Annual mass balance estimates for Haut Glacier d'Arolla from 2000–2006 using a distributed mass balance model and DEM's.

R. Dadić, J.G.Corripio, P. Burlando

Institute of Environmental Engineering, ETH Zurich

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Outline


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Motivation

- WHAT?
- Detailed understanding of the processes of snow accumulation and ablation in Alpine environments, as well as their climatic sensitivity.
- WHY?
- Assessing water resources in snow covered and glaciated basins through continuous modelling of distributed mass and energy balance.
- Improving future investigations concerning the impact on water resources availability in future climate scenarios.

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Haut Glacier d'Arolla

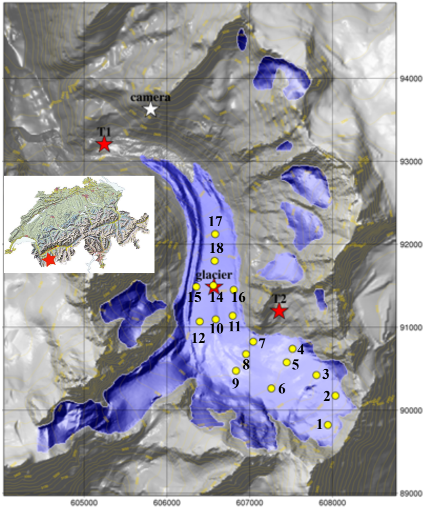


Figure 1: Digital map of the Haut glacier d'Arolla basin. In blue indicated is the glaciated area (5.3 km^2), red stars show the locations of three automatic weather stations, white is the location of an automatic camera and yellow circles show the locations of accumulation/ablation stakes. The total area of the catchment is 13 km^2 and the elevation range is from 2500–3800 m asl.

Hydrometeorological and Glaciological Measurements

- 3 permanent Automatic Weather Stations (AWS).
  - 1 AWS on the glacier, 2800 m asl, GLACIER.
  - 1 AWS in proglacial area, 2500 m asl, T1.
  - 1 AWS in non - glaciated part of the upper basin, 3000 m asl, T2.
- Discharge: pressure transducer in an artificial channel of known dimensions. (data source: Grand Dixence)
- SWE distribution in the end of the winter, directly measured.
- 15 accumulation/ablation stakes.
- DEM
  - 1999, 2005: DEM derived from aerial pictures (VAW Zurich).
  - 2006: DEM derived from LIDAR measurements of surface elevation.

Mass Balance Modeling

- Energy Balance: SnowDEM [Corripio 2002]
  - Distributed energy balance model.
  - Includes effects of topography.
- Mass conserving algorithm for gravitational Mass Transport and Deposition (MTD) [Gruber 2007].
  - Gravitational mass flow follows the DEM.
  - Deposition is controlled only by the available mass and a maximum deposition.

Elevation Differences 1999–2005

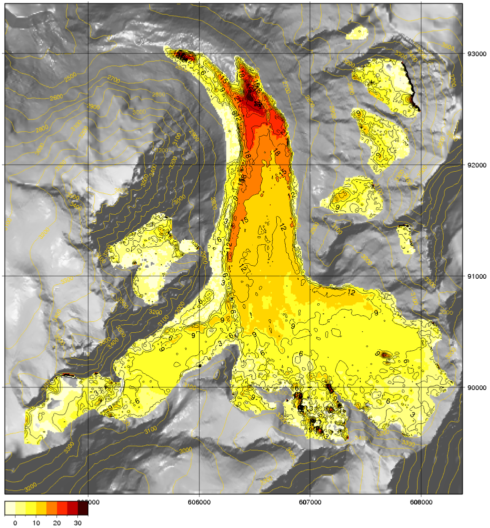


Figure 2: Difference (m) in elevation (1999–2005) in the glaciated area of the Haut Glacier d'Arolla catchment area in color. The accuracy is about 1 m. Maximum ice loss is observed at the tongue with 34 m and average ice loss over the glaciated area is 7.5 m. The background is a shaded image of the 1999 DEM.

Elevation Differences 2005–2006

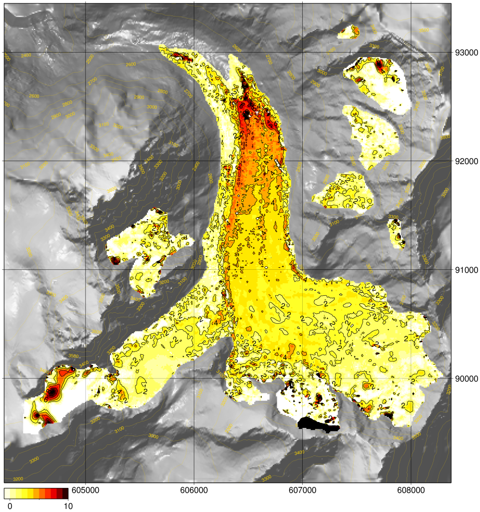


Figure 3: Difference (m) in elevation (2005–2006) in the glaciated area of the Haut Glacier d'Arolla catchment area in color. The accuracy is better than 1 m. Maximum ice loss is observed at the tongue with 6–8 m and average ice loss over the glaciated area is 2 m. The background is a shaded image of the 1999 DEM.

Runoff vs. Ice Volume Loss

Table: Different components contributing to runoff. Yearly average for the periods 1999–2005 and 2005-2006.

Period Water generation (10^6 m^3)	1999–2005 (yearly average)	2005–2006
Icemelt	6	10
Precipitation (measured, nc)	15	16
Runoff	25 (30 in 2003)	30
specific net balance (m)	-1.25	-2.0

Modeled Runoff vs. Ice Volume Loss

Table: Model results for MR1 (no MTD included) and MR2 (MTD included), showing the different components of the contribution to runoff in the 2005–2006 season. Both model runs overestimate the water contribution in the basin due to icemelt and precipitation.

Model run Water generation (10^6 m^3)	MR1	MR2
Icemelt	16	14
Precipitation	31	27
Runoff	47	41
specific net balance (m)(avg. ice thickness loss)	-3.0	-2.6

MR1 vs. MR2

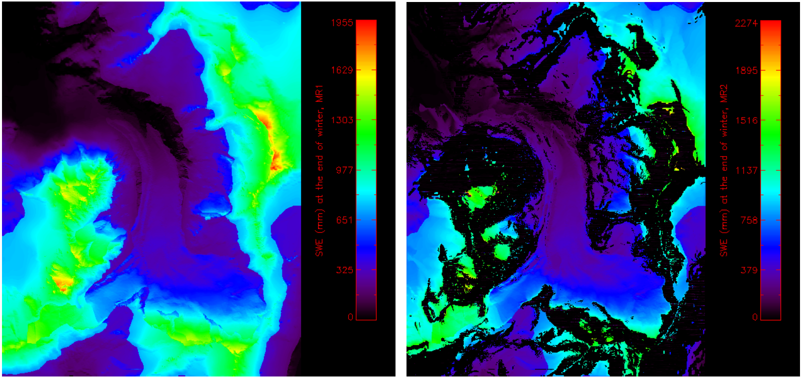


Figure 4: SWE at January 10th, 2006. Left figure does not include the gravitational mass transport and deposition routine (MR1), while in the right figure is including the mass transport routine (MR2).

Measured vs. Modeled 'End of Winter Accumulation'

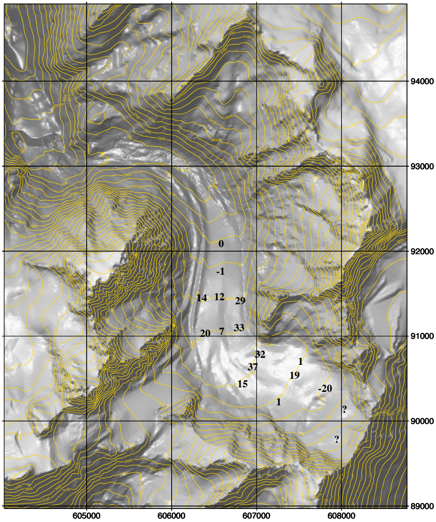


Figure 5: Measured - modeled(MR2) end of winter accumulation (May 24th) in cm! SWE at stake locations (for MR2). The model is underestimating SWE at almost all locations stake up to 30%.

Measured vs. Modeled Ablation

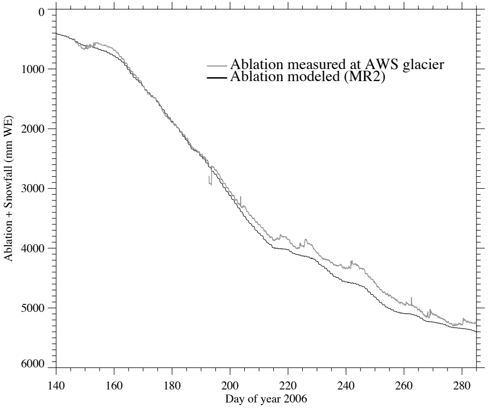


Figure 6: Measured ablation (grey line) against modeled ablation (black line) from the model run including the gravitational mass transport and deposition routine (MTD). The model is understimating snowfalls, which are good distinguishable in the automatic measurement at the AWS located on the glacier from day 210 on.

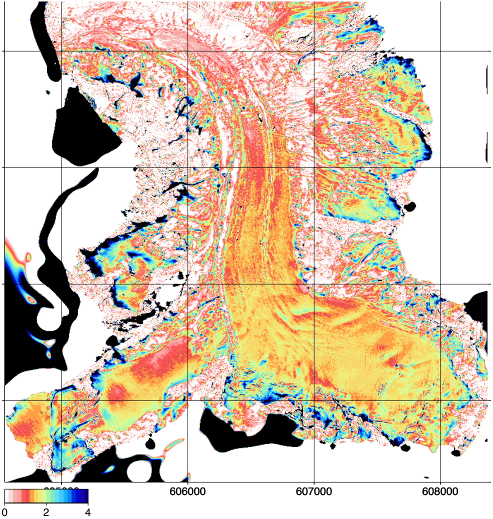
Discussion I: Modeling

* When snow distribution is not included, more ice melt occurs and overall, more water is generated.
* Model underestimates initial snowfall and/or overestimates snow melt.
    * Overstimation of snow melt:
        * Albedo distribution?
        * Correct distribution of meteorological variables?
        * Snow density?
    * Underestimation of snow accumulation:
        * Differential precipitation due to topography?
        * Snow drift due to wind transport?
        * Estimation of parameters used in MTD?

Discussion II

* The contribution from precipitation to the runoff is twice as big as the contribution from glacier melt.
* Snow distribution in the basin is important for the form of the hydrograph as well as for the overall water generation.
* The impact on water resources availability due to future climate scenarios is very much affected by the rise in the altitude where snow becomes rain due to temperature rise.

Outlook



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For Further Reading I

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PhD Thesis, The University of Edinburgh, 2002.

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