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A method for the estimation of snow water equivalent assisted by unmanned aerial vehicles

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A new method for estimating snow water equivalent (SWE) in a small river basin is proposed, and the results of its verification and validation are reported. The numerical HS maps are produced for the selected subareas of the basin using the automated procedure based on processing aerial images acquired by unmanned aerial vehicle (UAV). Since it is difficult to obtain spatial data about snow bulk density, we utilize pointwise meteorological data from the adjacent weather gauges and make use of the ISO 4355:1998 norm. For each subarea, HS maps are multiplied by density estimates. As a result, SWE rasters are produced for all the subareas. In order to extrapolate SWE values to the entire basin, where UAV is not used to observe snow cover, spatial regression methods are employed. The models predict SWE as a function of a few environmental variables introduced to the model formula using the stepwise method, excluding co-linear explanatory variables. A set of potential predictors covers: terrain height, slope inclination, terrain roughness, topographic position index, solar radiation, wind effects and distance from the nearest obstacles. The first approach is based on multiple linear regression (MLR) combined with inverse distance weighting (IDW) estimation for places where MLR extrapolated negative SWE. In the second approach, the area is divided into 24 zones being a combination of terrain height (4 zones) and distance from the closest obstacles (6 zones). In each zone, a MLR sub-model is specified and combined with IDW if needed, similarly to the first approach. In zones where the environmental correlation of SWE is not statistically significant, the mean (or median) SWE is used as an equivalent of MLR estimation. Finally, a SWE map for the entire basin is obtained. We integrated SWE over space to estimate the volume of water accumulated in snow at a time of UAV observation.

In order to verify and validate the approach we carried out the fieldwork in the Izerskie Mountains and Izerskie Foothills (the Sudetes, SW Poland). Since early 2015 we have performed a series of UAV flights over four subareas. We studied two sub-basins of the Kwisa river. Along with UAV missions, two meteorologists conducted a detailed assessment of snow cover (HS and SWE pointwise readings) in numerous places, both within and outside the subareas. In addition, meteorological data were recorded every 12 minutes at nine weather stations, and discharges were measured with the same sampling interval by discharge sensors installed at river outlets.

The procedures to validate the SWE estimates for each of the two sub-basins were twofold: (1) SWE maps were compared with pointwise data, having known that our approach produces rough estimates, (2) spatially integrated SWE rasters (volume of water) were compared with the snow-melt discharges integrated over time inferred from discharge sensor readings. The snow-melt signal was separated using TOPMODEL – the simulated discharges were subtracted from the measured data to get the snow-melt riverflow.

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