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THE LINK BETWEEN SNOW COVER CHARACTERISTICS AND DROUGHT PROPAGATION PROCESSES

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Abstract

- The ecological and hydrological impacts of snow cover are important for water-resource issues. This study presents the linkage between snow cover characteristics and standardized precipitation evapotranspiration index (SPEI). To quantify the change in current snow phenology, we identified the onset and termination dates of snow cover from 1961 to 2017 using 184 stations in the Czech Republic.
- The basic snow cover characteristics used in this study consist of the first day and the last day of snow cover, the number of days with snow cover (DSC) with ≥1cm, ≥10cm and ≥20cm, and snow water equivalent (SWE). Changes in the snow cover characteristics, the number of frost days and days with Tmin>0°C were anylised during the cold season (October-March) and winter season (December-February) over the periods 1961-2016, 1961-1990 and 2001-2016. Additionally, the SWE and precipitation (P) ratio was calculated to examine potential changes in the balance between snow and rain over the cold season.
- Results show a decline in the volume of snow melt water, and liquid precipitation is more than solid precipitation during the cold season. Decreasing trends in SWE/P ratio are most pronounced at lower elevations, and are associated with trends toward fewer snowfall days and the shortening of time that snow is on the ground.
- Decreases in the occurrences of frost days appear to be contributing to decreases in DSC ≥1cm, ≥10cm and ≥20cm. The period 2001-2016 shows substantially decreasing of DSC ≥10 cm and 20cm at higher elevations, its trend varies between 16.5 and 26.3 days decade^{-1} during the cold season. The end date of snow cover over the last 16 years shows a rapid advance mostly in the western hilly areas.

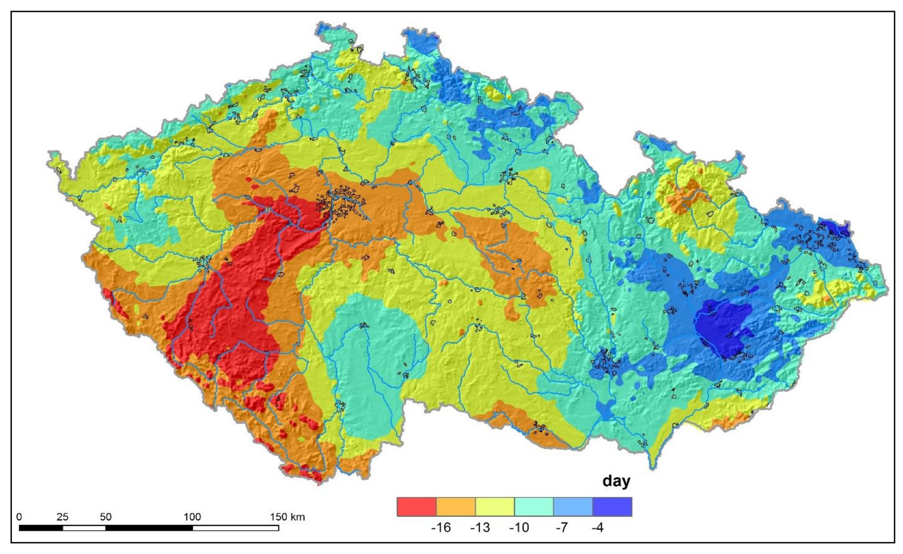

Fig. 1. The changes in the termination dates of snow cover between two periods 1961-1990 and 2001-2017 in the CR.

Tab. 1 Spatiotemporal statistical characteristics in the termination dates of snow cover in the CR.

m a.s.l.	Area, %	Earliest	Latest	Average
1961-1990				
<300	24.2	4 March	1 April	14 March
301-600	59.3	7 March	28 April	29 March
601-900	14.4	25 March	13 May	14 April
>900	2.1	10 April	27 May	2 May
2001-2017				
<300	24.2	23 February	24 March	5 March
301-600	59.3	28 February	19 April	18 March
601-900	14.4	9 March	6 May	2 April
>900	2.1	26 March	18 May	19 Apr

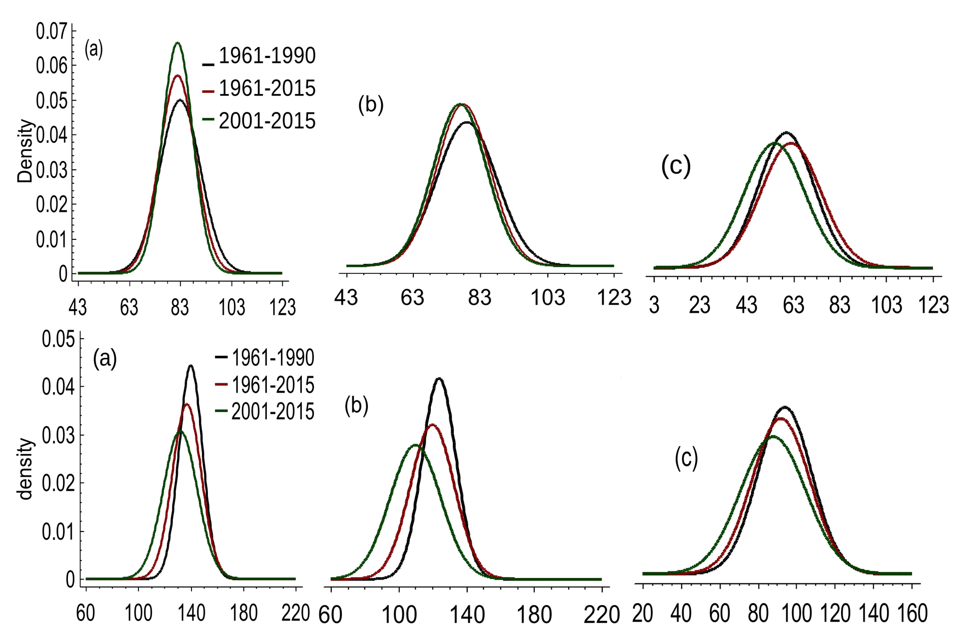

Fig. 2 Shifts in the number of frost days over the periods 1961-1990, 1961-2015 and 2001-2015 during the cold season (top) and winter season .

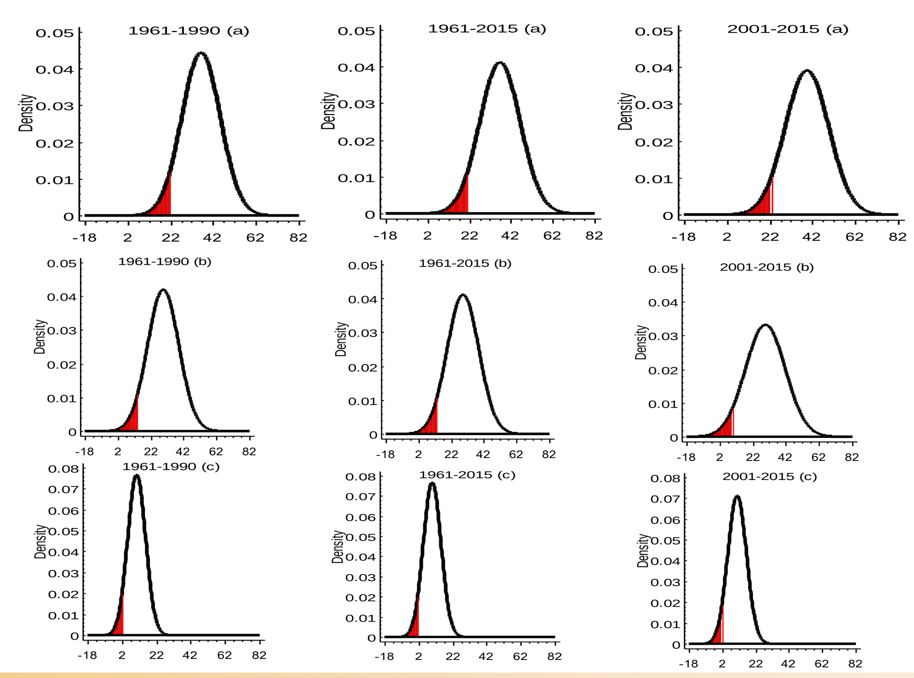

Fig. 3 Shifts in DSC ≥1cm (top), ≥10cm (middle) and ≥20 cm (bottom) during the winter season over the periods 1961-1990, 1961-2015 and 2001-2015 for three stations: (a) Churaňov, (b) Svratouch and (c) Doksany.

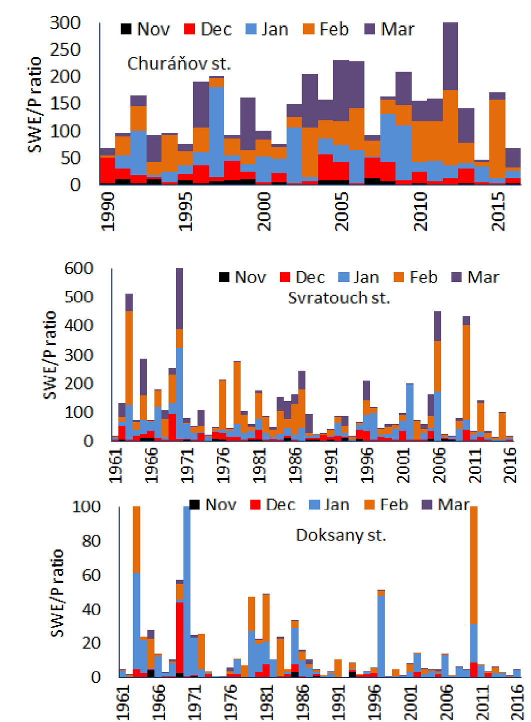

Fig. 4 Temporal evolution of the monthly SWE/P ratio during the cold season.

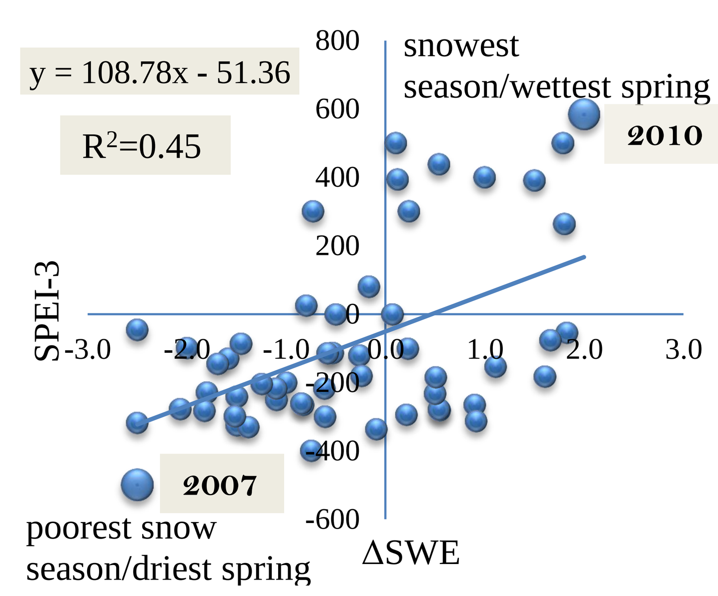

Fig. 5 Relationship between the winter SWE anomalies and spring SPEI-3 in the lowland of the north-western region.

Data and methods

- The basic snow cover characteristics used in this study consist of the first day and the last day of snow cover, DSC ≥1cm, ≥10cm and ≥20cm, and SWE. Changes in the snow cover characteristics, the number of frost days and days with Tmin>0°C were anylised during the cold season (October-March) and winter season (December-February) over the periods 1961-2016, 1961-1990 and 2001-2016.
- Additionally, the SWE and precipitation (P) ratio was calculated to examine potential changes in the balance between snow and rain over the cold and winter seasons.
- Correlation analysis and regression were used to analyse relationship between the spring SPEI-3 and winter SWE. The SPEI at 3-month lags was calculated for the period 1961-2016, based on precipitation and input dataset for potential evapotranspiration by the Penman-Montheith method. Snow cover characteristics from the Czech Hydrometeorological Institute was utilized for accuracy assessment of our results.
- This data originates from the snow-richest mountainous/highlands climatological stations (Churáňov/Svratouh), and lowlands reference station (Doksany) with more frequency of snow-free days.
- T o best represent the current snow phenology, we identified the changes in the termination dates of snow cover for 184 climatological stations.

Results

- At the snow- richest site (Churaňov), the mean number of days with snow cover in March and April varies from less than 5 days in the poorest snow seasons to more than 25 days in the snowiest seasons. Many more days with snow cover in November are observed at Churaňov and Svratouch, due to higher elevation, than in the lowland north-western part (Doksany). DSC in early autumn varies from year to year. In most of the highland sites, there were seasons when snow cover was not recorded at all in October; on the other hand, there are also years, where in single seasons snow cover persisted during the entire month.
- The shifts in both onset and end dates of snow cover toward later and earlier dates, respectively, are most pronounced at higher elevations. The end date of snow cover over the last 16 years shows a rapid advance mostly in the western hilly areas (Fig. 1 and Tab. 1).
- Decreases in the occurrences of frost days appear to be contributing to decreases in DSC ≥1cm, ≥10cm and ≥20cm (Tab. 2). The period 2001-2016 shows substantially decreasing of DSC ≥10cm and ≥20cm at higher elevations, its trend varies between 16.5 and 26.3 days decade^{-1} during the cold season.
- Regime shifts in the number of frost days (Fig. 2) have caused shifts in DSC (Fig. 3). The probability density functions displayed in Fig. 2-3 shown an asymmetric patterns in DSC ≥1cm, ≥10cm and ≥20 cm and the number of frost days during the winter season over the period 2001-2015 in the highland and lowland sites. This asymmetry implies a significantly skewness to the left in the lowest elevation site, shifting towards less frequent occurrences of DSC and the number of frost days.
- The ratio of SWE to P for October–March is calculated (Fig. 4). Temporal evolution of the monthly SWE/P ratio during the cold season for the snow-richest site shows maximum SWE reached around February-March, while rainfall is greater than SWE values in November-December (Fig. 4).
- On average, outside the mountains, has been experiencing strong decreases in the SWE/P ratio, a result suggesting that the precipitation has been falling as rain more often than snow in the last 5 decades. Results show decreasing trends in SWE/P ratio are most pronounced at lower elevations, and are associated with trends toward fewer snowfall days and the shortening of time that snow is on the ground.
- For Doksany, changes of either or both types of precipitation (SWE and rainfall) influence the SWE/P ratio. While for Svratouch, the fraction of winter precipitation that fell as snowfall has decreased.
- In the winter half-year, the correlation between SWE and P was not statistically significant. A positive correlation has been identified between the inter-annual variations of winter SWE (DSC) and the SPEI-3 in the subsequent spring (Fig. 5).
- Hence, the winter snow conditions control drought conditions through the following spring (around 45%). The shortened snow duration and the markedly low SWE (DCS) during the winter of 2006/2007, 2011/2012, 2014/2015 and 2015/2016 had a large impact on the following spring moisture conditions, much more so than spring-fall precipitation.
- From this, it can be concluded that the winter snow conditions supply much of the soil moisture that was similar to previous study.

Tab. 2. Observed long-term changes (day decade^{-1}) of the number of frost days and days with snow cover ≥1cm, ≥10cm and ≥20cm over the periods 1961-2016, 1961-1990 and 2001-2016.

	Changes of the number of days with snow cover per decade									Trend of the number of frost days		
	≥1cm			≥10cm			≥20cm					
	1961-1990	1961-2016	2001-2016	1961-1990	1961-2016	2001-2016	1961-1990	1961-2016	2001-2016	1961-1990	1961-2016	2001-2016
Churáňov – 1118 m a.s.l.												
Nov	0.1	-0.7	-4.1	-1.0	-1.0	-5.9	0.1	-0.6	-4.6	0.3	-0.9	-3.9
Dec	-0.7	0.0	-2.8	-2.1	-0.8	-5.1	-1.6	-1.3	-7.5	-1.5	-0.5	-5.7
Jan	1.3	0.5	0.4	-1.2	-0.5	-6.0	-0.3	-0.7	-11.3	-0.7	-0.5	-0.1
Feb	-0.1	-0.1	-3.1	0.1	-0.2	-6.0	0.7	-0.1	-2.1	-0.6	-0.3	3.4
Mar	-0.7	0.0	0.1	-0.2	-0.9	-5.6	0.1	-1.1	-7.4	-0.9	-0.5	2.7
DJF	1.5	0.9	-1.5	-3.9	-1.0	-8.5	-3.7	-2.2	-13.4	-1.1	-0.4	4.0
cold	0.8	0.3	-4.5	-6.6	-3.1	-16.5	-5.3	-4.4	-23.5	-5.6	-2.4	11.2
Svratouch – 737 m a.s.l.												
Nov	0.5	-0.5	-2.1	-0.4	-0.4	-2.4	0.4	0.0	-1.3	0.1	-1.7	-1.7
Dec	-0.6	-0.2	-6.5	-1.1	-1.1	-9.1	-1.9	-0.9	-5.4	-1.8	-0.8	-0.8
Jan	0.2	-0.2	0.5	-1.1	-0.7	-6.8	-1.7	-1.0	-13.1	-0.8	-0.6	-0.6
Feb	-0.3	-0.2	-3.7	0.0	-0.7	-1.7	0.2	-1.1	-3.4	-0.4	0.0	0.0
Mar	-0.3	-0.2	-1.3	-0.4	-1.1	-7.8	-0.8	-1.3	-7.0	-0.7	-0.6	-0.6
DJF	-0.2	-0.2	-6.6	-5.8	-3.0	-13.1	-5.7	-3.6	-19.3	0.1	-1.7	-1.7
cold	0.3	-0.8	-8.5	-7.3	-4.5	-20.8	-6.7	-4.9	-26.3	-1.8	-0.8	-0.8
Doksany – 158 m a.s.l.												
Nov	0.4	-0.1	-0.6	-0.1	0.0	-	-	-	-	0.1	-1.7	-6.2
Dec	-0.6	-0.1	-2.7	-0.6	-0.1	1.1	-0.2	0.0	0.4	-1.8	-0.8	-6.8
Jan	0.9	-0.1	0.3	0.0	-0.5	0.4	-0.2	0.0	0.4	-0.8	-0.6	-1.8
Feb	-0.4	-0.1	0.3	-1.1	-0.3	1.9	-0.6	-0.2	0.0	-0.4	0.0	1.3
Mar	-0.6	-0.1	0.3	-1.0	-0.4	-	-	-	-	-0.7	-0.6	-2.6
DJF	0.1	-0.2	-0.8	-2.1	-0.9	4.3	-1.1	-0.3	1.0	0.1	-1.7	-6.2
cold	-0.1	-0.3	-0.7	-3.4	-1.3	4.3	-1.1	-0.3	1.0	-1.8	-0.8	-6.8

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