# Detailed Spatial and Temporal Observations of Snow Covers in Mountainous Watersheds Using Numerous Low-Cost Standalone Sensors

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HYDROLOGY

## Introduction

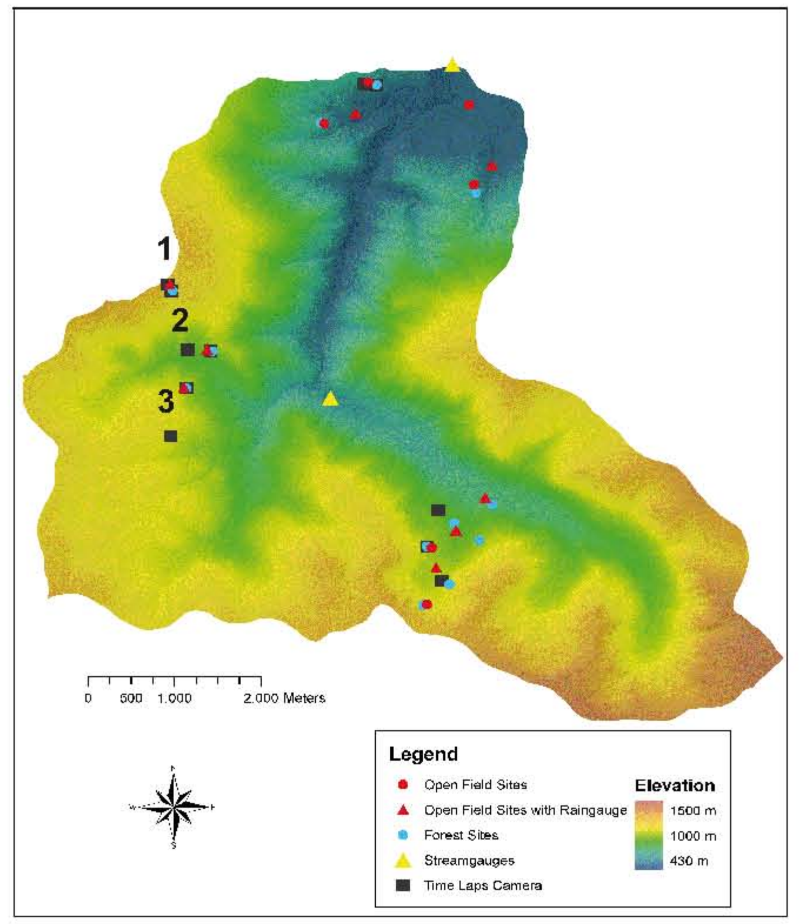
The project focuses on the modeling and forecast of stormflow runoff, from small and mid-size basins during the winter period. Special consideration will be given to the prediction of "rain on snow" (ROS) events in intermediate mountain regions, as these events have been shown to frequently produce potentially dangerous floods in such basins. The forecast of ROS events is highly uncertain at the moment. A reliable forecast requires detailed knowledge about the spatial variability of the snow cover and the snowmelt energy balance and the ability to include this knowledge in model applications. The study uses an innovative approach of augmenting existing meteorological stations with a network of numerous low cost, yet accurate, snow monitoring stations (LOCUS) delivering highly distributed data on snow cover and climate conditions throughout the study basins. Data collected by the sensors currently include: snow depth, air temperature and humidity, and total precipitation. A new generation of sensors being developed will also monitor global radiation, wind speed, and snow temperature. The collected data will be used to assess the naturally occurring spatial variability in snow accumulation and snowmelt processes including meltwater runoff resulting from topography and vegetation effects.

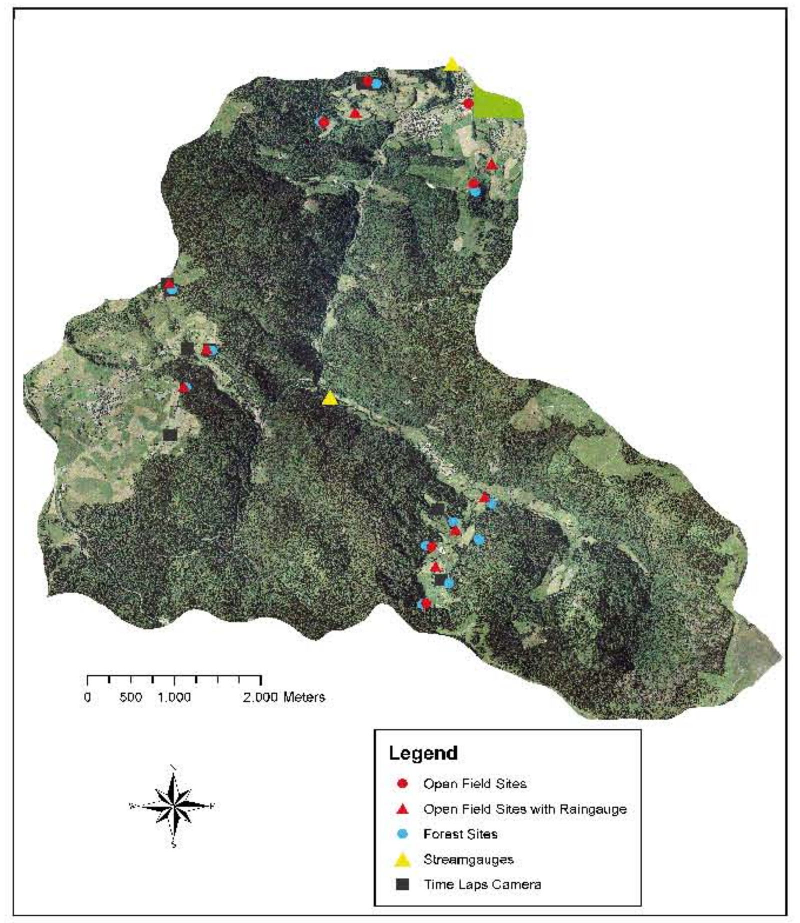
## Methodology

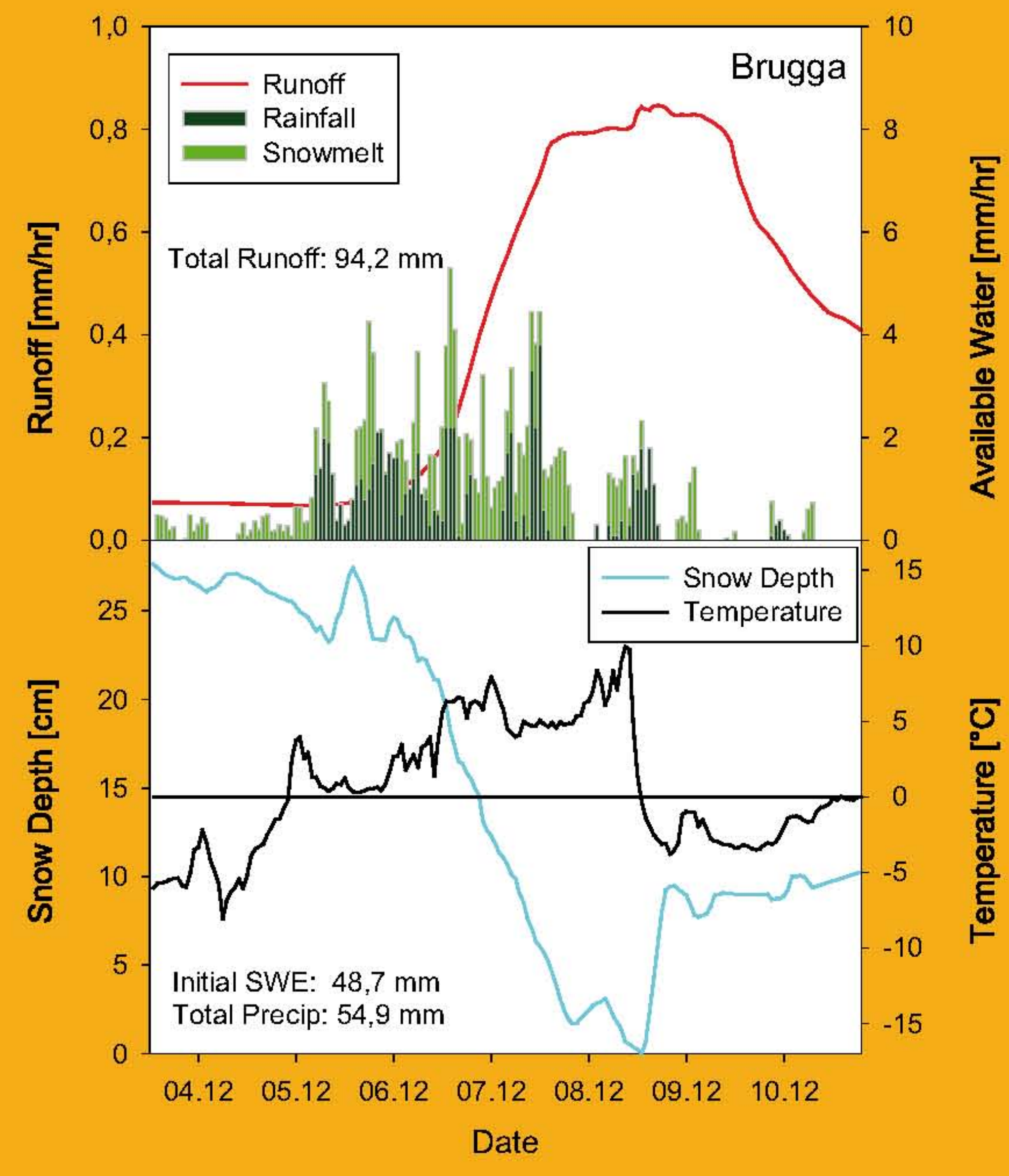
The sensors used are battery-powered standalone systems with a built-in datalogger. The distance between the sensor and the (snow) surface is measured with an ultrasonic range finder. The distance readings need to be corrected for pitch and roll of the sensor (which are recorded by the sensor) and for the air temperature at which they occur. Recordings are triggered at 1 hr intervals and consist of a number of consecutive readings (set to 20 in this study). Sample readings are flagged as corrupt should the sample variance exceed a user-defined threshold. The sensors are mounted on a L-bar and can run unattended for the full winter period. Selected sensors were additionally outfitted with a standard precipitation recording tipping bucket.


## Sensor Network Setup

26 stations were set up throughout the Brugga basin. The locations of the stations were chosen to cover a wide range of slope angles, elevations, and expositions as a stratified sampling design. Furthermore, "paired stations" located in close proximity to each other, one in an open area and one underneath various forest canopies, were set up to investigate the influence of the vegetation cover on snow accumulation and ablation in detail.
Additionally, 11 time-lapse cameras taking a picture every hour were installed, providing continuous information on snow interception in the forest canopies, the state of precipitation, and snow heights and albedo in open and wooded areas.



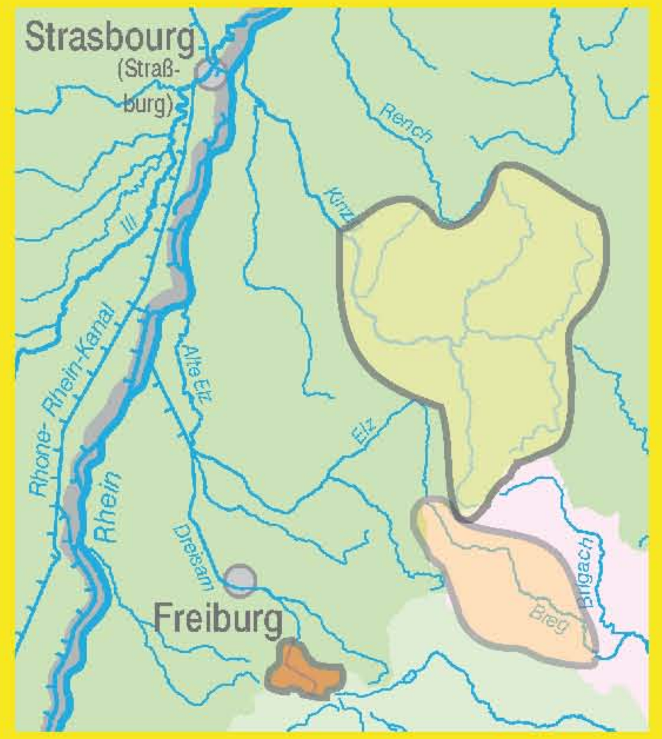



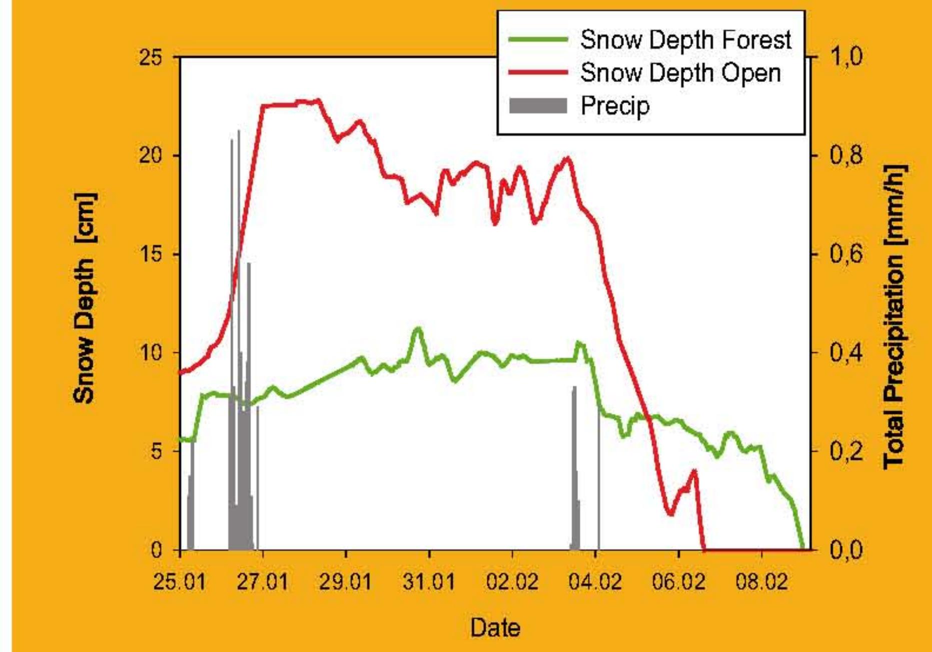

## First Results

A significant rain on snow event producing a 5-year flood occurred from Dec. 6 to Dec. 8 2010, shortly after the start of the project. An analysis of the event showed the crucial role the snow cover played in this event. Some of the initial rain was stored in the snow cover, indicating that snow initially acts as a storage buffer. The main rise of the hydrograph did not happen until the snow cover was saturated and isothermal and began to melt rapidly. Some additional precipitation on Dec. 8 did not produce another significant rise in runoff since it fell as snow in many parts of the basin as can be seen by the recorded rise in snow depth. Overall, water from snowmelt accounted for roughly 50% of the total flood volume.
Pre-event snow water equivalent (SWE) within the basin varied greatly, ranging from 12.5 mm in the forests of the lower elevations to 89.6 mm in the open areas of the highest locations with an overall basin wide average of 48.7 mm.
Another, smaller, ROS event occurred about one month later. In this event, water released due to snowmelt contributed about 39% of the total flood volume again indicating the important role snowmelt plays in many winter flooding events.


## The Study Basins

Sensor networks will be set up in three basins over the next two winters. The chosen basins differ in their sizes and topographical and vegetational characteristics. The first basin selected for the study is the „Brugga" catchment located approximately 15 km SW of Freiburg in the Black Forest region. The basin is 40.1 km² in area and has a fairly strong relief. The elevation within the basin ranges from 434 m NN at the basin outlet to 1493 m NN at the top of the „Feldberg" mountain. The maximum slope determined from a 1 m LiDAR DEM is 68° with an average of 20.2°. The basin is characterized by undulating terrain in the lower and upper reaches with some deeply incised valleys and steep forested slopes in the middle parts. The basin is tilted slightly towards the Northeast. Overall, the basin is about 70% forested with 26% being covered by open areas mostly pasture and hay meadows. The remaining 4% are settled, urban areas. Yearly precipitation ranges from 1340 mm near the basin outlet to 1740 mm on the „Feldberg" while yearly average temperature ranges from 9.0°C in the lower parts to 2.5°C in the upper parts of the basin.




## Vegetation Influence

The figure shows hourly snow depth measured at two stations located in close proximity (approx. 80m) to each other, one in an open pasture, the other underneath a dense deciduous forest for a 15-day period. Analysis shows that the snowfall between January 25 and 27 causes snowdepth to rise by 15 cm in the open location, while only a rise of 5 cm is recorded underneath the forest canopy. However, snowdepth underneath the trees continues to increase continuously for a further two days as previously intercepted snow is unloaded from the canopy. The influence of the vegetation cover is also clearly evident during the melt of the snow cover. Snowmelt in the open location is much quicker and the ground is snow free about two days ahead of the ground in the forest.

## Time Lapse Photography

The above figure shows some examples of the kind of information that can be gained from time lapse photography. The pictures from camera 1 (left) shows the decreasing amount of snow stored in the canopy after a snowfall event. This information will be used to gain a better understanding of snow interception in trees as well as unloading and sublimation of snow from the canopy. Camera 2 (middle) shows the progression of snowmelt on an open, south facing slope. In combination with other cameras, this will enable us to quantify the amount of snow covered area in different parts of the basins characterised by different elevation, aspect and slope angles. Camera 3 (right) provides the same information for a forested, north facing slope. Aside from comparing this to other forest locations, comparisons can also be made to adjacent open areas.

## Future Work

The meteorological data will be augmented by observations of soil moisture, ground water levels, and runoff in smaller streams to gain a better understanding of the spatially variable runoff response of basins to snowmelt and rain on snow runoff events. The obtained datasets will be used as input and validation data for several distributed hydrological models of different complexity. Models used will include complex, physically based research models and simpler process and index based models suitable for flood forecasting.

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