Importance of spatial patterns in snow accumulation and melt

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Contents

1. Purpose of the STSM

This scientific report summarizes results obtained during Short Term Scientific Mission (STSM) of Pavel Krajčí at the Institute of Hydraulic Engineering at Vienna University of Technology) in the period October - November 2016. Austria and Slovakia are neighbouring countries and significant snow cover is common in mountain areas of both countries. Measurements of snow cover parameters and snow hydrological research have long tradition in both countries, too. The main scientific objective of the STSM was to analyse the role and importance of spatial and temporal patterns in snow accumulation and melt in hydrological response of mountain catchments which has direct impacts on both the environment and human society, The another aim was also to share knowledge, methods, experience and to strengthen the cooperation between Institute of Hydrology, Slovak Academy of Sciences and Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology (TU Wien).

2. Description of work and main results obtained

Activities carried out during the STSM can be divided into three parts.

- (1) Preparation, processing and analysis of climate and snow data forKühtai (Austria) and Sokolný creek (Slovakia)
- (2) Modeling of snow accumulation and snowmelt processes (TUW model)in Sokolný creek
- (3) Processing and analyses of changes in satellite snow cover data during snowmelt driven floods(Snowline elevation experiment)

2.1. Preparation, processing and analysis of climate and snow data

This chapter describes the preprocessing and analysis of snow data measured in Kühtai station in Austrian Alps and Sokolný creek experimental catchment located in Slovakian part of Carpathian mountains. Data from Kühtai allows to analyse long-term (25 years) changes in snow accumulation and melt in an alpine valley. On the other hand, Sokolný creek measurements shows detail spatial pattern of snow accumulation and melt for two winter seasons. In case of Kühtai, our aim was to analyse data for a paper, describing unique observations of snow accumulation and melt from snow pillow and snow lysimeter located at the same place.. In case of Sokolný creek, data serve as an input for distributed snow model and allows to examine spatial patterns of snow accumulation and melt in small mountain experimental catchment.

2.1.1. Kühtai

The Kühtai snow monitoring station is located about 30 km west of Innsbruck, Tyrol, Austria , at an elevation of 1920 m above sea level (for location map, see Kirnbauer and Blöschl, 1990). It is situated in a steep alpine valley of the Austrian Alps. It was set up in 1989/90 on the site of an existing meteorological station near Kühtai hydropower station and Längental reservoir (Kirnbauer and Blöschl, 1990). Main idea of this part of work is to prepare data for a paper that will present this unique dataset to the scientists from all over the world. The dataset includes detailed information of the amount of water stored in snow, melt dynamics and corresponding meteorological, snow depth and profile snow temperature data at 15-minutes intervals for a 25 year historical period (1990-2015). This dataset is ideal for modeling of long-term snow melt changes in the alpine terrain.

Data

Continuous measurements of air temperature, precipitation, incoming and outgoing shortwave radiation, net radiation, air humidity, wind speed, and profile snow temperatures at six heights (20, 40, 60, 80, 100, 120, 140 cm) were checked for errors and gaps were filled by using measurements from neighbour stations. Snow water equivalent (SWE) and snowmelt outflow were also measured in Kühtai station. It was measured by the lysimetric snow pillow, based on a device described by Engelen et. al. (1984). The meltwater draining the pillow is collected in a gutter at the edge of the lysimeter and measured by a tipping bucket. Lateral inflow to the lysimeter is prevented by a 20 cm high metal lip (Kirnbauer and Blöschl, 1990).

Data processing and results

All observed data were automatically quality controlled for unrealistic outliers, constant values and extreme jumps (high/low range limits, rate-of-change limits, continuous no-observed-change with time limits). All values were carefully inspected for erroneous data by visually examining each variable record. Additional manual quality control was performed for individual observations as needed.

Gap filling was performed for air temperature, precipitation, incoming shortwave radiation, air humidity and wind speed data. These parameters are potentially inputs to the models and that is why we wanted to provide continuous time series. Missing values was filled using surrounding stations. More detailed description of the data processing methods will be presented in final data paper.

Part of the mentioned paper will be "Example Application of Data". In our case we have decided to examine the long term degree-day factors values calculated by the snow pillow and air temperature daily data. The inter-annual and within-year variability of daily degree-day factor (DDF) estimated from snow pillow measurements is presented in Fig.1. DDF is estimated as a ratio of daily decrease of snow water equivalent measured on snow pillow and mean daily air temperature in days without precipitation. Fig.1 shows that the mean annual DDF varies between 0.7 and 3.5 mm.°C^{-1}.day^{-1} and the average over 25 years is 2.2. Fig. 1 indicates relatively large variability of DDF within individual years. DDF is typically a constant parameter in degree-day snow models, so understanding factors that control its variability will be useful to improve such models in the future.

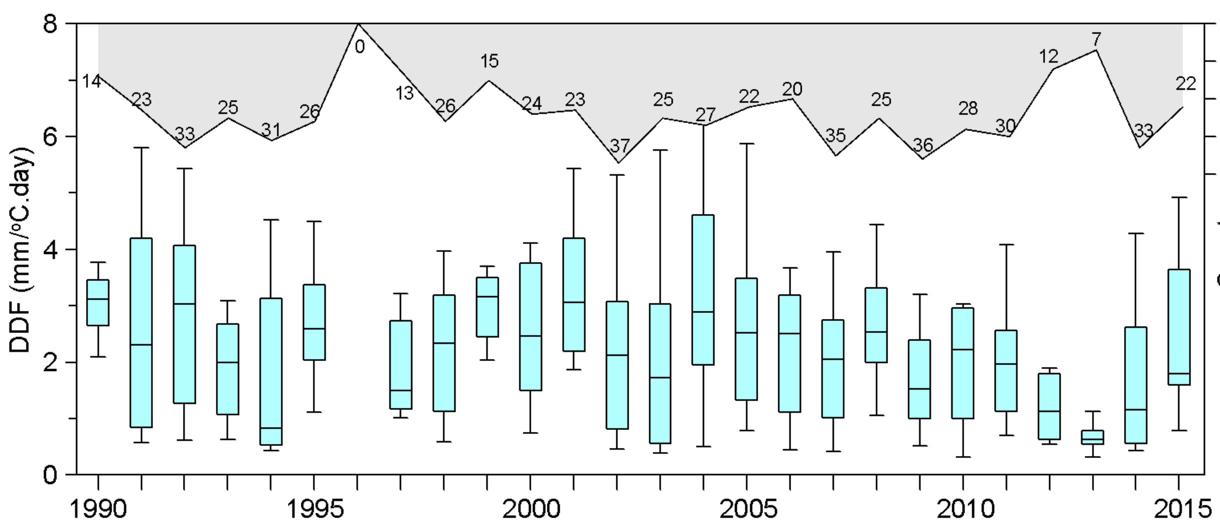

Fig. 1. Degree day factors in years 1989 - 2015. Upper part: number of DDF calculated in each year.

2.1.2. Sokolný creek

Sokolný creek is an experimental microcatchment located in the Western Tatra Mountains, northern Slovakia (Fig. 1). Its area is 0.059 km^2. The altitude ranges between 1450 m a. s. l. and 1560 m a. s. l. The study area is a subcatchment of the Jalovecký creek catchment. Detailed snow observations were performed in this catchment in winter 2014/2015 and 2015/2016. 2014/2015 data were used in the Krajčí et al. (2016) paper. This work analyses 2015/2016 data. This data were used in distributed energy –based snow model developed at the Institute of Hydraulic Engineering TUW. The data were preprocessed before the modeling. This chapter shows the data preparation. The modeling part is in detail presented in the next chapter.

Data

Air temperature, air humidity, wind speed, wind direction and solar radiation were measured at the station Červenec (CE1500) located 300 meters far from the catchment. Precipitation were measured at two sites marked as blue rectangles in Fig. 2. Cloudiness was estimated as a ratio between measured solar radiation and potential solar radiation calculated by the Solei model (Mészároš and Miklánek, 2006). Night time cloudiness was used for estimating night time long wave radiation. The global radiation procedure was tested by making use of the Solei model (Mészároš and Miklánek, 2006). Snow depth measurements were performed by global navigation satellite system (GNSS) receiver. Several measuring campaigns were carried out. Number of measured points in one campaign varied between 17 and 232. Besides GNSS measurements, there were also 27 static snow stakes that extended the number of snow depths. SWE measurements were also measured close to above mentioned 27 snow stakes (white dots on fig. 2). The SWE measurements were used for validation of the snow model. All observed data were automatically quality controlled for unrealistic outliers

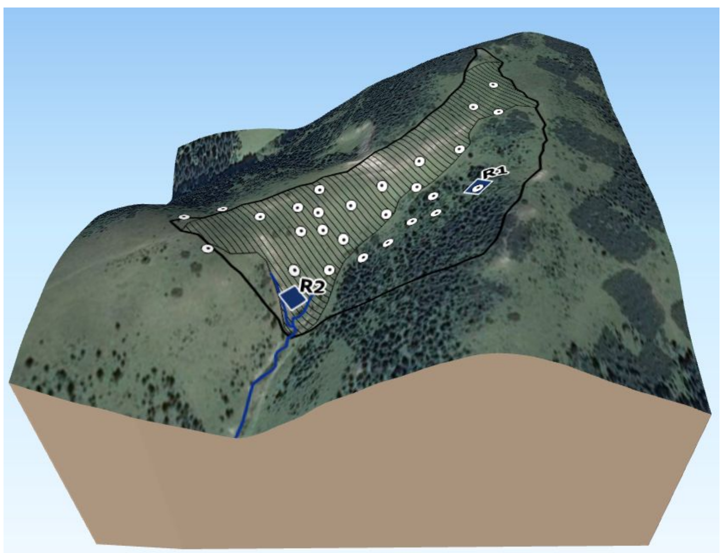

Fig.2. Sokolný creek microcatchment. Black line: catchment border; blue rectangles: rain gauges; white dots: SWE measuring points

2.2. Modeling of snow accumulation and snowmelt processes (TUW model)

2.2.1. Model description

The snow model is grid based, using the 5m resolution of the digital terrain model (DTM) in one hour time step. For each grid element, the energy balance components at the snow surface were simulated in the following way. Turbulent fluxes (latent and sensible heat fluxes) were estimated using a wind function along with air temperature and air humidity.

Long wave radiation was parameterised as a function of air temperature, humidity and cloudiness. Direct and diffuse solar radiation were estimated by observed global radiation as a function of solar position, terrain aspect and slope, local horizon as well as cloudiness. This means that horizon shading was accounted for. Snow surface albedo was assumed to decrease exponentially as a function of time after snowfall (i.e. an aging curve approach). The coupled heat and mass flow within the snowpack was simulated by a single layer snow model (Blöschl and Kirnbauer, 1991) with three main parameters - a coefficient of maximum water holding capacity (CWH), a coefficient of minimum cold content (CCH), and a factor of refreezing (FRF) that represents the night time depression of snow surface temperature. The state of precipitation was determined from the wet bulb air temperature (i.e., rainfall was assumed to occur above a threshold temperature and snowfall was assumed to occur below that temperature). Evaporation from the snow surface on the ground was assumed to be negligible (see e.g. Leydecker and Melack, 1999) while snow evaporation from the canopies was considered by the interception model (see below). More details on the model are given in Blöschl et al. (1991, 2002).

Atmospheric data used to drive the model are global radiation, air temperature, humidity, wind speed, cloudiness and precipitation on an hourly basis. These variables were observed at the meteorological stations.

GIS layers preparation

The GIS layers, that were used as an input to the model, were calculated from DEM (digital elevation model). DEM was created using precise GNSS manual measurements of x, y and z coordinates with horizontal and vertical accuracy about 4cm. More than 4500 points in area of less than six hectars were collected. These points were interpolated by GRASS GIS modul v.surf.rst. Resolution of the resulting DEM was 5 meters. This resolution was sufficient to our purposes. Morphometric parameters of the study were calculated in GRASS GIS, too. Slope, aspect and curvatures (plan, profile, tangential and general) were calculated. Methods and equations are deeper specified in GRASS GIS manual (GRASS, 2016a). 16 horizon angle maps were another input to the model. We used a GRASS GIS modul r.horizon for calculation. Horizon height is angular height of terrain horizon in degrees. One raster map is created for each direction. 16 maps were produced in 22.5° step.

Snow drift modelling

One of the essential question was how to represent the effects of wind drift in the model. This was done by correcting snowfall for terrain effects by a wind drift factor. Drift factor map was derived based on the analysis of relation between measured snow depth and morphometric parameters of the terrain. Horizon angle in northwest direction appeared to be influencing factor. Second factor used in construction of the snow drift map was tangential curvature. Analysis of snow depths shown that there are usually higher snow depths in deep valleys bottoms with high negative values of tangential curvature. Deeper explanation of the snow drift map construction will be proposed in new separate paper. Values in the drift map (fig. 3) are relative coefficients. All precipitation measured on the rain gauge R1 (fig. 2) are multiplied in the model by this map. Map is shown on fig. 3. Vegetation was also incorporated in the map of snow drift factor. Drift factor for the forested area was set to 1 because rain gauge R1 is also located in the forest and we expect here homogeneous precipitation.

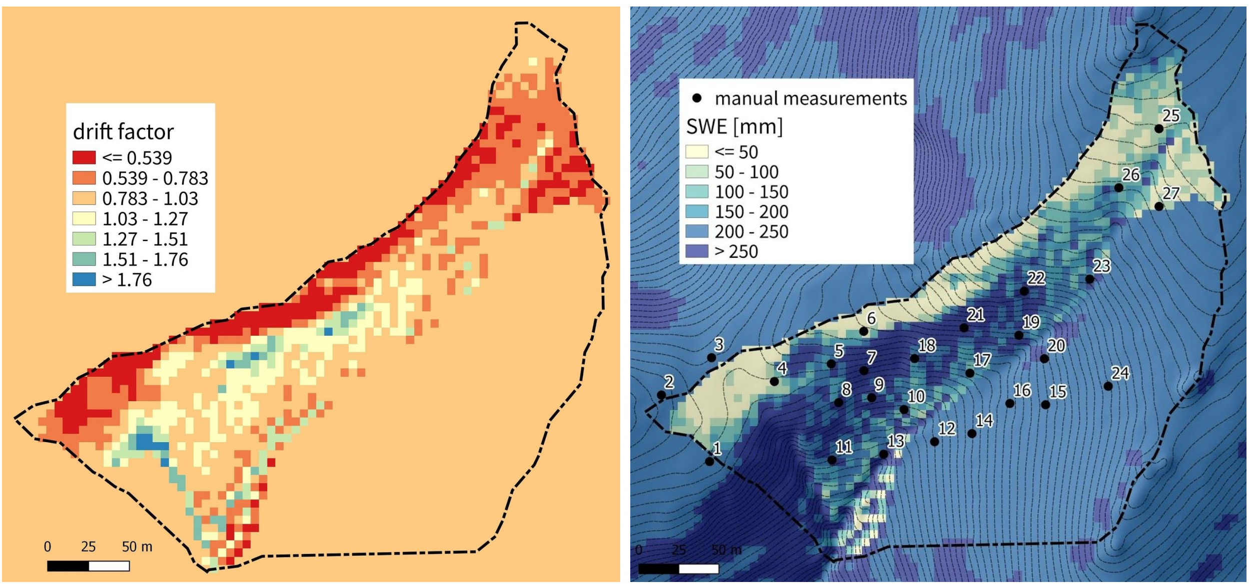

Fig. 3. Left: Map of the snow drift factor; Right: SWE simulation for 31st March 2016.

2.2.2 Modeling and validation

Model was run in 1 hour time step in the period November 2015- May 2016. Output of the model is distributed map of snow water equivalent (SWE). Snow drift factor appeared to be the most important spatial parameter. Fig 3. shows, that the highest values of SWE are accumulated just behind the ridge, that represents the barrier for the prevailing wind and it is the north-east catchment border. The lowest values of SWE were modelled on this ridge, where the highest wind speeds are expected. Differences in such a small area reached more than 250 mm on 31st March 2016, when the snow accumulation reached maximum.

The model has been validated by comparing measured and modelled SWE. On fig. 4 are examples of snowpack evolution on two sites, where SWE were manually measured. Upper part of the fig. 4 shows results of model on site 21. This comparison indicated good performance of the model in first half of the winter, otherwise not very good simulation in second half of the winter season from February till end of the melt season. On the other hand, the plot below shows much better performance of the model on site 15. In this case, both snow accumulation and melt was modeled well, too. Site 21 is located in open area and site 15 is located in forest. The calibration of the model was not finished, yet and up to now results indicated, that the modeling in open area of the catchment should be examined more and improved in the future.

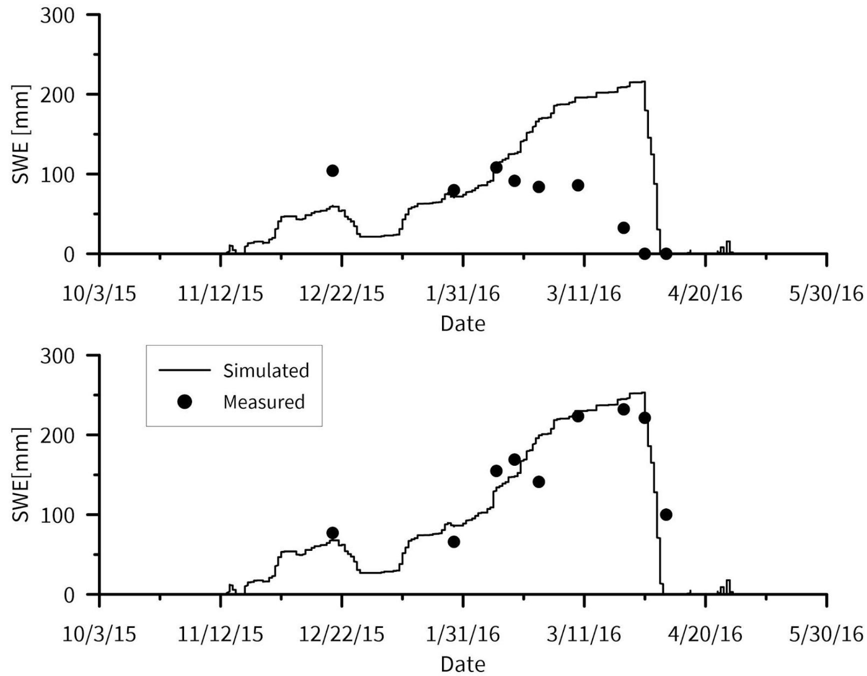

Fig. 4 Comparison of simulated and measured SWE on 2 measuring sites. Up: number 15. Down: number 21.

2.3. Remote sensing data processing (Snowline elevation experiment)

Method for estimation snow line elevation presented in Krajčí et al. (2014) was developed in cooperation between Institute of Hydrology SAS and Institute of Hydrology and Water Resource Management TUW. Idea of the new usage of this method is to examine Snowline elevation changes during snowmelt floods in Europe. The objective of the project is to find the answer for the following questions:

- How does the snowline elevation change during snowmelt runoff events?
- What factors control this change?
- What are the spatial and temporal differences across Europe?

Data

MODIS snow cover data (500m, daily, Terra and Aqua). Daily runoff data from the period 2000-onwards (e.g. GRDC time-series) for basins not strongly affected by reservoir manipulations (e.g. hydropower operations). Basin boundaries (e.g. CCM database), EHYPE simulations (precipitation)

Methods

Identification of runoff events by using methodology (and tools) from FLOOD TYPE experiment (already ready for GRDC data, tool available for local runoff time-series). Estimation of regional snowline elevation (RSLE) by using methodology from Krajčí et al.(2014) (Open code/tool will be developed and available). Evaluation of changes in RSLE (depletion rate) in individual basins (temporal changes for different winters). Comparison of results for different basins (spatial changes) and evaluations of controls.

Results

The complete analyses is not finished yet, but fig. 5 shows example from Austria. Here can be seen increase of discharges at station Matreier Tauenhaus at Tauernbach in April 2003. This increase clearly corresponds to increase of snowline elevation. This result is very promising, but it needs to be repeated in other stations and deeper analysed in the future.

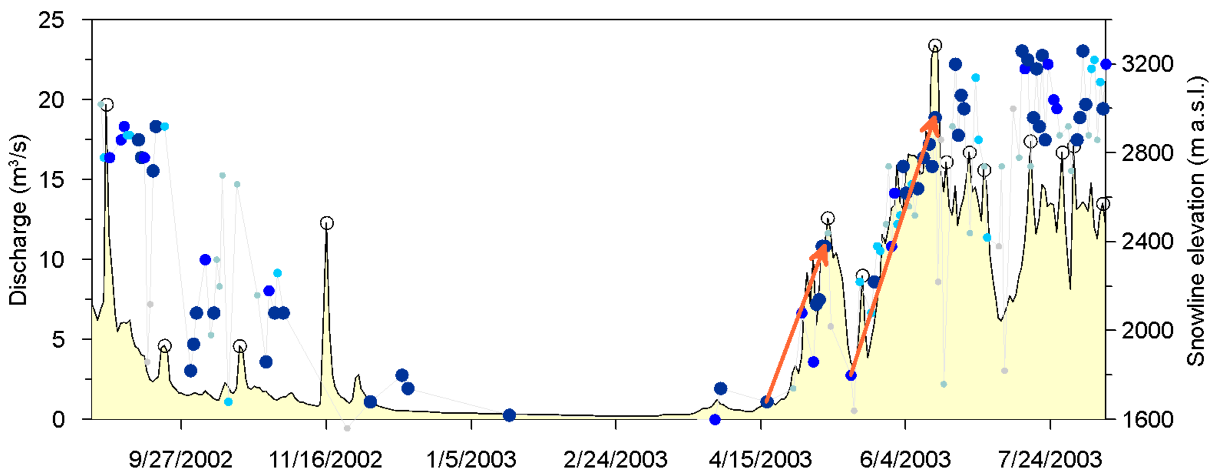

Fig. 5. Change in snow line elevation (blue points) during snowmelt events (snowmelt discharge represents black line). The size of blue points indicates the cloud coverage (larger/darker symbol indicates smaller cloud coverage). Station Matreier Tauenhaus at Tauernbach.

3. Future collaboration and foreseen publications

Results of the STSM were briefly reported here. The main objectives were achieved, and some of the analyses will serve as a basis for future collaboration. The results of the collaboration will be a basis for three planned papers. The first will present the data and temporal changes in snow accumulation and melt in Kuhtai. The Second will analyse the effect of snow drift for estimation of spatial patterns of snow in Sokolny creek. The third planned paper will analyse changes in snow line during snowmelt runoff events in selected catchments in Europe.

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