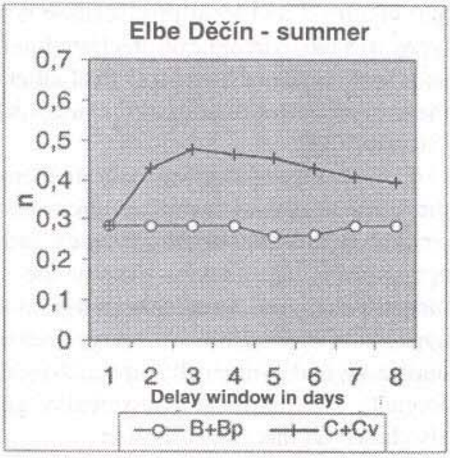


*Fig. 2* Lead-time of synoptic situations B, Bp, C and Cv in the Elbe basin at Děčín in summer period (VI–VIII)

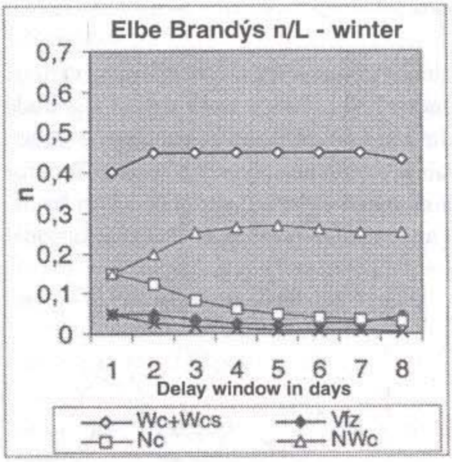


*Fig. 3* Lead-time of synoptic situations Wc, Vfz, Nc, NWc and NEc in the Elbe basin at Brandýs n/L. in winter period (XII–II)

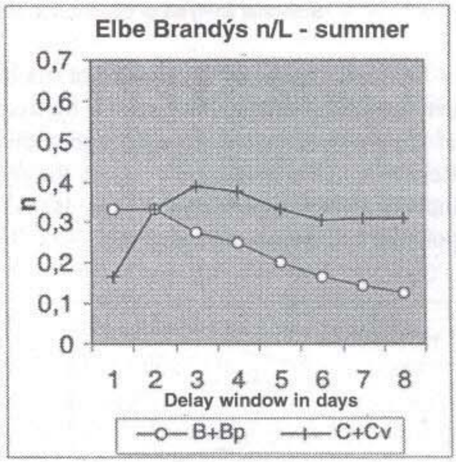


*Fig. 4* Lead-time of synoptic situations B, Bp, C and Cv in the Elbe basin at Brandýs n/L. in summer period (VI–VIII)

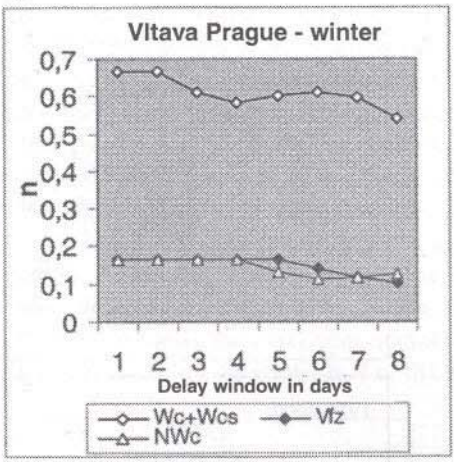


*Fig. 5* Lead-time of synoptic situations Wc, Vfz and NWc in the Vltava basin at Prague in winter period (XII–II)

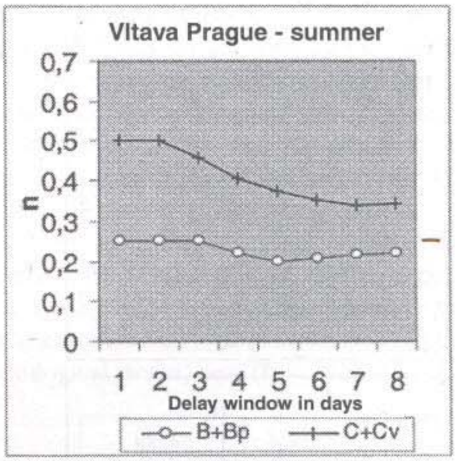


*Fig. 6* Lead-time of synoptic situations B, Bp, C and Cv in the Vltava basin at Prague in summer period (VI–VIII)

number of all situations that generated flood in the observed season of the given period. The ratio is calculated for each day separately before occurrence of culmination. The maximum of this value shows then with the highest probability the required time relative interval or the probability of advance of the relevant type of synoptic situation. For example, the situation Cyclone above the Central Europe (C) gives for water gauging stations Děčín and Brandýs n./L. on the Elbe River during summer lead-time of three days, but for the Vltava River in Prague only one to two days.

### Seasonal analysis of occurrence of floods

Seasonal regime of occurrence of floods can be characterised according to various derived characteristics, but mainly by frequency of occurrence and by the magnitude of the observed maximum discharge within the same set of flood events. In the Czech Republic, in the long-term average, the probability of occurrence of floods differs for individual months during the year. It is demonstrated by the diagrams shown in the polar co-ordinate system in Figs. 7–12. The annual rose also show that the seasonal

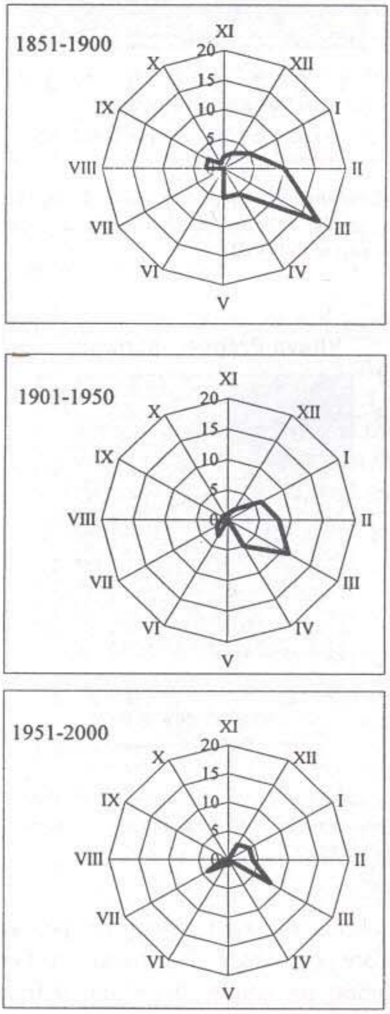


*Fig. 7–9* Frequency of occurrence of floods in 50-year intervals during 1851–2000 period on the Elbe at Děčín

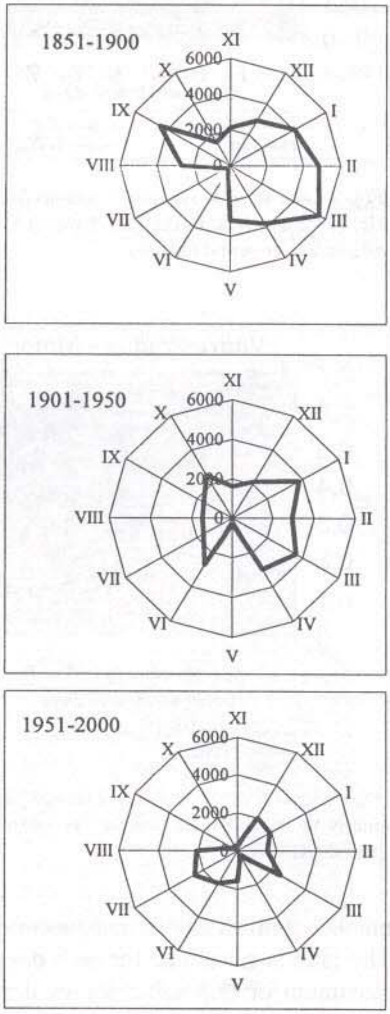


*Fig. 10–12* Seasonal occurrence of maximum discharges [$m^3 \cdot s^{-1}$] in 50-year intervals period during 1851–2000 on the Elbe at Děčín

occurrence of floods can also change during a relatively long period, i.e. it is non-stationary.

The statistics of historical floods and therefore their seasonal analysis is always affected by limiting value of discharge, above which the floods are recognised. If it is selected relatively low, cases of flood waves due to convective rain will be included in a significant rate, while estimates of occurrence and development of flood situations are based rather on precipitation of frontal origin. If the limit is set corresponding to the value when water leaves the river channel (flood stage), the number of such flood events will be small for the needs of statistical assessment. It is therefore necessary to select the appropriate limit between the two possibilities.

Such seasonal changes can be demonstrated, for example, by dividing the 150-year series of culmination discharges on the Elbe River at Děčín into three 50-year periods (see Figs. 7–9). It is apparent that the March annual maximum of frequency of occurrence remains stable, although its peak and asymmetry gradually decrease significantly. In July, there is apparent increase rather than decrease of floods in the long-term. Another characteristic feature is the shift of the maximum frequency of occurrence of flood events in the summer half of the year from May (1851–1900) to July (1951–2000). Along this feature there is also the shift of the period with low probability of occurrence of floods, so-called flood depression, from June to April, that is towards the winter months. The length of this transitional period between the summer and winter regime in the occurrence of floods ranges between one to two months. A similar depression is apparent in the autumn. Concerning the long-term distribution of maximum culmination flood discharges during the year (see Figs. 10–12), it is possible to observe that its shape is more or less similar (conform) to the shape of the occurrence of floods. In addition, this analysis demonstrates that in the 19th century there were more floods than in the 20th century.

Geographical differences between the selected river basins are also a reason for spatial differences between seasonal occurrence of flood events at the closing sites of various river basins (see Fig. 13–18). In a majority of sub-basins considered in the Elbe River basin, the maximum number of occurrences of flood events appear, in the long-term, during the winter half of the hydrological (water) year (from November for

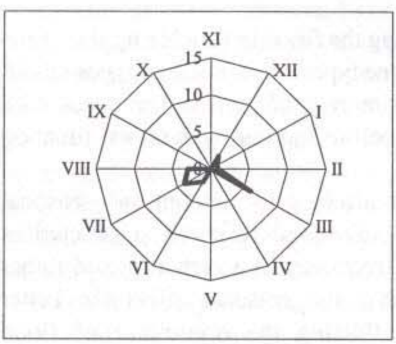


*Fig. 13* Frequency of occurrence of floods on the Vltava at Prague during 1951–2000

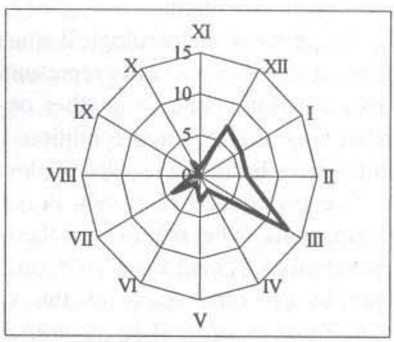


*Fig. 14* Frequency of occurrence of floods on the Elbe at Brandýs n/L. 1951–2000

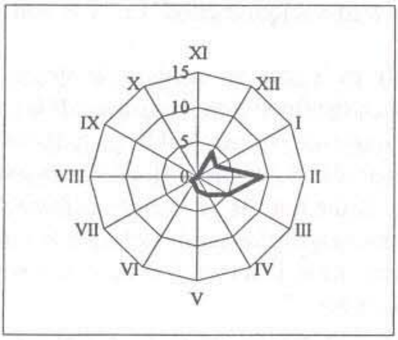


*Fig. 15* Frequency of occurrence of floods on the Ohře at Louny in 1951–2000

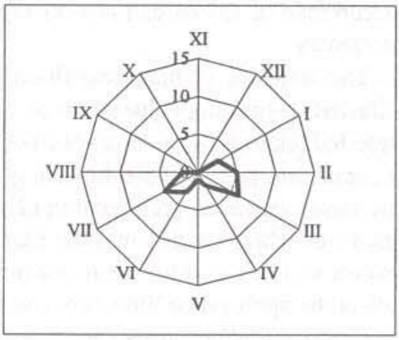


*Fig. 16* Frequency of occurrence of floods on the Berounka at Beroun in 1951–2000

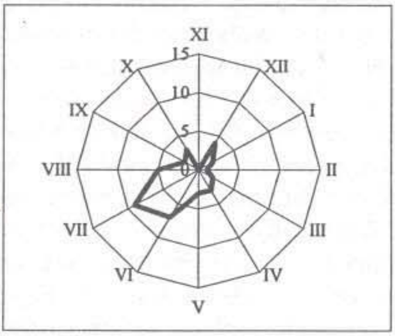


*Fig. 17* Frequency of occurrence of floods on the Otava at Písek in 1951–2000

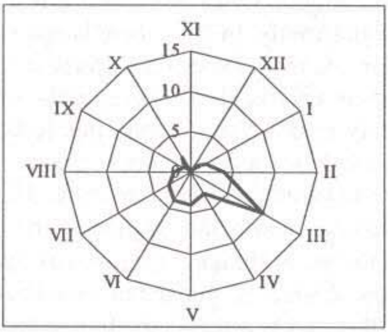


*Fig. 18* Frequency of occurrence of floods on the Sázava at Poříčí in1951–2000

April). The river basins of some of the watercourses demonstrate exception, such as the Otava River. In general, it can be stated that distribution of occurrence of floods during the year on the individual sub-basins will usually differ due to different sensitivity to the same circulation pattern which can be attributed to differing orographic conditions.

A number of meteorological situations preceding the flood in the closing site of the given river basin is usually represented by either one type or by a range of types rebuilt from the initial one to another or gradually to more other types. The cases with rebuilding of circulation conditions in the period before and during the flood situation in the river basin are usually predominant.

The occurrence of floods in a river basin is affected by random and seasonal components. The relation of these parameters, expressed relatively, characterises probability of occurrence of floods with higher frequency in a certain period rather than in the other parts of the year. The higher the seasonal effect the better identification of hydrometeorological factors affecting the occurrence of flood situations. In the Elbe River basin approximately 2/3 of occurrences of floods are due to the seasonal component and 1/3 by the random component (Freiburgová 1978).

Precipitation fields, which are formed by the fall-out across the river basin, are resulting not only from circulation processes in the atmosphere (mainly upward movements of the air on the frontal line, and also in the lower layers of the atmosphere in the cyclone area and zonal troughs, during thermal convection etc.), but also from the contact with the surface of the relief (orographic windward effects, exposition to mountainous ranges, altitude, configuration of the relief etc.). When making the hydrosynoptic analysis, it is evaluated whether the precipitation fields induced by the characteristic type of the meteorological situation posses also certain signs of conformity (Bárdossy, Plate 1992). Areal distribution of precipitation is usually a decisive factor in development of runoff situation and phased setting the individual parts of the river basin into flood stage. From the time delay between time of the generating phase of the circulation dynamics and occurrence of the peak runoff in the basin, physically realistic time limit of the lead-time interval can be assessed for warning against possible flood situations. As the physical-geographic conditions of individual river basins in the meso-scale differ, it can be assumed that also these time intervals will differ. For the same reason, it is necessary to take into account also differing reaction, i.e. sensitivity of the basin to various types of meteorological situations.

Analysis of variability of the day of occurrence of generating meteorological situations (DD) before the peak of the flood wave (D) for various types of meteorological situations resulted in an idea that these can be divided into two subsets according to the speed of movement of their cloud cover (Brázdil, Štekl 1986). If the cloud cover is moving rapidly across the study area and if it has relatively small areal extent, the danger of local floods is not as high as if the movement is slow and the extent large. For meteorological situation with a relatively fast spatial transfer of precipitation impulses the advance of DD to D can be reduced. In a number of cases the speed of movement of the cloud cover can be estimated from aerological data on direction and velocity of wind at various levels, which are regularly measured four times a day in the Czech Republic. As regards the areal extent of the precipitation cloud cover, satellite observation can be of help (Gottwald 1981).

An important role in detection of the mechanisms of development of floods is, however, played by not only size of the precipitation system and the speed of its movement, but also by direction of the transfer and sequence of precipitation impulses (Doswell 1996). For example, a flood wave with multiple peaks with large volume is often generated by a meteorological situation, which produces several subsequent precipitation impulses in such intervals that the river basin is no longer capable to balance the impulses through its retention capacity and the response is appearance of another peak of the flood wave. As a significant modern tool for identification of these parameters in analyses of historical flood events data from the radar screen can be used.

From this it is clear that if the generating meteorological situation lasts for a longer period (several days), there is not usually persistent continuous precipitation during whole this period. Its circulation conditions function rather as a source of time and spatially uneven precipitation impulses, which can, in combination with features of the relief of the given river basin, form characteristic precipitation fields.

In assessing the mechanism of development of floods it is however not sufficient to determine only the resulting topology of the precipitation field in the given physical-geographic conditions of study region. In flood protection practice it is necessary to obtain always at least rough idea on dynamic development of the flood situation. Therefore it is necessary to divide the precipitation periods into smaller discrete time units. The modern hydrosynoptic techniques use for this purpose time images of precipitation fields.

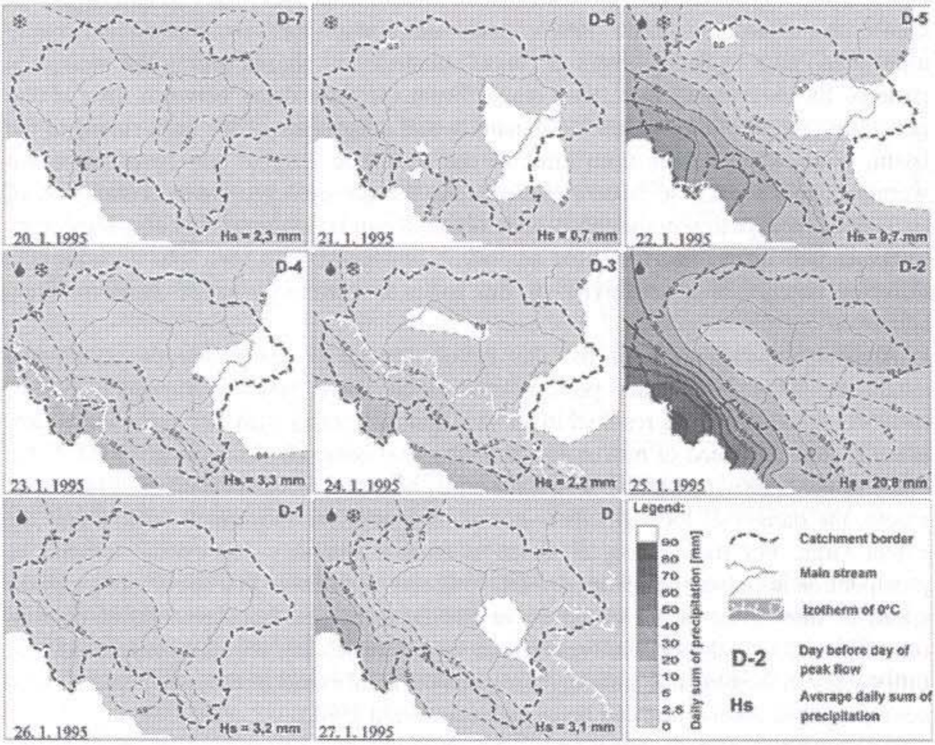


*Fig. 19* Dynamics and topography of precipitation fields during seven days before the peak discharge of the winter flood from January 27, 1995 on the Otava River at Písek

The sequence of images in the Fig. 19 is an example of such a presentation showing distribution of precipitation in the Otava River basin (the basin area is 2913 km$^2$) in each of the seven days before the peak flood discharge in closing river cross-section of the basin. Data on precipitation were interpolated into maps through kriging using GIS tools. It concerned winter flood from snowmelt accompanied by rain. Average precipitation depth, average temperature and average depths of snow cover in four selected altitude levels were determined for the area of the basin.

Hydrosynoptic analysis has shown that the extreme winter floods in this river basin are not formed by only snowmelt, but are always a result of a combined effect of warming and accompanying rain, possibly with ice movement. The process of intensive snowmelt on its own can, at worst, be equivalent to the runoff effect of only medium rain. Deep snow layer behaves as absorbing sponge. It can retain the melted water until its retention capacity is depleted.

#### Runoff response

The study of historical flood waves in significant sites of the river network of the study river basin presents the last important component of the complex hydrosynoptic analysis of floods. The basic aim is to identify links in interactions of meteorological factors with variable landscape forming processes (soil saturation, capacity of river channels, vegetation season etc.) and with permanent physical-geographic conditions of the river basin. An example of such an interaction can be not only the speed of movement of precipitation zone and strong precipitation cells on the area of river basin as already noted, but also direction of their transfer in relation to the main watercourse. Transfer of significant precipitation along the watercourse generates usually a flood wave with higher peak than otherwise. Therefore the analysis of runoff response can help in clarification of many dominant features of certain type of generating circulation conditions. In this respect a basic question therefore arises whether the given type of meteorological situation has also a related type of runoff response. It means in practical terms whether the flood waves generated by similar circulation conditions have in some of the characteristics also similar features.

Such an approach was examined by Vlasák (2000). He categorised the winter floods in the Otava River basin using a simple method of visual comparison of their shapes in the closing site of Písek. He determined in total three categories on a basis of characteristic features on the raising branch of the wave. He succeeded in categorisation of 18 out of 22 studied cases into these classes; the remaining four cases were not possible to classify using this approach. For the categories the common variable physical-geographic factors were described by the main features (state of snow cover, distribution of precipitation, etc.) and by the characteristic types of synoptic situations preceding the floods. The classification of the floods is shown in Figs. 20–22.

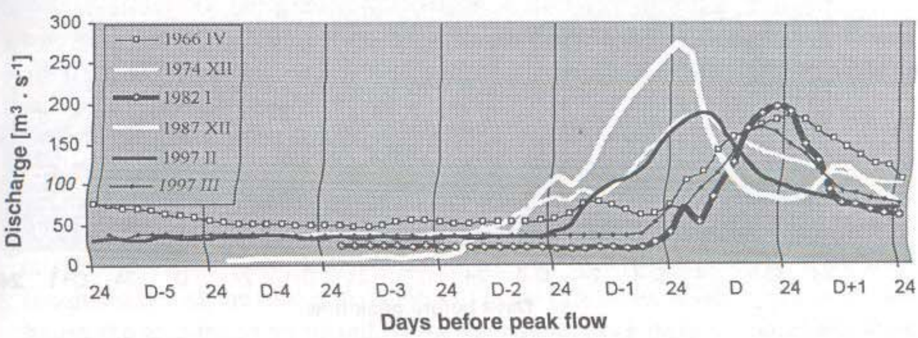


*Fig. 20* Flood waves of the 1st category from the Písek station on the Otava River

**1st category**

*Common features of flood waves:* Simple waves with relatively fast increase of discharge with characteristic occurrence of secondary peak approximately a day before peak flow.

*Common features of hydrometeorological situation:* The effect of rain precipitation was bigger than the effect of snowmelt, runoff was formed mainly in the middle and lower parts of the river basins.

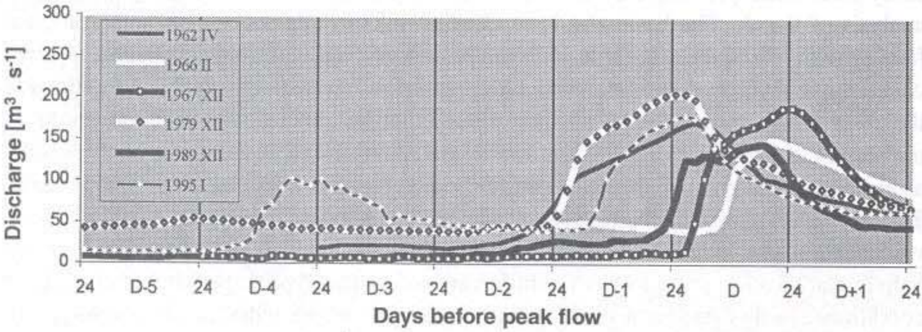


Fig. 21 Flood waves of the 2nd category from the Písek station on the Otava River

**2nd category**

*Common features of flood waves:* Simple waves with sharp increase of high flows with subsequent flattening of the peak.

*Common features of hydrometeorological situation:* The effect of rain precipitation was significantly bigger than the effect of snowmelt, rain precipitation was increased by the orographic effects, and the generating precipitation followed western cyclone situations of the type Wc or Wcs.

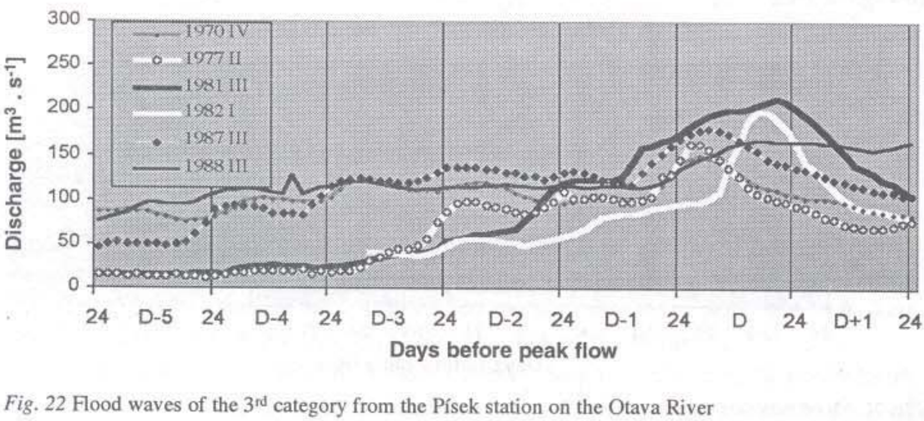


*Fig. 22* Flood waves of the 3rd category from the Písek station on the Otava River

**3rd category**

*Common features of flood waves:* There are distinct secondary peaks on the waves appearing in daily cycle, the increase of discharge is relatively moderate.

*Common features of hydrometeorological situation:* The major part of the volume of flood waves originated from snowmelt, inter-daily increase of discharge was not higher than 50 $m^3 . s^{-1}$ without contribution of rain precipitation. The peak flow was always reached through contribution by rain. Seasonally the situations appeared usually between winter and spring. Warming that was the main cause of the discharge increase was linked with western situations with southern component of the type Wc and $SWc_2$.

Even the possibility alone of the categorisation of winter flood waves on the Otava River is demonstrating that the mechanism of development of floods is guided by processes having a tendency to repeat in time. This shows that the efforts to increase lead-time by analysis of meteorological symptoms preceding the occurrence of flood situations are not hopeless.

## Conclusions

The new hydrosynoptic approaches to explain generation of floods started to be developed intensively mainly during the last two decades. The relevant methodologies differ from similar studies in the past by complexity of the approach and interdisciplinarity of the conception. The current aim of the studies is to reveal relationships and interactions taking place in the causally integral system originating in the atmospheric processes and resulting in the development of runoff in the enclosing site of the river basin under study. Through this approach the regime features and dynamic behaviour of the flood generating mechanisms are analysed not only from the viewpoint of meteorology and hydrology but also on the basis of physical-geographic aspects.

In the Czech Republic several hydrosynoptic studies have already been carried out motivated by both the internal needs and the results of international research. This paper presents information on some of the approaches and resulting important findings.

1. The sensitivity of individual river basins in the meso-scale differs in relation to various types of meteorological situations having a potential to induce floods. Therefore it is necessary to investigate the mechanism of floods in every river basin individually.
2. Every type of generating meteorological situation differs in varying lead-time of the peak flow of the flood wave in the closing site of the river basin.
3. Duration of the lead-time depends not only on the type of circulation conditions in the atmosphere but also on physical-geographic characteristics of the river basin, orientation of the main watercourse in relation to dynamics of the circulation conditions and on the season of the flood. On the Elbe River at Děčín and on its sub-basins the lead-time was identified for various types of meteorological situations within the range of one to five days.

4. The relatively highest number of generated floods within the total number of meteorological situations having a "flood" potential in the Elbe basin relates to the Wc and Wcs situations in the winter season and C and Cv situations in summer season (according to the Brádka's Catalogue).
5. Occurrence of floods during a year is affected by both a range of factors dominant for a given season – seasonal component and a range of other random factors – random component. The ratio of the two components is varying in time between the months. The most significant, in the major part of the Elbe River basin, is the seasonal component in the spring season.
6. The analysis of long-term series of floods on the Elbe River at Děčín has shown that 19th century was more abundant in terms of occurrence of floods than 20th century, which might lead to a conclusion that the ratio between the seasonal and random component can be a time-varying characteristic feature during short reference periods (for example 50-year periods).
7. On a basis of a data bank of historic floods established from information on generating circulation conditions and related precipitation and temperature fields, as well as measured values of runoff response, an attempt was undertaken to relate similar hydrometeorological conditions in the atmosphere to corresponding types of flood waves. For the closing site of the Otava River at Písek three categories were defined according to characteristic shapes of the waves and 18 out of 22 studied events were successfully classified into these categories.

The results of these and similar hydrosynoptic studies represent a valuable basis for regionalization of a territory in view of flood risks, for improvement of effectiveness of hydrometeorological modelling and for improvement of expert knowledge of forecasters taking part in activities of the flood warning and forecasting services.

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HYDROSYNOPTICKÉ PŘÍSTUPY
K IDENTIFIKACI MECHANISMU POVODNÍ

Resumé

Moderní hydrosynoptické přístupy pro objasňování vzniku povodní se začaly rozvíjet intenzivně zejména v posledních dvou desetiletích. Jejich metodologie se liší od podobně zaměřených prací dřívějšího data komplexností řešení a interdisciplinárním pojetím. Současným námětem zkoumání jsou vazby a interakce probíhající v kauzálně uceleném systému od dějů v atmosféře až po průběh odtoku v závěrovém profilu povodí. Při tom režimové projevy a dynamické chování tohoto povodňového mechanizmu je třeba analyzovat jak z pozice meteorologických a hydrologických aspektů, tak i ve vztahu k fyzicko-geografickému prostředí zájmového povodí.

V České republice se uskutečnilo již několik takto pojatých hydrosynoptických studií. Příspěvek se pokouší informovat o několika důležitých poznatcích, které vyplynuly z těchto prací.

1. Jednotlivá povodí v mezoměřítkovém rozsahu jsou rozdílně senzibilní na různé typy povětrnostních situací náchylných vyvolat povodeň, proto je třeba zkoumat mechanizmus povodní v každém povodí samostatně.
2. Jednotlivé typy příčinných meteorologických situací se vyznačují rozdílným časovým předstihem oproti kulminaci povodňové vlny dosažené v závěrovém profilu povodí. Časový předstih závisí na typu cirkulačních poměrů v atmosféře, fyzicko-geografickém charakteru povodí, orientaci zájmového toku a na sezóně výskytu povodně. V závěrovém profilu českého Labe byl tento předstih pro různé typy příčinných meteorologických podmínek zjištěn v rozsahu od 1 do 5 dnů (obr. 1–6).
3. Relativně nejvyšší počet vyvolaných povodní z celkového počtu vyskytujících se „povodňových" atmosférických cirkulací vykazuje (podle označení Brádkova Katalogu) v povodí Labe situace Wc a Wcs v zimním období (obr. 1, 3, 5) a C a Cv v období letním (obr. 2, 4, 6).
4. Na výskyt povodní v průběhu roku má vliv jednak souhrn faktorů, které jsou dominantní pro danou sezónu – složka sezonální a dále souhrn ostatních příčin, jejichž výskyt je nahodilého charakteru – složka nahodilá. Poměr obou složek je v průběhu jednotlivých měsíců proměnlivý. Nejvýrazněji se uplatňuje složka sezonální na převážné ploše povodí Labe v jarním období (obr. 13–18).
5. Analýza dlouhodobých řad povodňových případů na Labi v Děčíně prokázala, že 19. století bylo na výskyt povodní bohatší než 20. století, z čehož vyplývá, že poměr sezonální a nahodilé složky je v průběhu kratších úseků (např. padesátiletí) časově proměnlivá charakteristika (obr. 7–12).
6. Na základě banky historických povodní vytvořené z údajů o příčinných cirkulačních podmínkách, vyvolaných srážkových (obr. 19) a teplotních polích a z naměřených hodnot odtokové odezvy byl realizován pokus přiřadit daným meteorologickým podmínkám odpovídající typ povodňových vln. Pro závěrový profil Otavy v Písku se podařilo takto definovat tři kategorie charakteristického průběhu povodňových vln a zařadit do nich 18 z 22 uvažovaných případů (obr. 20–22).

Výsledky těchto a jiných hydrosynoptických přístupů jsou cenným podkladem pro regionalizaci zatížení krajiny povodňovým nebezpečím, pro zdokonalení účinnosti meteorologického a hydrologického modelování, jakož i pro rozšiřování znalostí prognostiků zapojených do výstražné předpovědní povodňové služby.