# Sensitivity of energy balance to the measuring height of input variables

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## Introduction

In the European Alps and in most other areas in the world, the retreat of glaciers is a widely observed fact. It is reflecting the climate change, which is best observable in the temperature rise. Valley glaciers represent storages of water over long timescales and therefore have a large impact on worldwide water resources. Energy balance models help us to understand processes that lead to glacier retreat. However, model results are dependent on the input parameters they are driven with.

In this study, we are analyzing the sensitivity of the energy balance to measuring height of input variables using an energy balance model with different input data from Haut Glacier d'Arolla. Haut Glacier d'Arolla is a small, temperate valley glacier in southwestern Switzerland. Our data set contains meteorological variables from three automatic weather stations and ablation stakes. Two of the weather stations are located outside the glacier and one is located on the glacier. Due to winter accumulation and summer ablation, the weather stations are not at a constant height above the surface, but vary from 1 to 5 m. We are applying corrections to temperature and wind speed using the bulk method to correct the measurements to a standard height of 2 m. The relative humidity is corrected according to temperature changes.

## Methods

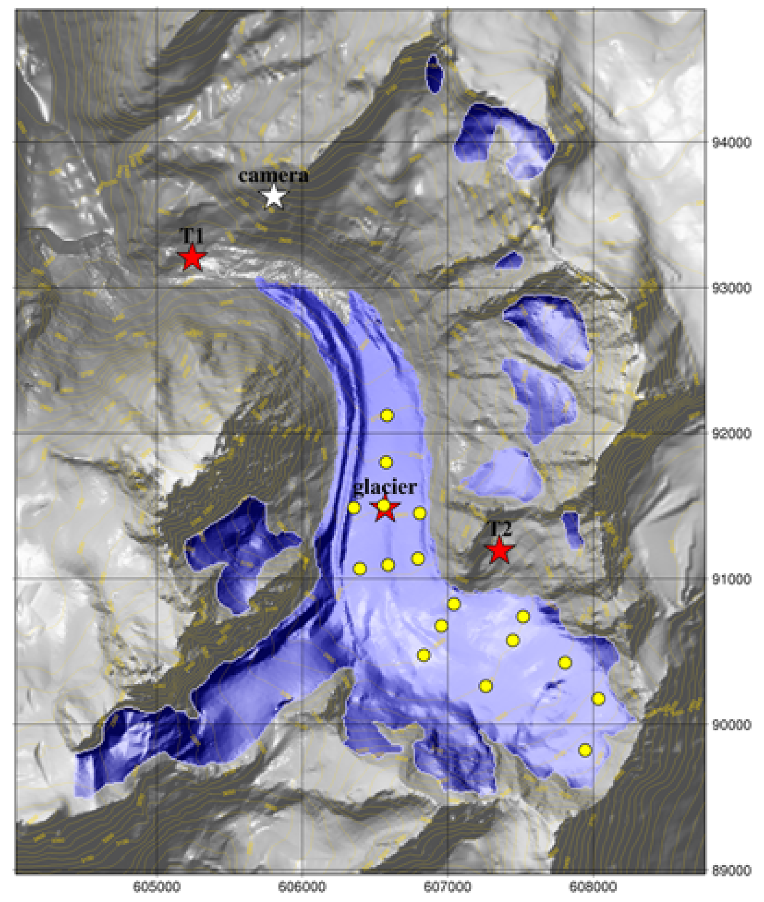


*Figure 1: Digital map of the Haut glacier d'Arolla basin. In blue indicated is the glaciated area (5.3 km²), red stars show the locations of three automatic weather stations, white is the location of an automatic camera and yellow circles show the locations of accumulation/ablation stakes. The total area of the catchment is 13 km² and the elevation range is from 2500–3800 m asl.*

### Height corrections for temperature and wind speed

The automatic weather stations (T1, T2, GLACIER) have a varying height due to snow in winter, or ice melt in summer. The stations T1,T2 outside the glacier have a constant height during summertime of 3 m and 5 m, respectively, the GLACIER station also in summer due to icemelt. In order to be able to compare the measured values of temperature and wind speed at different times, the measurements are corrected to a standard height of 2 m using the bulk method, which has the advantage that measurements of horizontal wind speed and humidity need only be made at one height above the surface, as long as the roughness lengths for momentum and temperature ($z_0$, $zh$) and the temperature $T_s$ of the underlying surface are known (Denby and Greuell, 2000; Brock et al., 2006). The bulk method is based on the similarity theory based on the work of Monin and Obukhov (Garratt, 1992) and assumes a constant flux in the surface boundary layer and a mechanically generated small-eddie turbulence within the wall shear flow (Brutsaert, 1982; Andreas, 1987; Stull, 1988):

$$Windspeed \qquad u(z) = \frac{u_\star}{k} ln\frac{z}{z_0} \underbrace{+\alpha_m \frac{z}{L}}_{stability\ correction} \qquad with \qquad u_\star = \frac{k\ u_h}{ln\frac{h}{z_0}} \tag{1}$$

$$Potential\ temperature \qquad \bar{\Theta}_s - \bar{\Theta}_z = \frac{H}{a_h k u_{\star_z} \rho c_p} ln\frac{z-d_0}{z_{0h}} \qquad z \gg z_{0h} \tag{2}$$

For most practical purposes, $\bar{\Theta}$ can be replaced by the air temperature $T$, and we can determine $T_s$ at any given height. Relative humidity is corrected according to temperature changes.

### SnowDEM

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 on the glacier and computes hourly energy fluxes of :

- Incoming and outgoing short-wave radiation, direct, diffuse and reflected 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 albedo based on local accumulated melt.
- Incoming and outgoing long-wave radiation, both atmospheric and emitted from surrounding ground. It approximates the effect of increased long wave 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.

## Variations in EB modeled with corrected and uncorrected input variables

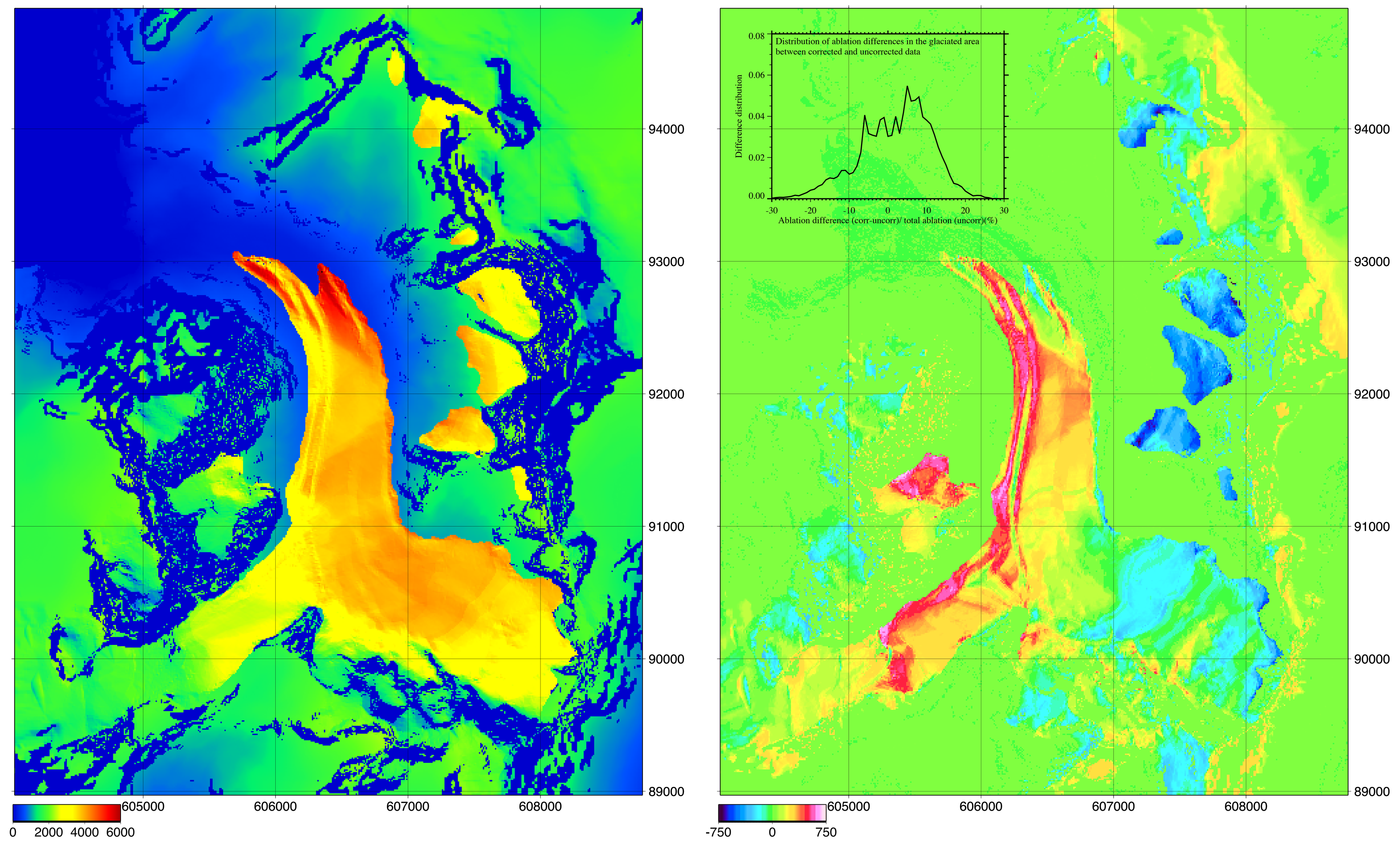

*Figure 2: Ablation for the summer 2005, with indicated Swiss topographic grid. The left figure shows the ablation in mm WE, calculated with corrected data (Tair, ws, rh). The right figure shows the difference between ablation modeling with uncorrected input data and left figure. The differences between uncorrected and corrected input data are positive on north and east facing slopes, and negative on west facing slopes. The are no differenes on the nonglaciated area, as these become snow free in both calculations. The inset on the right figure shows a distribution of differences for the glaciated area (blue area in Fig. 1).*

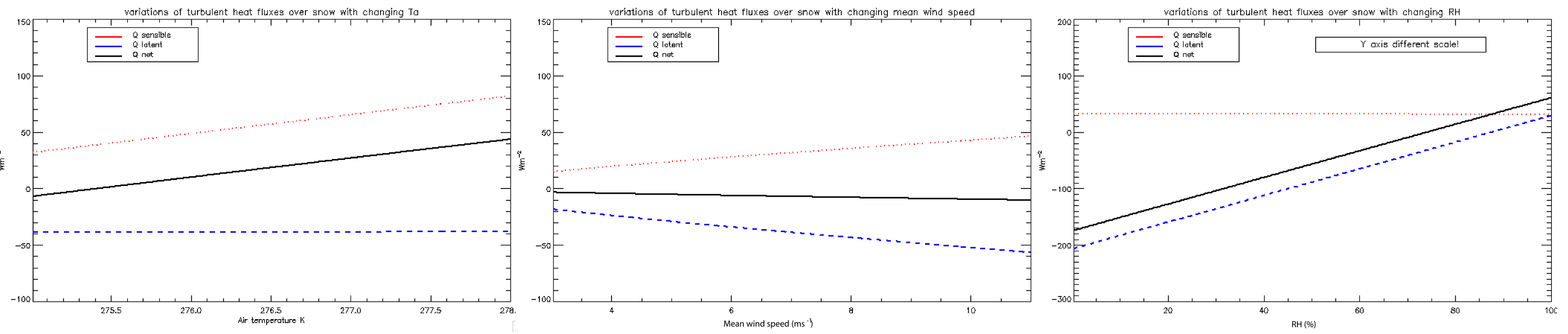

*Figure 3: Variations of turbulent fluxes as they are caused by the SnowDEM model with changing Tair, RH and WS. The changes in windspeed do not have as large an effect as changes in Tair and RH.*

## Differences in tair, ws and rh with changing station height

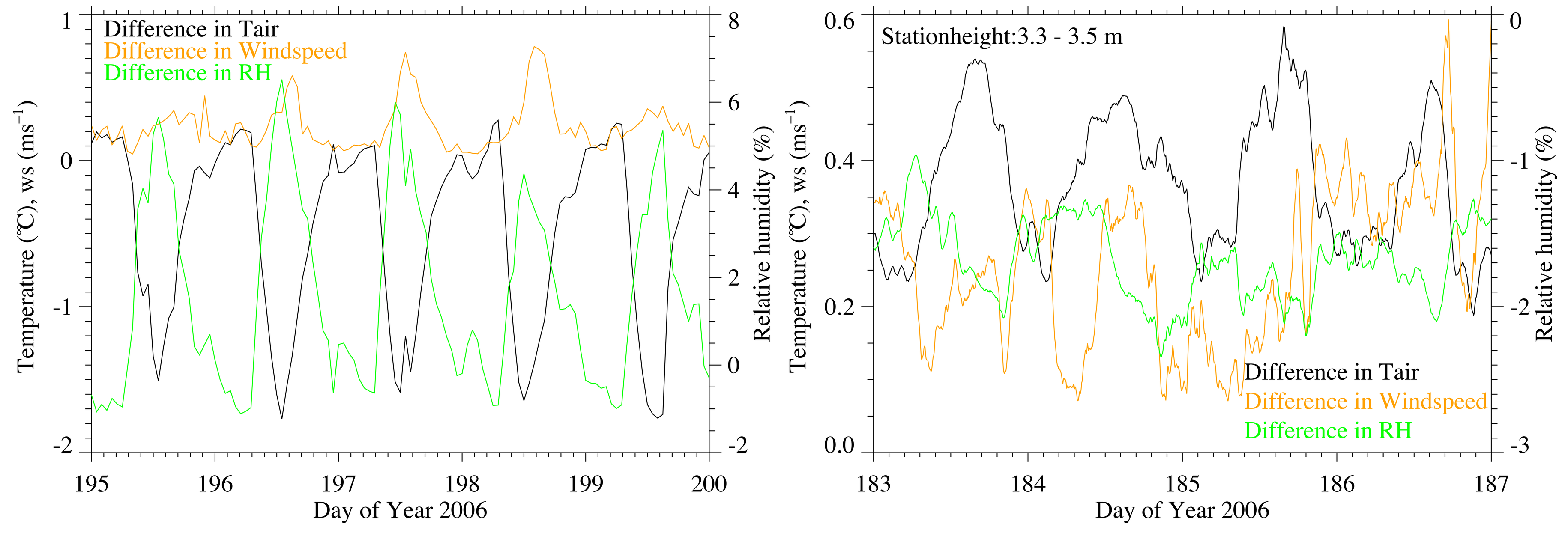


*Figure 4: Daily variations in differences in tair, ws and rh with changing station height for a station outside the glacier (left) and on the glacier (right). While the differences in tair outside the glacier are negative, the differences on the glacier are positive due to a constant temperature of the ice. Differences in ws are always positive, and differences in rh are always opposite to differences in tair. Largest differences are always observed during daytime. Differences outside the glacier in tair are up to 1.8 °C, differences in windspeed up to 1 ms$^{-1}$ and differences in rh up to 8%. Differences in all variables vary around ±10% from the actual measured value for tair and rh, and remain at about 12% for ws at stationheight of 5 m.*

## Discussion and Conclusions

- The height of the weather station has an effect on energy balance modeling in glaciated areas. A station, which is 5 m above ground has temperature differences of up to 1.8 °C, differences in wind speed of p to 1 ms$^{-1}$ and differences in relative humidity up to 8 %. The differences are up to 10 % of the measured value.
- In the energy balance model that we used, the differences are up to 20 % in ablation. In our case, the corrected inputs are only used to calculate turbulent fluxes.
- The differences between uncorrected and corrected input data are positive on north and east facing slopes, and negative on west facing slopes. The west facing slopes have more ablation in general, as they are are already heated up before the sun touches them. This effect seems to be enhanced for corrected data, because the temperatures in summertime are higher at 2 m than at 5 m. Snow on the ground would have an opposite effect on temperatures and therefore on the sensitivity at different locations within the basin. The afternoon shading of the east facing slopes also has a larger effect with corrected input data.
- The sensitivity to the measurement hight of input variables will be even larger for models, which are mostly based on temperature, like degree day factor models.
- Even if the temperature correction does not seem to have a large effect on the non-glaciated area throughout the whole melt season, it will affect the timing of maximum runoff in the basin due to a change in timing of snow depletion.
- Further studies should be done in order to include the effect of snow on the ground during winter and spring time.

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