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Determination of Precipitation Gradients in Mountains

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ABSTRACT

The areal distribution of precipitations in mountains is described by means of precipitation gradients using long term standard network data and comparing them with the experimental catchment study. Presented results have proved the importance of more accurate determination of precipitation gradients, heavily depending on the location of the network stations, observational and mainly windy conditions within the catchment. Seasonality of precipitation gradients as well as redistribution of snow have also been documented.

INTRODUCTION

Hydrological processes in mountainous areas can not be fully understood without a proper knowledge on the areal distribution of precipitation. The mountainous environment in contrary to less rugged lowland areas has strong impact on distribution of precipitation.

Dependency of different meteorological elements upon the earth surface is the basic task of climatology. Therefore, a lot of attention is also paid to changes of precipitation with altitude. The subject problem is complicated by higher ratio of snow in the yearly amount of precipitation and by high winds occurrence in mountainous areas. Various vegetation cover, unevenly distributed within the area, is also influencing studied relation between precipitation and the altitude. All this results in typical local and seasonal character of precipitation gradients in mountains.

However, lack of directly measured and reliable data on precipitation in mountains is forcing hydrologists to extrapolate data collected over the lowlands. Justification of such approach calls for comparative studies of precipitation gradients using standard network data against more representative data collected within the experimental catchments studies.

METHODS

The distribution of precipitation in mountains is described by means of precipitation gradient that expresses changes of precipitation with the altitude. This vertical gradient is used for estimation of areal precipitation which is counted among dominant hydrological problems in mountainous areas. The usual increase of precipitation with altitude is limited by the mean height of clouds and decreasing of vapour pressure with the altitude. Thus, a decreasing of precipitation with altitude can take place in high mountains above the certain level. The similar effect is obtained due to the snow redistribution by wind from steep rocky areas down to the forest barier. Unevenly wind speed distribution over the mountainous terrain causes that local precipitation gradient usually differs from the general gradient in particular catchment. As it was proved by Sevruk /2/ and Molnár, Trizna /3/, calculated precipitation gradients also depend on the location of selected stations. Stations located in valleys give usually higher gradients than those on wind exposed slopes.

In presented study an analysis of standard network data (1960-1980) from the Tatry mountains region by Kubjatko /4/ was compared with results obtained by Molnár, Trizna /3/ and Holko /5/ in experimental catchment studies (1987-1991) of the Jalovecký creek which is a typical part of the same region. Such approach should give an idea about the actual representativeness of precipitation gradients in mountains.

STUDY AREAS

The Tatry mountains are the highest part of the Carpathians mountain arch in Central Europe with the elevation range 500-2655 m a.s.l. Selected network of 29 stations equipped with the standard rain gauges METRA is vertically distributed as follows: 500 - 600 m a.s.l. - 3 stations, 600 - 700 m a.s.l. 7 stations, 700 - 800 m a.s.l. - 7 stations, 800 - 900 m a.s.l. - 3 stations, 900 - 1000 m a.s.l. - 3 stations, over 1000 m a.s.l. - 6 stations only. For the study of precipitation gradients for the period 1960-1980 were selected 8 orographically justified profiles with 3 to 4 stations each (see Table 1).

Experimental catchment of the Jalovecký creek is considered representative for the highest part of the Tatry mountains. The area of the catchment is 42 km sq. a half of which is typical mountainous with elevation range 800 - 2178 m a.s.l.

Table 1. Monthly precipitation and gradients (1960 - 1980)

Pro. No.	Stations	m a.s.l.		△	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC	SUM
1.1	POPRAD-LOM.STIT	703	2635	1932	77.8	80.1	76.	54.5	30.4	55.1	57.	53.1	48.1	51.2	61.8	76.2	
	mm/100m				4.	4.14	3.9	2.8	1.6	2.9	2.95	2.7	2.48	2.65	3.19	3.94	36.9
1.2	POPRAD-SK.PLESO	703	1778	1075	34.3	31.8	37.1	38.9	51.9	111.	142.	87.2	54.6	52.4	24.8	42.8	
	mm/100m				3.2	3.	3.5	3.6	4.8	10.3	13.2	8.1	5.	4.9	2.3	4.	65.4
1.3	SK.PLES.-L.STIT	1778	2635	857	43.6	48.3	38.9	15.6	-21.5	-55.5	-85	-34.1	-6.5	-1.2	37.	33.4	
	mm/100m				5.1	5.6	4.5	1.8	-2.5	-6.5	-9.9	-4.	-.7	-.2	4.3	3.9	1.2
1.4	T.LOM-SK.PLESO	850	1778	928	20.9	19.6	28.9	25.4	35.3	89.5	104.4	69.3	31.9	37	10.8	28.7	
	mm/100m				2.3	2.1	3.1	2.7	3.8	9.6	11.3	7.5	3.4	4.2	1.2	3.1	53.3
2.1	L.MIK.-CHOPOK	576	2008	1432	33.7	36.	42.4	20.5	21.7	64.8	35.5	35.7	22.8	12.1	13.3	33.7	
	mm/100m				2.4	2.5	2.9	1.4	1.5	4.5	2.5	2.5	1.6	0.8	0.9	2.4	25.9
2.2	L.MIK.-LUKOVA	576	1780	1204	13.4	23.7	34.8	26.9	28.4	77.	31.9	68.5	56.1	69.9	42.8	16.4	
	mm/100m				1.1	2.	2.9	2.2	2.4	6.4	2.6	5.7	4.7	5.8	3.6	1.4	37.8
2.3	L.MIK.-JASNA	576	1300	724	26.1	38.3	38.3	52.1	61.9	87.5	56.9	65.8	46.1	74.8	78.6	32.	
	mm/100m				3.6	5.3	5.3	7.2	8.6	12.1	7.9	9.	6.4	10.3	10.9	4.4	88.5
2.4	JASNA-CHOPOK	1300	2008	708	7.7	-2.3	4.1	-39.6	-40.2	-22.7	-21.4	-30.1	-23.3	-62.7	-65.3	1.7	
	mm/100m				1.1	-.3	.6	-4.5	-5.7	-3.2	-3.	-4.3	-3.3	-8.9	-9.3	.2	-38.3
3.1	L.HR.-STR.PLESO	648	1353	705	27.7	33.5	30.	21.6	31.9	24.3	43.7	20.7	17.4	12.2	21.2	28.7	
	mm/100m				3.9	4.8	4.3	3.1	4.5	3.4	6.2	2.9	2.5	1.7	3.	4.	44.5
3.2	PODB.-ST.PLESO	940	1353	413	8.3	14.9	14.	6.9	6.7	4.2	-4.7	-14.4	-5.5	-2.6	18.6	8.3	
	mm/100m				2.	3.6	3.4	1.7	1.6	1.	-1.1	-3.5	-1.3	-.6	4.5	2.	15.2
3.3	PRIB.-ST.PLESO	765	1353	588	13.2	21.9	21.	26.7	33.4	27.6	52.7	14.7	16.5	8.	21.8	6.8	
	mm/100m				2.2	3.7	3.6	4.5	5.7	4.7	8.9	2.5	2.8	1.4	3.7	1.2	45.1
4.1	BREZNO-CHOPOK	510	2008	1498	30.7	20.5	31.6	18.6	22.	61.1	46.3	21.6	17.	5.5	0.4	26.4	
	mm/100m				2.04	1.37	2.11	1.24	1.47	4.	3.	1.44	1.13	0.36	0.03	1.76	19.9
4.2	BREZ.-H.P.DUMB.	510	630	120	9.	7.6	7.5	7.6	19.4	15.7	6.1	3.4	7.	16.3	19.2	9.9	
	mm/100m				7.5	6.3	6.3	6.5	16.2	13.1	5.1	2.8	5.8	13.6	16.	8.3	107.5
5.0	KR.LEH.-V.BOCA	677	951	274	15.6	22.9	28.6	29.5	41.6	48.8	14.5	33.9	35.8	25.			
	mm/100m				5.7	8.4	10.4	10.8	15.2	17.8	5.3	12.4	13.1	9.1	19.7	10.7	138.6
6.1	L.HRADOK-V.BOCA	648	951	303	24.4	32.9	38.4	32.7	47.1	50.5	13.4	36.2	36.4	39.7	61.3	34.2	
	mm/100m				8.	10.9	12.7	10.8	15.5	16.7	6.4	11.9	12.	13.1	20.2	11.3	150.9
6.2	MALUZ.-V.BOCA	702	951	249	16.8	23.6	23.7	16.5	20.7	42.2	13.8	20.2	26.5	24.2	39.3	24.9	
	mm/100m				6.7	9.5	9.5	6.7	8.3	16.9	5.5	8.1	10.6	9.7	15.8	10.	122.7
7.1	L.MIK.-ZIAR	576	725	149	8.	7.5	7.	3.4	3.	7.1	24.4	14.2	6.6	7.5	1.7	9.	
	mm/100m				5.4	5.	4.7	2.3	2.	4.7	16.4	9.5	4.4	5.	1.1	6.	66.6
7.2	L.MIK.-BOBROVCEK	576	668	092	11.6	3.7	4.3	-2.9	-1.6	13.8	11.7	3.1	3.8	3.8	10.1	10.5	
	mm/100m				12.6	4.	4.7	-3.2	-1.7	15.	12.7	3.4	4.1	4.1	10.9	11.4	74.8
8.0	KONSKA-RAC.DOL.	690	900	210	11.	18.9	16.6	-5.5	9.1	23.5	2.	31.	8.2	11.9	6.5	32.8	
	mm/100m				5.2	3.	7.9	-2.6	4.3	11.2	.9	14.8	3.9	5.7	3.1	15.6	78.6

The lowland part has the elevation range 570-800 m a.s.l. Basic precipitation network consists of 7 shielded storage gauges located in the elevations 570 - 1775 m a.s.l. and 4 unshielded standard rain gauges METRA located in the range 570 - 1500 m a.s.l.

RESULTS

Proper coverage of the Tatry mountains region (app.1100 km.sq) required rather dense network of 29 rainfall stations. Monthly precipitation gradients were than computed at 8 profiles representing all possible orientations within the area. Obtained results for the period 1960-1980 are shown in Table 1. Table 2 presents seasonal precipitation gradients (summer season VI-VIII, IV-IX and winter season XII-II, X-III).

Table 2 Precipitation gradients (1960-1980)

Profile No.	Stations	Summer VI-VIII	Summer IV-IX	Winter XII-II	Winter X-III	Annual
1.1	Poprad-Lom.Štít	8.55	15.43	12.08	21.82	36.9
1.2	Poprad-Skal.Pleso	31.60	45.00	10.20	20.9	65.4
1.3	Skal.Pleso-L.Štít	-20.40	-21.80	14.60	23.20	1.2
1.4	T.Lomnica-Sk.Pleso	28.40	38.30	7.50	16.00	53.3
2.1	L.Mikuláš-Chopok	9.50	14.00	7.30	11.90	25.9
2.2	L.Mikuláš-Luková	14.70	24.00	4.50	16.80	37.8
2.3	L.Mikuláš-Jasná	29.00	51.80	13.30	39.80	88.5
2.4	Jasná-Chopok	-10.50	-24.00	1.00	-16.60	-38.3
3.1	L.Hrádok-Št.Pleso	12.50	22.60	12.70	21.70	44.5
3.2	Podban.-Št.Pleso	-3.60	-1.60	7.60	14.90	15.2
3.3	Pribil.-Št.Pleso	16.10	24.60	7.10	15.80	45.1
4.1	Brezno-Chopok	8.40	12.20	5.10	7.80	19.9
4.2	Brezno-M.p.Ďumb.	21.00	49.50	22.10	58.00	107.5
5.0	Král.Leh.-V.Boca	35.50	74.60	24.80	64.00	138.6
6.1	L.Hrádok-V.Boca	35.00	73.30	30.20	76.20	150.9
6.2	Malužiná-V.Boca	30.50	56.10	26.20	61.20	122.7
7.1	L.Mikuláš-Žiar	30.60	39.30	16.40	30.20	66.6
7.2	L.Mikuláš-Bobrovček	31.10	30.30	28.00	47.70	74.8
8.0	Konská-Rač.dolina	26.90	32.50	23.80	40.50	78.6

Presented tables served data for relation between the altitude of stations and long term annual precipitation gradients within the studied region (see Figure 1). The range between maximum and minimum of precipitation gradients depends on elevation. However, the Figure 1 clearly indicates how difficult is to estimate the actual gradients without proper and direct measurements of precipitation.

Figure 1. Relation between altitudes of the stations and long term annual precipitation gradients in Tatry mountains

Note: Numbers refer to the profiles in Table 1

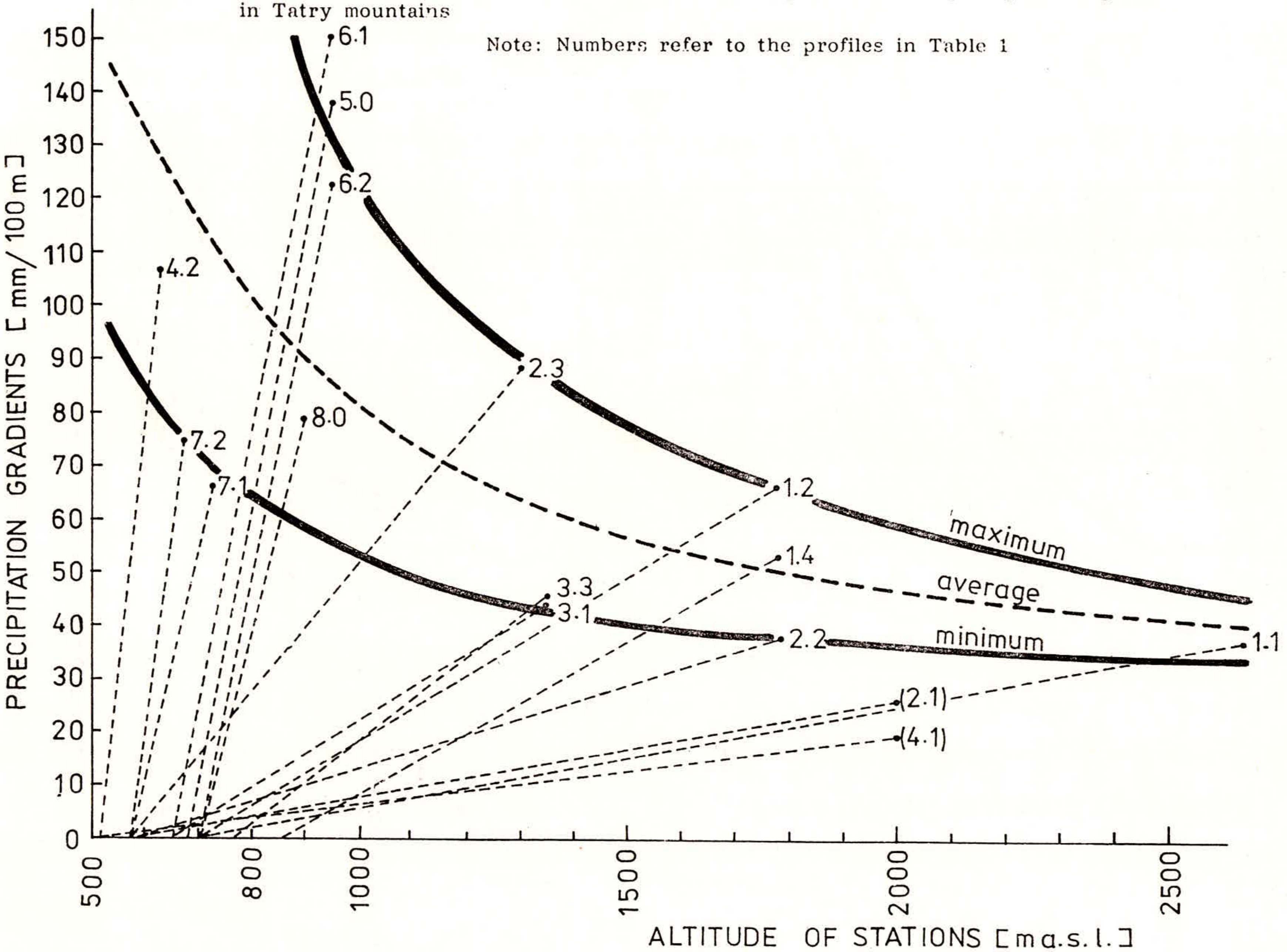


Figure 2. Summer period long term precipitation gradients in Tatry mountains

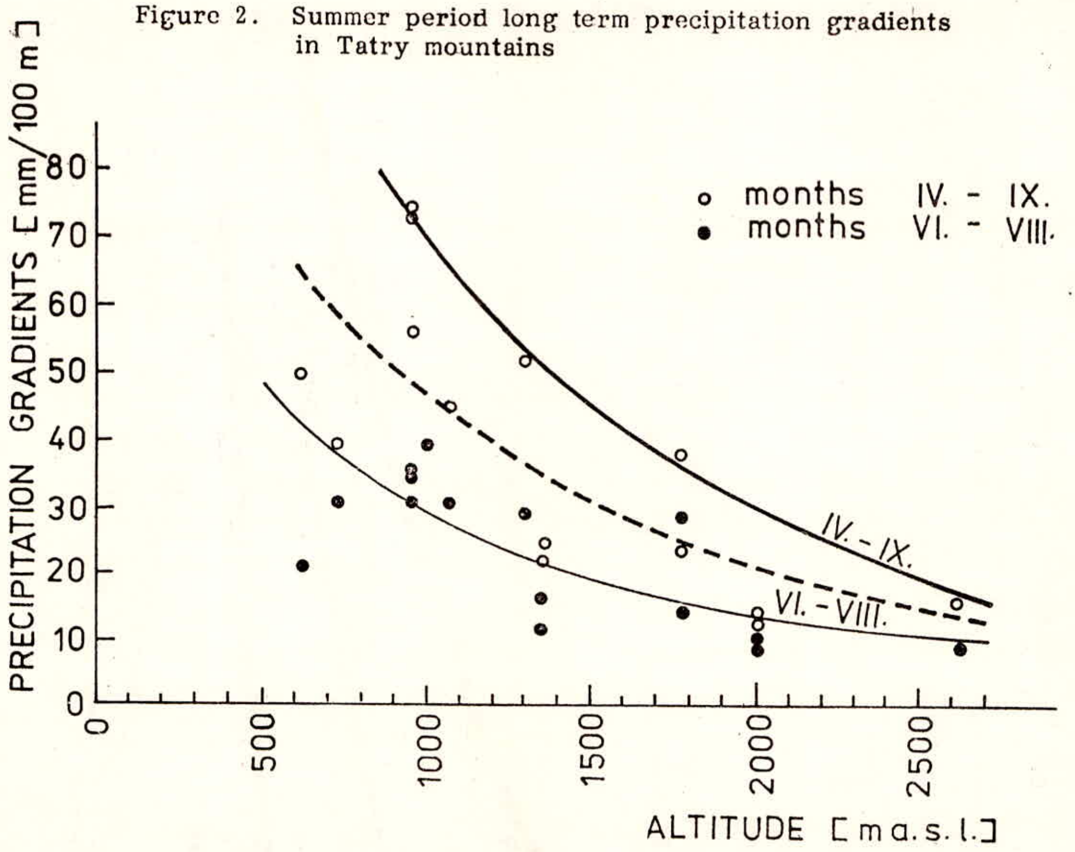
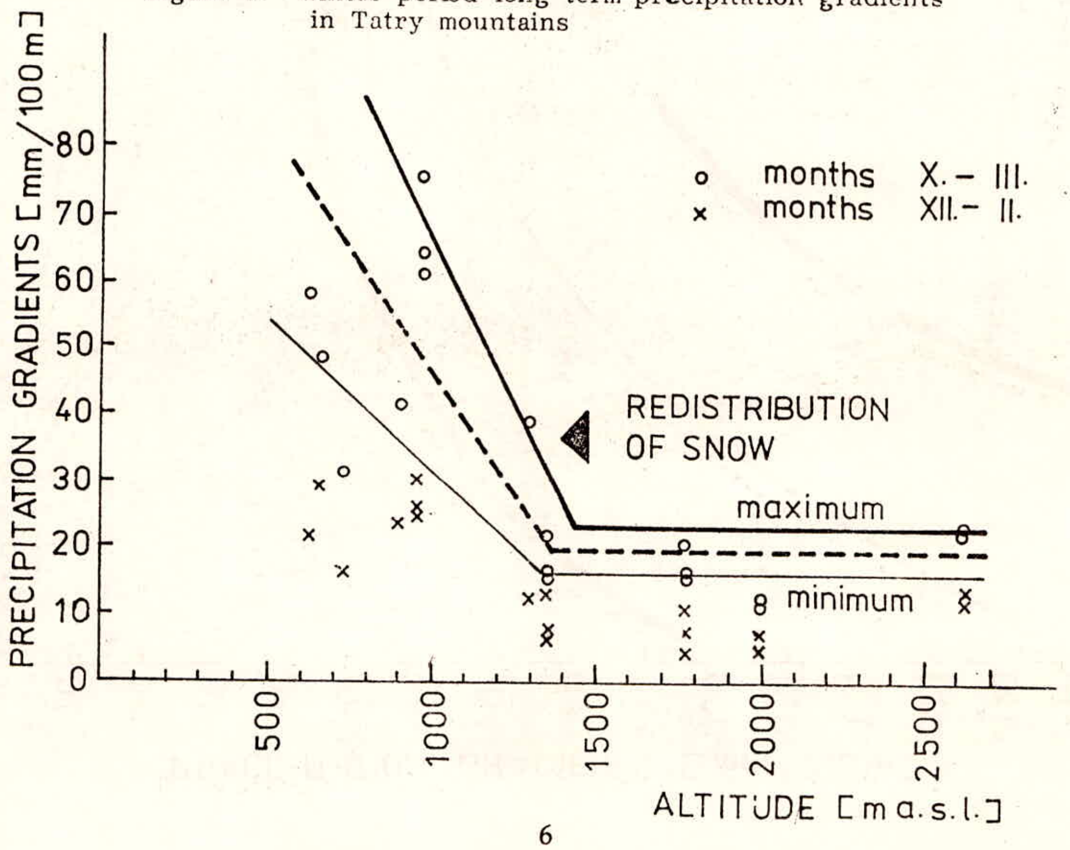


Figure 3. Winter period long term precipitation gradients in Tatry mountains



On Figures 2 and 3 the seasonal gradients related to the altitude of stations are shown. As it was expected, the obtained relationships are closer. The precipitation gradients in winter periods are proving that the redistribution of snow is taking place. The station Chopok (2008 m a.s.l.) is situated on top of the mountain and all the measurements are heavily affected by wind.

Within the programme of experimental catchment of Jalovecky creek, the precipitation gradients were calculated by means of regression analysis using data from storage gauges for the period 1989-1991. Results obtained by Holko /5/ have confirmed the long term annual precipitation gradient determined by Pacl /1/ equal to 86 mm/100 m. However, high variability of short term annual gradients (1989-1991) has not allowed for significant conclusions on scope of their fluctuations in time. Simple comparison of the long term estimate of annual gradient 86 mm/100m with the relation shown in Figure 1 places the experimental catchment of Jalovecký creek well over the maximum curve.

The regression analyses made by Holko for monthly precipitation amounts clearly proved a seasonality of precipitation gradients. Three seasons have been identified: spring - summer (48 mm/100 m), autumn (32 mm/100 m) and winter (7 mm/100 m). Annual subdivision on three seasons is based on typical rainfall-snow pattern within the area and it has only regional validity.

CONCLUSIONS

Presented results have proved the ultimate importance of more accurate determination of the areal precipitation in mountains as the basic input for any water resources assessment in the subject areas. Results obtained by long term (1960-1980) statistical analysis of the annual and seasonal precipitation gradients have indicated rather big discrepancies between regional and local studies. Therefore, the standard network has to be supplemented by more detailed experimental catchment studies. However, the methodology used for processing of precipitation data has proved to be useful for classification of stations within the region and for necessary corrections of precipitation measurements. Presented results have clearly proved the seasonal character of precipitation gradients. Subdivision on more then two seasons has to be documented by longer data series. Redistribution of snow down to the forest barier (1400 - 1500 m a.s.l.) was confirmed and direct measurement of snow cover in the mountains was justified.

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