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Thermal and Hydrological Response of Rock Glaciers to Climate Change: A Scenario Based Simulation Study

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Rock glaciers are ice-debris landforms characterized by creeping ice-rich permafrost. Recognition of their hydrological significance is increasing and is of particular relevance to the dry Andes, where rock glaciers cover greater area than glaciers. However, additional knowledge and research approaches pertaining to the seasonal hydrological contributions and climatic sensitivities of rock glaciers are necessary for improved water resource planning in many regions around the world.

This work explores the utility of the energy and water balance model GEOtop to quantify the thermal and hydrological response of rock glaciers to climate scenarios. Weather data was generated with the intermediate-stochastic weather generator AWE-GEN for a site in the Southeast Swiss Alps, which marked a novel approach in cryospheric studies. Weather data for a reference scenario was generated which approximates conditions during the observation period (1985-2012). AWE-GEN produced time series of weather data for the reference scenario with statistical properties of precipitation in close agreement with observations, but air temperature showed substantial negative biases in summer months, which are attributed to difficulties in modeling local climatic characteristics. To examine the influence of climate change, data for eight climate change scenarios were generated by specifying change factors for mean monthly air temperature.

The thermal and hydrological evolution of rock glacier soils were simulated for 50 years under the climatic forcing of the reference scenario followed by 50 years under each climate change scenario. Mean annual ground surface temperature (MAGST), active layer depth, permafrost total ice content, and the potential summer runoff contribution were quantified and compared before and after the onset of the climate change conditions. Air temperature increases in the climate change scenarios were amplified in MAGST. Stable rock glacier points were resistant to changes in active layer depth and total ice content under any annual, summer, and winter mean air temperature increase of 1°C, and summer and winter mean air temperature increases of 3°C despite notable changes in MAGST and summer runoff contribution. Under warming scenarios, the greatest increase in summer runoff contribution occurred for high elevation rock glacier points with the mean possible runoff contribution increasing 88% under 3°C of warming, which corroborates with increased runoff from high elevation permafrost in the Colorado Rockies in recent decades.