Comparison of ablation modeling by three mass balance models of differing complexity

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Introduction

In order to model the impact of climate change on glaciers it is important to understand the processes that control the mass budget of the ice bodies. Today a wide range of glacier mass balance models is applied, ranging from simple degree day models to complex energy balance models. Differences between the models do mainly concern the parameterizations for the calculation of the ablation. In this study we compare the output of three distributed mass balance models of differing complexity: a degree day model enhanced by calculated potential global and two energy balance models of differing complexity. Ice ablation on Haute Glacier dArolla, Switzerland, is simulated for the melt seasons 2005. All three models are driven by identical input parameters from two automatic weather stations outside of the glacier boundary layer.

Calculated melt rates are compared to ablation measurements taken at 11 stake locations. We present the results of the model runs and analyze the reasons for the differences among the models.

Methods

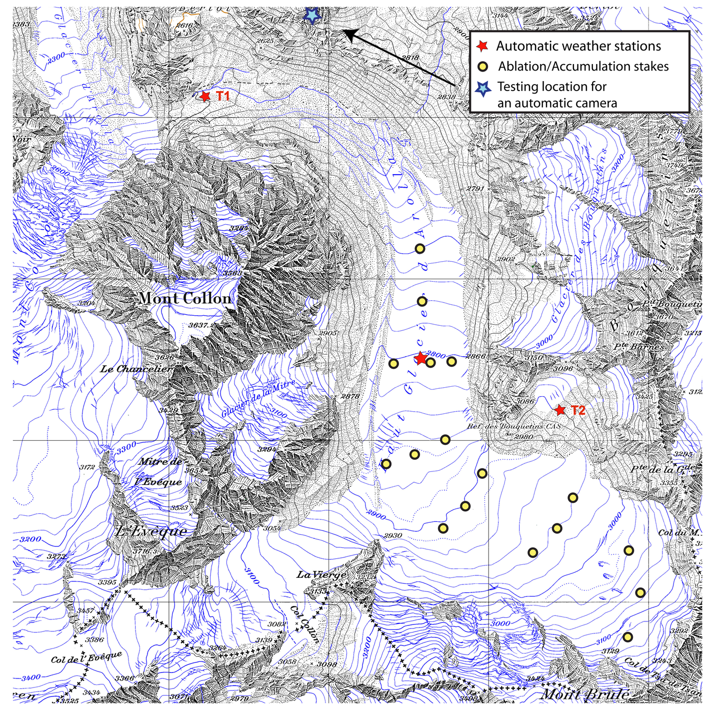

Figure 1: Map of the Haut Glacier d'Arolla with indicated locations of the automatic weather stations, ablation/accumulation stakes and the location, where an automatic camera, overviewing the glacier, is being located. The glaciated area is 5.3 km² and the total area of the catchment is 13 km² and the elevation range is from 2500–3800 m asl.

The three models use the same code for the calculation of potential clear sky radiation (Corripio, 2003) , taking into account all effects of topography.

Simple energy balance model (1)

The model is based on Oerlemans (2001). The model operates at daily steps. Surface temperature (T_{surf}) is fixed at 0 °C. Albedo of snow (α_s) is fixed at 0.6. The sum of longwave radiation and turbulent exchange is described as a linear function of the temperature in the free atmosphere T_a in °C.

Energy balance model of intermediate complexity (2)

The second model is decribed by Klok and Oerlemans (2002) and operates at half hourly time steps.

- Cloudiness is calculated from the ratio of measusered global radiation ($S_{in-meas}$) to modelled potential clear sky radiation (S_{in-cs}) and is interpolated linearly during nightime.
- The turbulent fluxes are calculated using equations from Oerlemans and Grisogono (2002).
- A snow ageing function, depending on surface temperature, describes the temporal variability of α_s and T_{surf} is calculated from a two layer subsurface model.
- Incoming longwave radiation (L_{in}) is a function of sky emissivity and T_a (in K), outgoing longwave radiation (L_{out}) is a function of T_{surf}.
- The emitted longwave radiation from surrounding slopes is not considered.

SnowDEM (3)

SnowDEM (Corripio, 2002) is a distributed physically based energy balance model for application to snow and glacier covered mountain regions. It is fed with data from an automatic weather station outside the glacier and computes hourly energy fluxes of :

- S_{in} and S_{out}, direct, diffuse and reflected S from surrounding terrain. It approximates the ratio of direct to diffuse solar radiation and corrects accordingly for shading and topography. It takes into account different degrees of cloudiness and implements a simple parametric model of α_s based on local accumulated melt.
- L_{in} and L_{out}, both atmospheric and emitted from surrounding ground. It approximates the effect of increased long wave radiation due to clouds based on direct measurements.
- Sensible and latent heat fluxes, a bulk method approach based on measured wind speed, temperature and relative humidity.

In contrast to model (2), cloudiness at nightime is calculated from the ratio $L_{in\ meas}$ to $L_{in\ calc}$. Furthermore, model 3 differentiates between glaciated areas and surrounding terrain whereas models 1 and 2 treat the whole basin as glaciated. The threshold temperature for solid precipitation is set to 0 °C, instead of 1.5 °C in models 1 and 2.

Results

None of the applied models was tuned to fit measurements on Haut Glacier dArolla. The models achieve correlation coefficients from 0.6 to 0.9. Independent of parametrisation complexity, modelled and measured melt values are within a range of +-0.5 m w.e.

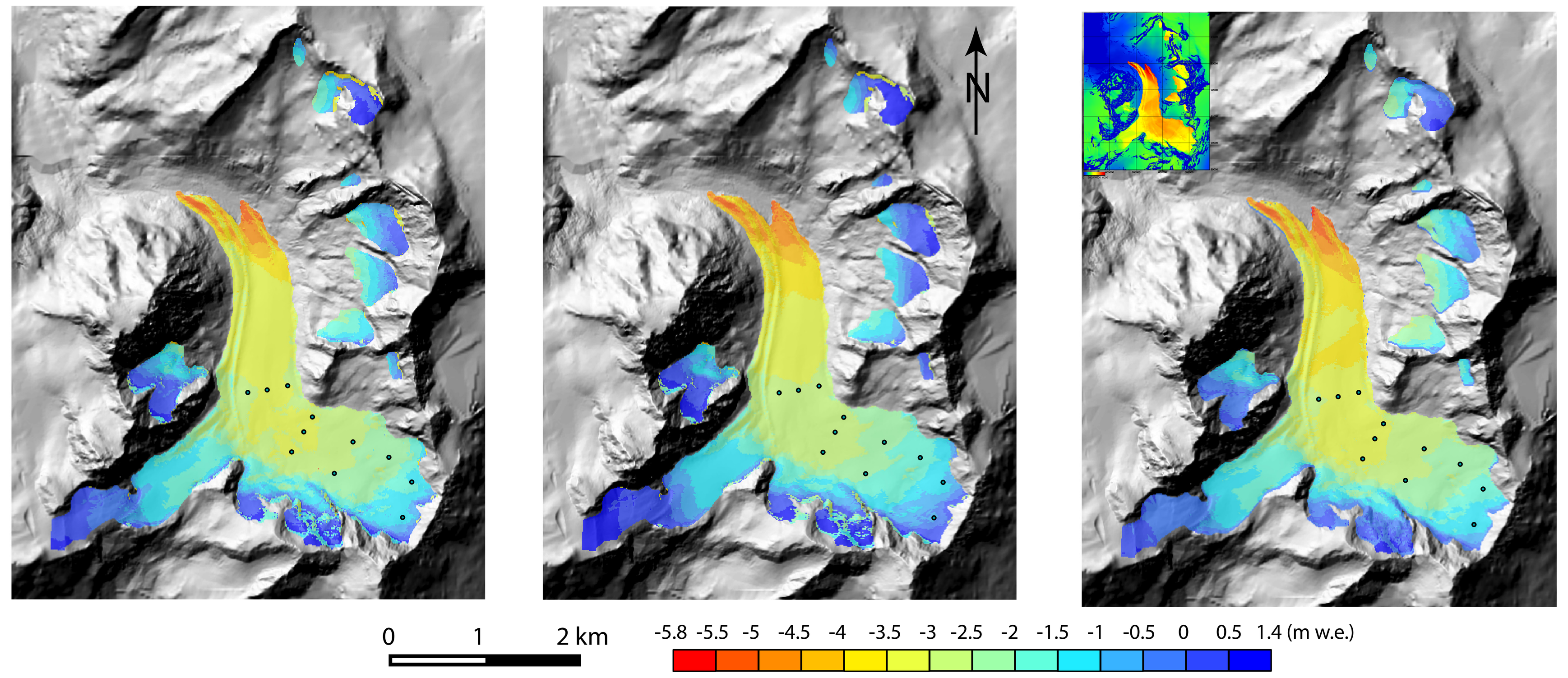

Figure 2: Summer ablation (June 11th 2005 – September 4th 2005). Models 1, 2 and 3 are shown from left to right with indications of the stake locations. The inset in the right figure shows that this model, which is modeling higher ablations than models 1 and 2, accounts for the non–glaciated area.

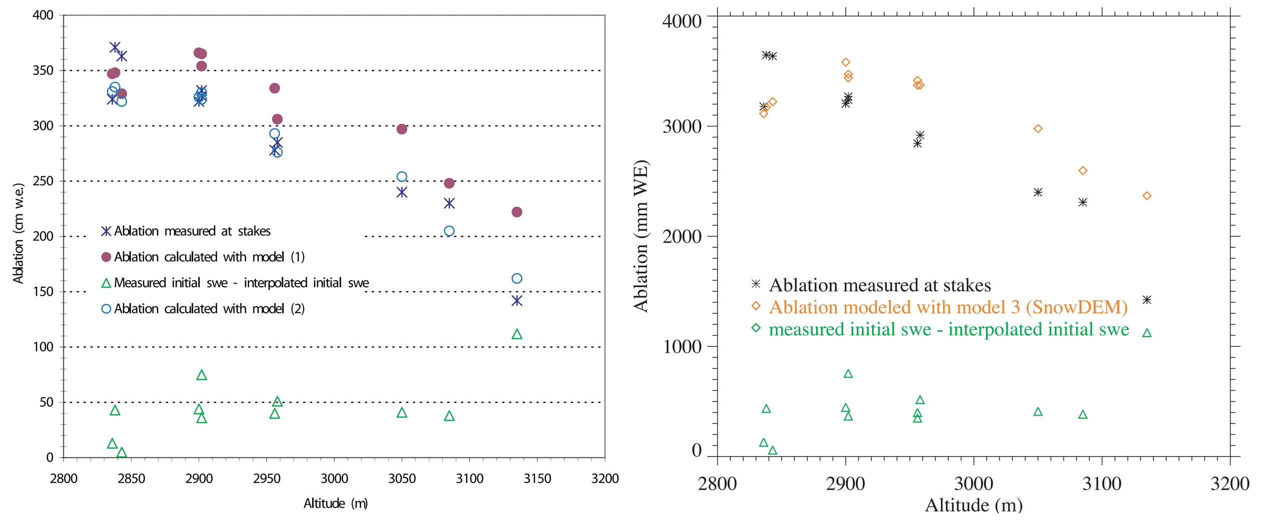

Figure 3: Summer ablation (June 11th 2005 – September 4th 2005) against altitude for 11 stake locations. The left figure shows results from models 1 and 2, the right figures shows the results from model 3. In green indicated are the errors in the initial snow cover at the corresponding stake locations.

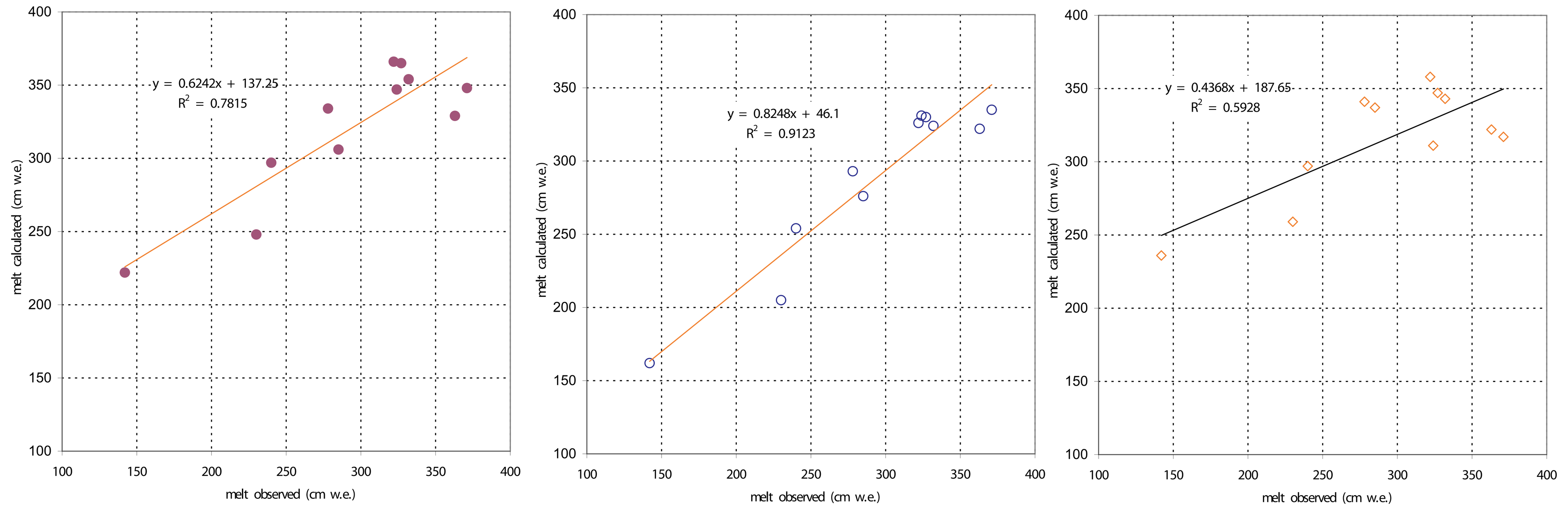

Figure 4: Direct comparison of measured and modeled ablation for all three models with linear regression. Models 1, 2 and 3 are shown from left to right.

Discussion

The spatial interpolation of initial snow depth is a critical point impacting on the accuracy of our results, making the comparison to measurements difficult.

The fixed α_s in Model (1) is a disadvantage when shorter calculation periods are chosen. α_s was usually set to 0.72 for model runs over time spans of one year or more. For this model-run, it had to be lowered to 0.6 because we are dealing only with melting snow.

The linear interpolation of cloudiness during nighttime, applied in model (2), becomes a disadvantage during winter. Daytime is short then and cloudiness for most of the day has to be interpolated. However, measurements of L_{in}, required in model (3) for calculation of cloudiness during nightime, are often not available.

Treating the entire DEM surface as glaciated (models 1 and 2) could have an impact on the mass balance calculation for the glacier surface of Haut Glacier dArolla, as the longwave outgoing radiation is modeled using the basin properties. However, this simplification makes melt discharge calculations impossible.

A reason for the different results might also be the different rain/ snowfall threshold temperature, which is 1.5 °C lower in model 3.

Conclusions

Direct comparison of stake measurements to modelled mass balance for specific points allow for a detailed analysis of the spatial distribution of the surface melt. Since none of the three models was tuned to fit the measurements, the study gives confidence in the applicability of glacier energy balance models to new glaciers. However, three major restrictions apply to our results:

- We can only compare measurements at one point, being representative for an area of unknown size, to the calculated value of one specific grid cell, covering 100 m² in the present study.
- The spatial interpolation of initial snow distribution is not represented correctly and makes it difficult to actually compare our results, because the uncertainties of the initial snow cover are in the same order as model differences.
- We avoided the largest difficulties in mass balance calculations by confining our model period to summer time.

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