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Simulation of slow geomorphic flows with r.avaflow

Martin Mergili[1], Andreas Kellerer-Pirklbauer-Eulenstein[1], Christian Bauer[1], and Jan-Thomas Fischer[2]

[1]University of Graz, Institute of Geography and Regional Science, Graz, Austria (martin.mergili@uni-graz.at)
[2]Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW), Department of Natural Hazards, Innsbruck, Austria

GIS-based open-source simulation tools for extremely rapid mass flow processes such as snow avalanches, rock avalanches, or debris flows are readily available, covering a broad range of complexity levels – e.g., from single-phase to multi-phase. However, these tools are not suitable for slower types of mass flows characterized by high viscosities. The conventionally used momentum balance equations for rapid flows often appear numerically unstable for high viscosities, leading to the immediate reversion of flow direction or stopping, without appropriate numerical treatment. GIS-based simulation efforts of slow geomorphic flows are reported in the literature, and open source tools are available for specific phenomena such as glaciers, but no comprehensive and readily usable simulation tools have been proposed yet.

We present a simple depth-averaged model implementation for the simulation of slow geomorphic flows, including glaciers, rock glaciers, highly viscous lava flows, and those flow-type landslides not classified as extremely or very rapid. Thereby, we use an equilibrium-of-motion concept. For each time step, flow momentum and velocity are computed as the equilibrium between accelerating gravitational forces and decelerating viscous forces, also including a simple law for basal sliding. Momentum balances are not carried over from one time step to the next, meaning that inertial forces, which are not important for slow-moving mass flows, are neglected. Whereas these basic principles are applied to all relevant processes, there is flexibility with regard to the details of model formulation and parameterization: e.g., the well-established shallow-ice approximation can be used to simulate glacier flow.

The model is implemented with the GRASS GIS-based open-source mass flow simulation framework r.avaflow and demonstrated on four case studies: an earth flow, the growth of a lava dome, a rock glacier, and a glacier (considering accumulation and ablation). All four processes were reproduced in a plausible way. However, parameterization remains a challenge due to spatio-temporal changes and temperature dependency of viscosity and basal sliding. Our model and its implementation open up new possibilities for climate change impact studies, natural hazard analysis, and environmental education.