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Contributions to Geophysics and Geodesy Vol. 47/4, 2017 (287–297)

Effect of snow cover on soil frost penetration

Jaroslav ROŽNOVSKÝ[1,2], Jáchym BRZEZINA[1]

[1] Czech Hydrometeorological Institute,
Brno, Kroftova 43, Brno 616 67, Czech Republic; e-mail: roznovsky@chmi.cz

[2] Department of Breeding and Propagation of Horticultural Plants,
Faculty of Horticulture, Mendel University in Brno,
Valtická 337, 691 44 Lednice, Czech Republic

Abstract: Snow cover occurrence affects wintering and lives of organisms because it has a significant effect on soil frost penetration. An analysis of the dependence of soil frost penetration and snow depth between November and March was performed using data from 12 automated climatological stations located in Southern Moravia, with a minimum period of measurement of 5 years since 2001, which belong to the Czech Hydrometeorological institute. The soil temperatures at 5 cm depth fluctuate much less in the presence of snow cover. In contrast, the effect of snow cover on the air temperature at 2 m height is only very small. During clear sky conditions and no snow cover, soil can warm up substantially and the soil temperature range can be even higher than the range of air temperature at 2 m height. The actual height of snow is also important – increased snow depth means lower soil temperature range. However, even just 1 cm snow depth substantially lowers the soil temperature range and it can therefore be clearly seen that snow acts as an insulator and has a major effect on soil frost penetration and soil temperature range.

Key words: snow cover, soil frost penetration, soil temperature

1. Introduction

Wintering of animals and plants is to a large extent affected by snow cover, which significantly influences the radiation balance in landscape. Most importantly it has high albedo and low heat conductance (*Zhang et al., 2008*). Long-term analyses of snow cover show that the total amount of snow and snow depth are decreasing, as well as the overall period with snow on ground (*Zahradníček et al., 2016*).

Snow cover affects soil temperature and soil frost penetration (*Pokladníková and Rožnovský, 2006*). Such condition arises when the soil solidifies

doi: 10.1515/congeo-2017-0016

during temperatures below freezing point. Depth of soil frost penetration depends not just on the actual snow depth, but also the decrease in temperature (frost intensity) and vegetation and soil processing, as mentioned in the Meteorological dictionary (*Sobíšek et al., 1993*).

Frost intensity and duration, especially when there is no snow, affects wintering of agricultural crops (*Vašák et al., 2000; Středa and Rožnovský, 2007; Prášil, 2002*). Snow cover decreases soil temperature fluctuation and acts as an insulator. The soil temperature amplitude is much smaller when snow is present compared to the amplitude of air temperature. In the absence of snow cover and occurrence of severe frosts, there is a risk of significantly low soil temperatures, which has negative impact on plants (*Inouye, 2000*).

For example, in 1994, Pilon and his team removed snow around maple trees at high elevations, which resulted in decrease of soil temperature by 10 °C and this in turn had an immediate effect on certain physiological processes and led to significantly larger and earlier leaf loss (*Pilon et al., 1994*).

Based on the most recent climatological models, as a result of the ongoing climate change it is likely that average air temperatures will rise (*IPCC, 2013*). The level of increase will depend on the emission release of greenhouse gases in the future. There are several emission scenarios. The RCP 4.5 (stable emissions) assumes an increase in the Czech Republic by the end of 21st century by on average 2.4 °C. The RCP 8.5 scenario predicts an increase of 4.9 °C (*Štěpánek et al., 2016*). Higher air temperature leads to lower soil temperatures, because there is lower probability of snowing, snow accumulation and snow melts quicker. Absence of snow means the soil has no insulation and frosts can have significant negative impact on vegetation.

This paper analysed the effect of snow cover on soil temperature at a 5 cm depth. The effect was analysed for different snow depth and compared with air temperature amplitude at 2 m.

2. Data and methods

The input data used were from 12 automated climatological stations of the Czech Hydrometeorological Institute, all located in South Moravia and with a minimum of 5 years in operation. Data for snow are recorded daily at 7 AM. Soil temperature at 5 cm depth is measured in 10-minute interval. For the air temperature at 2 m data is also available in 10 minute steps. Prior to the analysis, the data was subjected to a quality check (*Štěpánek et al., 2016*).

Given the difficulty of measuring soil frost penetration there are currently no data available for this parameter, it is not measured at the climatological stations. It was therefore assumed that soil frost is present at temperatures below 0 °C. Authors are aware that this assumption is not completely accurate. The analysis looked at a period between November and March, the three winter months (Dec–Feb) and the individual months separately. This period was chosen because snow between April and October is only very rare in the Czech Republic, usually only present at very high elevations. The parameters analysed included maximum and minimum daily air temperature at 2m, average, maximum and minimum soil temperature, daily temperature amplitude and comparison of the differences depending on whether snow was present ($\geq$ 10 cm) or there was no snow or snow cover was $<$ 10 cm, and similar analysis performed also for the depth threshold 5 cm and 1 cm.

3. Results

November–March

Daily air temperature amplitudes at 2 m (difference between daily maximum and minimum) were compared for days with snow cover higher than or equal to 10 cm and days with no snow cover or snow cover less than 10 cm deep. Fig. 1 shows that there are no significant differences, sometimes the amplitude is higher for days with snow cover, at other stations it is the other way around.

Subsequently an equivalent graph was created, but instead of using 2 m air temperature, the soil temperature at 5 cm depth was used. Fig. 2 shows a very clear difference, where at all stations, the average daily soil temperature amplitude was much lower when there was snow cover present ($\geq$ 10 cm).

Table 1. summarizes the average differences between minimum and maximum temperature for all stations included in the analysis.

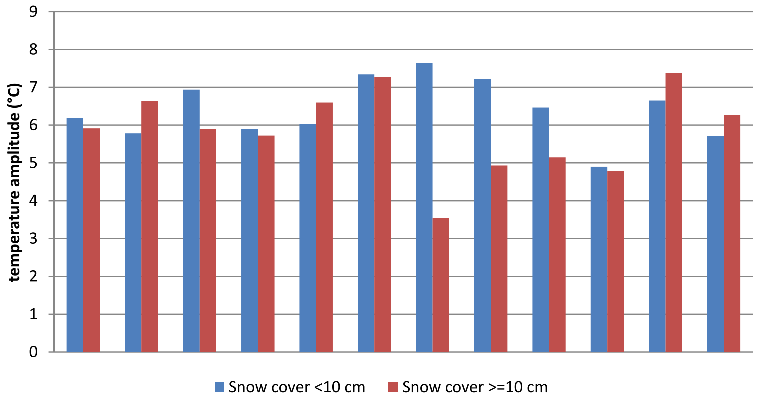

Fig. 1. Average daily air temperature amplitude at 2 m for Nov–Mar for the 12 stations analysed.

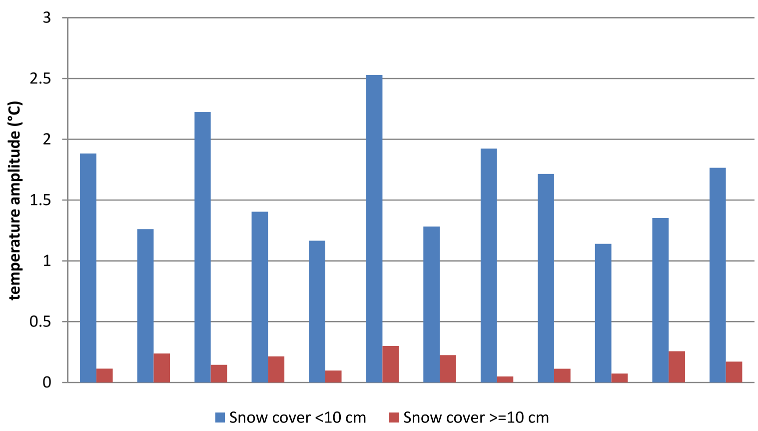

Fig. 2. Average daily soil temperature amplitude at 5 cm depth from Nov to Mar for the 12 stations analysed.

To determine the importance of the actual snow depth, a similar analysis was performed, but using s threshold of 5 cm and 1 cm (i.e. period "with snow" classified as snow cover deeper than or equal to 5 or 1 cm). Results are given in Table 2 and Fig. 3.

Results are compared in Fig. 4. The figure shows the station in Kroměříž as an example, and a period from Nov 2005 to Mar 2006. This particular winter there was relatively lot of snow.

The graph shows the snow depth (grey) and air temperature amplitude

Table 1. Summary of amplitudes, maximums, minimums of air temperature at 2 m and soil temperature at 5 cm depth, from Nov to Mar.

	Air temperature (2 m)		Soil temperature (5 cm)	
	Snow $<$ 10 cm	Snow $\geq$ 10 cm	Snow $<$ 10 cm	Snow $\geq$ 10 cm
Average daily amplitude	6.40 °C	5.84 °C	1.64 °C	0.17 °C
Maximum average daily amplitude	7.64 °C Brod nad Dyjí	6.64 °C Dukovany	2.53 °C Brod nad Dyjí	0.26 °C Velké Meziříčí
Minimum average daily amplitude	4.90 °C Protivanov	3.54 °C Pohořelice	1.14 °C Protivanov	0.05 °C Lednice
Absolute maximum daily amplitude	24.6 °C Brod nad Dyjí	23.9 °C Vatín	26.7 °C Kuchařovice	9.1 °C Kostelní Myslová
Average	2.00 °C	–2.91 °C	3.07 °C	0.24 °C
Average daily maximum	5.22 °C	–0.07 °C	3.96 °C	0.33 °C
Average daily minimum	–1.17 °C	–5.91 °C	2.32 °C	0.16 °C

Table 2. Average daily air temperature amplitude (2 m) and soil temperature amplitude (5 cm) at various snow depths from Nov to Mar.

	Air temperature (2 m)	Soil temperature (5 cm)
Snow cover $\geq$ 10 cm	5.84 °C	0.17 °C
Snow cover $<$ 10 cm	6.40 °C	1.64 °C
Snow cover $\geq$ 5 cm	6.08 °C	0.24 °C
Snow cover $<$ 5 cm	6.43 °C	1.74 °C
Snow cover $\geq$ 1 cm	5.85 °C	0.38 °C
Snow cover $<$ 1 cm	6.58 °C	1.92 °C

at 2 m (red) and soil temperature amplitude (blue) at 5 cm depth. The graph clearly shows that while the air temperature (red) shows no clear correlation with snow depth, there is a significant correlation between snow depth and soil temperature amplitude. On days with snow cover, the soil temperature amplitude is either 0 °C or very low – i.e. the soil temperature on days with snow cover fluctuates only very little.

4. Individual months

Equivalent analysis was also performed for each winter month separately and winter period as a whole (Dec–Feb). Results of this analysis are given in Fig. 5.

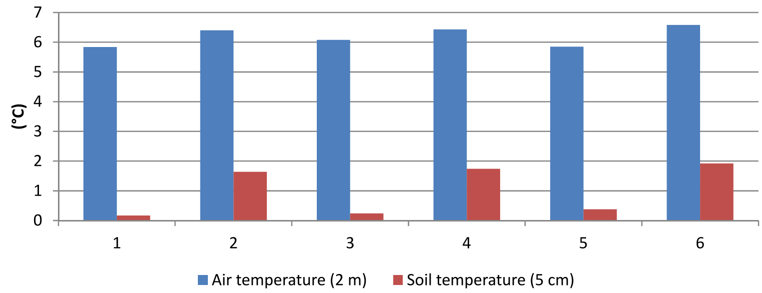

Fig. 3. Average daily air temperature amplitude at 2 m and soil temperature (5 cm) amplitude at various snow depth from Nov to Mar. 1 – snow $\geq$ 10 cm, 2 – snow $<$ 10 cm, 3 – snow $\geq$ 5 cm, 4 – snow $<$ 5 cm, 5 – snow $\geq$ 1 cm, 6 – snow $<$ 1 cm.

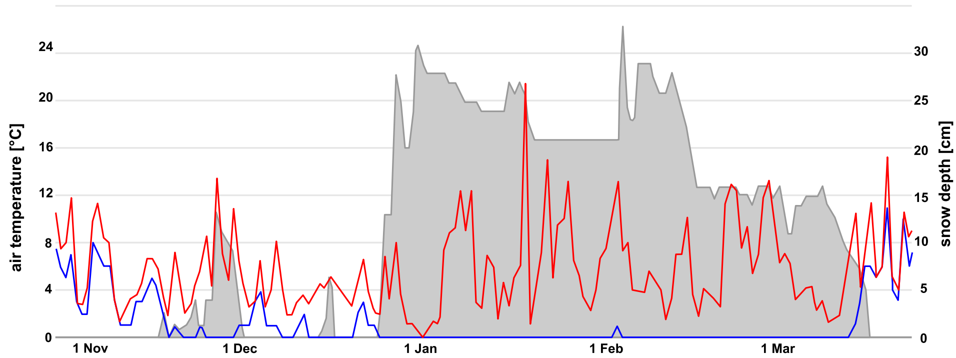

Fig. 4. Daily air temperature amplitude at 2 m (red) and soil temperature amplitude at 5 cm (blue) correlated with snow depth (grey) for the station in Kroměříž from Nov 2005 to Mar 2006.

5. Discussion

Results show that in snow presence, soil temperatures fluctuate to a much lesser extent compared to periods with no snow (or snow depth below a specific threshold). When there is no snow cover, or only very little snow, the soil temperature amplitude can even exceed the air temperature amplitude at 2 m for that day. For example, the absolute overall amplitude of air temperature at 2 m (Nov–Mar) was 24.6 °C, while for soil temperature at 5 cm depth it was 26.7 °C. The difference would be even larger if warmer months were included in the analysis as well.

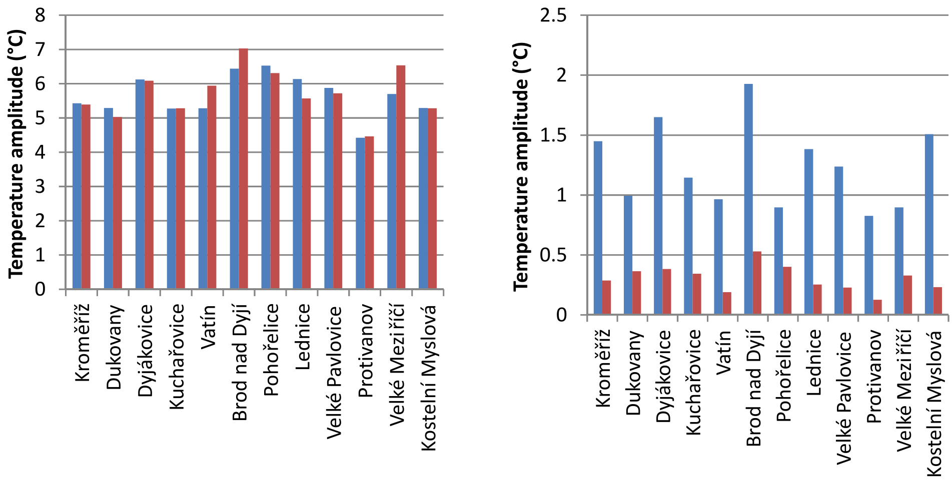

Fig. 5a. Average daily air temperature amplitude at 2 m (left) and soil temperature amplitude at 5 cm (right), for winter period (Dec-Feb). Snow depth < 10 cm (blue), snow depth ≥ 10 cm (red).

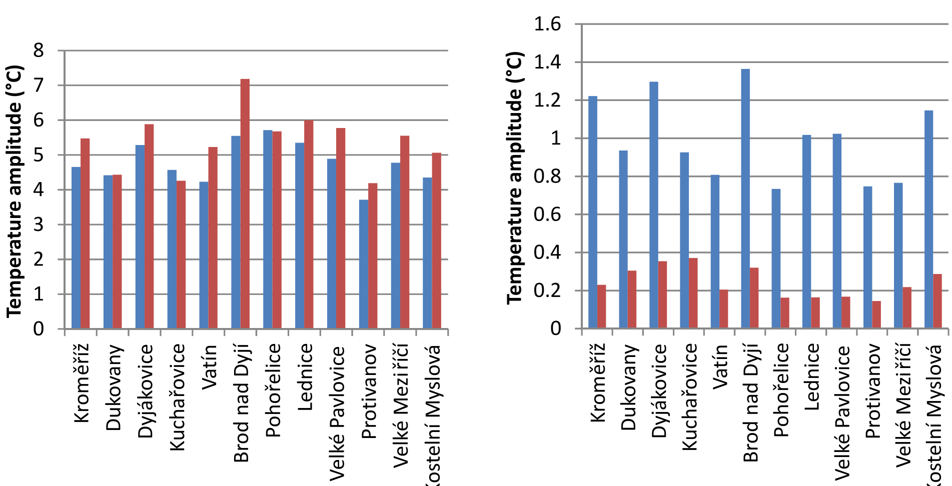

Fig. 5b. Average daily air temperature amplitude at 2 m (left) and soil temperature amplitude at 5 cm (right), for December. Snow depth $<$ 10 cm (blue), snow depth $\geq$ 10 cm (red).

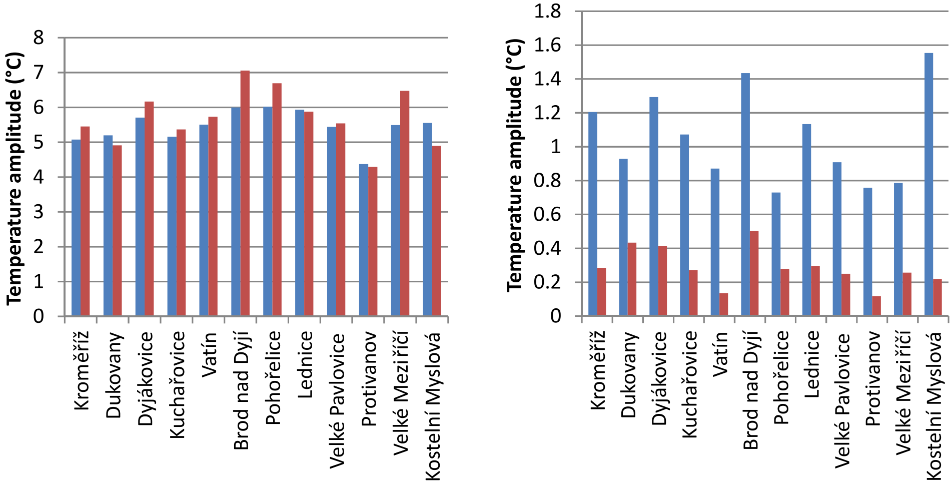

Fig. 5c. Average daily air temperature amplitude at 2 m (left) and soil temperature amplitude at 5 cm (right), for January. Snow depth < 10 cm (blue), snow depth ≥ 10 cm (red).

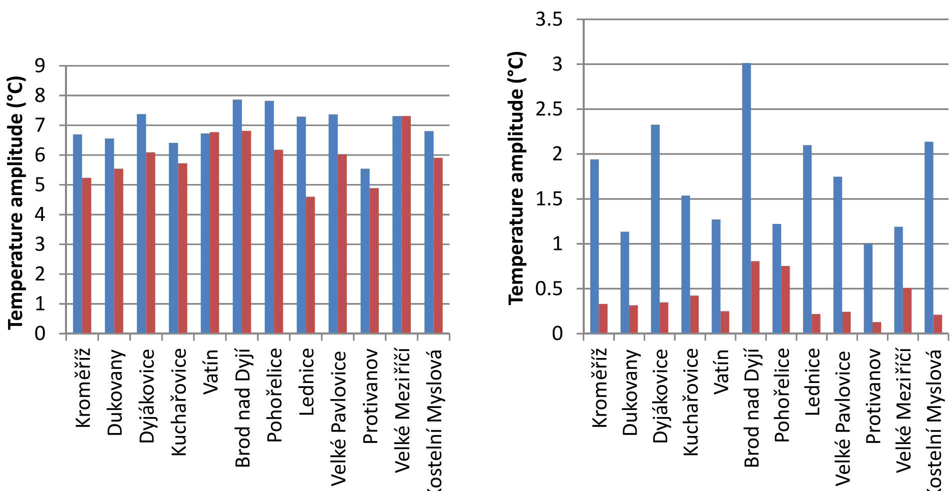

Fig. 5d. Average daily air temperature amplitude at 2 m (left) and soil temperature amplitude at 5 cm (right), for February. Snow depth < 10 cm (blue), snow depth ≥ 10 cm (red).

The differences in temperature fluctuation can be seen even when looking at daily maximum and minimum. Daily maximum temperatures of air temperature at 2 m during snow depth above or equal to 10 cm, in the entire period from Nov-March, were on average 5 °C or more lower, the difference in daily minimums is even larger. In contrast, the differences in daily soil temperature on days with snow cover 10 cm or higher are only very small or none. Next part of the analysis looked at the effect of the actual snow depth. Results in Table 2 and Fig. 3 show two facts. First, as the snow depth decreases, the daily amplitude of soil temperature increases, which proves the hypothesis and is most likely due to the fact that lower snow depth does not have such insulation properties. The average daily amplitudes of soil temperature during snow cover of $\geq$ 10 cm, $\geq$ 5 cm and $\geq$ 1 cm are 0.17, 0.24 and 0.38 °C respectively. Second, even when the snow depth is only 1cm, the daily amplitude of soil temperature is still much lower than in the complete absence of snow (0.38 vs 1.92 °C). This shows that even 1 cm of snow has significant insulation effect. Differences in amplitude of air temperature at 2 m show no correlation with snow depth.

Analysis of individual months and winter period shows that largest differences are in February, however it should be mentioned that this could be due to larger amplitudes in temperature in general, observed in February. End of February is characterized by higher temperatures, while at night the temperatures still fall very low. The trends mentioned above, however, can be observed in each period analysed.

6. Conclusion

Soil temperature affects physiological processes of wintering plants. Very low temperatures have negative impact on cells, which can be clearly seen from the damages caused by black frosts. An analysis of the effect of snow cover on soil frost penetration was performed at 12 stations in South Moravia in the period from November to March. It showed that snow cover thanks to its physical properties has significant insulation effects and to a great extent decreases soil temperature fluctuation. Higher snow depth resulted in lower soil temperature amplitude; the difference however, was significant even for just 1 cm deep snow. Unlike soil temperature, the air temperature amplitude at 2 m has no correlation with snow cover.

Given the current trend of global warming and in accordance with the most recent climatological models, it can be assumed that the temperatures will be increasing in the future and there will be less days with snow on ground, however this does not mean there will be no frosts and such frosts, in the absence of snow, can potentially cause major damages for example in agriculture.

Acknowledgements. This paper has been created as part of a project of the National Agriculture Research Agency "Development of automated tools for optimization of erosion monitoring of cropland using remote methods", registration number QK1720289.

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