SNOW ACCUMULATION AND MELT IN A MOUNTAIN HEADWATER CATCHMENT

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Background

High variability of snow accumulation affects runoff generation during snowmelt period. We have established a dense measurement network in the highest part of the Carpathians (Krajčí et al., 2016) to study variability of snow distribution and its melt in the alpine zone. This poster presents:

1. Data on spatial and temporal variability of snow characteristics
2. Estimation of snowmelt water contribution to catchment runoff
3. Spatially distributed modelling of snow accumulation and melt model considering the influence of snow drift and radiation

Study area and network

The study was conducted in the Sokolný jarok catchment (The Western Tatra Mountains, Slovakia) in winters 2015 and 2016 (Fig. 1). Catchment area is 0.056 km^2, elevation ranges from 1439 to 1565 m a.s.l. The bedrock if formed by limestone and dolomite. The vegetation is represented by Alpine grassland and young spruce forest .

Measurement network in winter 2016 consisted of:

- 27 snow stakes marking the sites for snow depth and water equivalent measurements
- up to 232 points with snow depth measured by GPS
- 26 ground themometers installed at soil surface near the snow stakes
- 5 snow lysimeters with the tipping bucket measuring temporal evolution of snowmelt
- 5 sites with passive capillary samplers (5 samplers at each site) to collect winter integrated snowmelt samples for isotopic hydrograph separation
- 9 soil moisture sensors
- 2 weighting raingauges and a meteorological station providing input data for the model
- Thomson weir at catchment outlet measuring water level and conductivity

Methodology

- Spatial and temporal variability of snow water equivalent was measured manually near the snow stakes.
- Duration of stable snow cover was determined from the readings of the ground thermometers.
- Snow depth measured by GPS was used to prepare the map of snow redistribution by the wind. Tangential curvature and horizon angle were taken into account in map preparation.
- Two-components isotopic hydrograph separation was made using $\delta^{18}O$ as tracer. Isotopic composition of the snowmelt water was determined from the samples collected by passive capillary samplers.
- Spatially distributed snow accumulation and melt was simulated with hydrological model MikeSHE. Snow redistribution by the wind was incorporated into the model by the correction of input precipitation which was based on the map combining tangential curvature and horizon angle. Degree-day factor was calculated using snow density measured at snow stakes in winters 2015-2017 and the relationship developed for the long-term snow data at the nearby meteorological station. Simulated snow water equivalents at the snow stakes were validated against measured data from both winters (data from winter 2015 were not used in the construction of precipitation correction map).

Spatial and temporal variability of snow characteristics

- Winter 2015 had more snow than winter 2016. Stable snow cover (determined as period when the ground temperatures variability was small) lasted 93-126 days in winter 2015 and 8-86 days in winter 2016.
- Spatial variability of snow water equivalent, snow depth and density in the catchment was very large (Fig. 2). Coefficients of variability confirmed that snow density varies much less then snow depth.
- Snow redistribution by the wind (prevailing wind direction is NW-N) formed the snow drift along the western part of the water divide while very little snow was measured on the ridge. Although the general orientation of the entire catchment is to the south-east, incoming solar radiation and vegetation further affected spatial variability originated from the wind drift (Fig. 3).
- Soil in the studied area does not freeze. Smaller snow depth in winter 2016 are reflected also in lower soil surface temperatures (Fig. 4).

Snow water equivalent modelling

- Observed variability of the snow cover presented challenge for the modelling of snow accumulation and melt. Because we used spatially distributed model (Mike SHE) which did not account for snow transport, we have applied input precipitation redistribution as a surrogate for physical approach to snow transport modelling.
- Dense network of GPS-measured snow depths in winter 2016 was used to analyse the influence of morphometric characteristics of the terrain on snow distribution. Combination of tangential curvature and horizon angle with buffer zones along the erosion-accumulation zones provided the map of precipitation redistribution indices (Fig. 6). We have run the model also with input precipitation redistributed by Thiessen polygons constructed around the snow stakes. The GPS-measured snow depth were used to calculate the weights for individual polygons. Performance of both approaches in reproduction of measured snow water equivalent at snow stakes in winters 2015 and 2016 was evaluated. Seasonally variable degree-day factors were computed from the snow density using the relationship developed on the basis of the long-term data from the nearby site (Holko et al., 2012). Spatially distributed snowmelt from radiation was considered as well. The model was run with hourly time step and spatial resolution 20 m.
- Comparison of measured and simulated snow water equivalents (SWE) suggested that precipitation redistribution based on morphometric characteristics of the terrain was superior to Thiessen polygons especially in winter 2015 when Thiessen polygons performed much worse than in winter 2016 in which they were derived. It confirms that the snow distribution patterns remain relatively stable in different winters. The snow stakes where the simulated SWEs did not well reproduce the measured ones, are still located in the zone of the most active snow transport. It suggests that morphometric characteristics do not explain all variability of snow distribution.

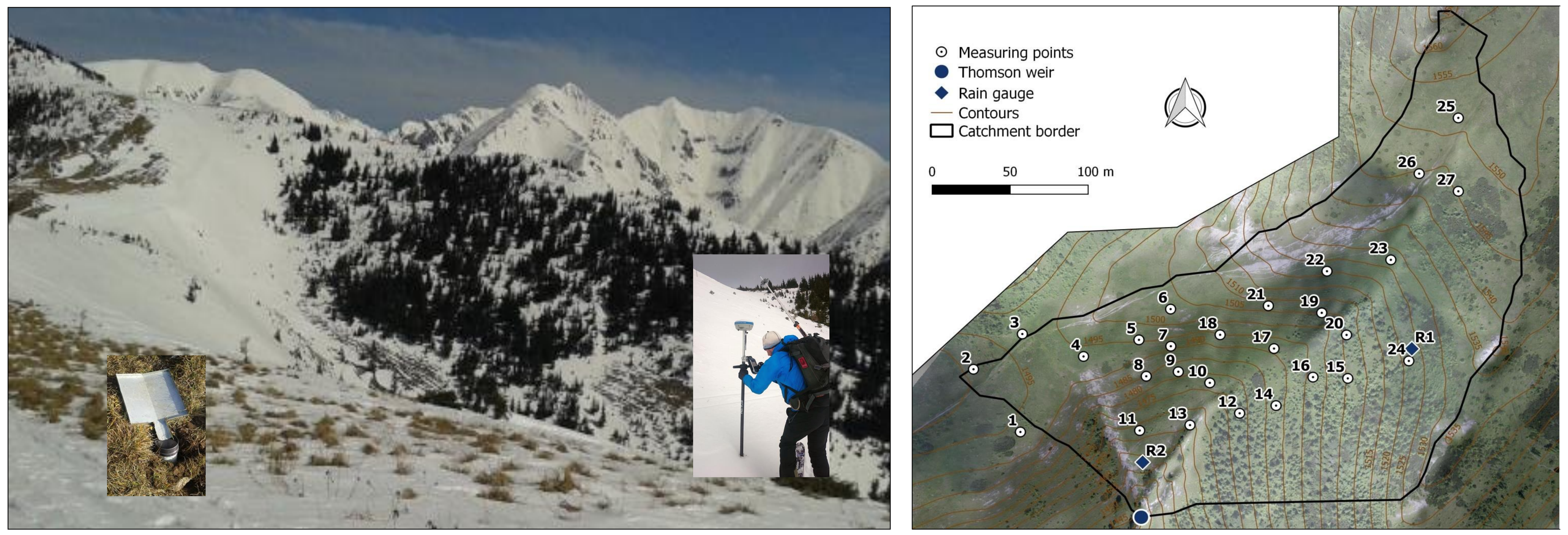

Fig. 1. The Sokolný jarok catchment (left) and measurement network (right)

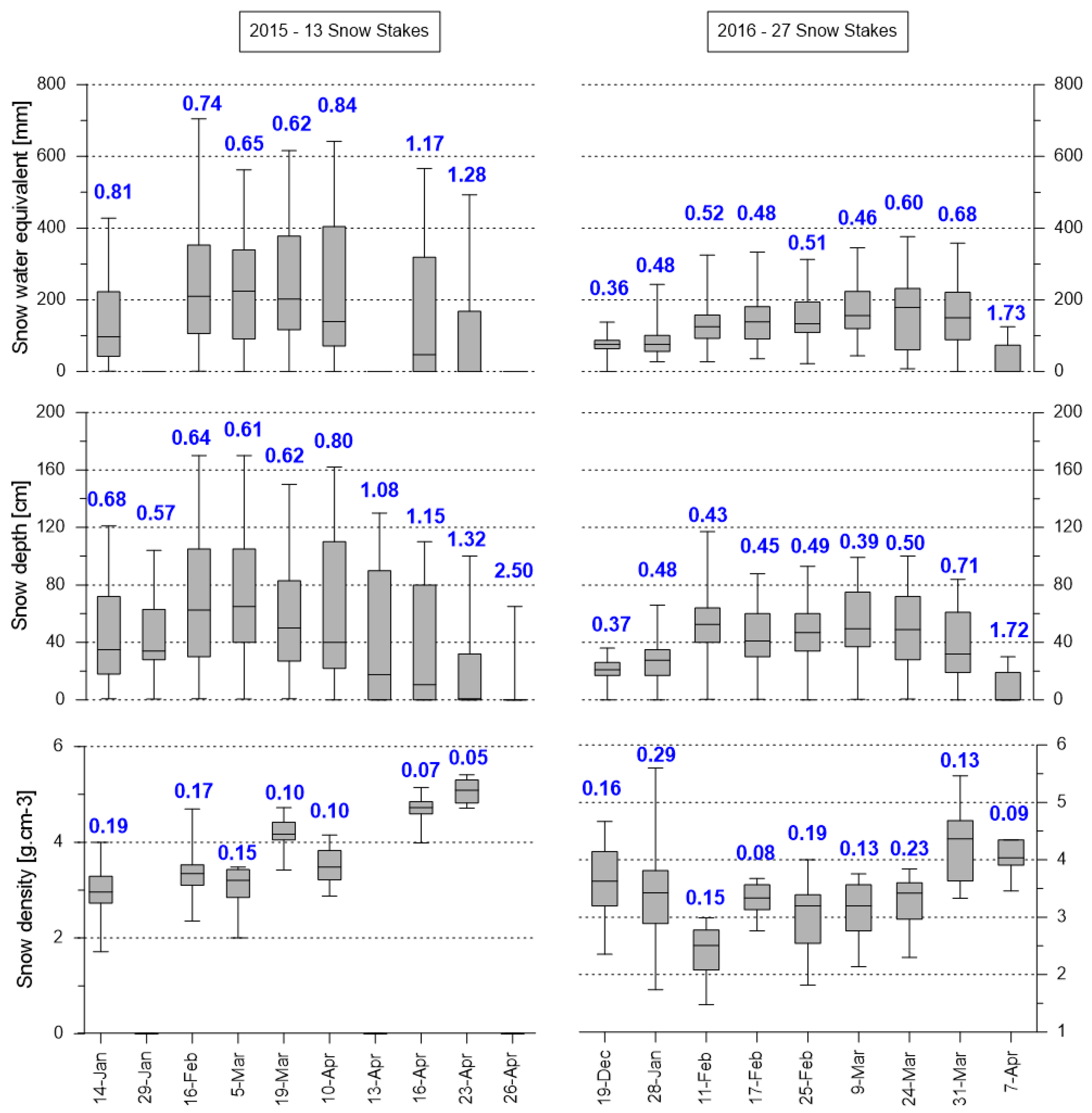

Fig. 2. Spatial and temporal variability of snow water equivalent, snow depth and density measured near the snow stakes; the numbers represent coefficients of variation.

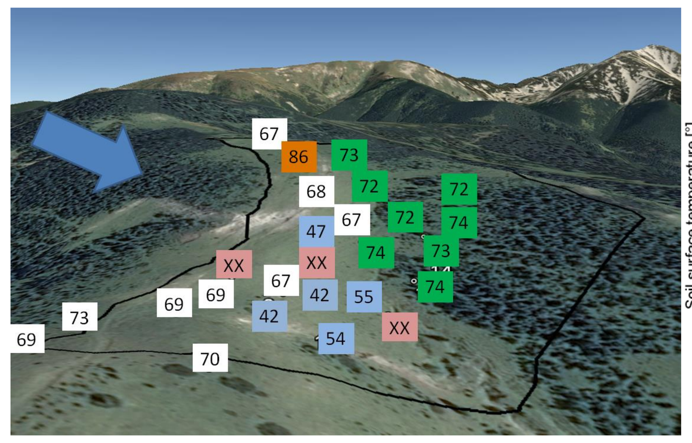

Fig. 3. Duration of stable snow cover in days i winter 2016; XX means that the stable snow cove did not develop; the arrow shows prevailing wind direction.

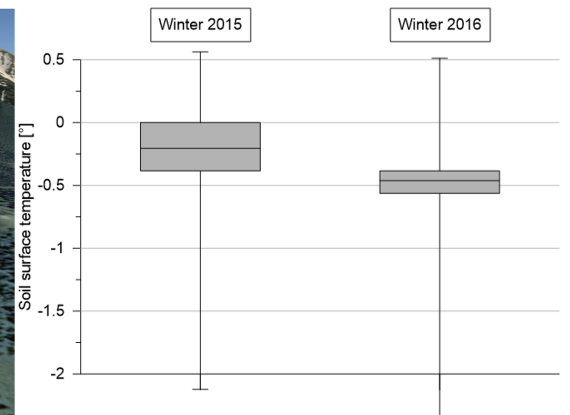

Fig. 4. Box plots of surface temperature of the soil at snow stakes under permanent snow cover

Snowmelt water contribution to catchment runoff

- Passive capillary samplers (PCS) used in this study allowed comfortable collection of season integrated data from many points (Penna et al., 2014). $\delta^{18}O$ of most snowmelt water samples in our study varied between -13‰ and -14 ‰ (Fig. 4). The only exception was the sampling site near snow stake 13.
- Isotopic signature of pre-event water was characterised by stream sample before the increased discharge. Based on the data from PCS, $\delta^{18}O$ of snowmelt water varying between -13 ‰ and -14 ‰ were used in hydrograph separation. Different $\delta^{18}O$ of snowmelt water influenced only the results for the biggest discharge event which occurred between April 1st and 9th. Snowmelt water contributions with $\delta^{18}O$ of snowmelt water equal to -13.5 ‰ are shown in Fig. 5. Snowmelt water fractions for the main snowmelt period from 29 March 2016 until 8 April 2016 ranged between 0.19 and 0.83 (mean 0.51, median 0.55).
- Variability of stream water conductivity at catchment outlet was very similar to that of $\delta^{18}O$. (Fig. 5) which provides an additional option for hydrograph separation.

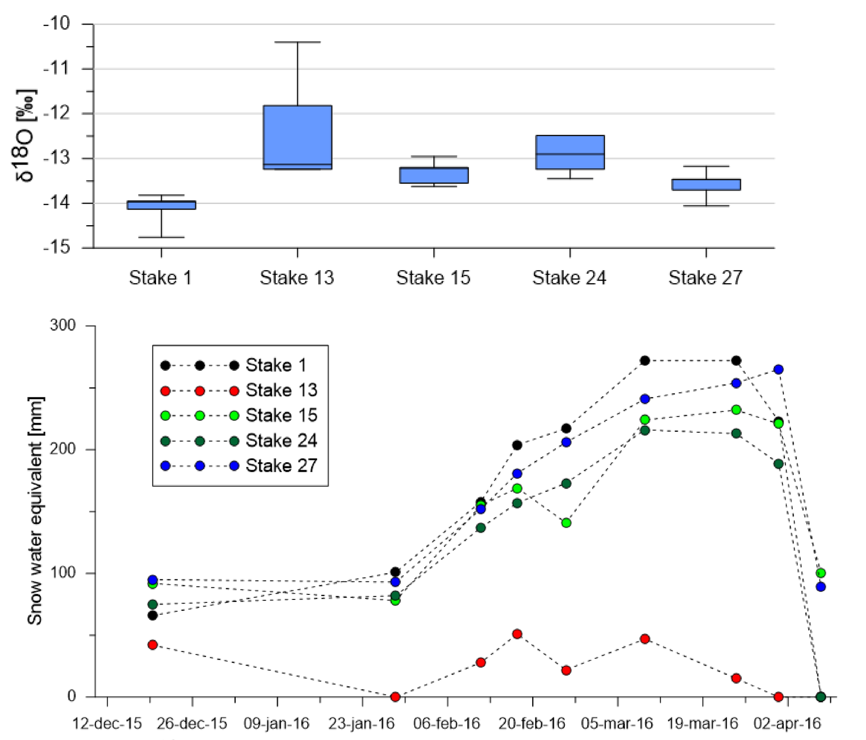

Fig. 4. $\delta^{18}O$ of snowmelt water samples collected by passive capillary samplers over the entire winter season 2015 (the boxplots represent 5 samples from each site) and measured snow water equivalent at each sampling site.

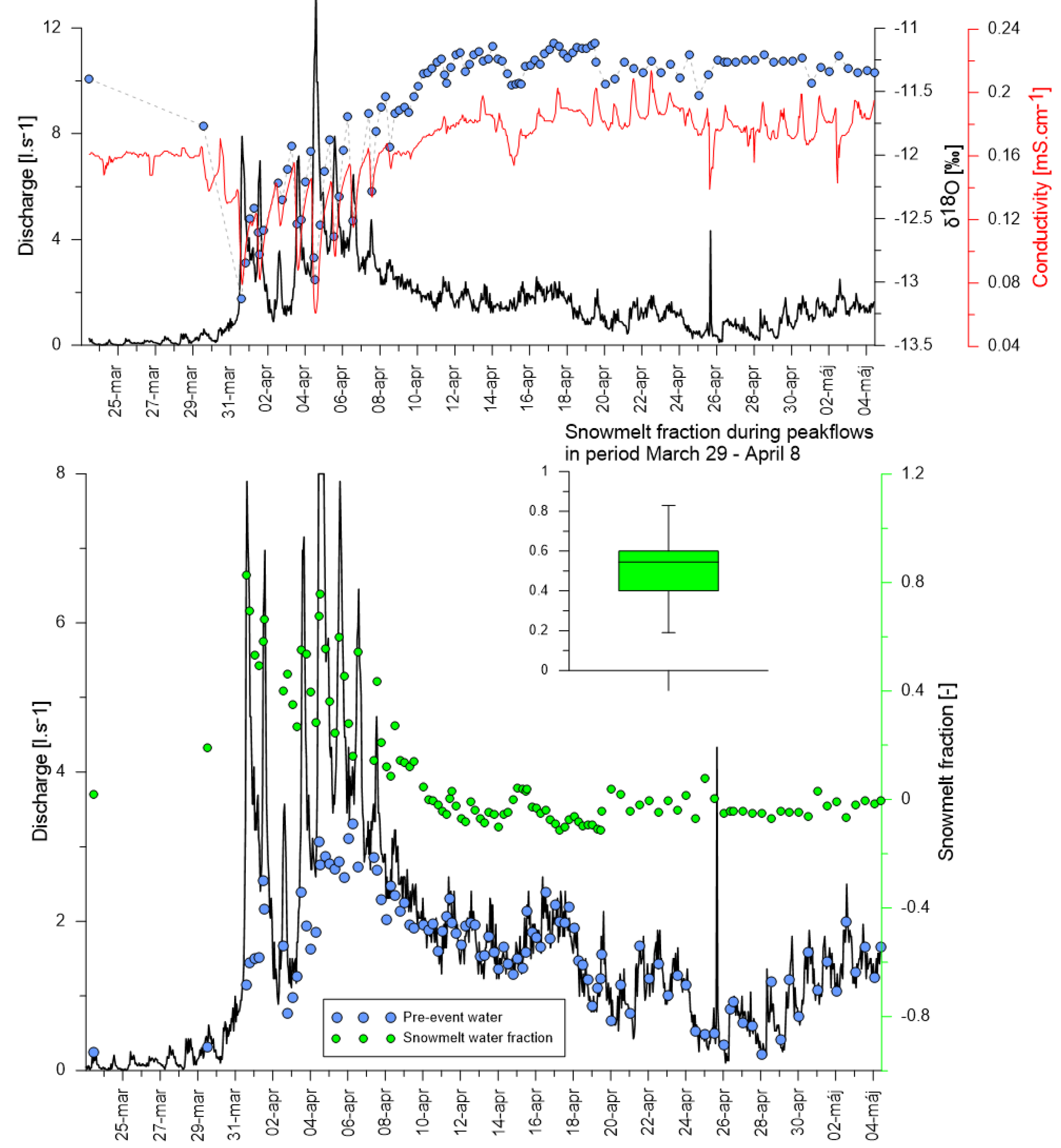

Fig. 5. Catchment discharge, $\delta^{18}O$ and electrical conductivity of the stream at catchment outlet in spring 2016 (above); catchment discharge, separated contribution of pre-event water and snowmelt water fraction (below)

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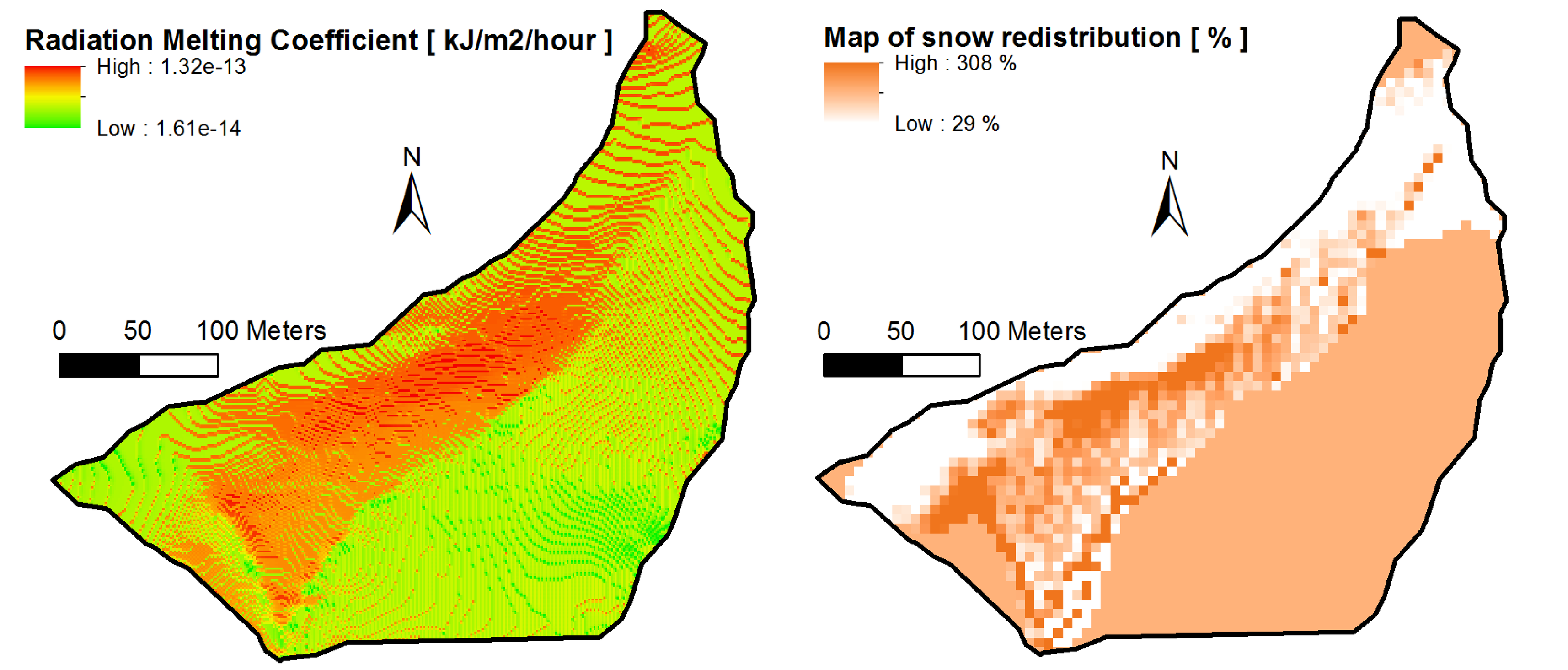

Fig. 6. Maps of radiation melting coefficients (left) and snow redistribution (right).

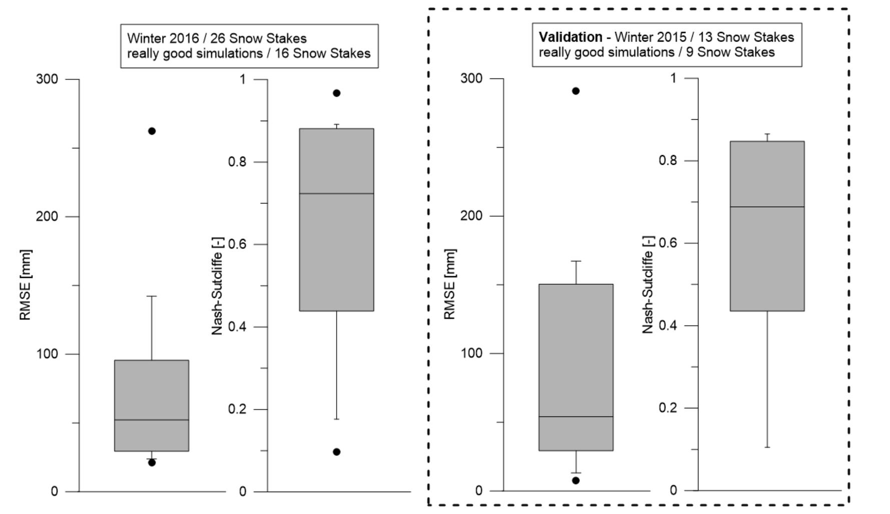

Fig. 7. Objective functions for SWE simulation at snow stakes in winters 2015 and 2016.

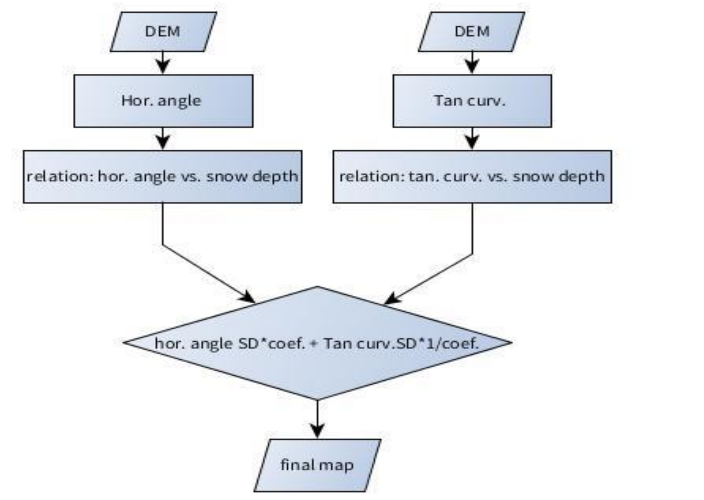

Fig. 8. Construction of the precipitation redistribution map based on snow depth and terrain morphometric data.

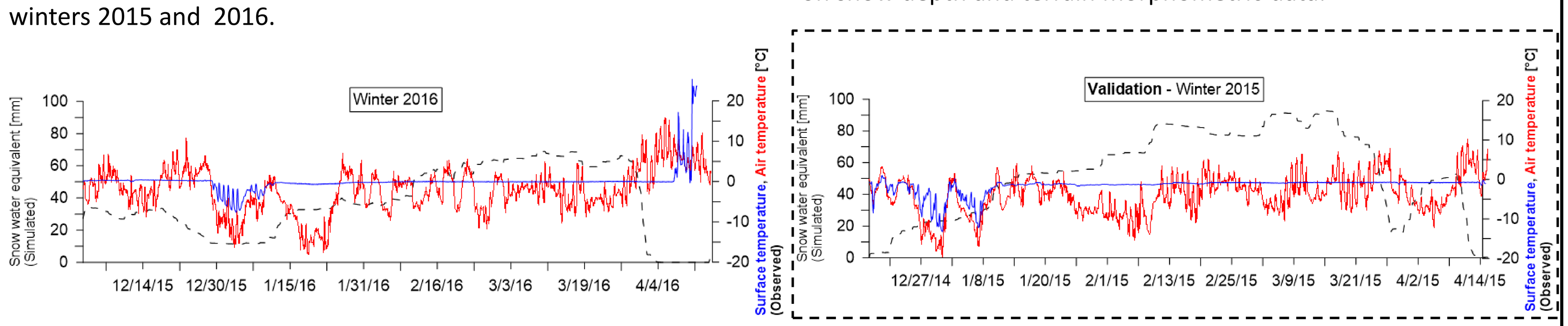

Fig. 9. Use of surface thermometers for validation of simulated SWE for snow stake 13.

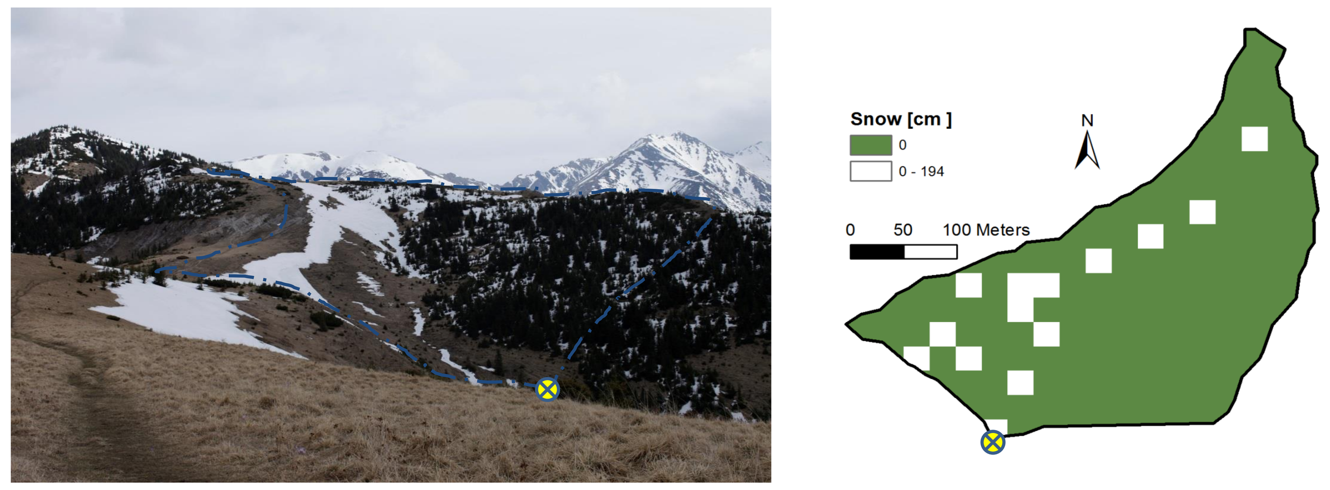

Fig. 10. Spatial distribution of snow on 26 April 2015 according to a photograph (left) and simulated snow water equivalent (right).

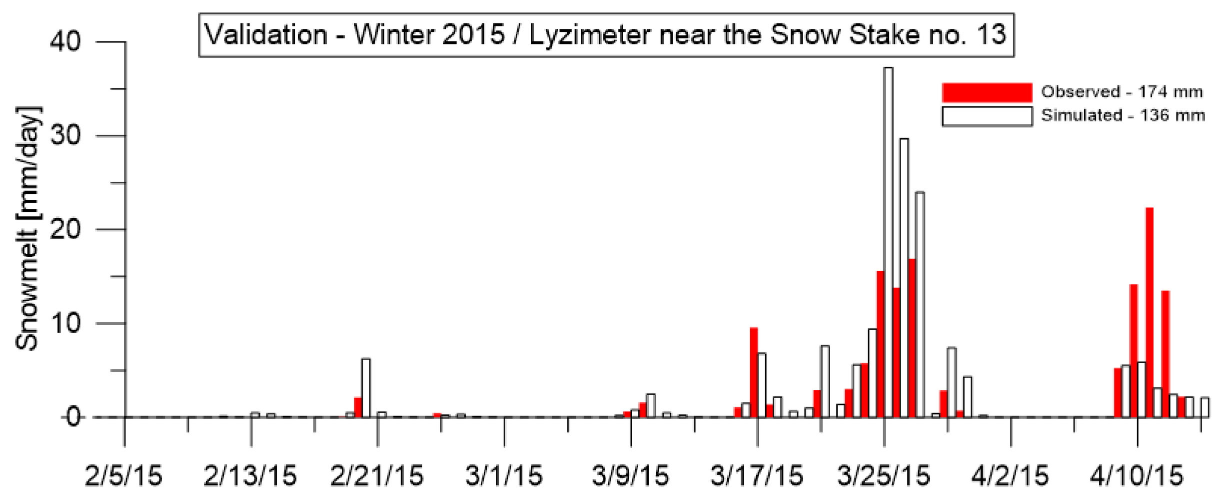

Fig. 11. Simulated and measured outflow from melting snow.

References:
Holko, L., Danko, M., Kostka, Z. (2012): Classification of winters, density of new snow and the degree-day factor in the Jalovecký creek catchment. *Acta Hydrologica Slovaca*, 13, 2, 342-349.
Krajčí, P., Danko, M., Hlavčo, J., Kostka, Z., Holko, L. (2016): Experimental measurements for improved understanding and simulation of snowmelt events in the Western Tatra Mountains. *J. Hydrol. Hydromech.* 64, 4, 316–328.
Penna, D., Ahmad, M., Birks, S. J., Bouchaou, L., Brenčič, M., Butt, S., Holko, L., Jeelani, G., Martínez, D. E., Melikadze, G., Shanley, J. B., Sokratov, S. A., T. Stadnyk, T., Sugimoto, A., Vreča, P. (2014): A new method of snowmelt sampling for water stable isotopes. *Hydrological Processes*, DOI: 10.1002/hyp.10273