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Data analysis and mapping of the mountain permafrost distribution

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In Alpine environments mountain permafrost is defined as a thermal state of the ground and corresponds to any lithosphere material that is at or below 0°C for, at least, two years. Its degradation is potentially leading to an increasing rock fall activity, rock glacier accelerations and an increase in the sediment transfer rates. During the last 15 years, knowledge on this phenomenon has significantly increased thanks to many studies and monitoring projects. They revealed a spatial distribution extremely heterogeneous and complex. As a consequence, modelling the potential extent of the mountain permafrost recently became a very important task.

Although existing statistical models generally offer a good overview at a regional scale, they are not always able to reproduce its strong spatial discontinuity at the micro scale. To overcome this lack, the objective of this study is to propose an alternative modelling approach using three classification algorithms belonging to statistics and machine learning: Logistic regression (LR), Support Vector Machines (SVM) and Random forests (RF). The former is a linear parametric classifier that commonly used as a benchmark classification algorithm to be employed before using more complex classifiers. Non-linear SVM is a non-parametric learning algorithm and it is a member of the so-called kernel methods. RF are an ensemble learning method based on bootstrap aggregating and offer an embedded measure of the variable importance.
Permafrost evidences were selected in a 588 km^2 area of the Western Swiss Alps and serve as training examples. They were mapped from field data (thermal and geoelectrical data) and ortho-image interpretation (rock glacier inventorying). The dataset was completed with environmental predictors such as altitude, mean annual air temperature, aspect, slope, potential incoming solar radiation, normalized difference vegetation index and planar, profile and combined terrain curvature indices. Aiming at predicting the permafrost occurrence where it is unknown, the mentioned supervised learning techniques inferred a classification function from labelled training data (pixels of permafrost absence and presence). A particular attention was given to the pre-processing of the dataset, with the study of its complexity and the relation between permafrost data and employed environmental variables. The application of feature selection techniques completed this analysis and informed about redundant or valueless predictors.

Classification performances were assessed with AUROC on independent validation sets (0.81 for LR, 0.85 with SVM and 0.88 with RF). At the micro scale obtained permafrost maps illustrate consistent results compared to the field reality thanks to the high resolution of the dataset (10 meters). Moreover, compared to classical models, the permafrost prediction is computed without recurring to altitude thresholds (above which permafrost may be found). Finally, as machine learning is a non-deterministic approach, mountain permafrost distribution maps are presented and discussed with corresponding uncertainties maps, which provide information on the quality of the results.