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Characterization of short term velocity variations of perma-frost slope movements using GPS-derived positions

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Introduction and Aims

- Slope instabilities are a potential risk for infra-structure and human life.
- The timing of acceleration or deceleration helps to understand influencing factors.
- Combination of inclinometer and GPS allows for continuously monitoring the translation and rotation of a boulder (Fig. 1).
- GPS-measurements on slopes-movements typically have a high noise level.
- Velocity-estimations depend on the temporal-resolution, because of measurement-errors.
- Parameter-choice for established methods (e.g. Spline) depends on the velocity-regime.

In order to study the short-term variability, it is important to develop and test a method that:
a) performs in variable movement-regimes
b) can separate the signal from the noise.

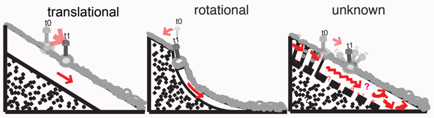

Fig. 1) Slope movement types: a) translational slide, b) rotational slid, and c) complex slide with unknown failure plane and various processes involved. If the movement type is unknown, it is important to now the amount of rotation.

Data and methods

- Daily GPS- and inclinometer-data from summer 2011 to 2012 (355 days).
- Total horizontal displacement of the station is 4.65 m (σ=3.3 mm).
- Ground-surface-temperatures (GST) measured with 5 temperature-loggers (iButtons) that are distributed within a 2 m-radius.

- Monte Carlo Simulations (MCS) are preformed to estimate the uncertainty of the data.
- Temporal-support depends on the signal to noise ration (SNR). It is increased untill the SNR is higher than a predefined threshold.
- Velocities are estimated with linear regression.

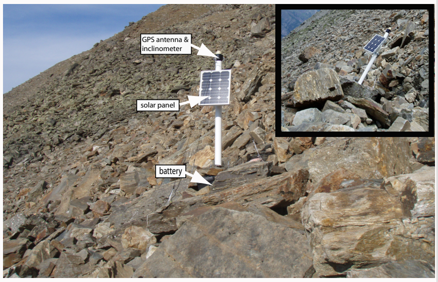

Fig. 2) GPS-station is mounted on the tongue of a fast rock glacier (2650 m a.s.l.). The GPS-sensor and the two inclinometers are installed on top of a mast. The station is strongly tilted after one year (33°, small picture).

Data interpretation (Fig. 5)

- Velocities follow a seasonal trend with the lowest velocities at the end of winter.
- Zero-curtain and variability of the GST indicate that a thick snow cover only existed in April.
- While reactions of velocities to changes in the GST are smooth and phase-lagged, snow-melt caused a sudden high peak in velocity.

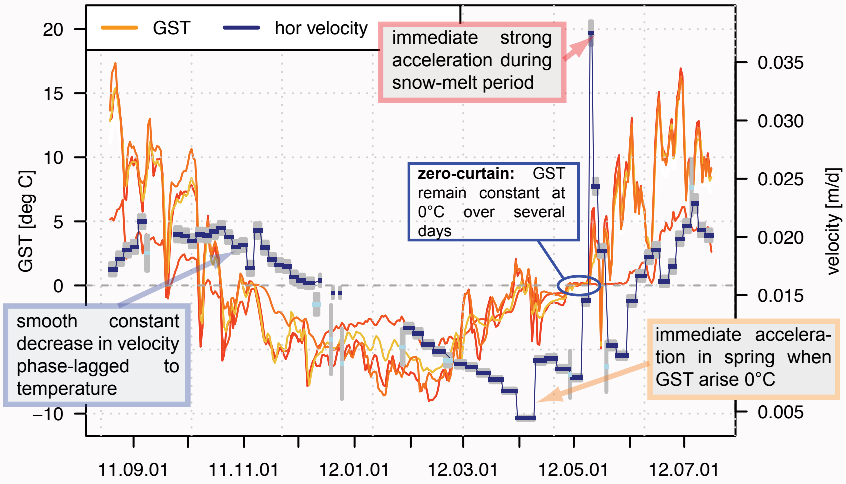

Fig. 5) Mean daily ground- surface temperatures (GST, orange) and horizontal velocities (SNR-threshold of 30, darkblue) and its uncertainties (σ, grey). Velocity-periods with a SNR below the predefined threshold are indicated (light-blue).

Test velocity-methods (Fig. 3)

- The main difference between methods occur if the the noise-level is high.
- With the MC-method, both the low constant velocities and the peak in velocities are well reproduced.
- With Spline, estimated velocities strongly depend on the degree of freedom.
- For a high noise-level, it is not possible to obtained good results with the same degree of freedom for velocity-regimes.

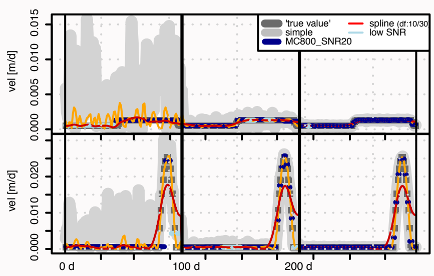

Fig. 3) Synthetic time-serie of positions following a linear displacement with a) two periods of slighly different velocities (top), and b) a short-peak in velocity (bottom), and three different noise levels. Velocities are estimated with different methods: MC-method (dark-blue), simple (Δd/Δt, grey), spline with different degrees of freedom (orange: df=30, red: df=10), and velocity without noise ('true' velocities, dark-grey).

Separation of rotation (Fig. 4)

- >12% of the measured displacement at the antenna is caused by the rotation of the station.
- The direction of movement is most constant, if a mast-height of 2.5 m is modeled. This means that the center of rotation lies ~2.5 m below the GPS-antenna, and ~1 m within the boulder.

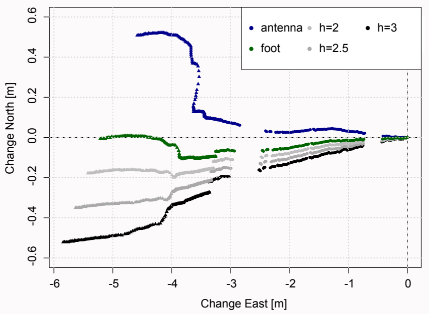

Fig. 4) Changes in the East- and North-position of the antenna (blue) and the foot (green, corrected for the mast-tilt) and positions corrected for the mast-tilt applying different distances to the GPS-antenna (h=2–3 m, grey-black).