SNOW COVER CHANGES SCENARIOS FOR THE TATRA MOUNTAINS IN SLOVAKIA

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Abstract: Monthly snow characteristics dependence on monthly air temperature and precipitation values in the High Tatras and the Low Tatras region in Slovakia in the 1921-2006 period is presented in the paper. The obtained results proved the unequal snow regimen in the region. The most significant differences were found between the northwestern and southeastern part. Increase of air temperature by about 1.2 °C and change of precipitation totals from –10% to +20% in the November-April season are the main reasons of obtained trends. It seems that the expected warming of climate up to 4.8 °C and some further increase in winter precipitation totals by +5% to +22% in the 21st century can significantly change the future snow conditions in this region. This influence probably depends significantly on the altitude and local topography conditions. Another reason is possibly connected with changed atmosphere circulation patterns.

Keywords: *snow cover, statistical analysis, influence of topography, mountainous area, climate change, areal aspects*

1. INTRODUCTION

The Tatra Mountains (2655 m a.s.l.) cover an area of about 7 thousands sq km in Slovakia, including valleys. Because of upwind and lee effects the snow conditions are very complex there. Some upper slopes have even more than 250 cm maximum of snow cover with very high probability of depths above 50 cm from December to March. On the other hand, in the area of Popradská hollow (about 700 m a.s.l.) the snow cover occurrence is relatively low also in January and February.

Regular observations of daily snow cover, new snow and precipitation totals have started in this region at about 100 stations in 1921 (data from 25 stations are complete up to present). Air temperature measurements are to disposal from 3 stations since 1901 and from another 6 stations from 1951 (1961). Finally only 14 stations with complete precipitation and snow cover data have been selected for the correlation analysis. In case of air temperature and snow cover dependence five reliable stations are considered as sufficient base for the correlation analysis. We consider the 85-year series of data as enough long for statistical analysis of variability and trends of basic snow cover characteristics on the one side and for preparing of the GCMs-Analogue scenarios of future snow conditions change on the other.

In the paper the correlation analysis between monthly characteristics of daily snow cover, air temperature and precipitation totals is presented. These results can be applied on any GCMs based scenarios of monthly air temperature and monthly precipitation changes until 2100. It was found that due to the increase in air temperature the significant decrease in snow cover characteristics is expected mainly at the altitudes below 1100 m a.s.l. On the other hand the expected increase in winter precipitation totals by about 20% will probably cause the increase of snow cover depth and occurrence mainly at altitudes above 900 m a.s.l. (more significantly in the altitudes above 1100 m a.s.l.).

This region is quite reach in ski resorts, at least 30 sites with good infrastructure, including technical snow, are situated there. Some of them have the base altitude below 600 m a.s.l., but some reach the upper altitude above 1600 m a.s.l. Presented results can be used for an economical profitability assessment of individual ski resorts during any 10-year periods in the next century. Because of limited space only selected figures and tables are included.

2. GENERAL CLIMATE CONDITIONS IN THE TATRA REGION IN 1901-2006

Figure 1 describes snow conditions in the region using special characteristic – *sum of daily snow cover depths in the July-June season*. This value is calculated as a sum of all snow cover depths measured everyday at 7 h MLT (mean local time) during 12 months staring in July of previous year and ending in June of given year. More over the location of all stations in the region with observations longer than 1951-2006 is shown. The northern and top High and Western Tatras as well as the top Low Tatras have the highest snow cover. In Figure 2 and 3 the precipitation and temperature trends in 1901-2006 are shown.

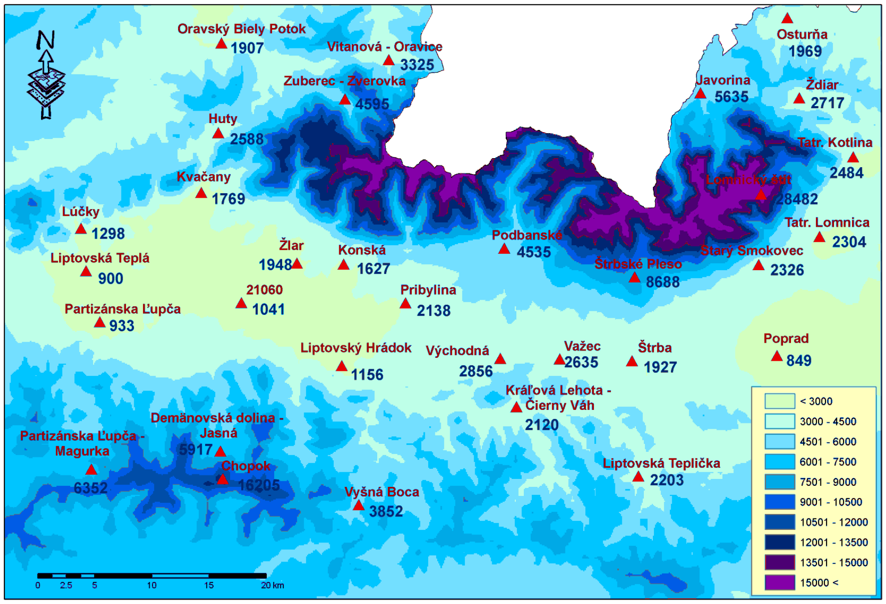

Figure 1: Sum of daily snow cover depths [cm] during the whole July-June snow season in 1920/21-2005/06 period and location of all considered stations in the region (the mean snow cover dept can be obtained by dividing of this values by mean number of snow cover days; the station 21060 lies near to Liptovský Mikuláš city, Červený kláštor lies to the north east from Osturňa and Telgárt lies about 20 km to the south from Liptovská Teplička).

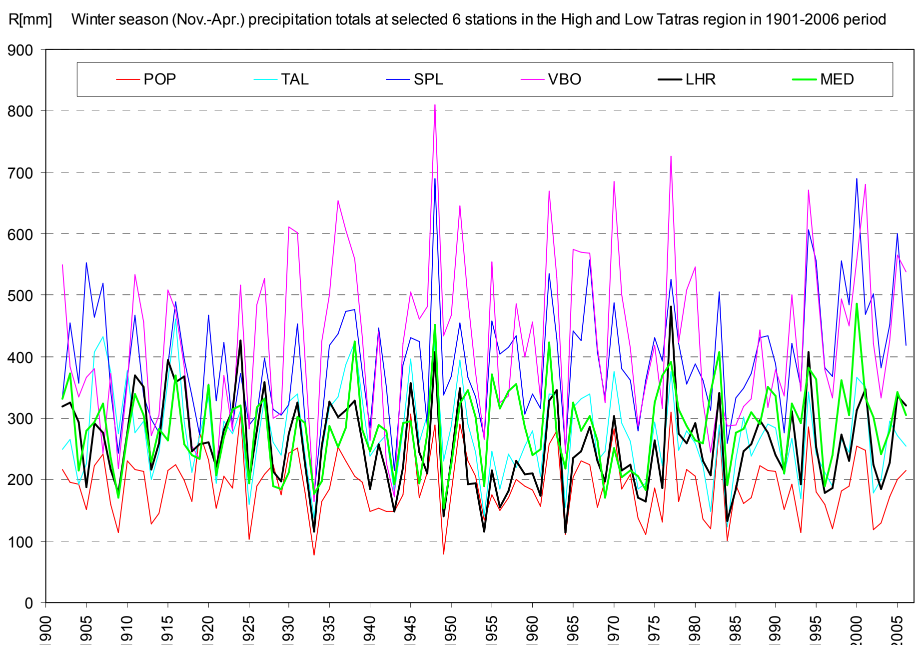

Figure 2: Winter season (November-April) precipitation totals at 6 stations (POP – Poprad, 694 m, TAL – Tatranská Lomnica, 827 m, SPL – Štrbské Pleso, 1354 m, VBO – Vyšná Boca, 930 m, LHR – Liptovský Hrádok, 640 m, MED – Tvrdošín Medvedzie, 618 m) in the High and Low Tatras region in 1901/02 – 2005/06 period.

Figure 2 shows that the winter season precipitation trend is different within the region, while at Poprad and Liptovský Hrádok (hollows) precipitation totals are decreasing, in the northern slopes, or near center of mountains precipitation totals are increasing (or have insignificant trends, Štrbské Pleso, Vyšná Boca). Figure 3 presents general increasing trend of air temperature, both for winter and summer seasons (at Liptovský Hrádok it makes 1.3 °C for summer season and 0.9 °C for winter season per century.

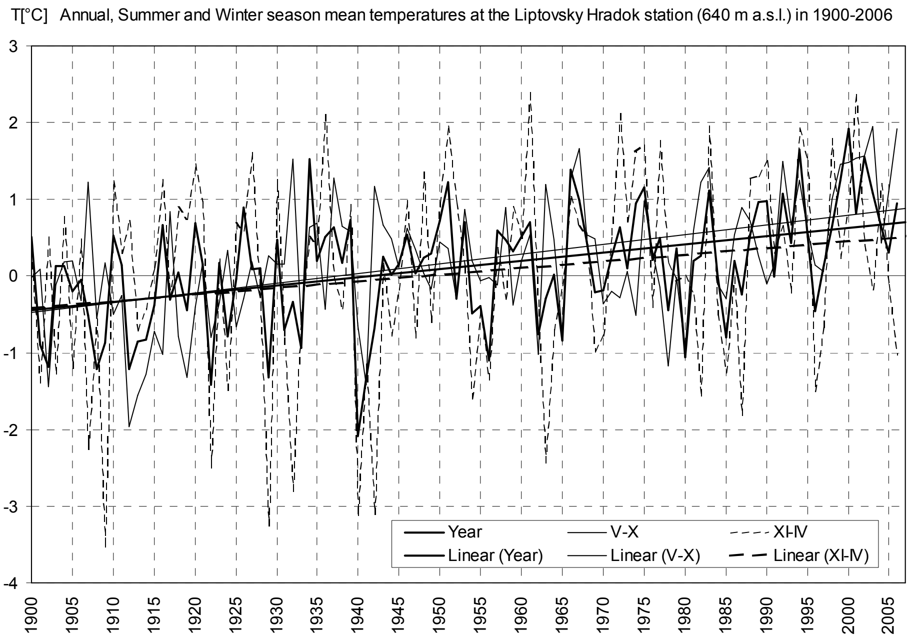

Figure 3: Annual, summer season (May-October) and winter season (November-April) air temperature means at the Liptovský Hrádok station (640 m a.s.l.) in 1900-2006 (this station roughly represents the temperature trends in the whole region, just some stations above hollows have higher rise of winter season mean temperature.

3. CORRELATION OF SNOW COVER, TEMPERATURE AND PRECIPITATION

The correlation analysis was done for every month and all reliable stations in the region. Some stations have reliable series only in 1931-2006 or 1951-2006 periods, so correlation coefficients and graphs for all relevant periods have been compared. It seems that correlation between snow characteristics and air temperature as well as between snow characteristics and precipitation totals are quite conservative without serious differences among different periods. Because of huge number of results, only data concerning all winter season are presented. Snow characteristics (number of days with snow depth ≥1 cm and ≥20 cm, sum of daily snow cover depths ≥1 cm and ≥20 cm) in whole July to June season were correlated with mean air temperatures and precipitation totals in November – April season. Selected results are in Tables 1 and 2.

Table 1: Example of correlation analysis between snow cover characteristics (N1, N20 – number of days with snow cover ≥1 cm and ≥20 cm, S1, S20 – sum [cm] of daily snow cover depths ≥1 cm and ≥20 cm) in the whole season July to June (12 months) and mean air temperature in winter season (November – April) at the stations Poprad, Štrbské Pleso, Lipt. Hrádok, Červený Kláštor and Telgárt in 1951/52 – 2005/06 winter seasons (H – altitude, r – correlation coefficient, dN1, dN20, dS1, dS20 – change of snow cover characteristics at increase of mean air temperature by 1 °C).

H[m]	Station	T(XI-IV)	r(N1)	r(N20)	r(S1)	r(S20)	N1	N20	S1[cm]	S20	dN1	dN20	dS1[cm]	dS20
694	POP	-0.5	-0.60	-0.42	-0.53	-0.41	80.6	12.2	883.6	387.7	-10.9	-7.5	-357.5	-285.6
1354	STP	-2.4	-0.47	-0.49	-0.39	-0.39	157.4	124.3	8678.7	8392.4	-8.2	-14.5	-1477.9	-1537.4
640	LHR	0.0	-0.61	-0.48	-0.56	-0.46	87.9	20.6	1170.8	642.6	-11.6	-9.9	-398.5	-353.0
465	CEK	-0.3	-0.59	-0.45	-0.46	-0.39	91.5	28.7	1480.7	938.4	-10.8	-9.0	-362.1	-311.3
901	TEL	-1.4	-0.59	-0.57	-0.54	-0.53	108.6	55.4	2997.4	2544.4	-13.5	-20.3	-1149.4	-1175.0

From Table 1 it follows that at consideration of mean temperature increase the relatively more significant changes can be expected at the stations with lower altitude and poor snow conditions (Poprad) and less significant at higher stations with high precipitation totals (Štrbské Pleso). Projected temperature scenarios for Slovakia show mean temperature increase up to 4 °C in time frame 2075 (by Table 3), so also in some lower localities round the Tatras only poor snow conditions can be expected compared to past century. On the other hand the influence of increasing precipitation is much more significant in higher altitudes (Štrbské Pleso).

Table 2: Example of correlation analysis between snow cover characteristics (N1, N20 – number of days with snow cover ≥1 cm and ≥20 cm, S1, S20 – sum [cm] of daily snow cover depths ≥1 cm and ≥20 cm) in the whole season July to June (12 months) and precipitation total in winter season (November – April) at the stations Poprad, Tatranská Lomnica, Kežmarok, Liptovská Teplička, Čierny Váh, Štrbské Pleso, Východná, Vyšná Boca, Lipt. Hrádok, Lipt. Mikuláš, Partizánska Ľupča, Tvrdošín Medvedzie, Červený Kláštor and Telgárt in 1921/22 – 2005/06 winter seasons (H – altitude, r – correlation coefficient, S1 and S20 are in [cm], dN1, dN20, dS1, dS20 – change of snow cover characteristics at increase of precipitation total by 10%).

H[m]	Station	XI-IV	r(N1)	r(N20)	r(S1)	r(S20)	N1	N20	S1	S20	dN1	dN20	dS1	dS20
694	POP	189.5	0.28	0.33	0.36	0.34	80.6	12.2	884	388	2.1	2.4	99.1	102.7
827	TAL	257.8	0.21	0.19	0.22	0.21	109.1	53.9	2580	2076	1.6	2.8	192.1	204.2
626	KEZ	181.6	0.31	0.26	0.28	0.24	76.9	11.6	822	344	2.3	2.0	93.4	87.4
903	LTE	301.7	0.23	0.18	0.17	0.15	105.5	48.1	2360	1848	2.2	2.5	134.6	132.4
738	CVH	296.0	0.15	0.19	0.19	0.20	106.2	50.8	2385	1879	1.7	2.9	153.6	164.0
1354	SPL	413.0	0.43	0.47	0.50	0.49	157.4	124.3	8679	8392	3.6	6.8	876.3	893.7
743	VCH	286.4	0.22	0.21	0.20	0.20	111.5	55.6	2634	2106	1.7	3.2	106.5	111.1
930	VBO	439.1	0.21	0.23	0.25	0.25	119.7	72.7	3768	3369	2.0	3.7	283.7	291.6
640	LHR	243.9	0.10	0.19	0.16	0.16	87.9	20.6	1171	643	0.8	1.6	49.8	53.7
567	LMI	236.8	0.05	0.11	0.11	0.09	74.4	18.8	982	538	1.4	1.6	49.5	48.1
573	PAL	232.2	0.01	0.18	0.18	0.19	85.9	20.5	1125	619	1.2	3.0	98.9	103.1
618	MED	296.2	0.14	0.18	0.18	0.17	89.7	29.2	1538	1053	1.7	2.7	112.9	117.6
465	CEK	243.1	0.32	0.30	0.33	0.31	91.5	28.7	1481	938	3.2	3.3	140.0	136.1
901	TEL	295.1	0.25	0.19	0.23	0.22	108.6	55.4	2997	2544	1.9	2.3	163.8	165.9

Table 3: Scenarios of mean monthly air temperature change [°C] (the first three lines) and scenarios of mean monthly precipitation change [quotient] (line 4 – 6) by three GCMs output modified for Slovakia Center (CCCM – Canadian CGCM1 and 2, GISS – Goddard Institute for Space Study GCM) for 2075 time frame compared to 1951-1980; temperature scenarios are the same for all Slovakia, precipitation scenarios nearly gradually slightly increase winter precipitation in the northern Slovakia and decrease summer precipitation in southern Slovakia (Lapin and Melo, 2004)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM 1997	2.2	2.9	2.8	2.3	2.3	2.9	3.4	3.6	3.6	3.0	2.0	1.8
CCCM 2000	3.5	4.2	4.8	3.8	3.2	2.7	3.5	3.4	3.3	3.0	2.2	2.6
GISS 1998	2.7	2.4	2.3	2.2	1.9	1.8	2.1	2.4	2.3	2.3	2.6	2.8
CCCM 1997	1.22	1.12	1.17	1.04	1.07	0.87	0.89	0.94	1.03	1.09	1.18	1.20
CCCM 2000	1.14	1.10	1.18	1.01	1.06	0.88	0.84	0.92	1.11	1.18	1.17	1.11
GISS 1998	1.18	1.16	1.10	1.07	1.05	0.99	0.97	0.98	1.02	1.05	1.05	1.10

4. CONCLUSIONS

Only selected results are presented in this extended Abstract. More detailed results will be published in 2007, including calculation of expected changes in monthly snow cover characteristics for the whole Tatras region. Besides three scenarios in Table 3 also another three IPCC scenarios applying the SRES emission scenarios A2, B2 (B1) will be calculated.

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