Changes in seasonal snowpack in mountain catchments in Czechia

Ondrej Nedelcev and Michal Jenicek
Charles University, Faculty of Science, Department of Physical Geography and Geoecology, Prague, Czechia

Contact autor: ondrej.nedelcev@natur.cuni.cz
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 ($R_{\text{runoff}}$)
  - Nash-Sutcliffe efficiency for SWE ($R_{\text{SWE}}$)
  - Volume error ($R_{\text{vol}}$)
- 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

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

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

Long-term trends [day/year]. Significant Mann-Kendall test highlighted in black bold (p < 0.05) and black (p < 0.1). Increasing trend in shades of red, decreasing trends in shades of blue.

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

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Melt onset</th>
<th>Melt out</th>
<th>SWE max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965-1974</td>
<td>15.11</td>
<td>14.5</td>
<td>15.3</td>
</tr>
<tr>
<td>1975-1984</td>
<td>4.11</td>
<td>18.5</td>
<td>23.2</td>
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<tr>
<td>1985-1994</td>
<td>14.11</td>
<td>10.5</td>
<td>2.3</td>
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<tr>
<td>1995-2004</td>
<td>5.11</td>
<td>2.5</td>
<td>5.3</td>
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<tr>
<td>2005-2014</td>
<td>11.11</td>
<td>2.5</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Number of days with SWE > 5 mm

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