Modeling Winter Snow Redistribution Processes in Alpine Terrain

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Introduction

Our project aims to improve the detailed understanding of the processes of snow accumulation and ablation in Alpine environments, as well as their possible response to future climate scenarios. The main task is assessing water resources in snow covered and glaciated basins. Accurate estimation of water stored within the snow and ice cover of such basins requires knowledge of a distributed snow and ice mass balance throughout the year. While many observations and models are available to describe the ablation season, the evolution of the winter snow redistribution is relatively unknown. In addition, models that are able to simulate winter snow accumulation processes over these mountain regions are limited.

The test research site is the Haut Glacier d'Arolla in southwestern Switzerland, with the intention to use a highly instrumented site in the Alps for testing and implementation of process based mass and energy balance models, which could be applied in other mountain regions of the world. As part of our research, we have implemented SnowModel on Haut Glacier d'Arolla. SnowModel is a spatially-distributed snow-evolution modeling system, that has been applied in Alaska, Norway, Greenland, Antarctica, and mountains of the Western United States, but it has never been applied to topographic distributions as steep and complex as the Swiss Alps.

Methods

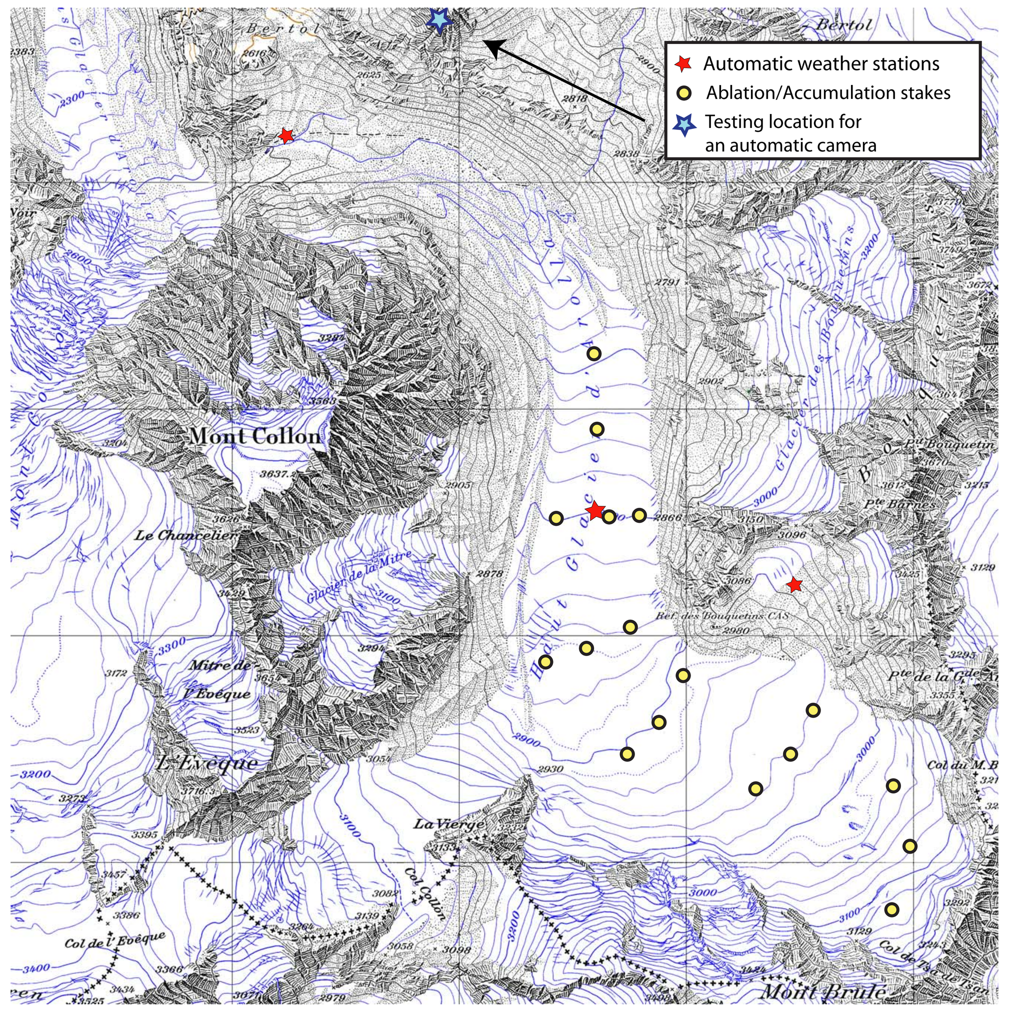

Figure 1: Map of the Haut Glacier d'Arolla with indicated locations of the automatic weather stations, ablation/accumulation stakes and the location, where the automatic camera, overviewing the glacier, is being located.

Instrumentation

We instrumented the Haut Glacier d'Arolla in southwestern Switzerland in order to get an idea of the accumulation processes in a glaciated Alpine basin (Fig. 1). This will also allow us to validate the models that we are using.

- 2 permanent Automatic Weather Stations outside the glacier (temperature, humidity, SW radiation in/out, LW radiation in/out, wind speed/direction, precipitation, snow height)
- 1 permanent Automatic Weather Station on the glacier (temperature, humidity, SW radiation in/out, wind speed/direction, snow/ice surface temperature, snow height)
- 18 ablation/accumulation stakes on the glacier
- Automatic camera overviewing the lower part of the glacier

SnowModel

SnowModel is a spatially-distributed snow-evolution modeling system designed for applications in landscapes, climates and conditions where snow occurs [LEed]. It includes an AWS-data-prepocessing routine, which fills in missing data from AWS and screens these files for realistic values. The model itself is an aggregation of four sub-models:

- **MicroMet** defines meteorological forcing conditions by distributing AWS data over a defined grid
- **EnBal** calculates the surface energy exchange
- **SnowPack** simulates the snow depth and the snow water equivalent evolution
- **SnowTran-3D** accounts for snow redistribution due to wind

We forced the temperature distribution with lapse rates measured at our stations outside the glacier. The precipitation distribution was forced with lapse rates adopted from the Hydrological Atlas of Switzerland [SDFS00].

Results

While applying the SnowModel to Haut Glacier d'Arolla, we realized that we need to make changes to the model in order to adapt it to a glaciated valley surrounded with steep slopes. The model did not account for the drop in air temperature due to ice melt in summer. To account for it, we preliminary lowered the air temperature over the glacier with a constant drop of 2.5 degrees [SCP+04, GKS97], when the surrounding slopes are snow free (Fig. 2). The calculated surface temperatures (Fig. 3) are very low for wintertime, and we have not been able to verify them yet as the surface temperature sensor has only been installed this winter, and we did not have access to the data yet.

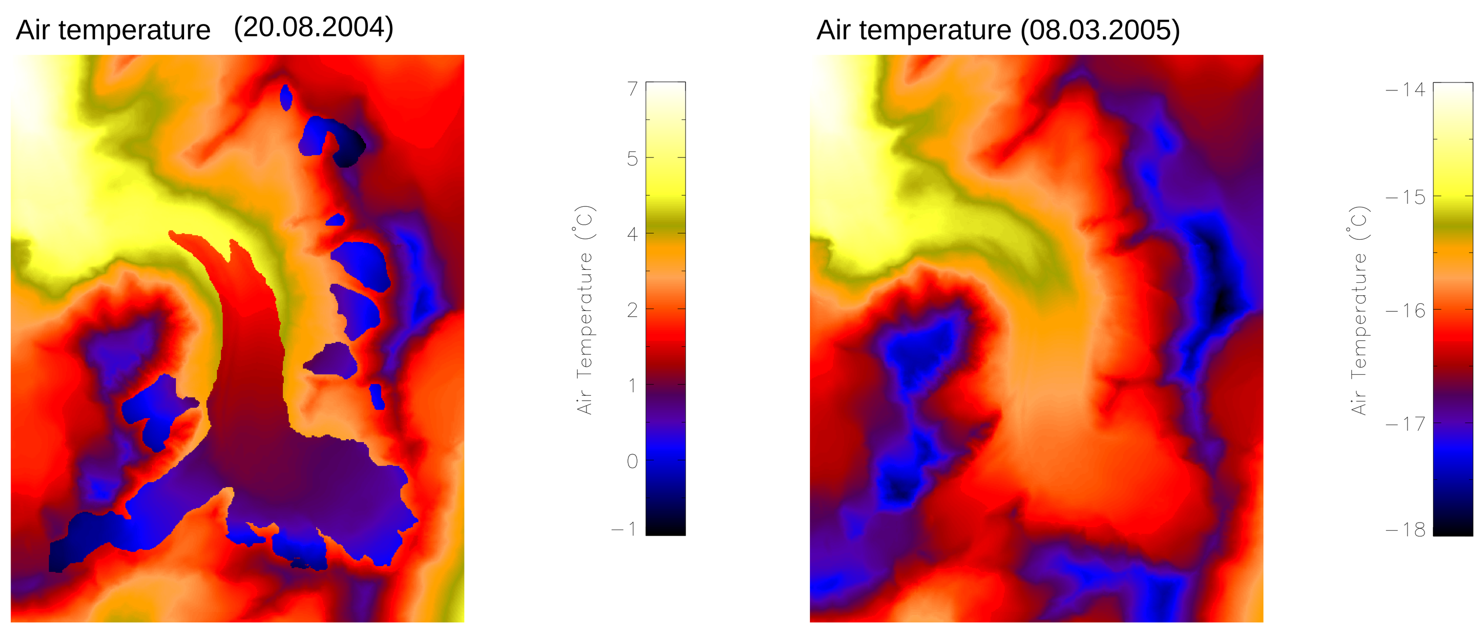

Figure 2: Air temperatures for a summer (left) and a winter day (right). Due to melting ice, the temperature over the glacier are lower than the surrounding air temperatures. (Note: The scales on these two plots are different.)

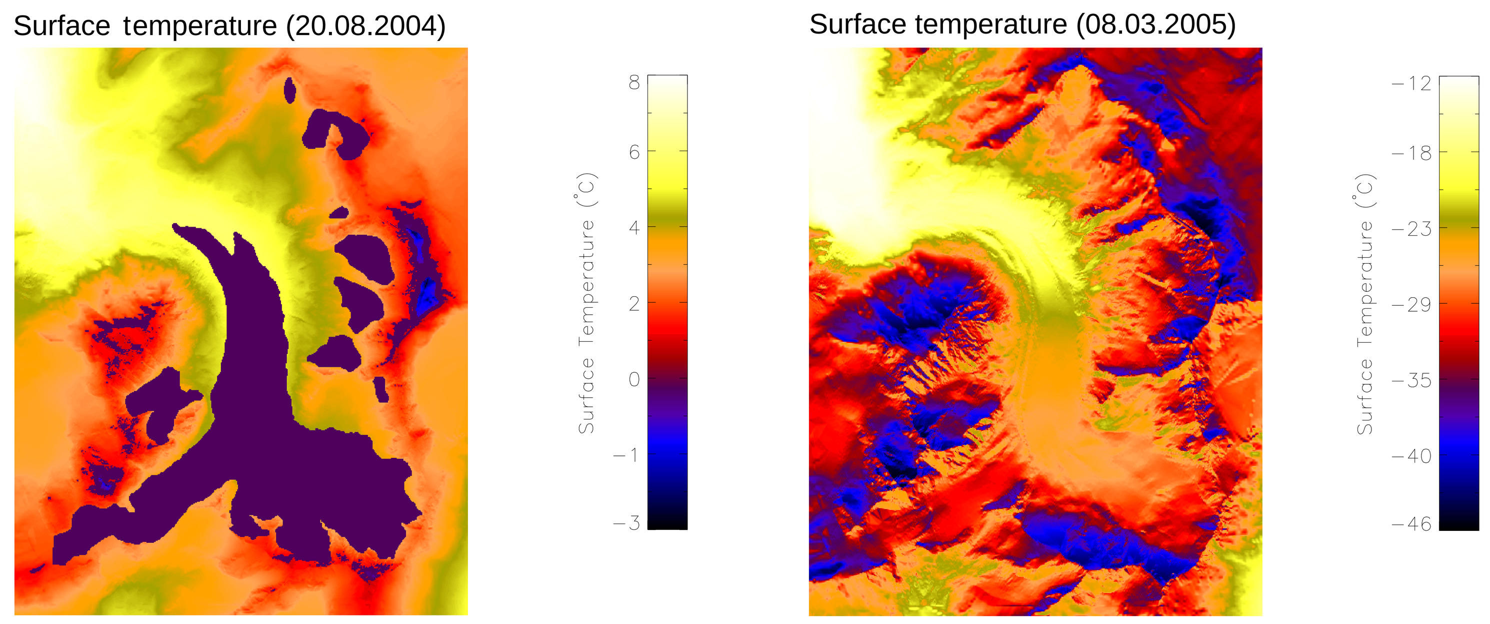

Figure 3: Surface temperatures for a summer (left) and a winter day (right). (Note: The scales on these two plots are different.)

Snow Depth

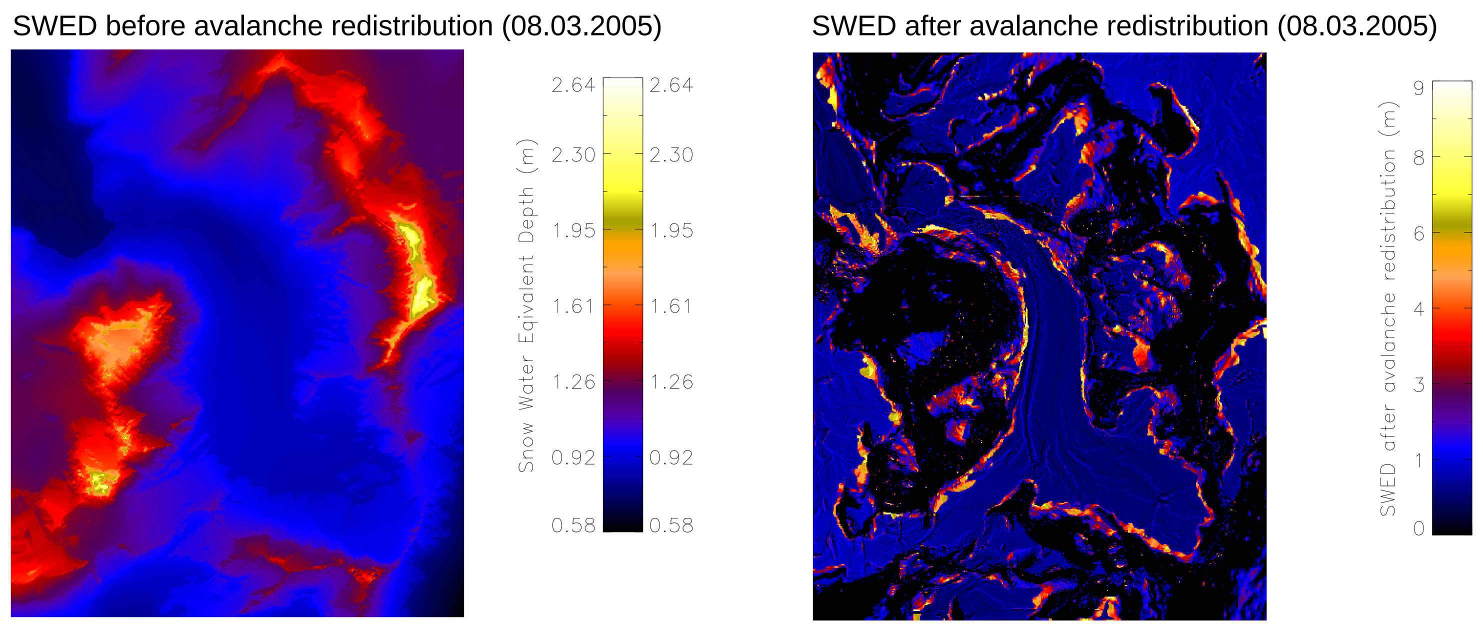

Figure 4: Snow water equivalent depths before (left) and after (right) applying the snow avalanche distribution model MFLOWTD. (Note: The scales on these two plots are different.)

The complex topography in a glaciated Alpine valley forced us to apply an additional model, which accounts for the snow redistribution due to avalanching on steep slopes. While the areas in which SnowModel was applied up to now did hardly exceeded slopes of more than 30 degrees, (where avalanching occurs) such slopes are a dominating feature in Alpine valleys. We used a model (MFLOWTD) for gravitational transport and deposition developed by [Gru05] in order to account for redistribution processes related to large topographic gradients within our research basin. The model gives reasonable values, considering that the snow which comes down from steep slopes accumulates at the "slopebreak", but still has to be verified with our field observations.

Outlook

- Coupling of MFLOWTD to SnowModel
- Adjusting MFLOWTD to observed values
- Adjusting the energy balance model to glacierized terrains with melting surfaces
- Including a precipitation sub-model, which accounts for enhanced precipitation in complex topographic terrain
- Acquiring a wind model, which represents realistic wind fields in a complex terrain like the Alps

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