Non-linearity of rockglacier flow law determined from geomorphological observations: A case study from the Murtèl rockglacier (Engadin, SE Switzerland)

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Rockglaciers are tongue-shaped permafrost landforms creeping downslope due to gravity. They consist of unconsolidated rock fragments (silt/sand–rock boulders) with interstitial ice. Therefore, their creep behavior (i.e., rheology) may deviate from the simple and well-known flow-laws for pure ice. Rockglaciers often feature a prominent furrow-and-ridge topography (figure A). The recent study of Frehner et al. (2015) identified viscous buckle folding as the dominant process forming this topography. Buckle folding is the mechanical response of layered viscous media to layer-parallel compression. For the Murtèl rockglacier (upper Engadin valley, SE Switzerland) as a case study, Frehner et al. (2015) were able to reproduce the wavelength, amplitude, and distribution of the furrow-and-ridge morphology using a linear viscous (Newtonian) flow model.

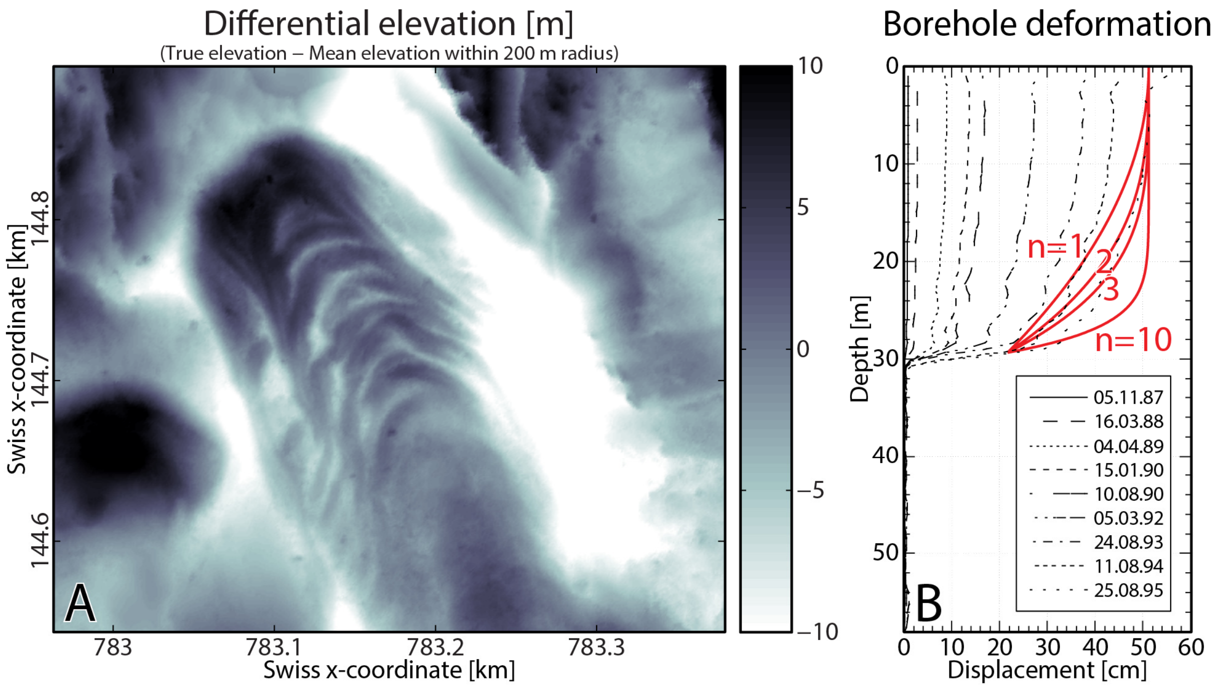
The Murtèl rockglacier is one of the best-studied rockglaciers in the world. Among others, high-resolution digital elevation models (DEM; figure A), time-lapse borehole deformation data (figure B), and geophysical soundings exist that reveal the exterior and interior architecture and dynamics of the landform. Arenson et al. (2002) presented borehole deformation data from the Murtèl rockglacier (figure B), which highlight the basal shear zone at about 30 m depth and a curved deformation profile above the shear zone. Similarly, the furrow-and-ridge morphology also exhibits a curved geometry in map view (figure A). Hence, the surface morphology and the borehole deformation data together describe a curved 3D geometry, which is close to, but not quite parabolic.

The study presented here uses this curved 3D geometry to constrain the viscous flow law that governs the creep of the Murtèl rockglacier. Linear viscous models result in perfectly parabolic flow geometries; non-linear creep leads to localized deformation at the sides and bottom of the rockglacier while the deformation in the interior and top are less intense. In other words, non-linear creep results in non-parabolic flow geometries.

Here we use a high-resolution DEM to quantify the curved geometry of the Murtèl furrow-and-ridge morphology. We then calculate theoretical 3D flow geometries using different non-linear viscous flow laws. By comparing them to the measured curved 3D geometry (i.e., both surface morphology and borehole deformation data), we can determine the most adequate flow-law that fits the natural data best.

Since this is a project in progress, we can only report preliminary data in this abstract. Figure B presents the borehole deformation data of Arenson et al. (2002) together with four theoretical flow geometries using different non-linear viscous flow laws. It is clear that both the linear (power-law exponent, n=1) and strongly non-linear models (n=10) do not match the measured data well. However, the moderately non-linear models (n=2–3) match the data quite well. Even though we did not perform a quantitative analysis yet, this preliminary result indicates that the creep of the Murtèl rockglacier is governed by a moderately non-linear viscous flow law, which has a power-law exponent close to the one of pure ice.

At the time of the conference, we will be able to present detailed quantitative results determining the most suitable flow law describing the Murtèl rockglacier creep. Our results are crucial for improving existing numerical models of rockglacier flow that currently use simplified (i.e., linear viscous) flow-laws.



A) Differential DEM of Murtèl rockglacier (Frehner et al. 2015). B) Time-lapse borehole deformation data (Arenson et al. 2002). Red: theoretical flow geometries using different non-linear viscous flow laws (n=1: linear viscous; n=10: strongly non-linear).

<u>References:</u>

Arenson L., Hoelzle M., and Springman S., 2002: Borehole deformation measurements and internal structure of some rock glaciers in Switzerland, Permafrost and Periglacial Processes 13, 117–135, doi:10.1002/ppp.414

Frehner M., Ling A.H.M., and Gärtner-Roer I., 2015: Furrow-and-ridge morphology on rockglaciers explained by gravity-driven buckle folding: A case study from the Murtèl rockglacier (Switzerland), Permafrost and Periglacial Processes 26, 57–66, doi:10.1002/ppp.1831