EGU23-893, updated on 07 Jun 2023
https://doi.org/10.5194/egusphere-egu23-893
EGU General Assembly 2023

Future evolution of glaciers in the Caucasus: focus on debris-cover evolution.

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Debris-cover representation is rarely included in regional or global glacier models although it plays a key role in the regulation of melt processes. Debris cover that is more than a few centimeters thick reduces melt by insulating glacier ice. However, mass loss and retreat of debris-covered glaciers are not necessarily slower than those of clear ice. Debris-covered glaciers are widespread in the Northern Caucasus. It is important to reliably quantify their evolution because the contribution of glacial runoff to total discharge is significant in the region.

This study assesses the influence of debris cover on the evolution of glaciers in the basins of the Terek and Kuban rivers in the Northern Caucasus in the 21st century and quantifies its effects on glacier mass balance, ice velocity, ice thinning, changes in glacier area, volume, and position of the glacier fronts. We use the GloGEMflow glacier model and introduce a new debris cover dynamic module. The mass balance is calibrated separately for the explicitly modelled debris cover and for clean-ice glaciers (debris cover is implicit in the degree-day factor calibration). The model is calibrated using newly mapped debris cover outlines and ice thickness data from Rounce et al. (2021). The debris evolution is simulated with a steady deposit model adapted from Verhaegen et al. (2020) and Anderson & Anderson (2016), where debris input onto the glacier surface is generated from a fixed point on the flow line.

We compare spatio-temporal changes in glacier geometry including the evolution of debris cover for the explicit and implicit debris-cover formulation for five SSP scenarios from CMIP6. The debris-cover evolution patterns differ significantly between the Terek and the Kuban basins. In the Kuban basin, glaciers located generally at lower elevations, retreat rapidly and lose ice at the debris-covered glacier tongues. On the contrary, the supraglacial debris of the Terek basin glaciers may, under certain climate scenarios, expand and play an increasingly-important role in glacier evolution with time. However, under the high-end warming scenario SSP5-8.5, the ice loss by 2100

overwhelms the debris-cover effects in both regions.

The maximum difference in glacier length, area and volume depending on the explicit or implicit mode of debris-cover modeling occurs before 2100, but by the end of the century it is eliminated due to the retreat of debris-bearing parts of the glaciers or due to the elevation-stabilization effect. In general, explicitly accounting for debris cover in the projections only has a minor effect on the overall projected regional mass loss, but improves the representation of processes on the intra-glacier scale.

This study was carried out under Governmental Order to Water Problems Institute, Russian Academy of Sciences, subject no. FMWZ- 2022-0001, and was funded by the RSF grant number 22-17-00133.