Hrvatski meteorološki časopis, 31, 15-21, 1996.

UDK: 551.578.43(46)
Izvorni znanstveni rad

THE SNOW REGIME IN THE NORTHERN PART OF MOUNT VELEBIT

Snježni režim na sjevernom Velebitu

MARJANA GAJIĆ-ČAPKA
Meteorological and Hydrological Service
Grič 3, 10000 Zagreb, Croatia

Primljeno 8. siječnja 1997, u konačnom obliku 15. lipnja 1997.

Abstract — The snow conditions in the Dinaric Alps are of great importance on a global scale for the albedo and heat balance, on a regional scale for support of ground water or because of possible flooding in the karst lowland area, and on a local scale for the vegetation season, the protection of the animal world, recreation and tourism, etc. These reasons initiated an investigation of the snow parameters at the main meteorological station Zavižan (1594 m a.s.l., 44°49´N, 14°59´E). It is the highest mountain station in Croatia, situated in the northern part of Mount Velebit and was established in 1953.

The snow conditions are presented by means of the annual course and the probability of occurrence of different snow parameters, their time fluctuations and trend, and their correlation with other meteorological parameters, as well as the beginning and end of the snow season.

The fluctuations during the 1953/1954 — 1992/1993 period are in accordance with the snow conditions in the Alps and The High Tatra mountains.

During the analized period 1953/1954— 1992/1993, snow was more abundant in the second half of the 1960s and 1970s as well as in the early 1980s. Winters with less snowfall, lower snow depth and shorter duration of snow cover are significatively correlated with warmer temperatures, higher air pressure and lower precipitation. The winter trend exhibits no significant decrease either in snowfall or in snow depth.

Key words: snow cover, snow depth, snow duration, trend, Zavižan, Dinaric Alps

Sažetak — Snježne prilike u Dinaridima od velike su važnosti na globalnoj skali zbog albeda i toplinske ravnoteže, na regionalnoj skali zbog snabdijevanja podzemnih voda ili poplavljivanja u kraškom nizinskom području i na lokalnoj skali za biljni i životinjski svijet, rekreaciju i turizam, itd. Zbog tih razloga započela su istraživanja snježnih veličina na glavnoj meteorološkoj postaji Zavižan (1594 m nm, 44°49´N, 14°59´E). To je najviša planinska postaja u Hrvatskoj, smještena na sjevernom Velebitu, na kojoj se meteorološka mjerenja i motrenja obavljaju od kraja 1953. godine, kada je postaja osnovana.

Snježne prilike prikazane su pomoću godišnjeg hoda, trajanja i percentila različitih snježnih veličina, njihovih vremenskih fluktuacija i trenda, kao i pomoću korelacije s drugim meteorološkim veličinama, te početka i kraja snježne sezone.

Karakteristični su rezultati analize vremenskih promjena u razdoblju 1953/1954— 1992/1993, koji su u skladu sa snježnim prilikama u Alpama i Tatrama. Obilniji snijeg javio se u drugoj polovici 1960-ih i 1970-ih te u ranim 1980-im. Zime s manje padanja snijega, manjim visinama i kraćim trajanjem snježnog pokrivača signifikantno su korelirane s višim temperaturama zraka, višim tlakom zraka i manjom količinom oborine. Trend padanja snijega i visine snježnog pokrivača ne pokazuje signifikantan pad niti kod jedne od te dvije veličine.

Ključne riječi: snježni pokrivač, padanje snijega, trend, Zavižan, Dinaridi

1. INTRODUCTION

The attention of the world climate community has been more and more focused on high elevation geophysical data around the world, because of the value of these observing sites for climate change detection. In the Dinaric Alps, on the territory of Croatia, the meteorological station Zavižan is the only station located above 1000 m a.s.l. It lies on top of the northern part of Mount Velebit which is located along the eastern Adriatic coast, 150 km in length, with the highest summits reaching about 1700 m a.s.l. This region is scarcely populated and extra efforts are invested in the maintenance of high elevation data gathering.

The probability and time distribution of snow data at Zavižan have been analyzed because of their importance for climate change detection efforts and for their direct implication in hydrology, tourism, forestry, etc. in the mountainous area, the populated inland valleys and the coast.

2. DATA AND METHOD

This paper deals with snowfall and snow cover data at the mountain meteorological station Zavižan (1954 m a.s.l.) during the period 1953/1954 to 1992/1993. The snow parameters selected for this analysis are: the beginning and the end of the snow season, the number of days with snow cover ≥1 cm, ≥10 cm, ≥30 cm, and ≥50 cm, the number of days with snow precipitation ≥0.1 mm, the daily snow depth and the maximum snow depth.

The appearance of snow is presented as the mean, the earliest and the latest start and end of snow cover and snowfall. The annual course of the number of days with snow cover ≥1 cm, ≥10 cm, ≥30 cm, and ≥50 cm, and the number of days with snow precipitation ≥0.1 mm includes their monthly mean values, and extremes. The annual course of the daily snow depth is presented by a 5-day period mean for each date. The probability of the number of days with snow cover and snowfall as well as the daily snow depth are discussed after the cumulative frequency distributions and their percentile values. The limits of "normal" snow conditions are determined as the interval between the lower and upper quartile of the snow parameter discussed (Juras and Juras, 1987).

The expected values of maximum snow depth for various return periods are estimated according to the Jenkinson model (Jenkinson, 1969).

The time series of the annual number of days with snow cover and snowfall during the last forty years have been smoothed by the 5-year binomial filter to eliminate short-term fluctuations and to highlight long-term variations. Simultaneous temperature changes are presented by means of winter temperature fluctuations. The original data series have been tested for linear trend by the Mann-Kendall rank test (Mitchell et al., 1966).

3. RESULTS

3.1 Snowfall

On the average, snow falls for the first time in the first half of October, and for the last time at the end of May. This means that the mean snow season lasts over seven months. During the observed 40-year period 1953/54 — 1992/93 the earliest first day with snowfall was observed on September 4, 1976 and the latest last day with snowfall on July 17, 1970.

The mean annual number of days when snow falls and snow precipitation amounts to ≥0.1 mm is 80 days at Zavižan. During the year, it falls for a nearly equal number of days in each month from December to April (11.4—13.0 days) while in the other months it is rather rare (Tab. 1).

According to the annual frequency distribution of the number of days with snow precipitation ≥0.1mm (Fig.1-above) snow falls for 30—120 days with the greatest probability of a duration of 80 to 90 days.

According to the limits of "normal" snow conditions (lower to upper quartile), determined by means of the monthly cumulative frequencies, it can be expected that, for example, in spring, snow would fall for 9 — 10 days in March and April, but for only 2 — 5 days in May (Fig. 2-above).

Every snowfall is not necessarily linked with snow remaining on the ground and the formation of a snow cover. Whether the falling snow accumulates on the ground or melts depends on the amount of snow, air and ground temperature, the exposure of the location to wind and direct solar radiation. During low-temperature periods, when the longer part of the day is below 0°C, the snow

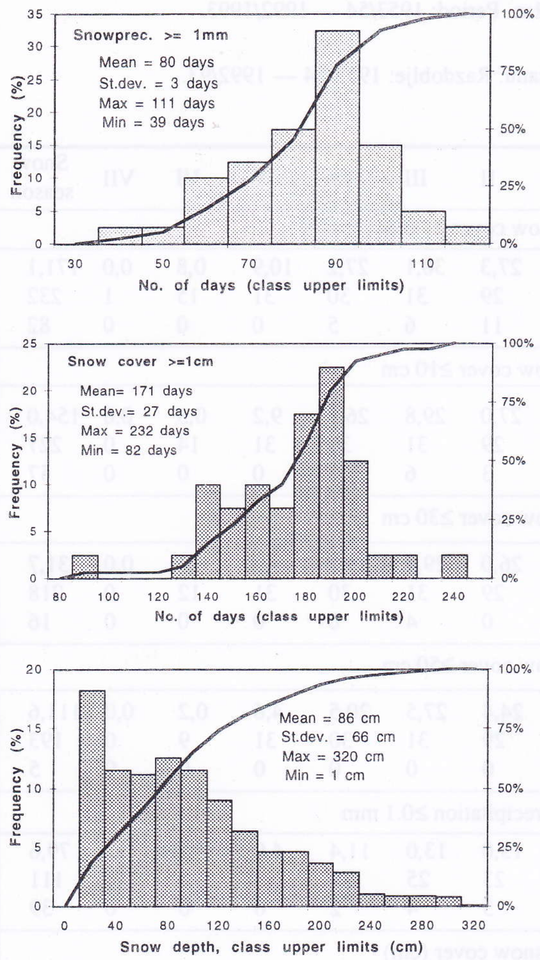

Figure 1. Frequency of the mean number of days with snow precipitation ≥0.1 mm (above), the mean number of days with snow cover ≥1 cm (middle) and the mean snow depth (below) at Zavižan. Period: 1953/54—1992/93.

Slika 1. Učestalost srednjeg broja dana sa snijegom (količina oborine ≥0.1 mm) (gore), srednjeg broja dana sa snježnim pokrivačem ≥1cm (sredina) i srednja dnevna visina snježnog pokrivača (dolje) na Zavižanu. Razdoblje: 1953/54 — 1992/93.

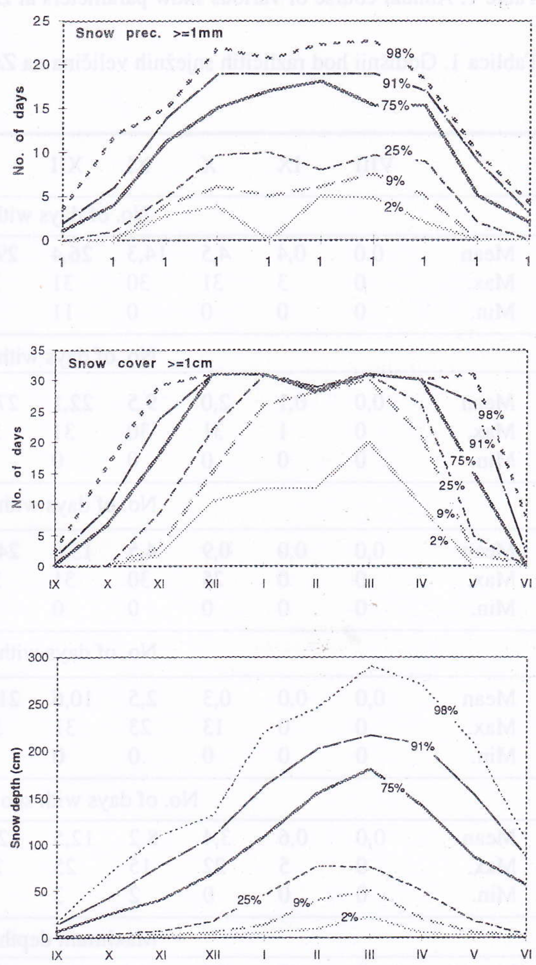

Figure 2. Percentiles of the number of days with snow precipitation ≥0.1 mm (above), the number of days with snow cover ≥1 cm (middle) and the mean daily snow depth (below) at Zavižan. Period: 1953/54 — 1992/93.

Slika 2. Percentili broja dana sa snijegom (količina oborine ≥0.1 mm) (gore), broja dana sa snježnim pokrivačem ≥1 cm (sredina) i dnevnih visina snježnog pokrivača (dolje) za Zavižan. Razdoblje: 1953/54 — 1992/93.

cover will stay on the ground for a longer time even after snow has stopped falling.

3.2 Snow cover

A snow cover ≥1 cm can be expected from mid October to the second half of May. The earliest day when snow cover was measured during the observed forty years was September 4, 1976, and the longest it stayed on the ground was till July 1, 1975.

The occurrence of higher snow cover can be expected during shorter periods (Fig. 3): a snow cover ≥10 cm from November 10 till May 13, a snow cover ≥30 cm from November 28 till May 3, and a snow cover ≥50 cm from December 22 till April 25. During these periods, such snow cover depths

Table 1. Annual course of various snow parameters at Zavižan. Period: 1953/54 — 1992/1993.

Tablica 1. Godišnji hod različitih snježnih veličina na Zavižanu. Razdoblje: 1953/54 — 1992/93.

	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	Snow season
No. of days with snow cover ≥1 cm													
Mean	0.0	0,4	4,5	14,3	26,4	29,3	27,3	30,1	27,2	10,9	0,8	0,0	171,1
Max.	0	3	31	30	31	31	29	31	30	31	15	1	232
Min.	0	0	0	0	11	0	11	6	5	0	0	0	82
No. of days with snow cover ≥10 cm													
Mean	0,0	0,1	2,0	9,5	22,1	27,9	27,0	29,8	26,1	9,2	0,5	0,0	154,0
Max.	0	1	31	30	31	31	29	31	30	31	14	0	227
Min.	0	0	0	0	0	0	3	6	0	0	0	0	57
No. of days with snow cover ≥30 cm													
Mean	0,0	0,0	0,9	4,5	15,8	24,7	26,0	29,2	23,7	6,7	0,3	0,0	131,7
Max.	0	0	25	30	31	31	29	31	30	31	12	0	218
Min.	0	0	0	0	0	0	0	4	0	0	0	0	16
No. of days with snow cover ≥50 cm													
Mean	0,0	0,0	0,3	2,5	10,6	21,0	24,4	27,5	20,5	4,6	0,2	0,0	111,6
Max.	0	0	13	23	31	31	29	31	30	31	9	0	193
Min.	0	0	0	0	0	0	0	0	0	0	0	0	5
No. of days with snow precipitation ≥0.1 mm													
Mean	0,0	0,6	3,4	8,2	12,5	12,5	13,0	13,0	11,4	4,0	1,0	0,2	79,6
Max.	0	5	22	15	25	23	23	25	19	13	5	2	111
Min.	0	0	0	2	3	0	5	4	2	0	0	0	39
Maximum depth of snow cover (cm)													
Max.	0	18	87	142	167	230	287	320	298	272	106	3	320
Min.	0	0	0	0	8	0	20	38	8	0	0	0	58

occurred in 83%, 84% and 90% of all days, respectively. The first and the last date of the occurrence of snow cover with different depths is very variable from year to year.

The annual course of the mean monthly number of days with snow cover with different depth classes (≥1 cm, ≥10 cm, ≥30 cm, and ≥50 cm) indicates that autumn (September — November) and the first part of winter (December) are characterized by a greater number of lower snow cover depths than the second half of the snow season. During the period of snow cover formation, the difference between the mean monthly number of days with snow cover ≥1 cm and ≥50 cm is greater than during the snow-melting period in spring (Tab. 1).

A snow cover ≥1 cm can be expected on average for 47% days/year, for 36% days/year it is higher than 30 cm, and for 31% days/year it is not lower than 50 cm. These data are interesting as they provide information about the period when skiing is possible without greater problems.

The appearance of a snow cover of different depths during the period December — April is very stable, while in the other months it varies from year to year.

According to the annual frequency distribution of the number of days with snow cover ≥1 cm (Fig. 1-middle), snow cover can be expected in 80 to 240 days with gaps in the 90—120 day and 220—230 day intervals. The greatest probability is of a duration of 170—190 days.

In a "normal" snow season, snow cover is present on all days in each month during the period

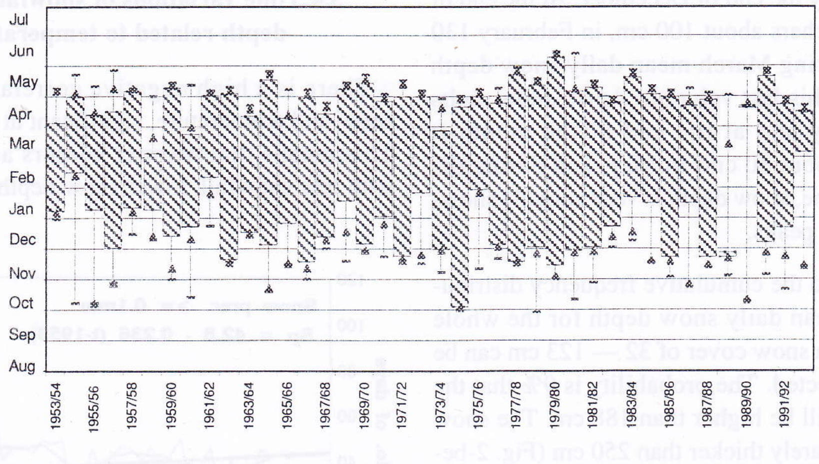

Figure 3. The first and the last date of occurrence of snow depth ≥10 cm (lines), ≥30 cm (triangles), and ≥50 cm (bars) at Zavižan. Period: 1953/54 — 1992/93

Slika 3. Prvi i posljednji datum pojave snježnog pokrivača visine ≥10 cm (crte), ≥30 cm (trokuti) i ≥50 cm (stupići) na Zavižanu. Razdoblje: 1953/54 — 1992/93.

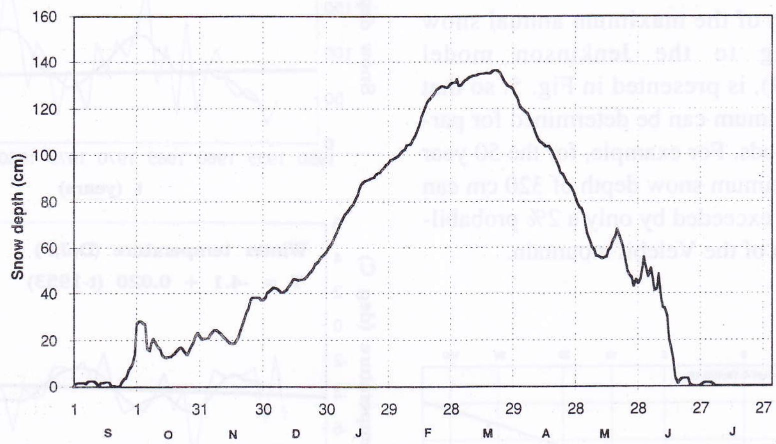

Figure 4. Annual course of the 5-day period means of daily snow depth (cm) at Zavižan. Period: 1953/54 — 1992/93.

Slika 4. Godišnji hod 5-dnevnih srednjaka dnevnih visina snježnog pokrivača (cm) na Zavižanu. Razdoblje: 1953/54 — 1992/93.

January to March, in December for 22 — 31 days and in April for 26 — 30 days (Fig. 2-middle). At the end of autumn (November) snow will be on the ground for 9 — 18 days and at the end of spring (May) the duration of snow cover is between 5 days and two weeks. Outside this interval, snow cover is a rather rare phenomenon.

3.3 Snow depth

The annual course of the mean daily snow depth, obtained as 5-day period averages, presents an important information for different users of the snow data (Fig. 4). A snow cover of about 20 cm during October and the first half of November rises up to about 60 cm by the end of December. At the end of January it reachers about 100 cm, in February 130 cm, while during March mean daily snow depth varies about this last value. In April, snow melts rather rapidly and at the end of the month it amounts to about 80 cm. In May, and during the first half of June, snow depth is very variable showing occasional peaks.

According to the cumulative frequency distribution of the mean daily snow depth for the whole snow season, a snow cover of 32 — 123 cm can be normally expected. The probability is 9% that the snow depth will be higher than 188 cm. The snow cover is very rarely thicker than 250 cm (Fig. 2-below).

The annual maximum snow depths measured during the observed 40-year period at Zavižan appeared most frequently in March (17 cases) and in February (12 cases). The greatest snow depth in a particular winter was from 58 cm in the winter of 1988/89 to 320 cm in the winter of 1983/84 (Tab.1).

The estimation of the maximum annual snow depth according to the Jenkinson model (Jenkinson, 1969), is presented in Fig. 5. so that the expected maximum can be determined for particular return periods. For example, for the 50 year return period maximum snow depth of 320 cm can be expected to be exceeded by only a 2% probability on the top area of the Velebit mountain.

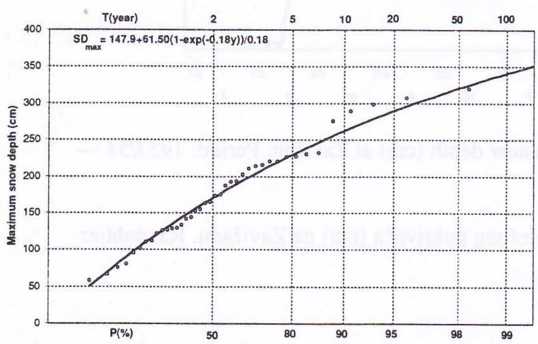

Figure 5. Estimates of maximum snow depth, according to the Jenkinson model, for Zavižan. Period: 1953/54 — 1992/93.

Slika 5. Procjene maksimalnih dnevnih visina snježnog pokrivača prema Jenkinsonovu modelu za Zavižan. Razdoblje: 1953/54 — 1992/93.

3.4 Time variations of snowfall and snow depth related to temperature

There is a high negative correlation between snow and temperature, significant at α=0.05 level. This means that warmer winters are associated with less snowfall, lower snow depth and a shorter

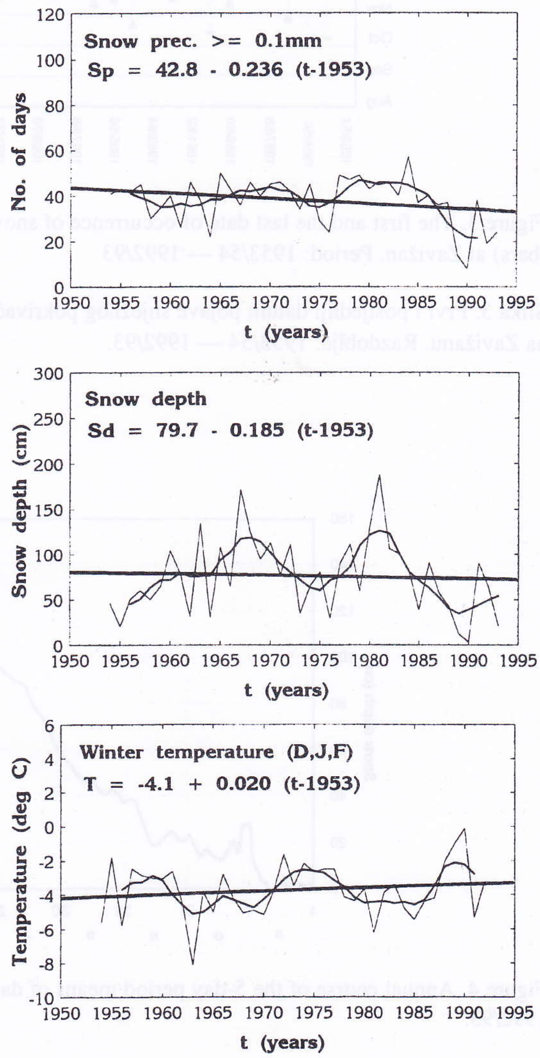

Figure 6. Variations of the mean number of days with snow precipitation ≥0.1 mm (above), mean snow depth (middle) and mean temperature (below), the 5-year binomial moving average series and the linear trends for winter at Zavižan during the period 1953/54 — 1992/93.

Slika 6. Varijacije srednjeg broja dana sa snijegom (količina oborine ≥0.1 mm) (gore), srednja dnevna visina snježnog pokrivača (sredina) i srednja temperatura zraka (dolje), 5-godišnji binomni klizni srednjaci i linearni trendovi za zimu na Zavižanu. Razdoblje: 1953/54 — 1992/93.

Table 2. Correlation coefficients for various snow parameters and air temperature, air pressure and precipitation in winter at Zavižan. Period: 1953/54—1992/1993.

Tablica 2. Koeficijenti korelacije za različite snježne veličine te temperaturu zraka, tlak zraka i oborinu za zimu na Zavižanu. Razdoblje: 1953/54 — 1992/93.

	Temperature	Air pressure	Precipitation
Snow cover	-0,366	-0,393	0,531
Snowfall	-0,463	-0,721	0,728
Snow depth	-0,490	-0,507	0,624

duration of snow cover. The same relations have been obtained on the Swiss Plateau at lower altitude sites up to 1000—1500 m a.s.l. (Rebetez, 1996). At the same time snow exhibits an even stronger negative correlation with air pressure and a positive correlation with precipitation (Tab. 2).

The year-to-year fluctuations (Fig. 6) indicate a less than average number of days with snowfall in 1960/1961, 1963/64, 1988/89, 1989/90, 1991/92 and 1992/93, which in the late 1980s, were also connected with low snow depth. Snow was scarce in the sense of snow duration, in 1953/54 and 1960/61. Poor snow seasons in the sense of duration and abundance, occurred in 1958/59 and the late 1980s. Snow was more abundant in the second half of the 1960s and 1970s and in the early 1980s. Similar snow conditions, regarding duration as well as abundance, appeared also in the Swiss Alps (Beniston et al., 1994) and in the Slovenian Alps (Cegnar, 1996).

The linear trend of winter (D,J,F) snowfall, determined by means of the number of days with snow precipitation ≥0.1 mm and snow depth, indicates a decrease which is not significant, according to the Mann-Kendall test for trend. At the same time, the winter temperature experiences an insignificant increasing trend during the observed 40-year period (Fig. 6-below).

The decrease in days with snow cover and higher snow depths is characteristic of the broader central European area identified also in the High Tatra Mountains (Lapin and Faško, 1996).

4. CONCLUSION

Snow cover can be expected on average for 47% days/year, out of which, for 31% days/year not less than 50 cm. During the snow season, a mean daily snow depth of 32 — 123 cm can be normally expected. The annual snow maximum appears most frequently in March. For the 50 year return period, a maximum snow depth of 320 cm can be expected to be exceeded by an only 2% probability at Zavižan.

The interannual variability is more pronounced in snow depth than in snowfall. Snow has been more abundant in the second half of the 1960s and 1970s as well as in the early 1980s. The linear trends in winter snowfall and snow depth indicate an insignificant decrease in the period 1953/1954 — 1992/1993. The fluctuations of snow parameters, both depth and duration, are in good accordance with the fluctuations of air temperature and air pressure, having a significant negative correlation, and with precipitation, having a significant positive correlation. The obtained results show that the western Dinaric Alps (the northern part of Mount Velebit) experience similar extreme snow conditions as the Alps and Tatra Mountains.

REFERENCES

Beniston M., M. Rebetez, F. Giorgi, M.R. Marinnuci, 1994: An Analysis of Regional Climate Change in Switzerland, *Theor. Appl. Climatol.* **49**, 135-159.

Cegnar T., 1996: Relations Among Significant Temperature, Pracipitation and Snow Cover Anomalies, Proceedings of the 24th International Conference on Alpine Meteorology, ICAM 96, Bled, September 9-13, 1996, 230-236.

Jenkinson A.F., 1969: Statistics of Extremes. Estimation of Maximum Floods. WMO Tech. Note No. **98**, Chapter 5, 183-257.

Juras V. and J. Juras, 1987: Methods of classification of extraordinary meteorological phenomena (in Croatian, abstract in English). Treće jugoslavensko savjetovanje o elem. atm. nepogodama - Opasne pojave na moru, Split, 16-18 XII 1987, Zbornik radova, 1-8.

Lapin M. and P. Faško, 1996: Snow Cover and Precipitation Changes in Slovakia in the 1921-1996 Period, Proceedings of the 24th International Conference on Alpine Meteorology, ICAM 96, Bled, September 9-13, 1996, 259-266.

Mitchell J. M. Jr., et al., 1966: Climate Change, WMO, Tech. Note **79**, Geneva, pp79.

Rebetez M., 1996: Seasonal Relationship Between Temperature, Precipitation and Snow Cover in a Mountainous Region, *Theor. Appl. Climatol.* **54**, 99-106.