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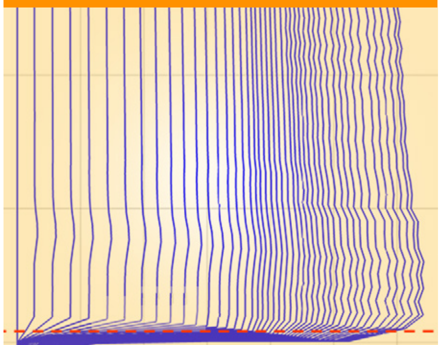

Amendments to Interpretations of SAAF Inclinometer Data from the Furggwanghorn Rock Glacier, Turtmann Valley, Switzerland: Results from 2010 to 2012

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Raw data processing from a ShapeAccelArray field (SAAF) inclinometer were made using proprietary software from Measurand, the manufacturer of the SAAF inclinometer. When the inclinometer data obtained from the same borehole were reprocessed with an updated software version, the results were found to differ significantly from the values derived using the previous version of software. Neither the absolute displacements, nor the curve representing displacements with depth, agreed with the previous values, despite best attempts to compare data with alternative sparse field measurements of surface displacements. There was a change in inclination of the segments above the shear zone, and the strain rates in the shear zone were reduced significantly during the winter months. In contrast, there was no change in the depth of the shear zone. Therefore, the ground model presented in the original study is still considered to be the optimal ground model of the Furggwanghorn rock glacier. Finally, a simple trigonometrical approach was conducted to investigate the validity of both software versions. The simplified recalculations could confirm mostly the results of the updated software version.

Core Ideas

- Raw data from an SAAF inclinometer were processed using proprietary software.
- Results differed significantly from values derived using the previous software version.
- Direct connection between creep velocity and air and soil temperature can no longer be proposed for this specific rock glacier.

A ShapeAccelArray field (SAAF) inclinometer (Danisch and Lowery-Simpson, 2007) was installed in 2010 on the Furggwanghorn rock glacier to measure the creep movements within the soil and to detect possible shear horizons (Buchli et al., 2013). It became apparent, while processing data for two subsequent inclinometers of the same type, that the inclinometer results for Borehole F5, presented in Buchli et al. (2013), were incorrect. Calculations to transform raw data from an SAAF inclinometer into real displacements in a predefined x,y,z coordinate system (Buchli et al., 2013) were made using proprietary software from the manufacturer, Measurand (http://www.measurand-geotechnical.com/software.html). The results for the inclinometer profile in Borehole F5 were found to differ significantly (up to 30% in magnitude) from the values derived using the previous version of the proprietary software (1.32), when the inclinometer data were reprocessed with an updated version of the same software (3.21). The newly processed data showed differences not only in the magnitude and direction of the displacements but also in the profiles, although the depth of the shear zone remained unchanged at about 15 m.

A simple trigonometrical approach was conducted manually to investigate the validity of both software versions by recalculating the results and analyzing the data for Borehole F5. This revealed that these significant changes were not due to a few steeply inclined inclinometer segments near the shear zone but mainly from the less steeply inclined elements above, which could not be based only on minor adaptations of calibration factors or curve fitting. It is not possible to reproduce the data exactly because of incomplete information about the calculation steps used in the software and lack of support from the manufacturer. Nevertheless, the mathematical approach that led to the new results confirmed the shape of the deformation profile, as well as the direction and the location of the shear zone. Only

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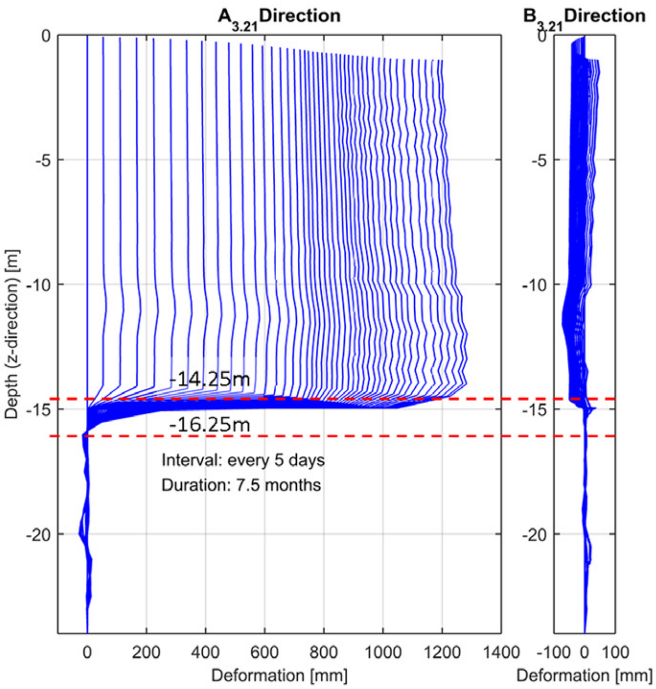

Fig. 1. New inclinometer profiles (Borehole F5) separated in the A and B directions, calculated with the ShapeAccelArray software version 3.21.

the magnitudes could not be modeled precisely. We assume that the proprietary software contains additional steps in between the logical mathematic steps to take into account the combined effects of bending and tension and any compliance in the joints of the coupled segments.

Buchli et al. (2013, Fig. 12) showed the vectorial addition of the *x*,*y* displacements at half-weekly intervals for Borehole F5. The reprocessed inclinometer data are presented now in Fig. 1 (software version 3.21), separated into two orthogonal A and B directions (see also Fig. 2) for better interpretation of the differences between the two software versions. The orientation of the A direction can be assigned after the data processing and is set here to be parallel to the measured main flow direction of the rock glacier. It is obvious

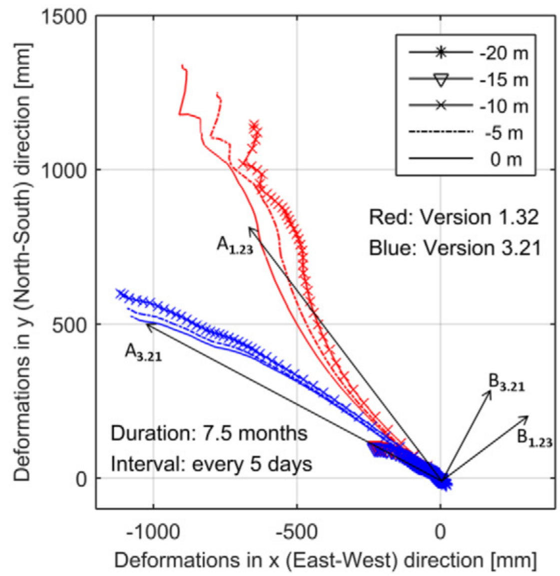

Fig. 2. Comparison of the inclinometer calculation methods, top view. The displacements at five different depths are shown, calculated with different software versions: Version 1.32 (red) and Version 3.21 (blue).

that the deformations above the shear zone are not congruent, whereas the deformations at and below the shear zone have hardly changed with the software update. The divergence at the surface is >500 mm after around 7.5 mo of measurements. In addition, the creep velocities have reduced during the autumn to reach more or less steady state over the winter and into the spring as a result of the new data processing, while previous analysis showed irregular behavior (Fig. 3).

The change in inclination of the segments above the shear zone is also obvious. A significant increase in inclination in the flow direction relative to the movements at the shear zone was identified for the upper 15 m from the previous calculations (Buchli et al., 2013, Fig. 12), whereas a small backward rotation can be detected using the new software version (see Fig. 1, Direction A), which is assumed to be due to a rotary motion of the ground in this region. Additionally, significant differences in directions are visible in the

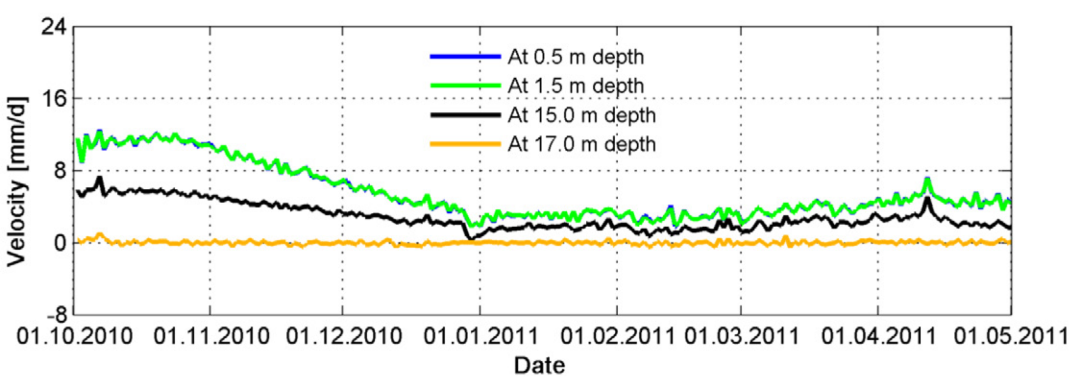

Fig. 3. Recalculated inclinometer velocities for Borehole F5 at four different depths in the rock glacier from October 2010 to May 2011. The blue curve is mostly lying below the green one.

view in the *x*,*y* plane (Fig. 2), where the main flow has turned from the $A_{1.23}$ direction to $A_{3.21}$, with a much smoother curve.

The shear strain presented by Buchli et al. (2013, Table 1) needs to be adapted as well, as a result of the recalculated raw data. The shear strains between the 14.25- and 16.25-m depths were considered to be the most relevant and are summarized in Table 1. The greatest strain rate for the shear zone, derived from the reprocessed data, still occurred in late autumn, a short time after measuring began. The strain rates in the shear zone were reduced significantly during the winter months, which can be observed pictorially from the reduced spacing between the inclinometer profiles (Fig. 2). The minimal net strain rate reached 0.0009 d^{-1} in February 2011 (see also Fig. 3).

There are some changes in the inclinometer velocities at different depths, as shown by Buchli et al. (2013, Fig. 3), especially for the sensors at depths of 0.5 and 1.5 m. The form of the curves looks similar, as had been calculated previously until March 2011, however with slightly smaller values. The two peaks described in the original study have disappeared with the new calculation. Therefore a direct connection between creep velocity and air and soil temperature cannot be proposed anymore. Nevertheless, we assume that the creep velocity of this rock glacier is primarily not temperature controlled but strongly dependent on the water content within the soil. In contrast, there is no change in the depth of the shear zone. Therefore, the ground model presented in the original study, which was further developed by Merz et al. (2015), is still considered to be the optimal ground model of the Furggwanghorn rock glacier.

This experience confirms the difficulty of using proprietary software without the ability to check the raw data and calibration factors adopted in a systematic way. Because a holistic understanding of the data handling process is not possible, it underlines the importance of having regular and sufficiently accurate data on movements at the top of the inclinometer. This can be hampered at elevations above 2800 m asl when there is snow cover for >6 mo of the year. Subsequent lidar and ground penetrating radar measurements have helped to interpret the surface movements around the locations of the boreholes.

Table 1. Cumulative shear strain γ since installation of the inclinometer and shear strain rate per day $\dot{\gamma}$, as well as the shear strain angle ψ and rate $\dot{\psi}$ across the shear zone, between depths of 14.25 and 16.25 m, calculated from inclination of the inclinometer segments.

Parameter	Oct. 2010	Nov. 2010	Dec. 2010	Jan. 2011	Feb. 2011	Mar. 2011	Apr. 2011
$\gamma = \Delta xy/\Delta z$	0.18	0.30	0.37	0.41	0.44	0.48	0.51
$\dot{\gamma}$ [d^{-1}]	0.0058	0.0043	0.0023	0.0014	0.0009	0.0012	0.0012
$\psi = \arctan(\gamma)$ [°]	9.93	16.83	20.30	22.39	23.75	25.41	27.02
$\dot{\psi}$ [° d^{-1}]	0.33	0.23	0.12	0.07	0.05	0.06	0.05

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