LONG-TERM RUNOFF FLUCTUATION IN THE DYJE RIVER BASIN

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SUMMARY

The paper is devoted to the analysis of long-term fluctuation of the runoff in the catchment area of the Dyje River (partial portion of the catchment area of the Morava River). By the spectral analysis of series of monthly and annual runoff from 20 stations for the period of 1931 - 1985 statistically significant periods of runoff fluctuation were found. Runoff fluctuation is further processed as the Markov process and the synchronism of runoff fluctuation is evaluated at individual stations in the watershed.

INTRODUCTION

The problems of the study of long-term runoff fluctuation is mostly connected with the solution of water economic tasks. The obtained level and state of the solution of these problems from the point of view of water economists is documented by the papers of e.g. (Votruba, Nacházel, 1975; Votruba et al., 1979). The regularities of long-term annual runoff on basis of the study of series from more than 400 rivers of the whole Earth is the subject of the study (Ratkovitch, 1976).

The fundamental trend of the study of long-term runoff fluctuation according to Schelutko (1984) is:

- the study of probable runoff values in time and space,
- the investigation of annual and monthly runoff fluctuations with the objective of determining groups of years with little or much water, their repetition and the delimitation of regions with synchronous and asynchronous runoff fluctuation,
- study of relations between runoff and geophysical processes (solar activity, atmospheric circulation, ocean thermic, etc.),
- the investigation of the effect of man-made activities on the runoff.

Shelutko (1984) says among others that nowadays three general statistical models are essentially used for the study and description of long-term runoff fluctuations: random variables, the simple Markov process and the complex Markov process.

When studying the probable values of runoff fluctuations in the time on the principle of mathematical models of random variable and the simple Markov process some well-known laws of probability distribution are used: the normal one, the logarhithmic one, the Pearson type III one, the Gumbel one etc. According to the selected law of distribution curves of exceeding probability are plotted, from which the values of annual or maximum runoff of the given exceeding probability are determined. Two problems are therewith solved:

a) the choice of the law of probability distribution

b) the determination of its parameters.

The solution of those problems is discussed in the papers (Benický, 1986; Nacházel, 1986; Procházka, 1989). For the spatial analysis of the structure of fluctuation of hydrological characteristics or for the regionalisation of the territory according to the character of long-term surface runoff fluctuation the methods of multivariate analysis can be utilised (Zhuk, Skornyakov, 1984).

The values of correlation coefficients (Kašpárek, 1977) were used for the study of synchronism of the regime of annual discharges from 60 stations of the territory of Czech Republic for the period of 40 years.

RUNOFF FLUCTUATION IN THE DYJE RIVER BASIN

For studying runoff fluctuations series of mean monthly and annual discharges at 20 stations in the catchment area of the Dyje river were used from the period of

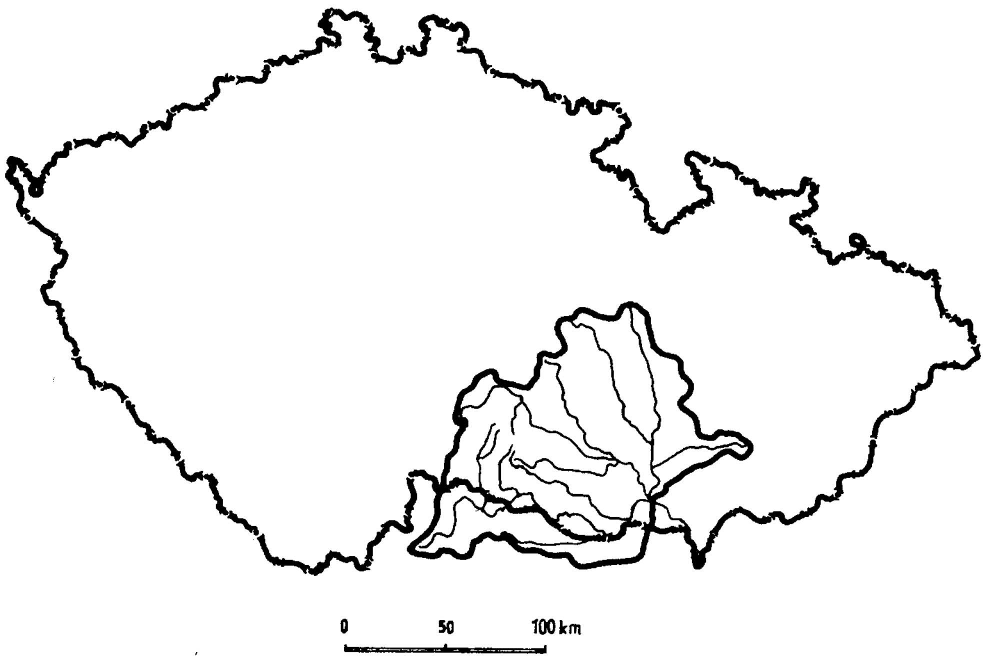

Fig. 1. Position of the catchment area of the Dyje within the Czech Republic

1931-1985 (Fig.1). Typical of the series studied are the distributions with left-hand side (positive) skewness and positive kurtosis. The greatest variability is that of the series of monthly discharges of the Jevišovka river at Božice from the periods of 1946 - 1985; from the period of 1931 - 1985 the greatest variability is that of the series of monthly discharges of the Loučka river at the station of Dolní Loučky and the series of monthly values in the station Dyje - Trávní Dvůr. The smallest variability of annual discharge is on the Svratka river at Borovnice.

It is necessary to state that the values of discharges of the series studied are affected by handling the water in the reservoirs in the catchment area of the Dyje. Even though the reservoirs affect all discharges, the most conspicuously is their effect reflected in culmination and low discharges. The effect on the long-term discharge is the smallest. The size of the effect is much greater in the series of mean monthly discharges than in the annual discharges one (Polišenský, 1985).

For the analysis of discharge rates the Method of Spectral Analysis according to Blackman and Tukey (in Brázdil, Netopil, 1985) was used. That method was implemented by Brázdil and Netopil (1985) in the analysis of monthly discharges of the Elbe river at Děčín and of the Morava river at Moravský Ján. In our case that method was applied to both the series of annual and monthly discharges and to the series of monthly anomalies, in which the annual trend is eliminated by subtracting the appurtenant long-term monthly average.

In analysing the series of annual discharges statistically significant periods were found in the length of 2.50 years, 3.33 years and 5.00 years. The period in the length of 3.33 years is identical with the length of the period of series of annual values of the base flow of the Svratka river up to Borovnice (Herber, 1987), the period of 5.0 years corresponds with the period of the same length for precipitation in Moravia (Brázdil, Netopil, 1985).

The most conspicuous component in the variation of the series of monthly discharges are oscillations shorter that 12 months, in 19 cases the statistically significant period of 11.67 months at the level of significance $\alpha = 0.01$, only for the Svitava river at Rozhrání it is significant for $\alpha = 0.05$.

After the annual discharge wave there appear the six month period and shorter ones, with the length of 4.00, 3.11, 3.04, 2.55 and 2.50 months. In the statistical analysis of monthly discharges statistically significant periods longer than 1 years were not found.

In the case of series of monthly anomalies periods of 2.50 and 2.55 months are preserved, as well as those of three and six months. Besides, there occur much longer periods, 140 months (i.e. 11.67 years), which were determined for the stations of the Svratka-Borovnice, the Loučka-Dolní Loučky, the Křetínka-Letovice, the Oslava-Dolní Bory and the Oslava-Nesměř. All series of monthly anomalies contain, however, a trend.

RUNOFF FLUCTUATION AS THE MARKOV PROCESS

One of the possibilities of studying the runoff is the implementation of the method of the Markov process and the determination of the so-called transition probability. This is considered to be the conditioned probability that process will pass from a certain state in one moment into some state in the following moment (Votruba et al., 1979).

The data about the annual discharges were included and marked according to three classes - phases of water bearing values, which are:

- below-average water bearing values S1
- average water bearing values S2
- above-average water bearing values ..... S3.

The average water bearing values phase is limited by the values of 90% and 110% of long-term mean discharge (Q_a).

The random process of Markov type is considered to be fully determined when defining its matrix of one-step transition probabilities and setting the distribution of the probability of states of the process.

The selected relation of the individual phases of the water bearing values is thus as follows:

S1 < 90 % Qa < S2 < 110 % Qa < S3

The transition matrix has the form:

$$\left\| P_{ij} \right\| = \left\| \begin{matrix} p_{11}, p_{12}, p_{13} \\ p_{21}, p_{22}, p_{23} \\ p_{31}, p_{32}, p_{33} \end{matrix} \right\| ,$$

when each line vector of this matrix represents the transition probability from the given initial stage to all final stages, and therefore the sum of values of each line must equal one.

Each column vector represents the transition probability from different initial stages into given final stage.

In further analysis of discharge series for determining the synchronism or asynchronism only the sequence of years with below-average, average and above-average water bearing values (states S1, S2, S3) were employed in operation. The synchronism of the phase of water bearing values between the individual stations was evaluated according to the following scale:

+1 .... coincidence of identical phases of water bearing values (S1,S1; S2,S2; S3,S3)
0 .... coincidence of neighbouring phases of water bearing values (S1,S2; S2,S3)
-1 .... coincidence of opposite phases of water bearing values (S1,S3).

For evaluating the non-synchronism of the runoff, more exactly of its three phases, the following relation was employed:

$$K_s = \frac{\sum n_i b_i}{N}$$, where

K_s - coefficient of synchronism
n_i - number of years - coincidence in respective scale degree
b_i - the values of the degree of scale employed (+1, 0, -1)
N - overall number of the members of the sequence.

Theoretically the values of K_s varies within limits of +1 and -1, when, with the values of +1 it is 100 % synchronism, on the other hand with the values of -1 absolute asynchronism. The structure of the calculation of coefficient K_s according to the chosen scale is, however, such that K_s can acquire its extreme values only in the hypothetical case when the phase S2 does not occur in the series compared, when its coincidence with phases S1 and S3 are evaluated by the scale degree 0.

As an asynchronism relation of two compared series are considered cases with the values $K_s < 0.4$ and as sufficiently synchronous relation that with values $K_s = 0.4$ and higher (Popov, 1979).

DISCUSSION OF RESULTS

The results of the study of runoff fluctuation using the above methods are given in Tables 1 - 4.

In Table 1 there is first of all the number of all series with different length of duration (one-year, two-year, three-year, four- or more-year ones). According to expectation most numerous are the one-year series, constituting 20-38 % of all members of the series. In the further part of the Table there are numbers of series of years of the same phase of water bearing values with different time of duration. And, finally, the third part of the Table consists of the Markov transition probabilities from one phase of the water bearing values to another one. In most cases the highest values are obtained on the main diagonal of the matrix of transition probability, particularly high are the values of probability p_{11} and p_{33}, clarifying the trends for grouping of years with little and above-average water bearing values.

When judging the synchronism of the runoff not all values of the synchronism coefficient K_s were found among all 20 stations, but first of all nine stations were chosen in catchment area of the Dyje, representing the individual streams, and as a rule situated in the upper part reaches of the catchment area (Table 2). The calculated values of K_s have the positive value, varying from 0.164 to 0.782. Very low values of K_s are on the Svitava river at Rozhrání, which can be explained by a different way of forming the runoff in the upper part of the catchment area of the Svitava river, when in the form of the runoff relatively considerable reserves of ground water in the

Table 1. Structure of fluctuation of annual discharges Q_r in the Dyje river basin for the period of 1931 - 1985

Stream Station Marking	No. of series of phase [length in years]				No. of series of different phase and length [years]				Matrix of transition probaility		
	1	2	3	>3	phase	2	3	>3	S1	S2	S3
Dyje	21	9	1	3	S1	4	1	2	0.520	0.160	0.320
Podhradí					S2	4	0	0	0.384	0.308	0.308
PDH					S3	1	0	1	0.438	0.312	0.250
Dyje	19	8	2	3	S1	3	1	2	0.538	0.154	0.308
Trávní Dvůr					S2	3	0	0	0.375	0.125	0.500
TDV					S3	2	1	1	0.450	0.150	0.400
Jevišovka	15	4	3	2	S1	2	3	1	0.550	0.100	0.350
Božice ++					S2	0	0	0	0.600	0.000	0.400
BOZ					S3	2	0	1	0.429	0.214	0.357
Svratka	17	7	4	2	S1	1	2	1	0.476	0.190	0.334
Borovnice					S2	5	1	0	0.333	0.467	0.200
BOR					S3	1	1	1	0.333	0.222	0.445
Loučka	17	7	0	5	S1	4	0	3	0.667	0.083	0.250
Dolní Loučky					S2	2	0	0	0.200	0.200	0.600
DLC					S3	1	0	2	0.300	0.300	0.400
Svratka	16	8	4	2	S1	4	2	1	0.500	0.208	0.292
V. Bitýška					S2	2	1	0	0.500	0.333	0.167
VBI					S3	2	1	1	0.333	0.167	0.500
Jihlava	20	5	3	4	S1	3	0	3	0.522	0.174	0.314
Dvorce					S2	1	1	0	0.417	0.250	0.333
DVR					S3	1	2	1	0.316	0.263	0.421
Jihlava	11	8	5	3	S1	4	1	2	0.542	0.167	0.291
Ptáčov					S2	2	2	0	0.385	0.462	0.153
PTC					S3	2	2	1	0.353	0.118	0.529
Oslava	16	7	3	3	S1	3	2	1	0.571	0.143	0.296
D. Bory					S2	2	0	0	0.300	0.200	0.500
DBO					S3	2	1	2	0.261	0.217	0.522
Oslava	20	7	2	3	S1	4	2	1	0.545	0.182	0.273
Nesměř					S2	2	0	0	0.417	0.166	0.417
NES					S3	1	0	2	0.230	0.300	0.450
Oslava	13	9	4	2	S1	5	2	1	0.609	0.174	0.217
Oslavany					S2	3	1	0	0.230	0.385	0.385
OSL					S3	1	1	1	0.333	0.222	0.445
Rokytná	12	3	3	3	S1	2	1	3	0.667	0.047	0.286
M.Krumlov ++					S2	0	0	0	0.250	0.000	0.750
MKR					S3	1	2	0	0.429	0.214	0.357

Stream Station Marking	No. of series of phase [length in years]				No. of series of different phase and length [years]				Matrix of transition probaility		
	1	2	3	>3	phase	2	3	>3	S1	S2	S3
Svitava	13	5	2	5	S1	1	0	3	0.800	0.150	0.050
Rozhrání					S2	1	2	0	0.133	0.333	0.534
ROZ					S3	3	0	2	0.158	0.368	0.478
Křetínka	18	9	3	2	S1	5	1	1	0.435	0.348	0.217
Letovice					S2	3	0	0	0.538	0.231	0.231
LKR					S3	1	2	1	0.333	0.111	0.556
Svitava	17	4	3	5	S1	2	1	2	0.500	0.400	0.100
Letovice					S2	1	1	1	0.412	0.353	0.235
LSV					S3	1	1	2	0.235	0.177	0.588
Punkva	19	11	2	2	S1	4	0	2	0.500	0.200	0.300
Skalní Mlýn					S2	5	0	0	0.313	0.313	0.374
SML					S3	2	2	0	0.278	0.389	0.333
Svitava	20	8	3	2	S1	6	0	1	0.391	0.435	0.174
Bílovice					S2	2	1	0	0.625	0.250	0.125
BIL					S3	0	2	1	0.267	0.133	0.600
Svratka	17	7	3	3	S1	5	1	2	0.538	0.154	0.308
Židlochovice					S2	1	0	0	0.625	0.125	0.250
ZID					S3	1	2	1	0.350	0.150	0.500
Jihlava	16	6	4	3	S1	4	1	2	0.542	0.167	0.291
Ivančice					S2	2	1	0	0.364	0.364	0.272
IVA					S3	0	2	1	0.368	0.158	0.478
Dyje	13	5	3	5	S1	4	1	3	0.615	0.154	0.231
D. Věstonice					S2	1	1	0	0.333	0.333	0.334
DVE					S3	0	1	2	0.368	0.105	0.527
Morava	19	10	4	1	S1	4	4	0	0.571	0.238	0.191
Raškov					S2	4	0	0	0.313	0.250	0.438
RAS					S3	2	0	1	0.294	0.412	0.294
Mor. Sázava	19	7	3	3	S1	3	1	2	0.480	0.160	0.360
Lupěné					S2	1	0	0	0.571	0.143	0.286
LUP					S3	3	2	1	0.409	0.136	0.455
Třebůvka	15	4	5	3	S1	3	2	2	0.593	0.148	0.259
Loštice					S2	1	0	0	0.571	0.143	0.286
LOS					S3	0	3	1	0.350	0.100	0.550
Morava	16	9	3	3	S1	4	1	2	0.545	0.182	0.273
Moravičany					S2	3	0	0	0.273	0.273	0.454
MOR					S3	2	2	1	0.333	0.238	0.429

++) only in 1946 - 1985

Table 2. Synchronism of annuall runoff in selected rivers in the catchment area of the Dyje river (1931-1985)

	Stream - Station	1	2	3	4	5	6	7	8	9	ΣK_s	$\overline{K_s}$
1	Dyje - Podhradí	1	0.525	0.582	0.545	0.164	0.527	0.600	0.600	0.550	4.093	0.512
2	Jevišovka - Božice+		1	0.275	0.500	0.225	0.350	0.450	0.400	0.775	3.500	0.438
3	Svratka - Borovnice			1	0.691	0.273	0.636	0.618	0.455	0.350	3.880	0.485
4	Loučka - D. Loučky				1	0.400	0.582	0.582	0.782	0.575	4.657	0.582
5	Svitava - Rozhrání					1	0.182	0.382	0.255	0.175	2.056	0.257
6	Křetínka - Letovice						1	0.618	0.525	4.266	0.533	0.467
7	Jihlava - Dvorce							1	0.618	0.525	4.266	0.533
8	Oslava - D. Bory								1	0.500	4.228	0.529
9	Rokytná - M.Krumlov +									1	3.800	0.475

Note:
+ only in 1946-1985
K_s - coefficient of synchronism
$\overline{K_s} = (\Sigma K_s - 1) / 8$

Cretatious beds participate. The highest value of K_s was reached in the pair of stations the Loučka-Dolní Loučky and the Oslava-Dolní Bory (0.782).

Table 3. Synchronism of annual runoff in discharge linking-up stations in the catchment area of the Dyje river (1931-1985)

Stream:		Svitava					Svratka		
	Station	1	2	3			1	2	3
1	Rozhrání	1	0.673	0.436	1	Borovnice	1	0.836	0.691
2	Letovice		1	0.727	2	V. Bitýška		1	0.818
3	Bílovice			1	3	Židlochovice			1

Stream:		Oslava					Dyje		
	Station	1	2	3			1	2	3
1	D. Bory	1	0.891	0.873	1	Podhradí	1	0.800	0.673
2	Nesměř		1	0.909	2	Trávní Dvůr		1	0.800
3	Oslavany			1	3	D.Věstonice			1

Stream:		Jihlava		
	Station	1	2	3
1	Dvorce	1	0.818	0.745
2	Ptáčov		1	0.855
3	Ivančice			1

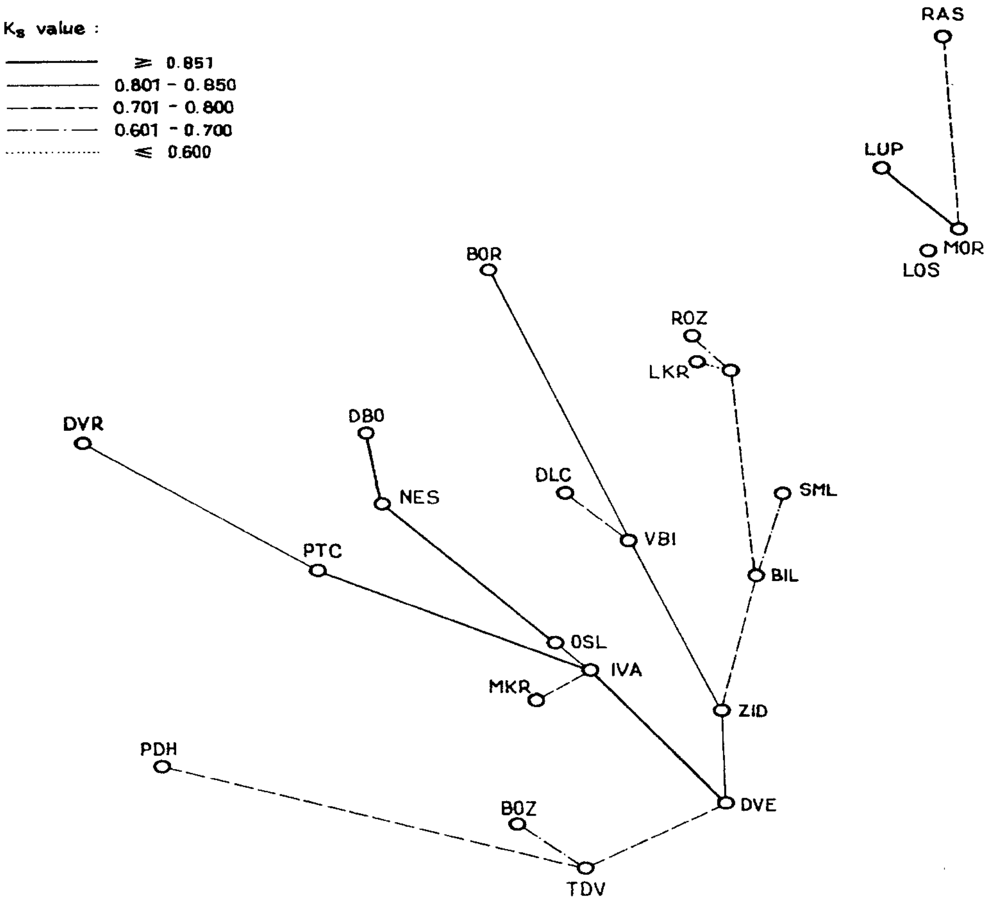

Fig. 2. Synchronism of annual runoff in discharge-linking stations in the Dyje river basin and the upper Morava river basin (1931-1985)

Further there were studied problems of synchronism of the runoff phases between series from discharge neighbouring stations on the same water stream. In accordance with Kašpárek (1977) there is a group of stations for which it holds that the water that runs through the lower station has run through the higher situated station. In the studied of the Dyje river basin 5 groups of such stations can be chosen, on rivers Svitava, Svratka, Oslava, Jihlava and Dyje, always with three stations.

The values corresponding to the synchronism coefficient K_s are given in the Table 3, being also represented in Fig. 2 and graphically differentiated according to the size of K_s, solely for the pairs of linking-up stations between which there is no further station. The highest values of K_s were obtained on the Oslava river and further on the Jihlava river between the stations the Jihlava-Ptáčov and the Jihlava-Ivančice.

Fig. 2 is further completed by the graphical differentiation of the values of K_s on the tributaries and in the confluence region of the Dyje river with the Jihlava river and Svratka river. The same as in Table 4, the situation for the upper part of the catchment area of the Morava river is expressed there, for the purpose of comparison. The basis is the division of the Morava river basin into three parts: the upper part (up to the confluence with the Bečva river), the Beskydy and Carpathian part (the left part of the catchment area starting with the Bečva river) and the western part (the catchment area of the Dyje river and of the main stream of the Morava river).

A relatively high value of the synchronism coefficient K_s is observed at the station the Svratka-Borovnice with stations in the upper part of the catchment area of the Morava, further in the station the Křetínka-Letovice.

With the gradual increase in distance (the Jihlava-Dvorce, the Dyje-Podhradí) the values of K_s between the stations in the catchment area of the Dyje and those in upper part of the Morava river basin are reduced.

Table 4 Synchronism of annual runoff at selected stations in the catchment areas of the Dyje river and the upper Morava river (1931-1985)

Stream - station	11	12	13	14
1 Dyje - Podhradí	0.327	0.509	0.436	0.418
2 Svratka - Borovnice	0.582	0.709	0.691	0.636
3 Loučka - Dol. Loučky	0.491	0.564	0.600	0.545
4 Křetínka - Letovice	0.509	0.655	0.618	0.709
5 Jihlava - Dvorce	0.436	0.582	0.509	0.455
6 Oslava - D. Bory	0.491	0.527	0.564	0.436
11 Morava - Raškov	1	0.709	0.800	0.582
12 Mor. Sázava - Lupěné		1	0.855	0.727
13 Morava - Moravičany			1	0.727
14 Třebůvka - Loštice				1

With the exception of the pair of stations the Morava-Raškov and the Třebůvka-Loštice the values of K_s are very high also in upper part of the catchment area of the Morava river, exceeding the value of $K_s = 0.700$.

For drawing further conclusions it will be necessary to increase the number of stations in the upper part of the Morava river basin and also include stations from the runoff area of the region of the Beskydy and the Carpathian Mts.

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