Monitoring and Analysis of Landslide-Glacier Interactions at the Great Aletsch Glacier (Switzerland)

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Overview

- This project deals with a detailed in-situ investigation of the spatial variations of the displacement field of the Great Aletsch Glacier in the surroundings of a large active slope instability, called Moosfluh Landslide.

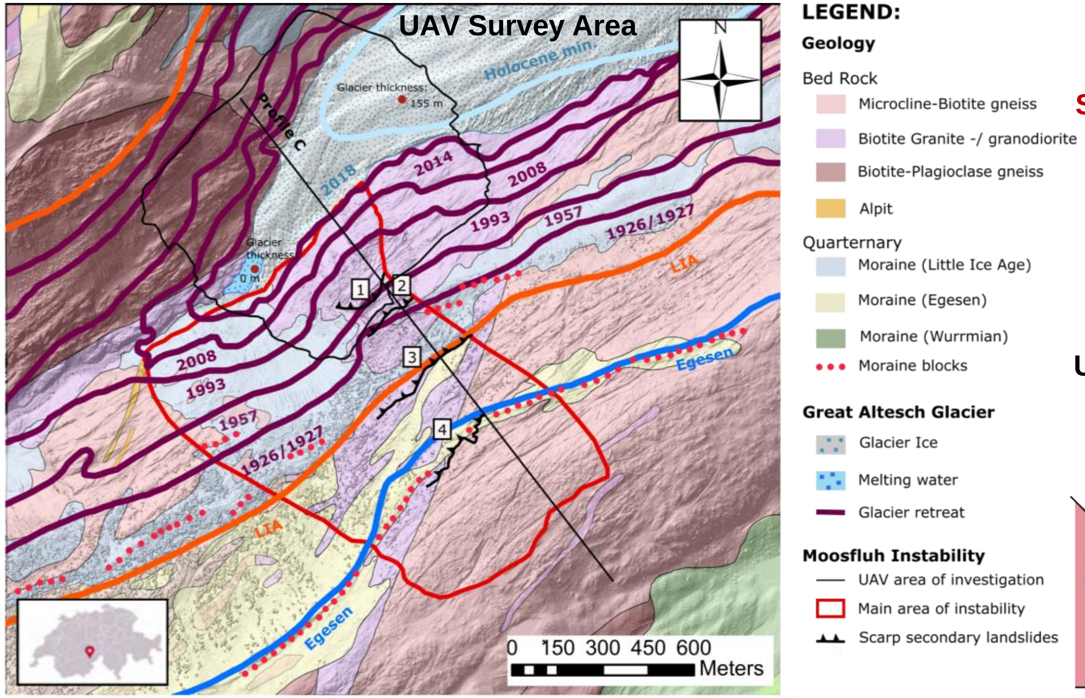
- Research questions:
  - Do the rapid Moosfluh landslide displacements cause modifications of the ice flow field in the area around the interface?
  - Does the viscous ice of the Great Aletsch Glacier has an influence on the adjacent Moosfluh landslide displacement rates?

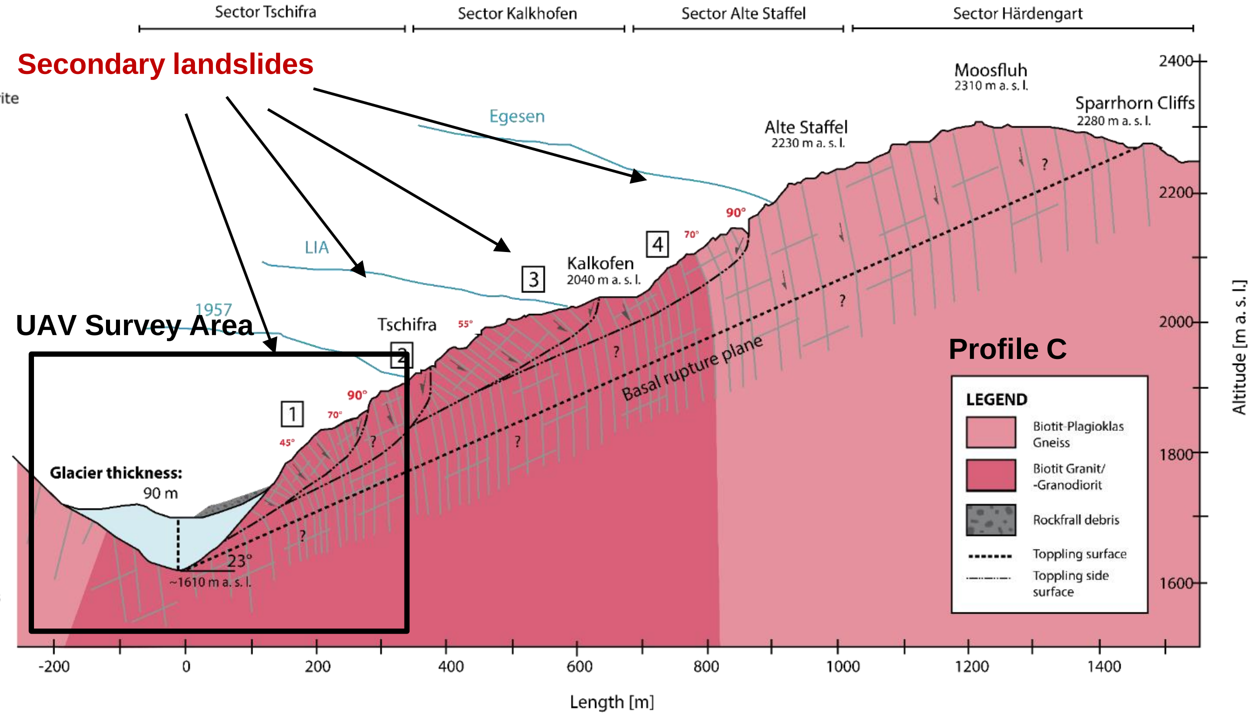
- Using UAV-based photogrammetric surveys we collect two time-lapse high definition images (74 h of difference) containing both the glacier tongue and landslide toe. Digital Image Correlation (DIC) techniques are applied to the derived orthophotos to assess high-resolution surface displacement vector fields of the landslide, stable slopes and adjacent glacier. Results shows that landslide movements clearly influence the glacier vector field.

Study site

The Moosfluh landslide can be classified as a DSGSD. The kinematics of this slope instability can be described by a slow deep toppling movement superimposed by four fast moving less-deep secondary rockslides.

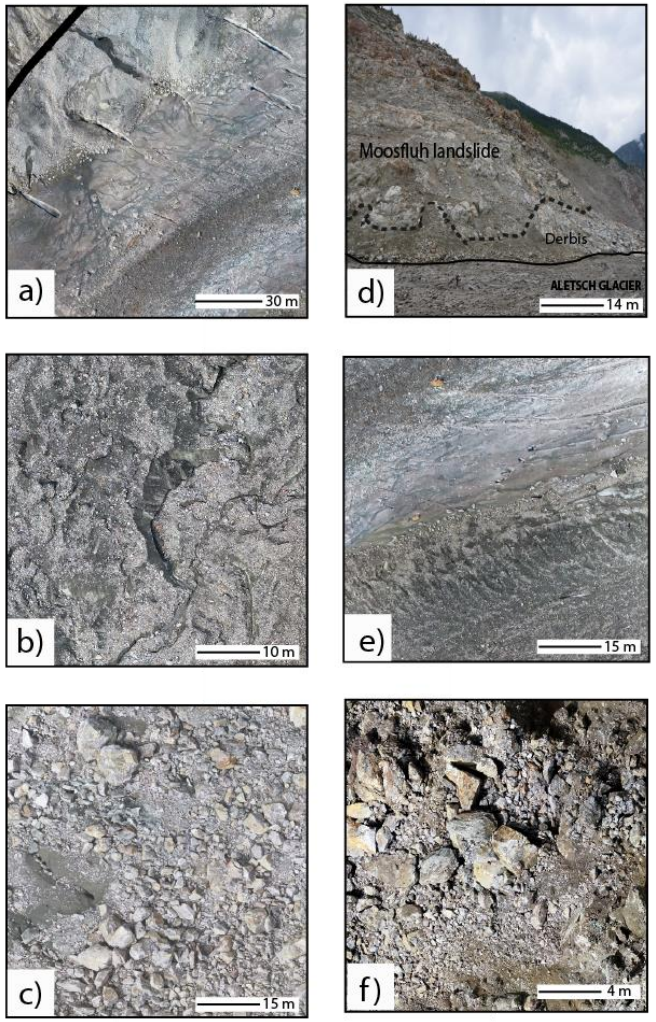
(modified after Güler et. al., 2019)

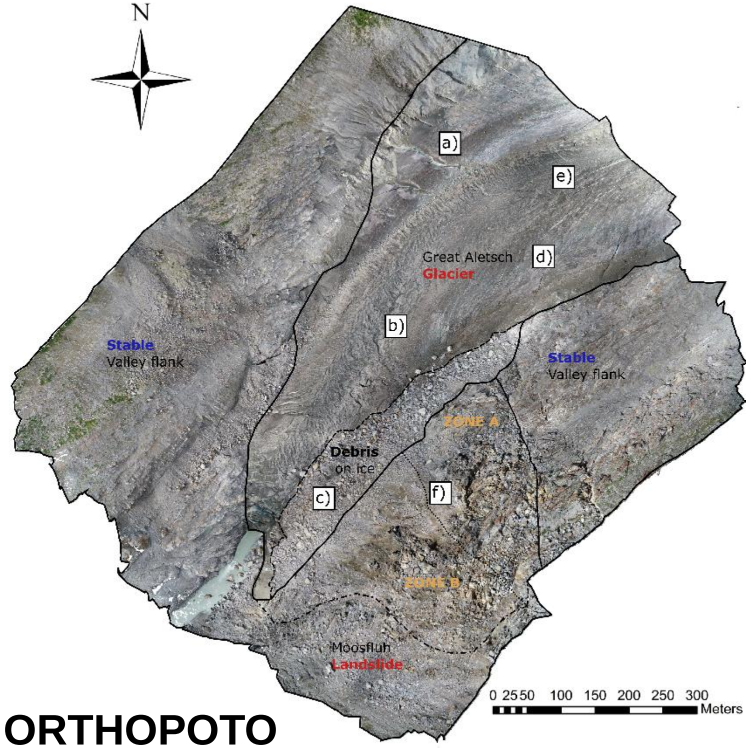




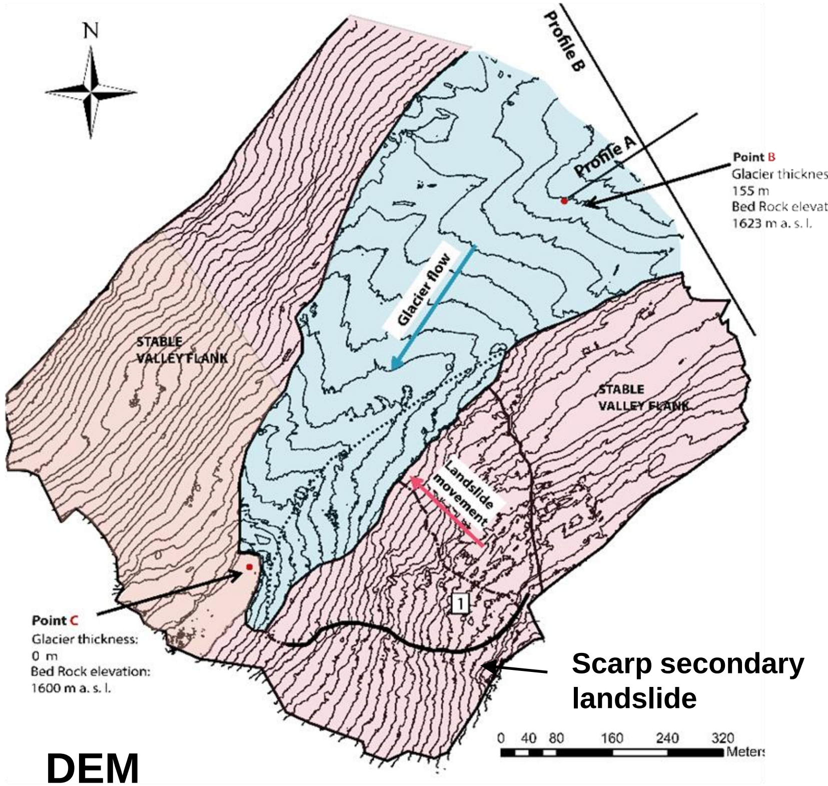
The end of glacial tongue has reached the landslide toe. The ice thickness in the study site lies between 100 m and 0 m (GlaThiDa Consortium, 2019). The thickness of secondary landslides is estimated to range between 40 and 100 m.

Geomorphological description





ORTHOPOTO

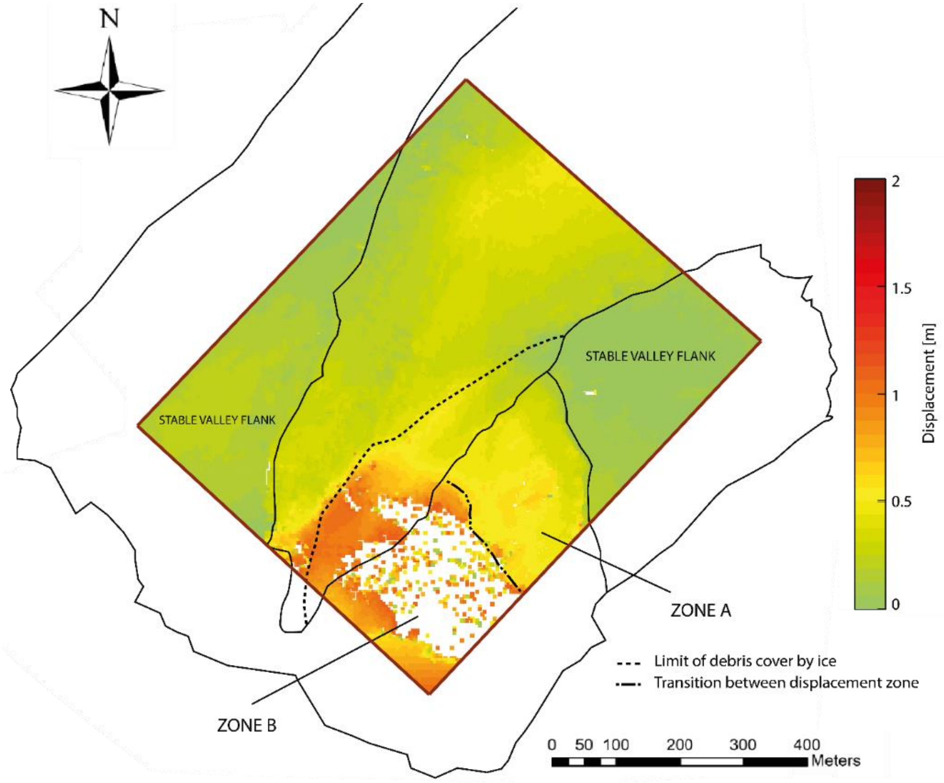


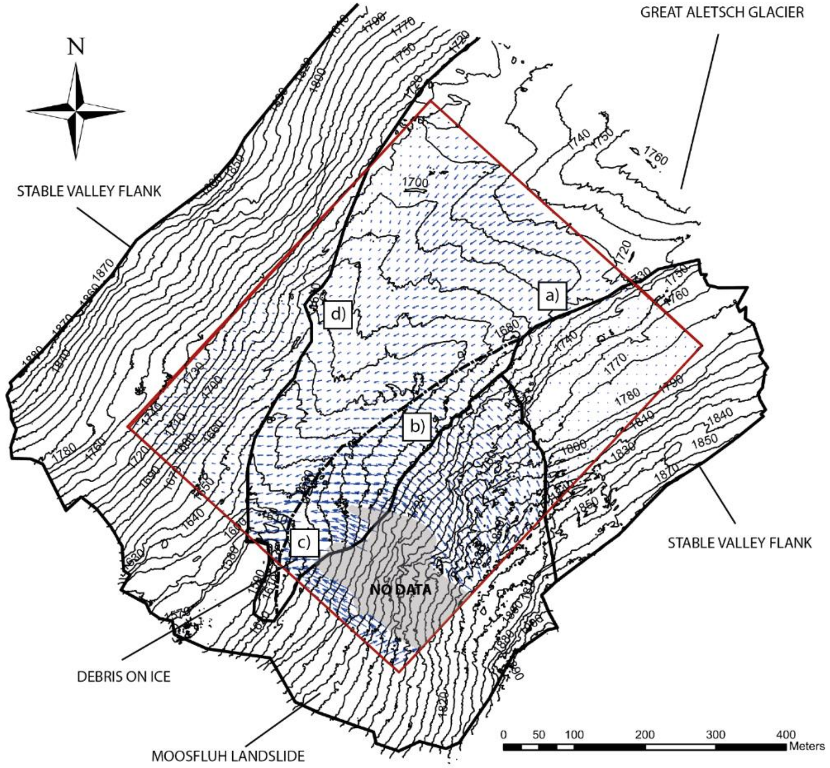
DEM

Here the 11.08.2018 orthophoto and DEM generated during UAV campaign are shown. Ice fractures **(a)** and surface water runoff **(b)** are clearly recognizable on the free ice. The presence of a middle moraine is shown by high surface concentration of dust and rock block **(e)**. Part of the ice mass is covered by unconsolidated debris **(c)** and rocks **(d)** deposited from the very active secondary rockslide **(f)**.

DIC Results – Landslide and ice compartmentation

Applying the DIC algorithm developed by Bickel et al. (2018) it was possible to extract offset magnitude and vector field directions of both flowing glacier and moving landslide. Morphological compartments are clearly recognizable on the landslide surface (**zone A** and **zone B**), and correspond to significantly different displacement rates (average values of **0.5** and **1.2** m) both oriented perpendicular to the glacier flow direction. Higher displacement rates were recorded where the glacier thickness was smaller.

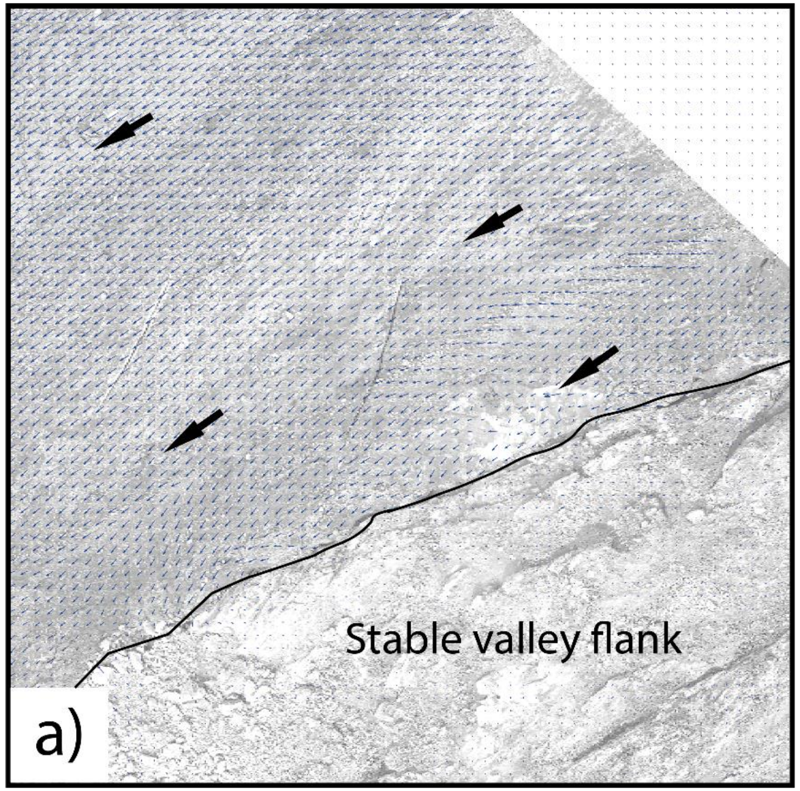


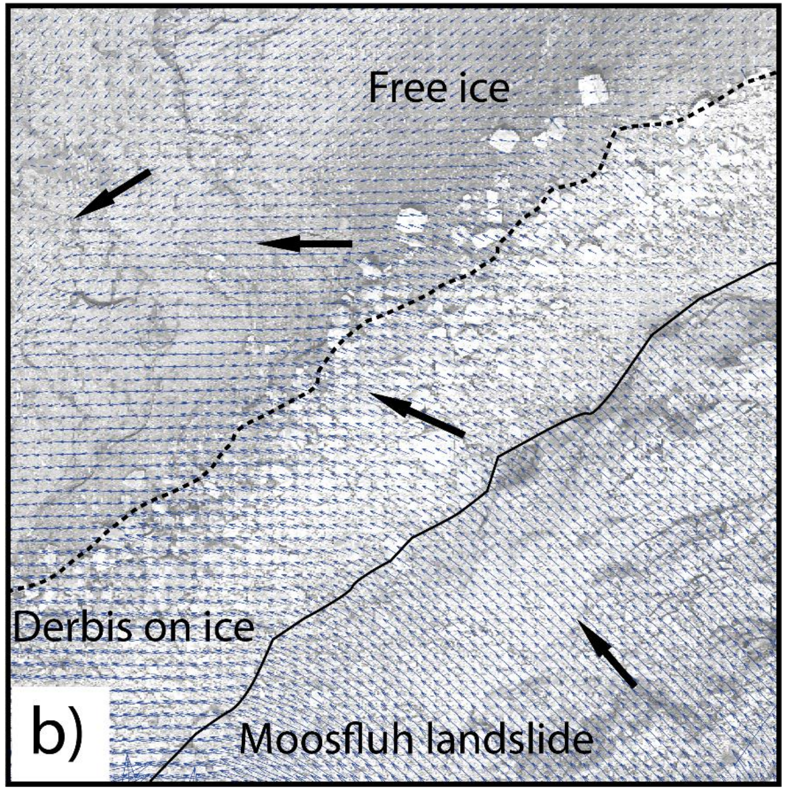


Zones labelled with **no data** are related with rockfalls areas which cause de-correlation artefacts.

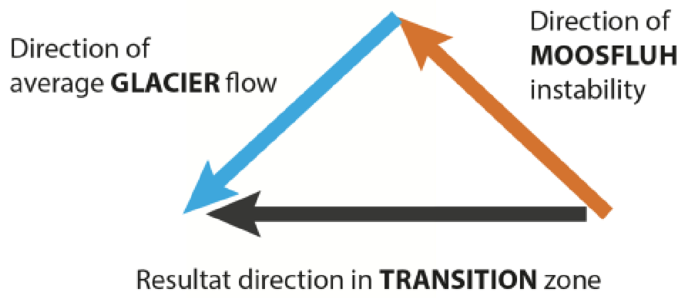
DIC Results – Glacier/landslide interactions

By comparing the orientation of the obtained glacier vector fields, the effect of the moving landslide is clearly recongizable. Where the valley flanks are stabile, the glacier flow is perpendicular to the rock slope **(a)**. In contrast, in the portions of ice directly in contact with the moving landslide **(b)**, the glacier velocity field is strongly deflected at the boundary to the active rockslide. Interacting glacier and landslide movements can be approximated by vector addition.





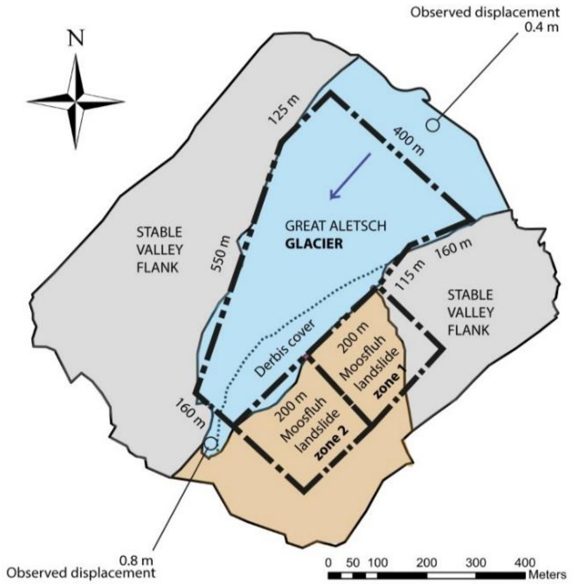
VECTOR FIELD INTERPRETATION:

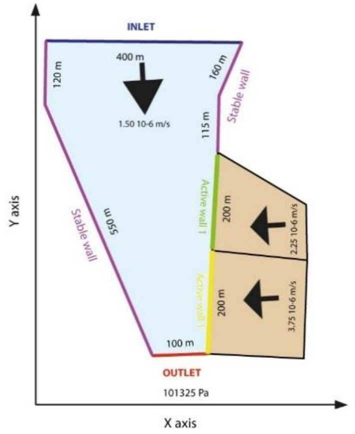


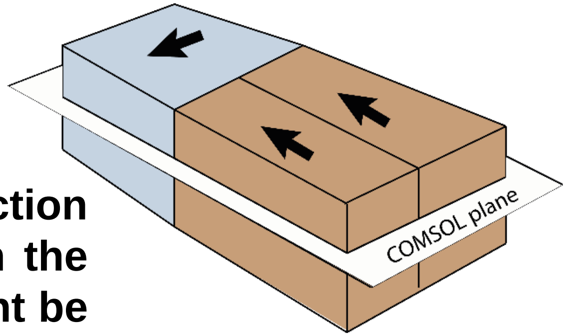
Black arrows: Resulting orientation of displacement vector in transition areas.
Blue and orange arrows: DIC derived displacement vectors.

Modelling approach - COMSOL

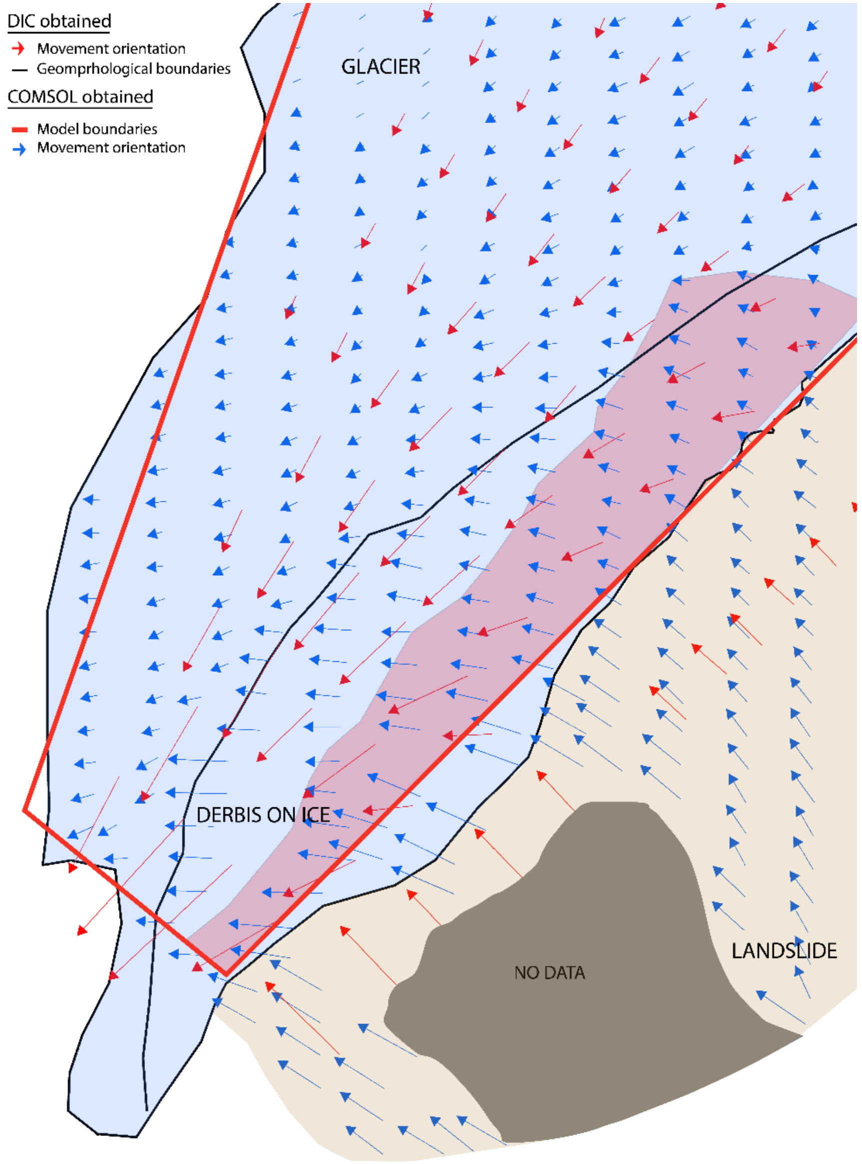
A simplified 2D model of the glacier ice field with vertical boundaries was created including measured displacement rates at the landslide boundary . The ice flow was modelled with Navy-Strokes equations (uncompressible Newtonian viscous fluid).







Glacier mechanics can be improved.

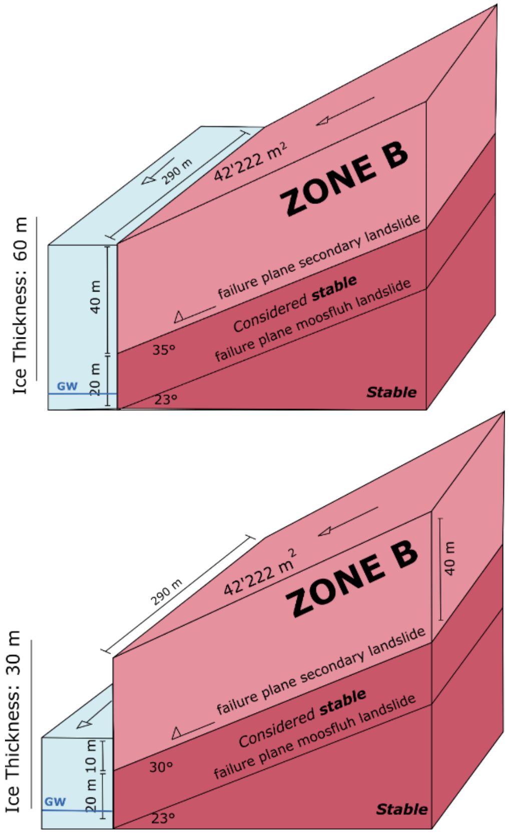


Model output: **The displacement deflection area (red) is significantly narrower than the observations (blue). This difference might be caused by the inclined geometry of the true glacier/landslide interface.**

Modelling approach – the McColl and Davies Model

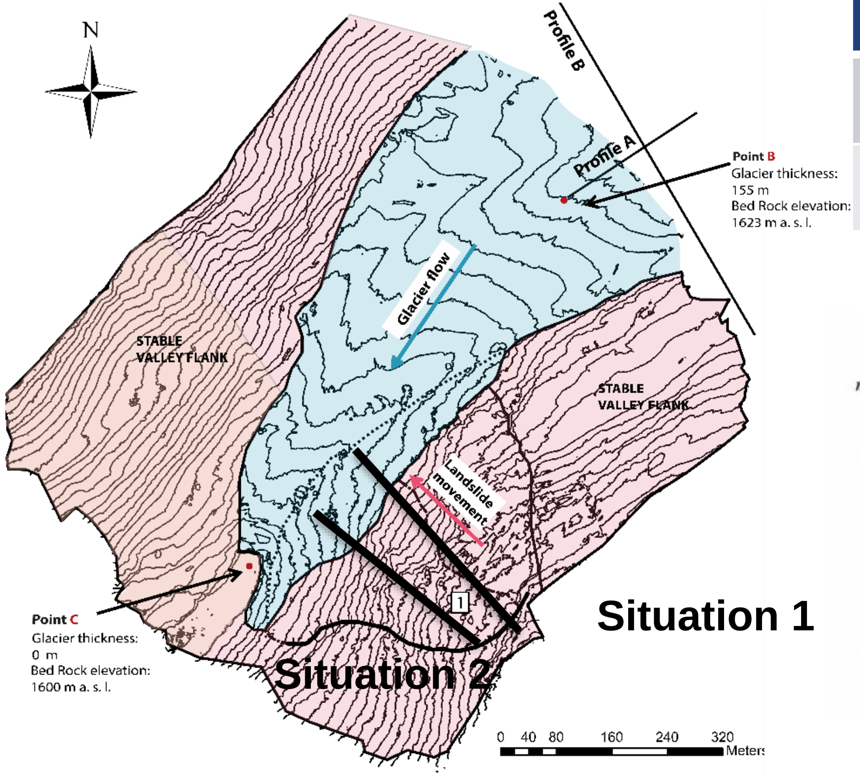
McColl and Davies (2013) developed a simple physical model describing a block landslide sinking through ice. The observed secondary rockslide (Zone B) was simplified as one rock block sliding on a plane in contact with an ice body. Assuming a secondary rupture plane depth of 40 m, it was possible to calculate the **velocity** of sliding landslide in ice (v) and the average **stress** acting on rock-ice interface (σ) for different glacier heights .

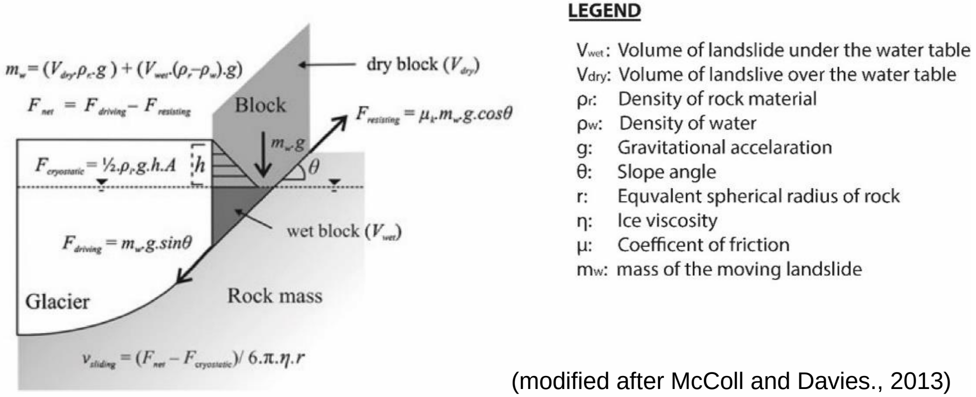
Situation	Glacier thickness	Calculated displ. (74h)	Recorded displ. (74h)	Caluated stress
1	40	0.80 m	0.9 m	$2.26 \cdot 10^{6}$ Pa
2	10	0.82 m	1 m	$1.05 \cdot 10^{7}$ Pa



Situation 1

Situation 2





(modified after McColl and Davies., 2013)

Conclusions

- The observed displacement magnitudes of the secondary rockslide at the toe of the Moosfluh instability recorded during 74 h show two main landslide compartments. Higher displacements rates (up to 1.5 m) were recorded where the supposed glacier thickness is lower, while smaller displacement rates (around 0.5) could be found where the ice is thicker.

- We can observe a clear interaction between the moving landslide and the flowing glacier. The valley parallel vector field of the glacier observed near stable valley flanks is rotated at the contact to the active landslide. Here the deflection arae of the glacier flow field has a width of upto 130 m in direction normal to the glacier margin.

- Numerical simulations with COMSOL show a very narrow zone with displacement vector deflections in the glacier, in comparision to the one observations during UAV survey. This difference might be caused by the glacier/landslide interface geometry.

- Using a simple analytical model derived by McColl and Davies indicates that the viscous deformation of the ice causes stresses at the landslide toe which can impact rockslide stability and velocity.

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McColl, S.T., 2012. Paraglacial rock-slope stability. Geomorphology 153–154, 1–16. doi:10.1016/j.geomorph.2012.02.015