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SOME SELECTED SNOW CLIMATE TRENDS IN SLOVAKIA WITH RESPECT TO ALTITUDE

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Abstract. The changes of snow cover duration and amount in Slovakia are very variable from region to region, as well as for different altitudes. The number of days with the total height of snow cover (HS, in cm) above several thresholds (since 1921/22), and precipitation amounts and types (since 1981/82) were investigated. 35 Slovakian mountain stations (above 700 m a.s.l.) were used.

General decrease of snow cover duration as well as of solid precipitations was observed; but there exists a critical altitude, where the negative trend reverts, because the higher and northern sites showed no significant trend or even a slight increase. High altitudes show only slight or even no changes and the trends (in most cases decreasing) become more pronounced at mid altitudes (1000 - 1500 m), where the mixed and liquid precipitations become prevalent. The liquid precipitations turn out to be dominant bellow 1000 m especially at the beginning and end of winter. The highest station showed all trends for snow cover amounts and duration to be positive. The estimated critical level, above which the snow trends become positive, lies in 1800 m on northern and in 2300 m on southern slopes.

The reduction of solid precipitations is little compensated with increase of precipitation amounts from November to April, while DJF sums proved rather slight decrease or no significant change, except the highest station (2635 m). Increasing trends of both precipitation amounts and temperature are the key factors that can and do change the snow duration as well as the ratio of solid, mixed and liquid precipitation. The results correlate with similar studies from Alps.

Yet in 1920's, the snow becomes attractive and regularly recorded on some stations in Slovakia. Another huge boom came with the development of winter sports and tourism in 1960's, when the number of stations increased. Changes in characteristics of snow are very important when studying impacts of climatic change, especially on mountain regions. Climatic change connected with global warming causes general decrease of snow cover (especially in spring) in recent decades. The snow cover extent loss, associated with significant warming of 1.26 °C per 100 years, was estimated by Brown [1999] as 3.1 106 km2 per 100 years over northern hemisphere midlatitudinal land areas. In mountain regions, an average rise of 1 °C is accompanied by a general rise of about 150 m in the altitude of the snowline [Haeberli a Beniston, 1998]. Some regional studies suggest the temperature rise by as much as 3 °C by 2050, with possibly increased precipitation in winter but substantial decrease in summer. Recent studies from Alps [Beniston et al., 2003; Laternser, 2002] showed that the trends of snow cover amounts depend on altitude, and hence on temperature. Negative trends turns over at higher altitudes to positive, because milder winters are associated with higher precipitation levels than colder winters, but with more solid precipitation at elevations exceeding 1 700 – 2 000 m a. s. l., and more mixed and liquid precipitations below.

In Slovakia, the change of snow amount and duration may positively or negatively affect the energy and hydrological balance, local ecosystems, tourism and other human activities in future. Various anomalies and non-standard regimes occur in the behaviour of precipitation during year. The long-term trends of quasi-summer precipitation (VI-IX) disclosed general decrease; recorded in Slovak Hydrometeorological Institute (SHMÚ) station network as well as in accumulative precipitation gauges (totalizers). The decrease of yearly precipitation amounts is observed on most stations in Slovakia, except the north mountainous regions of Slovakia. It follows that the winter, eventually the spring and the autumn precipitation amounts rise in mountainous regions.

The goal of this study was to find out whether the negative long-term trends of some selected snow characteristics reverse to positive, and to reveal the relationship with altitude in Slovakian Western Carpathians.

Methods

Available long-term digitalized snow data since the winter season 1921/22 from the observational network of SHMÚ were used. The stations selection was based on the data quality: shorter series than 20 winter seasons, and the series with many missing data were excluded. Finally, 35 mountain stations above 700 m a.s.l. were selected (Figure 1).

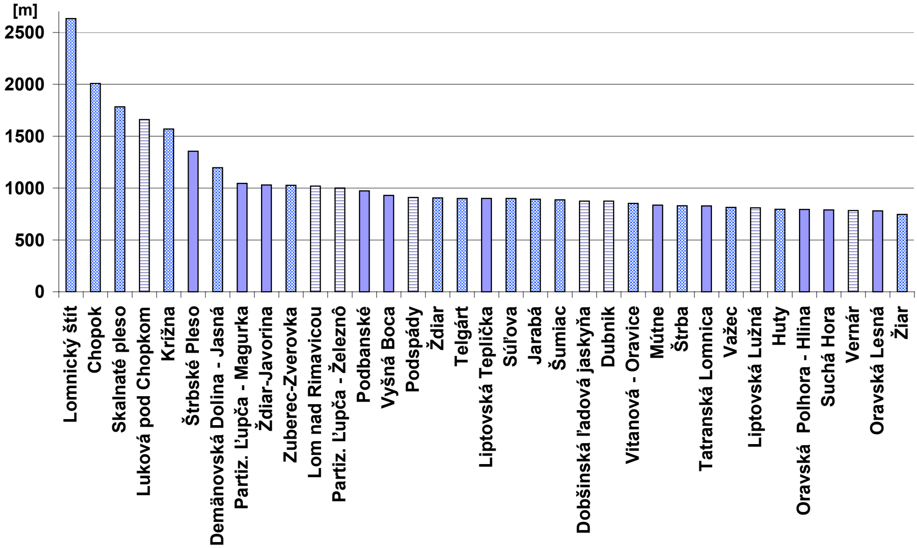

Figure 1: Meteorological stations ordered by altitude, divided into 3 groups depending on the number of winter seasons: less than 30 (horizontal hatching); from 30 to 59 (chessboard hatching); and the longest time series with 60 and more winter seasons (filled bars).

The number of days with the total height of snow cover (HS, in cm) above several thresholds was investigated. The thresholds used in Slovakia are HS ≥ 1, 10, 20 and 50 cm (eventually 100 cm) of daily snow height. This work focuses on mountainous regions (here defined as higher than 700 m), where the ratio of solid precipitations is sufficient.

In addition to snow height, also another digitalized data were analyzed: the type and amount (in mm) of precipitation was available in the climatological database of SHMÚ since 1981/82. The types of precipitation used in Slovakia were divided into 3 groups: solid, mixed and liquid (Table 1). Then the ratio of solid, mixed and liquid precipitation amounts to the total precipitation amount for winter months (DJF) and for longer period from November to April was examined by constructing a special graph (Figure 6 and 7), where the dependence on altitude is evident. Expressed mathematically:

$$P_S = \frac{\sigma}{\pi} \cdot 100\% \qquad P_L = \frac{\lambda}{\pi} \cdot 100\% \qquad P_M = \frac{\mu}{\pi} \cdot 100\%$$

, where σ, μ, λ, π are amounts of solid, mixed, liquid and total precipitation in mm. The slope of P_S, P_M and P_L (signed as *S*, *M* and *L* on graphs) represents the linear trend of the given time series.

Table 1: The types of precipitation used in Slovakia.

Precipitation Type Group	**Code**	**Description**
Solid	7	Only snow
Mixed	1	Mixed or variation of solid and liquid
	3	From solid to liquid
	4	From liquid to solid
Liquid	2	Freezing
	5	Drizzle or drizzle with rain
	6	Only rain
	8	Only liquid or solid shower
< Not studied >	0	Precipitation in vicinity
	9	Hail or hail with rain

Additionally, the trends of absolute winter precipitation amount (π) were confronted with altitude (Figure 8). Unfortunately, the number of stations near the expected break-point is not sufficient.

Results & Discussion

In time series of yearly number of days with HS $\geq$ 1 cm (Figure 2), the decreasing tendency occurs largely on lower situated stations. Proportionally to altitude the number of stations with negative trend falls down, and above the altitude of approximately 1000 m no significant negative trends are observed. The number of declining trends grows gradually with higher HS thresholds. The higher the threshold, the higher is the altitude, above which no negative tendencies occur.

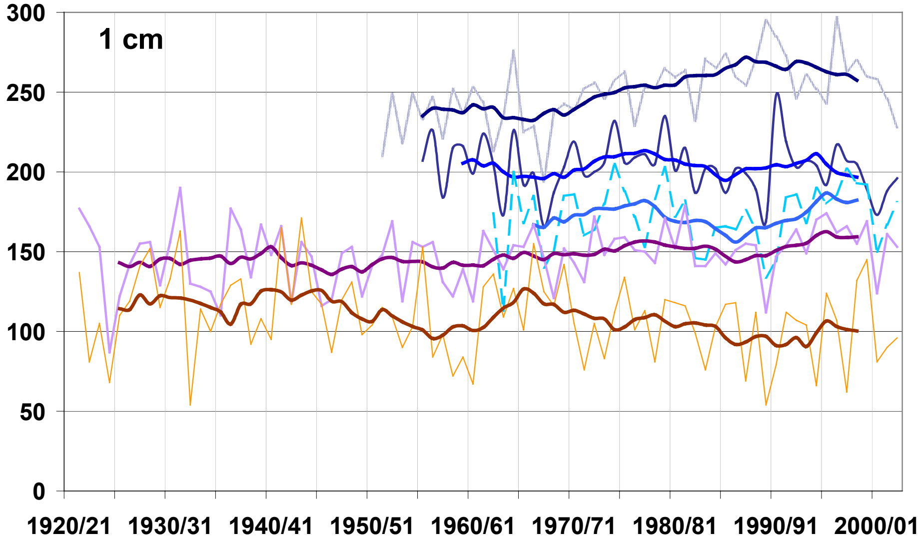

Figure 2: The number of days with snow cover ≥ 1 cm (and 9-year running averages) for winter seasons on selected stations: Lomnický štít (2635 m), Chopok (2008 m), Skalnaté pleso (1783 m), Ždiar - Javorina (1030 m) and Liptovská Teplička (900 m).

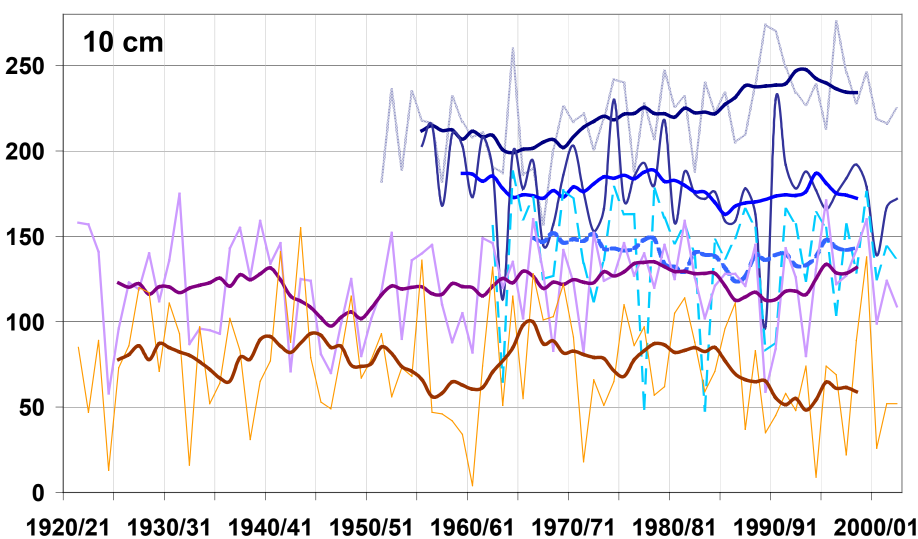

Figure 3: The number of days with snow cover ≥ 10 cm (and 9-year running averages) for winter seasons on selected stations: Lomnický štít (2635 m), Chopok (2008 m), Skalnaté pleso (1783 m), Ždiar - Javorina (1030 m) and Liptovská Teplička (900 m).

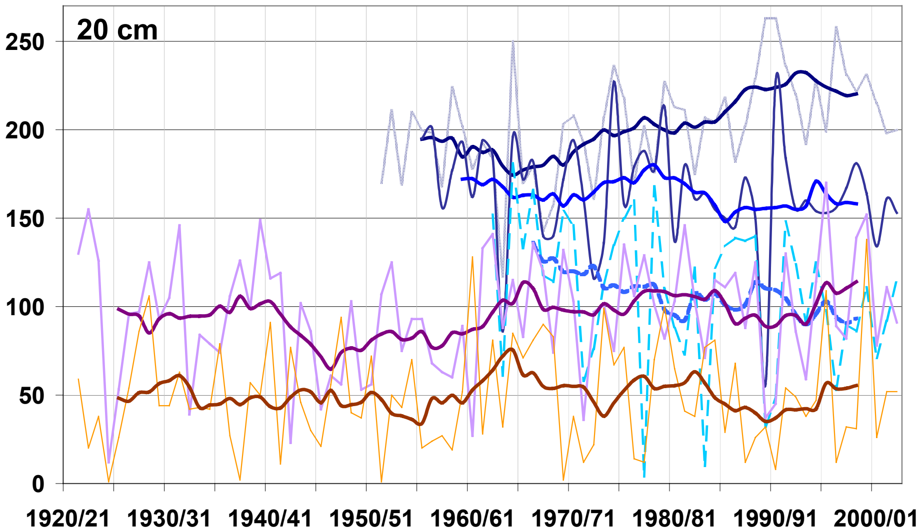

Figure 4: The number of days with snow cover ≥ 20 cm (and 9-year running averages) for winter seasons on selected stations: Lomnický štít (2635 m), Chopok (2008 m), Skalnaté pleso (1783 m), Ždiar - Javorina (1030 m) and Liptovská Teplička (900 m).

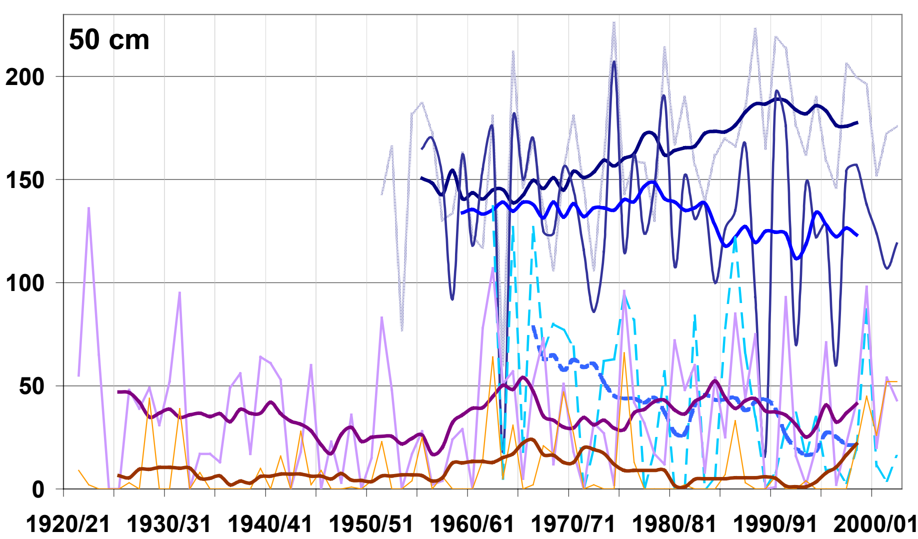

Figure 5: The number of days with snow cover ≥ 50 cm (and 9-year running averages) for winter seasons on selected stations: Lomnický štít (2635 m), Chopok (2008 m), Skalnaté pleso (1783 m), Ždiar - Javorina (1030 m) and Liptovská Teplička (900 m).

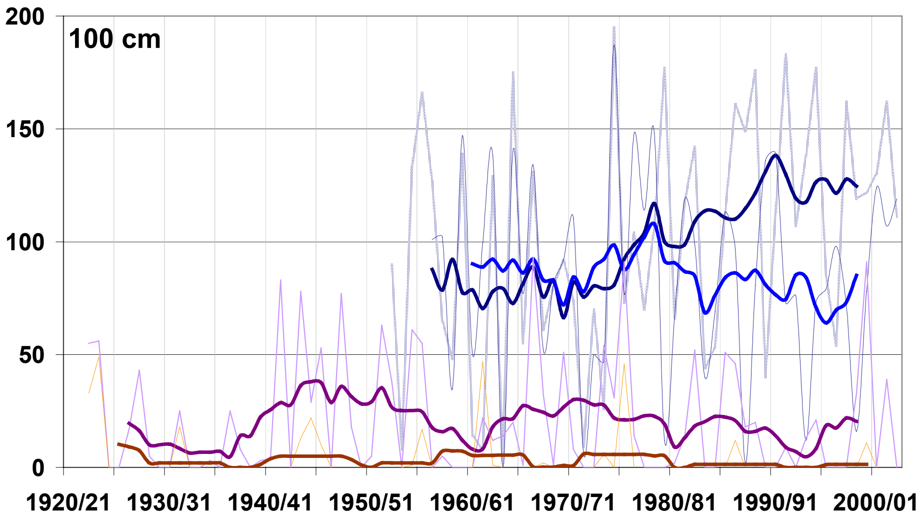

Figure 6: The number of days with snow cover ≥ 100 cm (9-year running averages) for winter seasons on selected stations: Lomnický štít (2635 m), Chopok (2008 m), Štrbské Pleso (1354 m) and Podbanské (972 m).

Moreover, certain specific behaviour of the number of days originates in geographical peculiarities of given region. For illustration, the station Skalnaté pleso shows rapid decrease for higher HS thresholds, because the warming on southern slopes and opened hollows is more expressive. On contrary, the lower station Ždiar - Javorina showed even slight increasing trend, probably because it lies on northern side of the mountain range, where the warming is not so striking during winter.

The time series of the ratio of solid, mixed and liquid precipitation amounts to the total precipitation amount (P_S, P_M, P_L) for winter months (Figure 6) and for Nov-Apr (Figure 7) support the theory of break-point. Even though only 22 winters were available, the rate of solid precipitation tends to fall for all stations, except the highest one (Lomnický štít, 2635 m). The maximum loss of solid precipitation appears approximately between 1000 – 1500 m, and the mixed precipitations occur more frequently. Below 1000 m the liquid precipitations become dominant, mainly at the beginning and at the end of winter.

Fortunately, this reduction of solid precipitation is a little bit compensated by the increase of absolute precipitation amounts from November to April (Figure 8). Surprisingly, the DJF precipitation tendencies are more variable, but rather declining or no significant trend is observed.

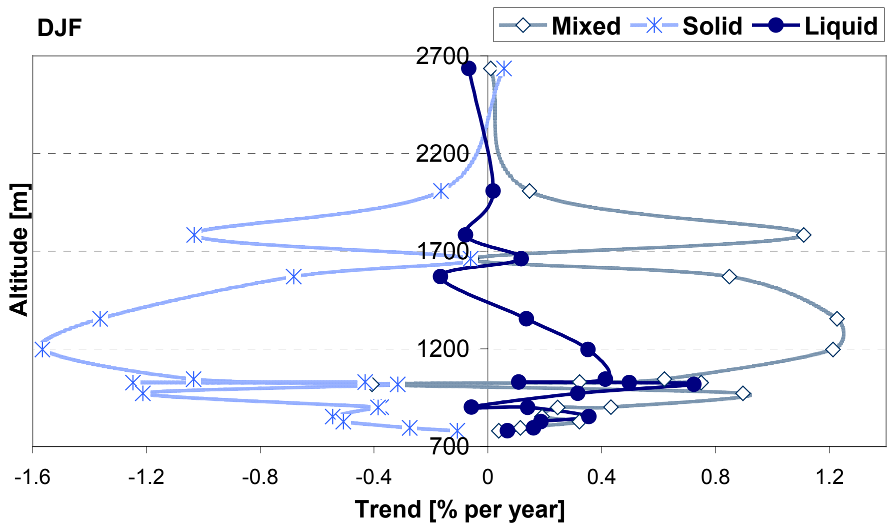

Figure 7: Trends (1981/82 – 2002/03) of ratios of mixed (M), solid (S) and liquid (L) precipitation amounts to the total precipitation amount in winter months (DJF) for selected meteorological stations above 700 m. The trend for station Krížna (1570 m) is for shorter period (1981/82 – 1999/00) because of finished measurements.

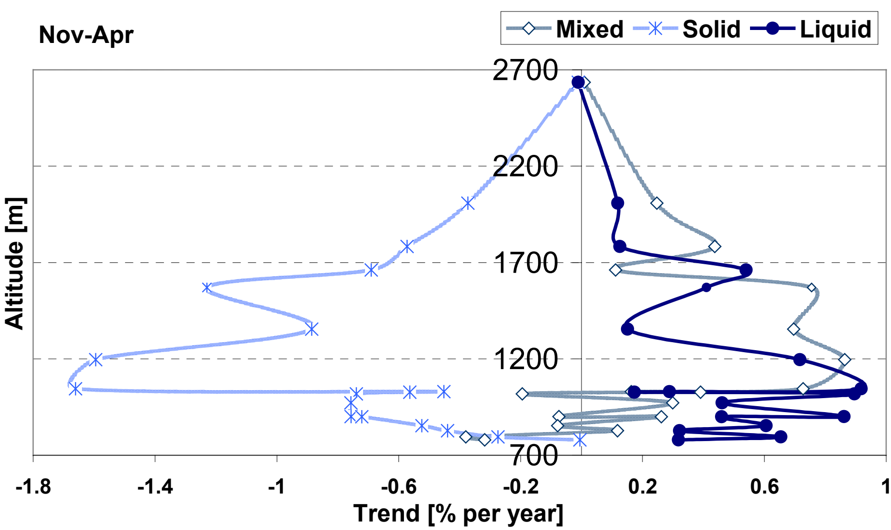

Figure 8: Trends (1981/82 – 2002/03) of ratios of mixed (M), solid (S) and liquid (L) precipitation amounts to the total precipitation amount in months from November to April for selected meteorological stations above 700 m. The trend for station Krížna (1570 m) is for shorter period (1981/82 – 1999/00) because of finished measurements.

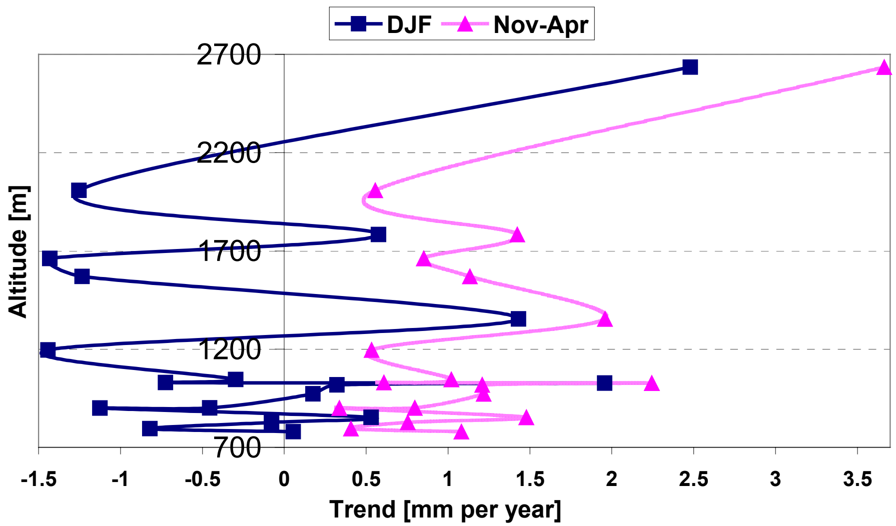

Figure 9: Trends (1981/82 – 2002/03) of absolute precipitation amounts in months from November to April for selected meteorological stations above 700 m. The trend for station Krížna (1570 m) is for shorter period (1981/82 – 1999/00) because of finished measurements.

The results are comprehensible, in connection with the global warming and increasing precipitations in this mountainous region. Moreover, no significant trend or even a slight increase of solid precipitation fraction in highest elevations and especially on northern slopes was discovered. The critical break-point, which presents here the altitude where no trends are observed, could be estimated from Figure 6 and 7. The difference between north and south station orientation is remarkable. Extrapolating via north situated stations Ždiar - Javorina (1030) – Luková (1661 m) we obtain the critical altitude at 1800 m level. For southern slopes this break-point level is near 2300 m. Above this level is the zone, where snow amount and duration is unchanged or increased. Of course, there are also some regional peculiarities, which must be regarded. For example, most stations in Low Tatras tend to have less precipitation amounts than those in High Tatras. Oravská Lesná (780 m) seems to be very stable station, without any significant changes. This may be caused by high precipitation amounts, which together with sufficiently low temperatures create favourable conditions for snow cover development during winter.

Conclusions

General decrease of snow duration as well as solid precipitation was observed; but there exists a critical break-point altitude, where the negative trend reverts, because the higher and northern sites showed no significant trend or even a slight increase. Rising trends of both precipitation amounts and temperature are the key factors that can and do change the snow duration as well as the ratio of solid, mixed and liquid precipitation. The results are consistent with similar studies from Alps.

Acknowledgements: Thanks go to SHMÚ for providing the necessary data.

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NIEKTORÉ VYBRANÉ TRENDY KLÍMY SNEHU NA SLOVENSKU V ZÁVISLOSTI OD NADMORSKEJ VÝŠKY

M. Vojtek - P. Faško - P. Šťastný

Súhrn. Rozloženie a trvanie snehovej pokrývky je na Slovensku veľmi premenlivé. Analyzovali sme dostupné časové rady počtu dní so snehovou pokrývkou väčšou alebo rovnou 1, 10, 20, 50 a 100 cm, ktorých dĺžka siahala maximálne do zimy 1921/22 (začiatky meraní) a minimálne do zimy 1981/82, na vybraných 35 meteorologických staniciach SHMÚ od nadmorskej výšky 700 m. Od zimy 1981/82 sme sledovali vývoj podielu tuhých, zmiešaných a tekutých zrážok na ich celkovom úhrne.

Pozorovali sme všeobecný úbytok trvania snehovej pokrývky a tuhej zložky zrážok. Podiel tuhých zrážok v zimných mesiacoch (DJF) na väčšine staníc za posledné obdobie klesá (najviac v polohách 1000 – 1500 m), najmä na úkor nárastu zmiešaných zrážok, prípadne v nižších polohách aj nárastu tekutých zrážok. Pod 1000 m n. m. začínajú dominovať tekuté zrážky nad zmiešanými, najmä na začiatku a na konci zimy. Naopak, v najvyšších polohách a najmä na severných svahoch je pozorovateľný veľmi mierny nárast podielu tuhých zrážok. Odhadovaná kritická hranica, od ktorej sa menia trendy na pozitívne, leží v severných polohách v 1800 m a na južných expozíciach asi vo výške 2300 m.

Pokles tuhých zrážok je mierne kompenzovaný celkovým nárastom úhrnov zrážok v období od novembra do apríla, ale zimné (DJF) úhrny vykazujú skôr mierny pokles, s výnimkou najvyššej stanice (2635 m). Kľúčový význam na vývoj snehovej pokrývky v stredných a vysokých horských polohách Slovenska v budúcnosti bude mať vývoj (momentálne pozorovaný nárast) teploty ako aj zrážok. Podobné výsledky ukazujú aj štúdie z Álp.