Physiographic and climatic controls of regional glacier retreat

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HYDROLOGY

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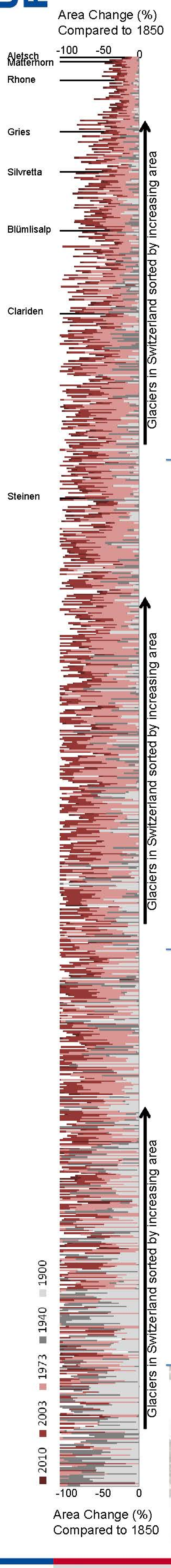


Motivation

Glacier melt provides an important part of the summer discharge of many European rivers. The understanding of the processes behind the glacier mass losses and glacier retreats observed during the last century is therefore relevant for a sustainable management of the water resources.

An overall retreat of all glaciers in the Swiss Alps was observed during the last 110 years (Figure left). However, the relative changes in glacier area compared to 1850 differed for the 998 glacier basins and **some glaciers decreased much faster than others.** This raises the question:

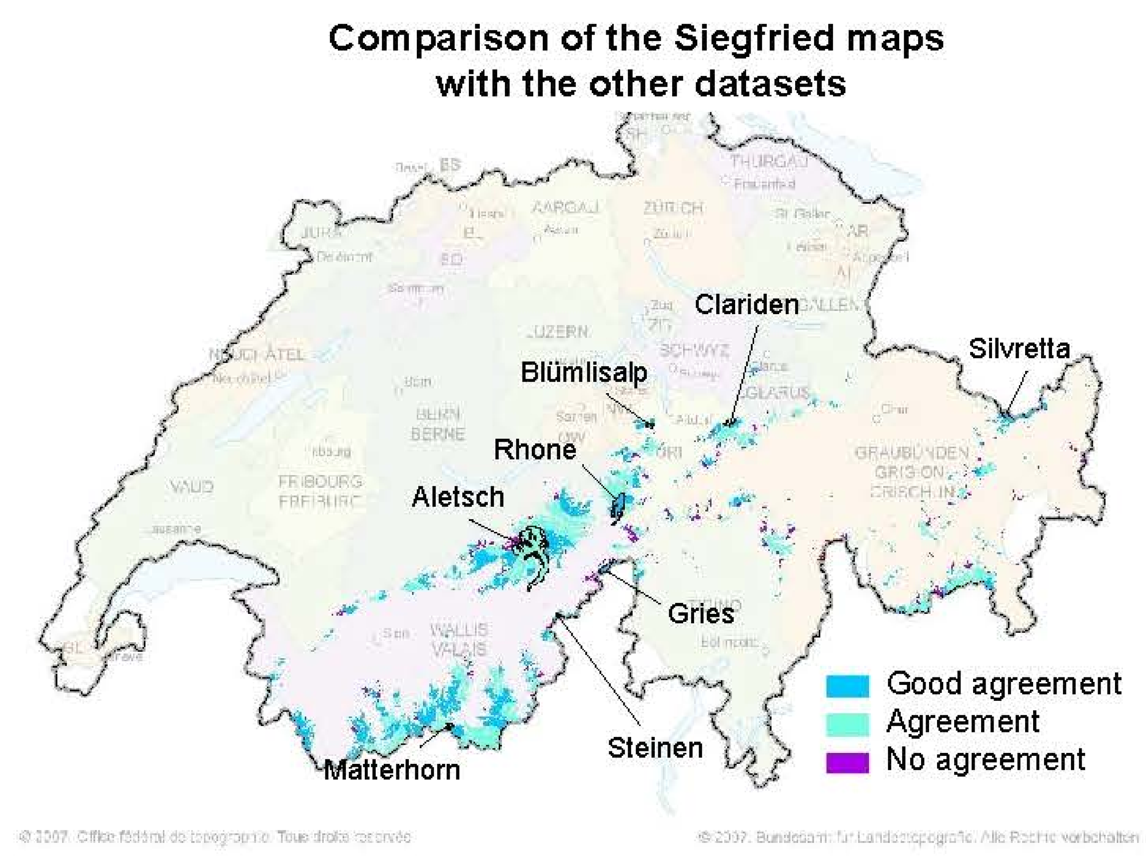
What are the potential controls on glacier retreat?

The aim of this study was to collect the available data on glacier outlines and to empirically investigate the controls of the glacier retreat in the Swiss Alps for the time period 1850 – 2010.

Glacier Outlines Data

Glacier outlines of the years **1900 and 1940** were manually digitalized from historic maps of Switzerland (Siegfried maps, 1892 – 1944, 1:50'000). The product was visually compared to other datasets (see Table) to obtain an homogenized time series of glacier outlines for 998 glaciers in the Swiss Alps.

> 75% of the digitalized Siegfried maps was found to be in good agreement with the other datasets.



Available glacier outlines data:

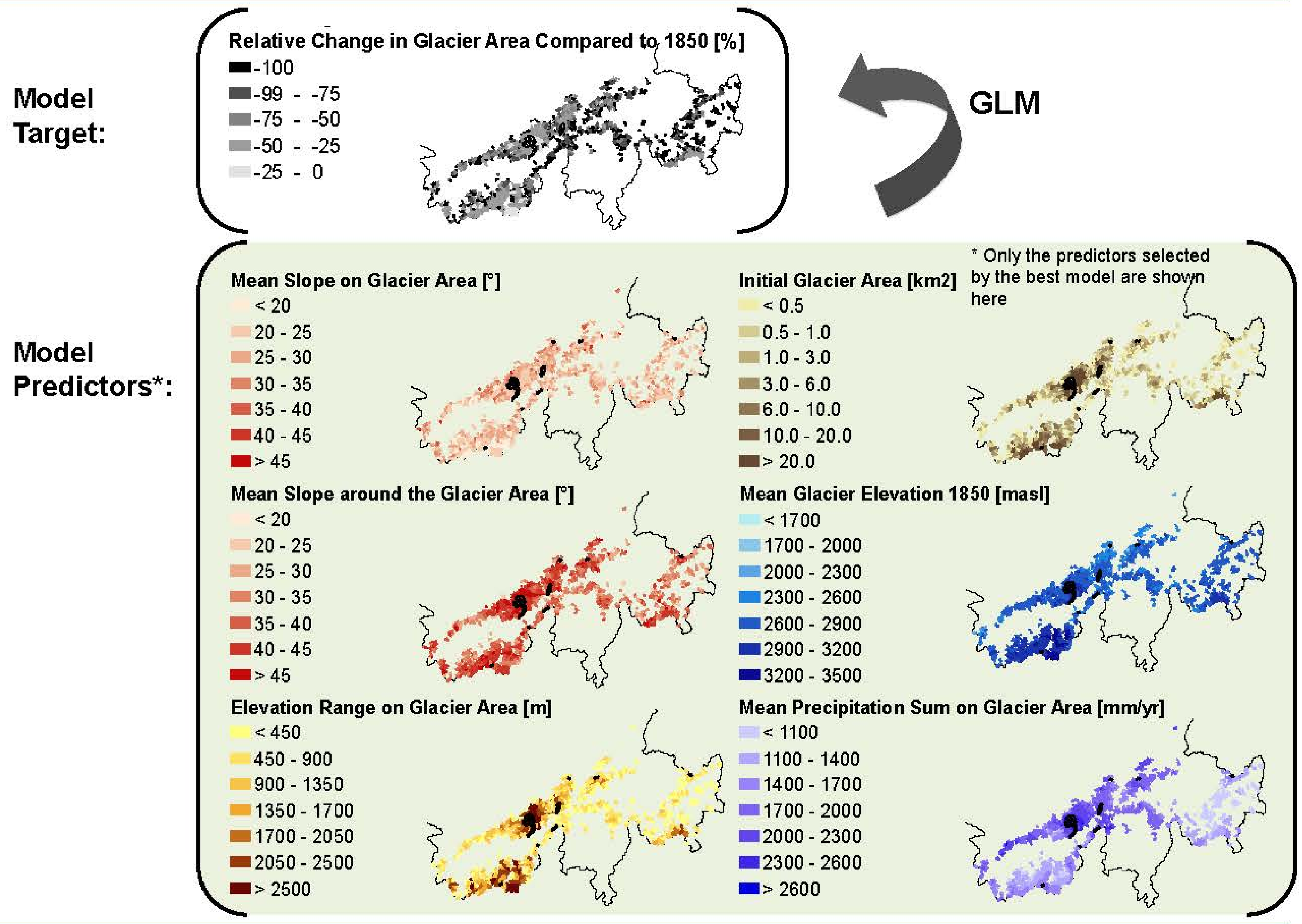
Year (Appr.)	Data assessed from	References
1850	Aerial photography, from moraine extends of retreated glaciers.	*Maisch et al., 2000*
1973	Aerial photography data from September 1973	*Müller et al., 1976; Maisch et al., 2000*
2003	Landsat imageries acquired in Autumn 2003	*Paul et al., 2011*
2010	Aerial ortho-imagery acquired between 2008 and 2011	*Fischer et al., 2014*

Methods

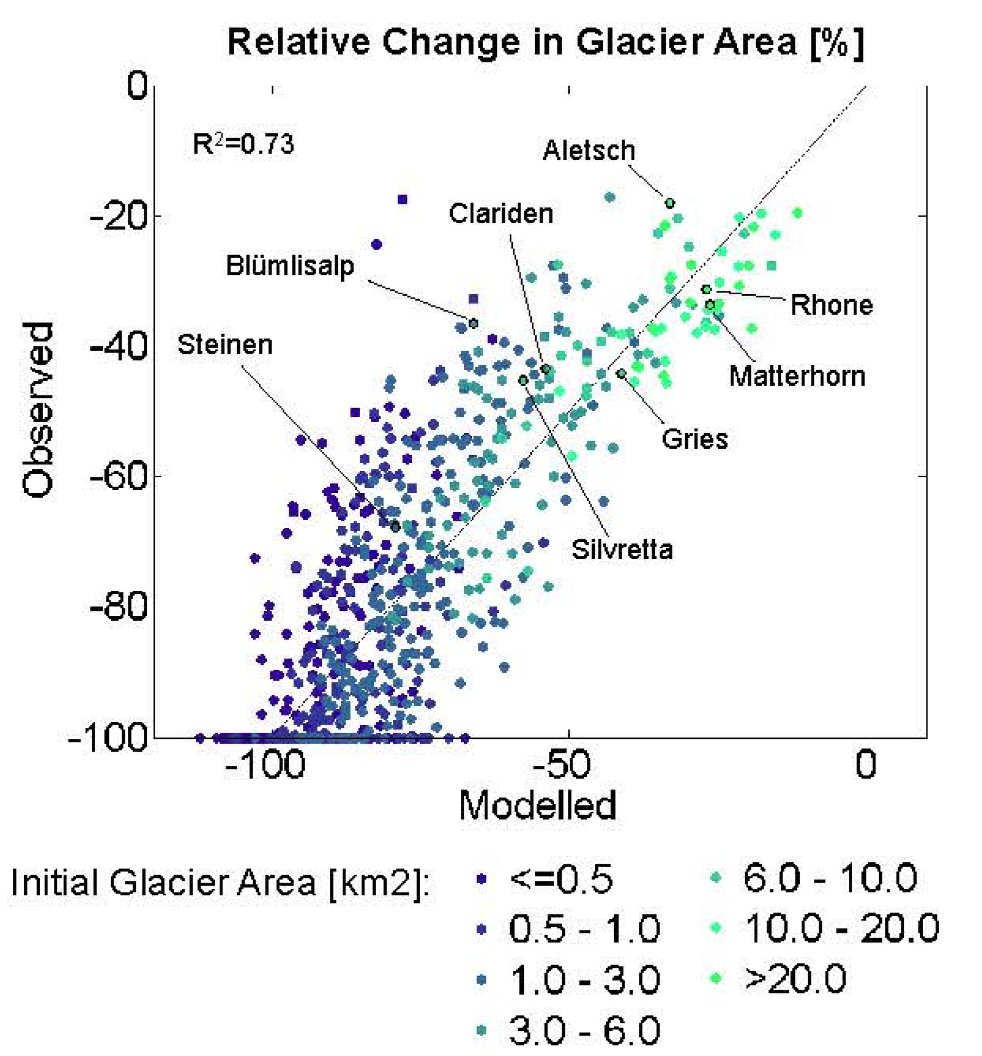
The effects of the potential controls on glacier retreat were assessed by fitting a **General Linear Model** (GLM). The predictors were tested for correlation and statistically significance ($p<0.05$).

Physiographic model predictors: initial glacier area, average slope on and around the glacier area, aspect, mean elevation of the glaciers in 1850 and of the retreated area, elevation range, and potential solar radiation were derived from the glacier outlines and the digital elevation model DHM25 of Switzerland.

Climatic predictors: mean yearly precipitation and temperature were calculated from the interpolated gridded datasets for daily Temperature and Precipitation TabsD v1.2 and RhiresD v1.0 (MeteoSwiss). Mean snow water equivalent was calculated with a Temperature Index Model.



Results

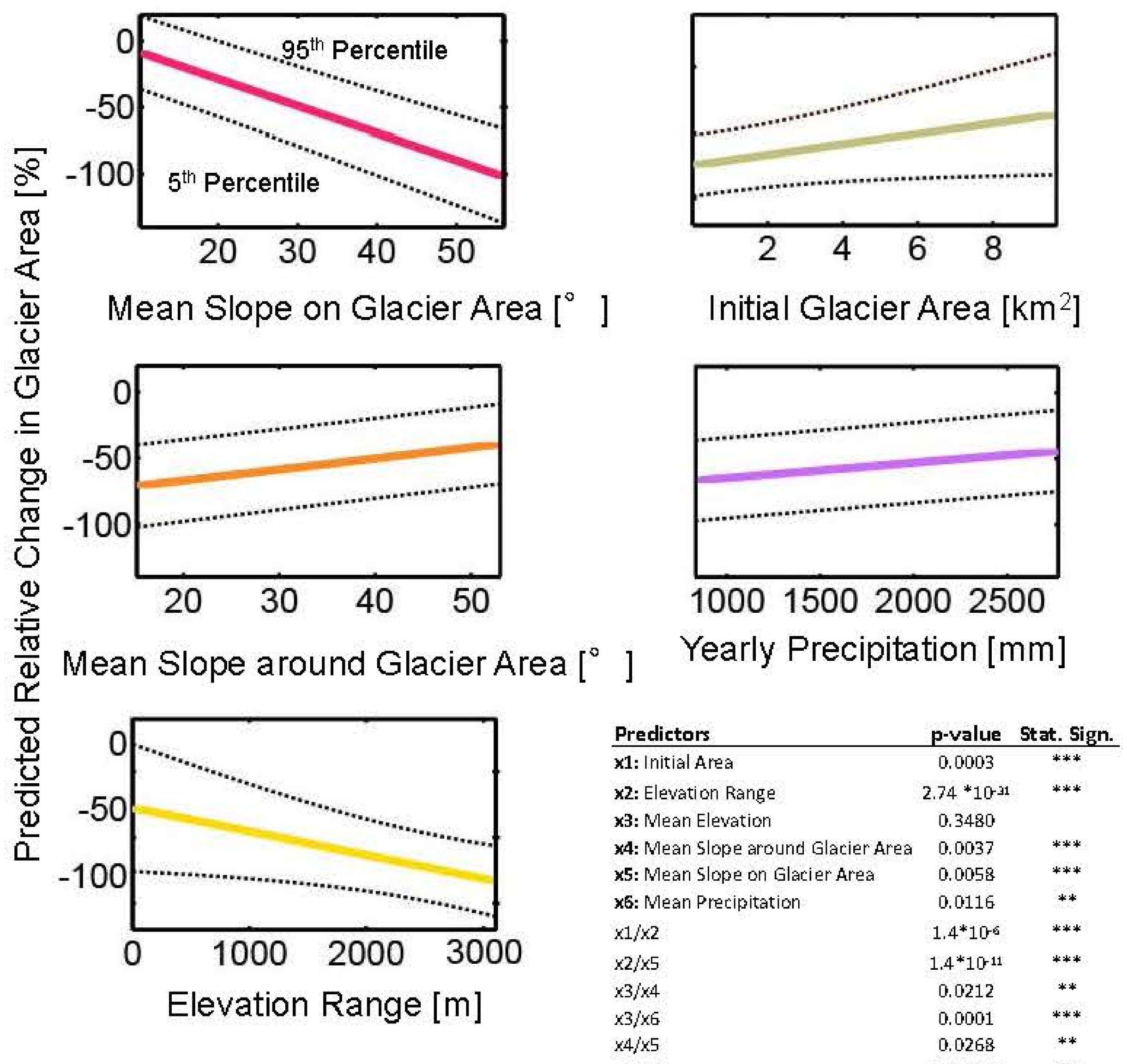


The fitted model explains 73% of the observed variance of the relative change in glacier area between 1850 and 2010 (998 glaciers).

6 of 11 model predictors were selected by the model and 5 of the selected predictors were statistically significant .

Higher initial glacier area, higher yearly precipitaition sum, and higher slopes around the glacier area led to lower relative changes in glacier areas, while higher slopes on glacier area and higher elevation ranges led to higher relative changes in glacier area.

Mean elevation was not statistically significant.



Predictors	p-value	Stat. Sign.
x1: Initial Area	0.0003	***
x2: Elevation Range	$2.74*10^{-31}$	***
x3: Mean Elevation	0.3480	
x4: Mean Slope around Glacier Area	0.0037	***
x5: Mean Slope on Glacier Area	0.0058	***
x6: Mean Precipitation	0.0116	**
x1/x2	$1.4*10^{-6}$	***
x2/x5	$1.4*10^{-11}$	***
x3/x4	0.0212	**
x3/x6	0.0001	***
x4/x5	0.0268	**
x4/x6	$1.2*10^{-5}$	***

Conclusions & Outlooks

The digitalized glacier outlines from the historical **Siegfried maps have shown to be suitable for the empirical analysis of** potential climatic and physiographic controls and could for example also be a useful product for the validation of mass balance modeling

The differences in **the relative changes in glacier area among 998 Swiss glaciers were related to several physiographic and climatic controls**. The model was able to explain 73% of the observed variance in relative change since 1850.

The important role of the slope around the glacier area in the model prediction indicates that **snow redistribution may play an important role for glacier mass balance** and needs to be considered appropriately in models.

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References
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DBU Deutsche Bundesstiftung Umwelt