Changes in seasonal snowpack in mountain catchments in Czechia

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Goals

- To analyse long-term changes and trends in selected snowpack characteristics, such as SWE, snow cover duration, and snow melt
- To relate the detected changes to changes in air temperature at different elevations





Data and methods

Study Area:

- 40 mountain catchments in Czechia
- 22 meteorological stations
- 40 hydrological stations



Mann-Kendall test and

Sen's slope was calculated for:

- mean temperature (T)
- precipitation rate (P)
- snowfall fraction (SF)
- snow water equivalent (SWE)
- number of days with SWE > 5 mm (DWS)
- snow melt rate
- day of year of snow cover onset (DOY onset)
- day of year of snow cover melt-out (DOY melt-out)

Conceptual semi-distributed hydrological model HBV-light was used to simulate daily SWE for defined elevation zones for years 1965-2014.



Model calibration



- Genetic algorithm procedure was used for model calibration.
- Combination of 3 objective criteria was used to evaluate the goodness-of-fit of the model:
 - Log Nash-Sutcliffe efficiency for runoff (Rrunoff)
 - Nash-Sutcliffe efficiency for SWE (RswE)
 - Volume error (Rvol)
- Split sample approach:
 - Calibration 1980-1997
 - Validation 1998-2014
- Median of 100 calibrations results was used for further statistical analysis



Long-term trends for cold season

Rolava -	0.025	3.394	-0.176	-0.399	-0.229	0.000	-0.250	-0.429
Rolava -	0.025	2.954	-0.189	-0.239	-0.442	-0.062	-0.333	-0.429
Ostruzna -	0.025	1.477	-0.224	-0.041	-0.233	0.147	-0.324	-0.600
Stassky_potok	0.028	0.231	-0.222	-0.156	-1.025	0.000	-0.462	-0.853
Tepla_Vitava -	0.027	-0.286	-0.363	-0.506	-1.866	0.000	-0.571	-0.706
Spulka -	0.028	0.180	-0.195	-0.044	-0.621	0.138	-0.467	-0.714
Studena_Vitava -	0.027	-0.280	-0.284	-0.318	-1.726	0.115	-0.511	-0.619
Volynka -	0.028	1.413	-0.343	-0.050	-0.791	0.160	-0.213	-0.750
Tepla_Vitava	0.027	-0.248	-0.303	-0.345	-1.606	0.083	-0.556	-0.880
Blanice -	0.021	0.903	-0.178	-0.009	-0.130	-0.026	-0.364	-0.318
Blanice -	0.021	0.857	-0.244	-0.003	-0.200	0.030	-0.321	-0.389
Jerice -	0.030	-1.679	-0.102	-0.321	-1.252	0.042	-0.615	-1.130
Cerna_Nisa	0.030	-2.144	-0.144	-0.895	-2.755	0.000	-0.561	-0.889
Smeda -	0.030	-2.094	-0.192	-0.842	-2.372	0.031	-0.444	-0.763
Luzicka_Nisa -	0.030	-2.004	-0.159	-0.597	-2.072	0.000	-0.524	-1.080
Cerna_Nisa -	0.030	-2.345	-0.193	-2.084	-4.224	0.000	-0.556	-0.833
Smeda -	0.030	-2.240	-0.193	-1.909	-3.876	0.000	-0.478	-0.765
Cerna_Desna -	0.027	-1.628	-0.148	-2.085	-2.949	-0.094	-0.450	-0.556
Kamenice -	0.027	-1.367	-0.160	-0.961	-1.833	-0.184	-0.429	-0.568
E Mumlava -	0.032	-0.821	-0.218	-1.662	-2.365	-0.033	-0.500	-0.618
Jizera -	0.032	-0.714	-0.231	-1.117	-1.761	-0.116	-0.458	-0.600
O Jizerka -	0.032	-0.804	-0.224	-0.928	-1.729	-0.074	-0.474	-0.600
Modry_potok -	0.032	-1.126	-0.265	-2.802	-3.451	0.000	-0.500	-0.667
Morava -	0.017	3.809	-0.054	0.073	1.135	-0.192	-0.120	-0.244
Krupa -	0.017	3.954	-0.061	0.094	1.296	-0.188	-0.133	-0.206
Telcsky_potok -	0.017	4.600	0.079	0.228	1.464	-0.188	0.188	0.111
Branna -	0.017	4.400	0.129	0.231	1.529	-0.200	0.176	0.162
Desna -	0.017	-0.358	-0.177	-0.252	-0.822	0.000	-0.286	-0.560
Stribrny_potok -	0.017	4.257	0.063	0.152	1.217	-0.093	0.192	0.161
Bela -	0.007	4.400	-0.132	0.118	1.379	-0.038	-0.111	-0.286
Moravice -	0.007	-2.012	-0.222	-0.508	-1.728	-0.167	-0.283	-0.590
Cerna_Opava -	0.007	0.913	-0.178	-0.191	-0.260	-0.174	-0.211	-0.400
Opava -	0.007	0.913	-0.168	-0.216	-0.164	-0.132	-0.143	-0.429
Opavice -	0.026	-0.760	-0.096	-0.130	-1.041	-0.030	-0.400	-0.846
Opava -	0.007	0.786	-0.139	-0.096	-0.073	-0.045	-0.192	-0.452
Lesti -	0.017	1.009	-0.014	-0.063	0.099	-0.174	0.033	-0.276
Vsetinska_Becva	0.017	1.009	-0.044	-0.100	0.066	-0.176	0.000	-0.196
Roznovska_Becva	0.024	1.063	-0.081	-0.329	-0.123	0.000	-0.324	-0.667
Mohelnice -	0.024	0.571	-0.053	-0.324	0.059	0.094	-0.378	-0.667
Moravka -	0.024	0.574	-0.013	-0.362	0.104	0.094	-0.378	-0.600
	Ť	ė	ŚF	SWE	melt rate	onset	melt out	DŴS

Temperature

- Increasing trend in all catchments
- Significant increasing trend at all elevation zones

DWS

• Significant decreasing trend in most catchments and higher elevations

DOY melt out

 Significant decreasing trend (earlier occurrence) in most catchments and higher elevations

DOY onset

• No significant trend

SF

 Significant decrease in Western part of Czechia

	1450 -	0.016	-0.376	-1.538	-0.794	-0.143	-0.222	-0.344
	1350 -	0.020	0.679	-0.920	-0.444	-0.103	-0.333	-0.429
12 11 10 9 7 6 6 5 5	1250 -	0.021	0.999	-0.861	-0.493	-0.105	-0.400	-0.471
	1150 -	0.021	1.311	-0.624	-0.267	-0.125	-0.432	-0.500
	1050 -	0.022	1.038	-0.751	-0.538	-0.080	-0.368	-0.600
	950 -	0.021	1.258	-0.566	-0.381	-0.167	-0.405	-0.567
	850 -	0.022	0.738	-0.594	-0.882	-0.174	-0.500	-0.643
	750 -	0.022	0.600	-0.387	-0.737	-0.115	-0.407	-0.594
	650 -	0.021	0.966	-0.203	-0.460	-0.100	-0.292	-0.500
	550 -	0.021	0.945	-0.082	-0.317	-0.116	0.000	-0.273
	450 -	0.023	0.632	-0.038	-0.317	0.091	0.065	-0.355
	350 -	0.023	-0.007	-0.022	-0.315	0.000	-0.137	-0.385
		Ť	P .	SWE	melt rate	onset	melt out	DWS

Long-term trends. Significant Mann-Kendall test highlighted in black bold (p < 0.05) and black (p < 0.1). Increasing trends in shades of red, decreasing trends in shades of blue. Catchments are sorted by longitude.





SWE

• Significant trends at the end of cold season

Melt rate

- Snow melt is shifting to earlier date
- Variability increased in 1990-2014





Snow cover duration (SCD)

Date of melt onset

 No significant trend in any catchment or elevation zone

Date of melt-out

- Is shifting to earlier date (due to increasing temperature)
- Variability is decreasing at elevation zones 850 1250



SCD

- Decrease in most catchments
- Decrease is significant in many catchments even if there is no increase of DOY onset



	1965-1974	1975-1984	1985-1994	1995-2004	2005-2014
Melt onset	15.11	4.11	14.11	5.11	11.11
Melt out	14.5	18.5	10.5	2.5	2.5
SWE max	15.3	23.2	2.3	5.3	11.3



Number of days with SWE > 5 mm

• Decreasing trend in the beginning and at the end of cold season is caused by increasing temperature



Long-term trends. Significant Mann-Kendall test highlighted in black bold (p < 0.05) and black (p < 0.1). Increasing trends in shades of red, decreasing trends in shades of blue. Catchments are sorted by longitude.



Conclusions

- Significant increasing trend in temperature was found in the beginning and at the end of cold season
- SWE decreased in most of catchments, especially in western parts of Czechia.
- Snow cover duration decreased, mostly because of earlier melt-out.
- No significant trend was found in date of snow cover onset.

