An Empirically-Based Permafrost Distribution Model for the Entire Alps

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1 INTRODUCTION

Permafrost distribution modeling in highly populated mountain regions is an important task and different modeling approaches exist. Mountain permafrost distribution models are typically calibrated for a local region and only applicable for a specific area. To analyze the permafrost distribution and evolution on an alpine-wide scale, one consistent model for the whole domain is required, instead of differing and therefore incomparable models. In this paper, we present a newly developed statistical permafrost model for the entire European Alps, that is based on direct permafrost evidences as ground-truth information. The evidences were collected in the framework of the EU Alpine Space project PermaNET and contain different types of data (e.g., rock glacier inventories, borehole temperatures, ground surface temperatures).

Two models were developed: one for debris covered areas (*debris model*) and one for steep rock faces (*rock model*). In both cases, the predictor variables are mean annual air temperature (MAAT) and potential direct solar radiation (RAD). To distinguish between the two surface types a third model (*surface type model*) was introduced. Logistic and linear fixed-effects and mixed models are used to account for the different response variables and grouping structures.

2 DEBRIS MODEL

The debris model is based on a stratified random sample from the PermaNET rock glacier inventory, which consists of a total number of 1858 intact and 2573 relict rock glaciers, including inventories from Austria, France, Italy and Switzerland. The final generalized linear mixed-effects model takes into account random inventory effects and uses a logistic link function to predict the probability of a rock glacier as being intact (i.e. active or inactive) as opposed to relict.

The area under the receiver-operating characteristic curve (AUROC) was measured to summarize the model's goodness-of-fit. The debris-model achieved an AUROC of 0.85, which is a good value.

3 ROCK MODEL

Data from 42 temperature loggers located in steep rock walls in the Swiss and Italian Alps with a minimum slope inclination of 55° were used for the rock model. Mean annual rock temperature (MART) ranged from –9.2 °C to 6.5 °C, which corresponds to elevations of 2380–3965 m a.s.l. The MART was adjusted with long-term observations of climate records in order to correct short-term temperature fluctuations.

The final linear regression predicts rock surface temperatures based on MAAT and RAD; the R^2 is 0.82. The RAD was calculated using local slope and aspect values, but terrain shading has not yet been considered, which we expect would further improve the model.

4 SURFACE TYPE MODEL

The surface type model is based on a stratified random sample of 400 points above 2000 m a.s.l in the Swiss Alps and uses the following prediction variables: Soil adjusted vegetation index (SAVI), slope and curvature. The logistic regression describes rock against debris-covered surfaces and has an AUROC value of 0.81.

5 FINAL MODEL

The final output product combines the three models and provides alpine-wide permafrost probabilities. Areas of dense vegetation (i.e. no coarse debris) as well as glaciers will be masked using remote sensing products. In the future, interpretation guidelines will be devised to communicate model limitations and local deviations to potential users (e.g., thermal offset for rock wall temperatures or spatial displacement of permafrost probabilities in debris covered areas due to movement of rock glaciers).