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Use of Convolution Neural Networks and Object Based Image Analysis for Automated Rock Glacier Mapping

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Rock glaciers are an important, but often overlooked, component of the cryosphere and are one of the few visible manifestations of permafrost. In certain parts of the world, rock glaciers can contribute up to 30% of catchment streamflow. Remote sensing has permitted the creation of rock glacier inventories for large regions, however, due to the spectral similarity between rock glaciers and the surrounding material, the creation of such inventories is typically conducted based on manual interpretation of remote sensing data which is both time consuming and subjective. Here, we present a method that combines deep learning (convolutional neural networks or CNNs) and object-based image analysis (OBIA) into one workflow based on freely available Sentinel-2 imagery, Sentinel-1 interferometric coherence, and a Digital Elevation Model. CNNs work by identifying recurring patterns and textures and produce a heatmap where each pixel indicates the probability that it belongs to a rock glacier or not. By using OBIA we can segment the datasets and classify objects based on their heatmap value as well as morphological and spatial characteristics and convert the raw probability heatmap generated by the deeo learning into rock glacier polygons. We analysed two distinct catchments, the La Laguna catchment in the Chilean semi-arid Andes and the Poiqu catchment on the Tibetan Plateau. In total, our method mapped 72% of the rock glaciers across both catchments, although many of the individual rock glacier polygons contained false positives that are texturally similar, such as debris-flows, avalanche deposits, or fluvial material causing the user's accuracy to be moderate (64-69%) even if the producer's accuracy was higher (75%). We repeated our method on very-high resolution Pléiades satellite imagery (resampled to 2 m resolution) for a subset of the Poiqu catchment to ascertain what difference the image resolution makes. We found that working at a higher spatial resolution has little influence on the user's accuracy (an increase of 3%) yet as smaller landforms were mapped, the producer's accuracy rose by 13% to 88%. By running all the processing within an object-based analysis it was possible to both generate the deep learning heatmap and automate some of the post-processing through image segmentation and object reshaping. Given the difficulties in differentiating rock glaciers using image spectra, deep learning offers a feasible method for automated mapping of rock glaciers over large regional scales.