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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Estimating velocity from noisy GPS data for investigating the temporal variability of slope movements" *by* V. Wirz et al.

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Interactive comment on " Estimating velocity from noisy GPS data for investigating the temporal variability of slope movements" by V. Wirz, S. Gruber, S. Gubler, and R. S. Purves

Dear Reviewer #2,

Firstly, as authors we would like to thank you for your constructive comments and suggestions. We have set out to respond fully to both the content and spirit of each comment in full, and hope that the edited manuscript reflects these changes. Below, we describe in detail how we have responded to each individual comment.

Author's responds to comments of Referee 2 (anonymous)

1. Please elaborate more on how the presented method may be applied for early warning considering the identified drawbacks (e.g. problem in detecting timing of acceleration or underestimation of the absolute velocities during accelerated phases). Sudden and considerably high accelerations are types of movements, which detection is crucial for the hazard estimation.

AC: Based on our analyses it is difficult to judge whether the developed method is useful for early warning in all cases (e.g. measurements with high noise levels), because for high noise levels the accurate timing of sudden acceleration is not always detectable. However, the application of the developed method allows further improvement of applied monitoring strategies and techniques in early warning, because it helps to investigate processes and, hence, increase our process understanding. Further, all the presented methods that include a smoothing of the data (SNRT, spline, lokern) will face this problem: For velocity estimations based on position data with high noise levels, either the temporal variability is over estimated, because the variation due to noise is interpreted as real velocity changes, or, the timing of acceleration can not be identified exactly due to the comparably large as smoothing window. However, strong accelerations would quickly be discernable from noise. In order to make this point more clear we changed the manuscript to the following (page 1169, line 24ff): "This allows separation of the signal from the noise and thus enhances the reliability of the estimated velocity and especially its variation. This is important when variations in velocity are used to investigate underlying factors and processes (cf., Coe et al., 2003; Buchli et al., 2013). Furthermore, distinguishing better between random fluctuation and real acceleration may carry benefits for early warning. A reliable assessment of SNRT in this context requires, however, more detailed investigation."

Buchli, T., Merz, K., Zhou, X., Kinzelbach, W., and Springman, S.: Characterization and moni- toring of the Furggwanghorn rock glacier, Turtmann Valley, Switzerland: results from 2010 to 2012, Vadose Zone J., 12, 1–15, 2013

Coe, J., Ellis, W., Godt, J., Savage, W., Savage, J., Michael, J., Kibler, J., Powers, P., Lidke, D., and Debray, S.: Seasonal movement of the Slumgullion landslide determined from Global Positioning System surveys and field instrumentation, Eng. Geol., 68, 67–101, 2003.

2. I suggest you to change the first ten lines of the Abstract – at the beginning you talk about acceleration/deceleration and its timing, but then the reader finds out that your work is about "average velocities" of specific period. I do not see the link between the two parts of the abstract.

AC: We changed the first ten lines of the abstract as follows: "Detecting and monitoring of moving and potentially hazardous slopes requires reliable estimations of velocities. Separating any movement signal from measurement noise is crucial for understanding the temporal variability of slope movements and detecting changes in the movement regime, which may be important indicators of process. Thus, methods capable of estimating velocity and its changes reliably are required. In this paper we develop and test a method for deriving velocities based on noisy GPS data, suitable for various movement patterns and variable signal-to-noise-ratios (SNR). We tested this method on synthetic data, designed to mimic the characteristics of diverse processes, but where we have full knowledge of the underlying velocity patterns, before applying it to explore data collected."

3. Referring to the last paragraph of the Chapter 7 (Conclusions . . .), please summarize more clearly for which movement patterns is your method suitable and for which it needs further improvements.

AC: We changed the last paragraph of the conclusions to the following (page 1174, line15ff): "Performance tests revealed that SNRT is a suitable method to detect changes in velocity, even for position data with a high noise level and variable SNR. According to our analysis, the SNRT method is better suited for the analysis of movements with small changes in velocities compared to their noise level (e.g. deep-seated

landslides) than common methods such as spline or lokern. The SNRT method can be used to analyse position data that include both periods of slow continuous displacement and short periods of high velocities (e.g. sudden acceleration of rock glaciers or slopes with gelifluction during the (snow-)melt period in spring). However, if the noise-level is high then detection of the exact timing of acceleration is difficult (as is the case for all of the methods tested). Further, additional tests on real movement patterns would help to further investigate the performance of SNRT."

4. Please insert simple location map of the monitored sites with their GPS positions (could become part of the Fig. 1).

AC: We added a map with the locations of the GPS positions to Fig.1 (see new figure and caption below).

5. For the rotation and tilting of the pos55, please add some explanation of this process, which is probably connected with internal dynamics of the rock glacier.

AC: This comment is closely related to that addressed in 8 above. In order to address this comment we changed the manuscript to the following (page 1172, line 14): "Here, more than 12 % of the measured displacement at the antenna is caused by a rotation of the station. We assume that the rotation of the station is caused by the high movement rates, which, in combination with the high slope angle (34°), led to an unstable surface. Further, a rotational slide occurring at the tongue and thaw consolidation might increase the rotation of the station (see Section 6.3)."

Changed Tables and figures:

Fig. 1: Locations and field impressions of the GPS stations of pos27 and pos55. The small photo of GPS station pos55 was taken at the end of June 2012, by then the station is strongly tilted towards the slope. Each GPS station includes a GPS antenna and two inclinometers that are mounted on top of a mast. The energy to operate the devices is provided by a photovoltaic energy harvesting system and backed by a

battery. (Photos: V. Wirz and R. Delaloye. LK200 from the year 2008, reproduced by permission of swisstopo BA14054)

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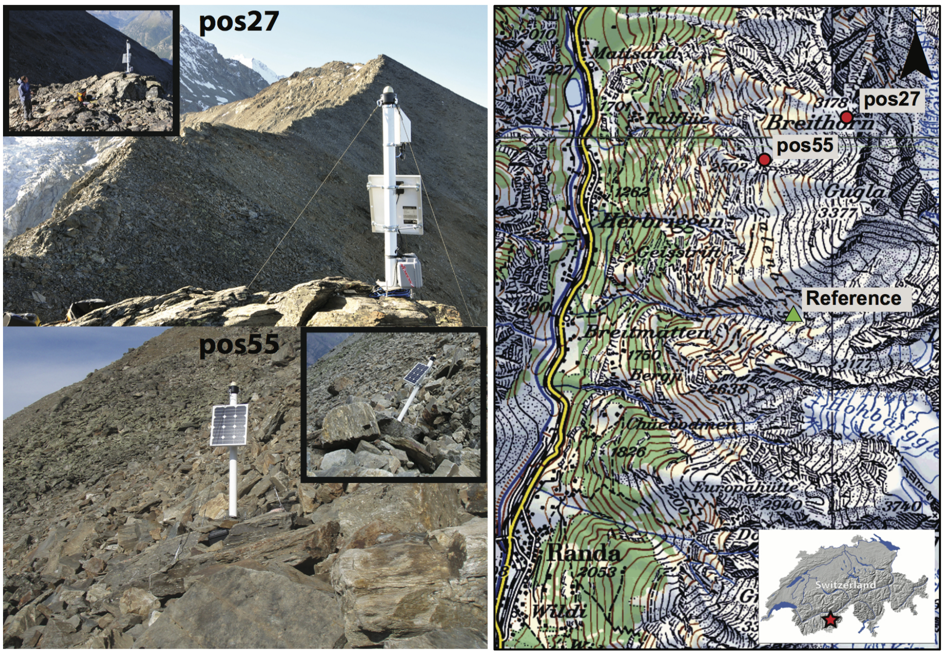

Fig. 1. see caption Fig 1