THE LINK BETWEEN SNOW COVER CHARACTERISTICS AND DROUGHT PROPAGATION PROCESSES

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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. Additionaly, 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.

Keywords: snow phenology, days with snow-cover, snow water equivalent, SPEI

INTRODUCTION

Previous studies have documented an earlier disappearance of snow cover in recent decades and subsequently an increase of snow-free days on a continental scale. Although, it has been proven that the amount of snow is decreasing, the snow cover extent on the lands of the Northern Hemisphere (NH) does not reveal such an obvious trend (Lemke et al., 2007). The reduction of snow is observed in the early spring due to higher air temperatures, while in winter the increase in snow extent is observed due to higher precipitation. The next question arises, namely what are the changes in snow cover in the 21st century. Raisanen (2008) reported that the sign of projected changes of seasonal snow water equivalent (SWE) at the end of the 21st century with respect to the present is spatially variable. Projected winter SWE change over the NH could be approximately divided into increasing and decreasing zones, with increasing SWE only observed over very cold regions. The largest SWE decreases projected over lower elevations. Shi and Wang (2015) showed that the multi-model ensemble projects significant decreases in SWE over the 21st century for most regions of the NH for representative concentration pathways (RCPs) 2.6, 4.5 and 8.5. SWE is projected to undergo the largest decreases in the spring period where it is most strongly negatively correlated with air temperature. Brutel-Vuilmet et al. (2013) provided a short assessment of the simulated present-day snow cover, including its current trends, and analyse the dominant factors determining the future evolution of NH spring snow cover as simulated by the CMIP5 models. They addressed the question: how well do CMIP5 models capture present day seasonal snow extent and observed recent trends? On average, the models reproduce the observed snow cover extent very well, but the significant trend towards a reduced spring snow cover extent over the 1979–2005 period is underestimated. SWE responds to both precipitation and air temperature which are both projected to increase in the 21st century in the CR (Štěpánek et al. 2016) and the magnitude of the changes (Raisanen, 2008) depended on the shortened snow accumulation period, the fraction of precipitation that falls as snow (influenced by total precipitation and air temperature).

In this paper, observed spatiotemporal patterns in the shifts in both onset and end dates of snow cover, and in the number of days with snow cover (DSC) ≥1cm, ≥10cm and ≥20cm across the CR are examined for the period 1961-2016. The aim on this study is also to determine the linkage between SWE anomalies and standardized precipitation evapotranspiration index (SPEI).

MATERIALS 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. Additionaly, 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. To best represent the current snow phenology, we identified the changes in the termination dates of snow cover for 184 climatological stations.

RESULTS

Figure 1 shows the monthly climatology of the number of days with snow cover, which is highest in January from 20.7% to 40.2%. At snowiest stations there are no large differences between DSC during individual winter months. 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.

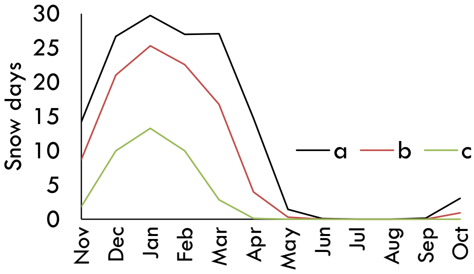

Figure 1. The multiannual cycle of the number of days with snow cover for three stations situated in mountain (a-Churaňov), highland (b-Svratouch) and lowland (c-Doksany) sites over the period 1961-2016.

Decreases in the occurrences of frost days appear to be contributing to decreases in DSC ≥1cm, ≥10cm and ≥20cm (Tab. 1). 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.

Table 1. 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

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.

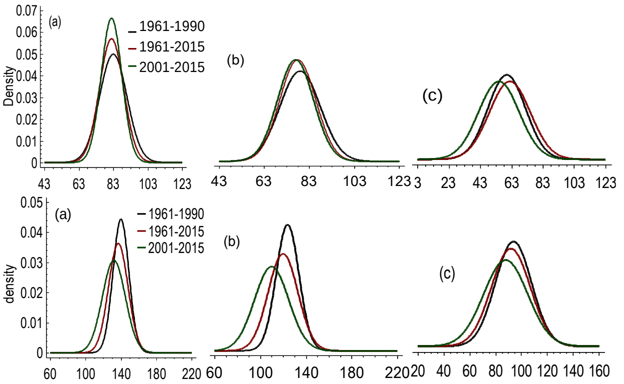

Figure 2. Shifts in the number of frost days over the periods 1961-1990, 1961-2015 and 2001-2015 during the cold season (top) and winter season (bottom) for Churáňov (a), Svratouch (b) and Doksany(c).

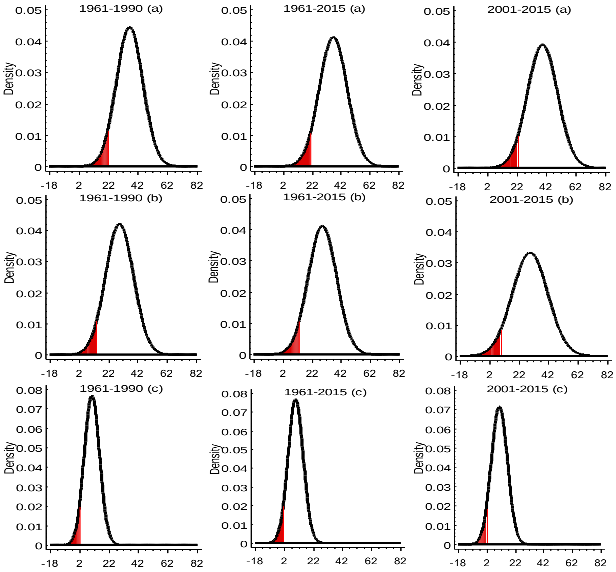

Figure 3. Shifts in DSC ≥1cm (top), ≥10cm (middle) and ≥20 cm (bottom) during the winter season over the periods 1961-1990, 1961-2015 and 2001-2015 for three stations: (a) Churaňov, (b) Svratouch and (c) Doksany.

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.

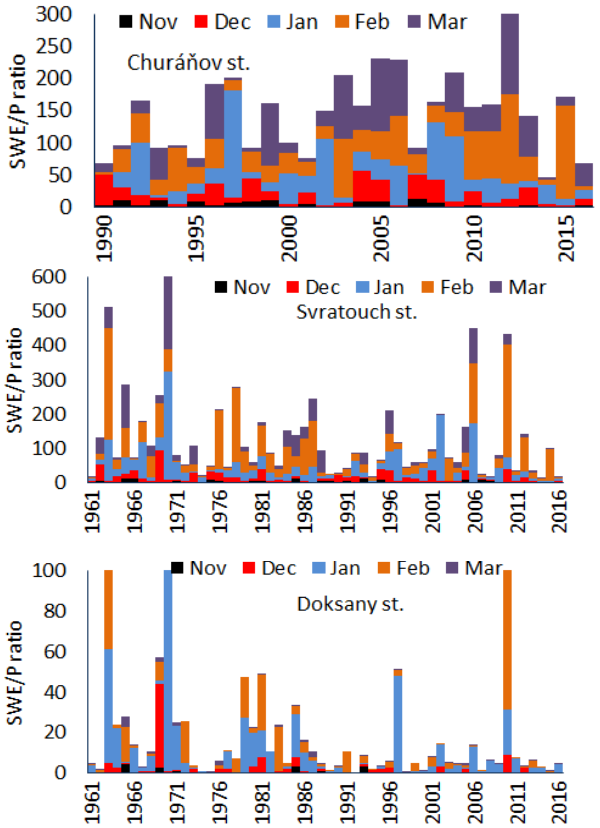

Figure 4. Temporal evolution of the monthly SWE/P ratio during the cold season.

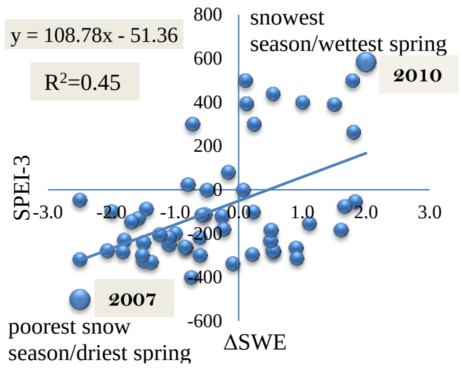

Figure 5. Relationship between the winter SWE anomalies and spring SPEI-3 in the lowland of the north-western region.

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 (Potopová et al., 2016).

Table 2. 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

**various altitude levels: up to 300m, 301-600m, 601-900m and >900m.*

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. 6 and Tab. 2).

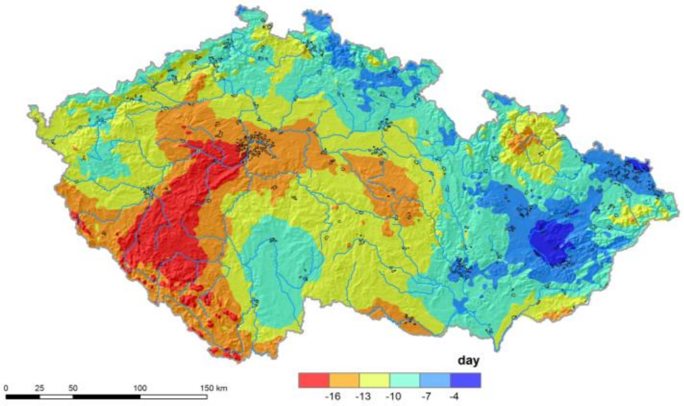

Figure 6. The changes in the termination dates of snow cover between two periods 1961-1990 and 2001-2017 in the CR.

CONCLUSION

The presented snow cover characteristics for the CR includes mean snow cover start, and snow cover melt for the period 1961-2017. Changes in DSC are very likely associated with changes in the number of frost days and decreasing snow cover duration. The number of days with Tmin>0° during the cold season increases, and may change the rain–snow ratio (fraction of solid precipitation), and will act to increase the rate of snow melt. Precipitation amount during the cold season shows an increase, but DSC and SWE decreases in all month of the cold season, this indicates that the competition between liquid and solid precipitation influences the change in SWE/P ratio. The reduced DSC (SWE) impacted the following early summer’s moisture conditions, and this impact was not remediated by early summer precipitation.

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LITERATURE

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