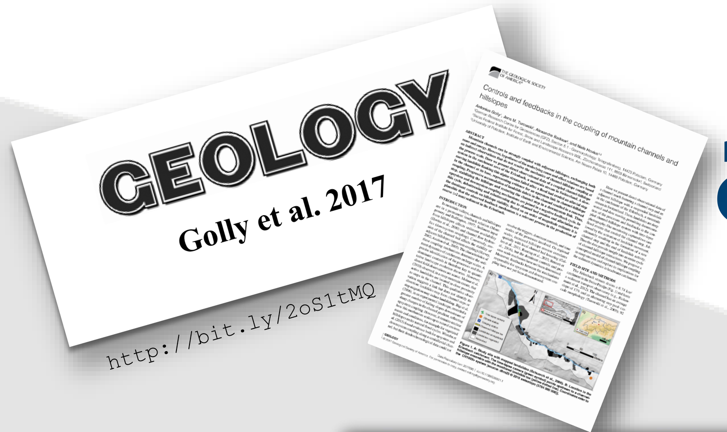

Landscape response to rare flood events: a feedback cycle in channel-hillslope coupling

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Fig. 2: The time-lapse imagery of the monitored site

Motivation

Fluvial channels and their surrounding landscape are **permanently coupled**, exchanging mass and energy. Only rarely we get the opportunity to **observe the coupling at work**, resolving cause and effect relations, especially during large flood events.

Field site

The Erlenbach, **a steep mountain stream** in the Swiss Prealps (**Fig. 1**), features a large number of landslides with direct connection to the channel. We study the mechanistic relation between **hydrology**, **channel morphology** and the **hillslope displacement** to identify controls on channel-hillslope coupling processes.

Methods

Over the summer season 2014 we observed a **suspended slow-moving** landslide next to the channel with timelapse cameras (**Fig. 2**) at a 30-min interval. From the time-lapse images we extracted **surface displacement rates** of the landslide body by tracking objects through the data set.

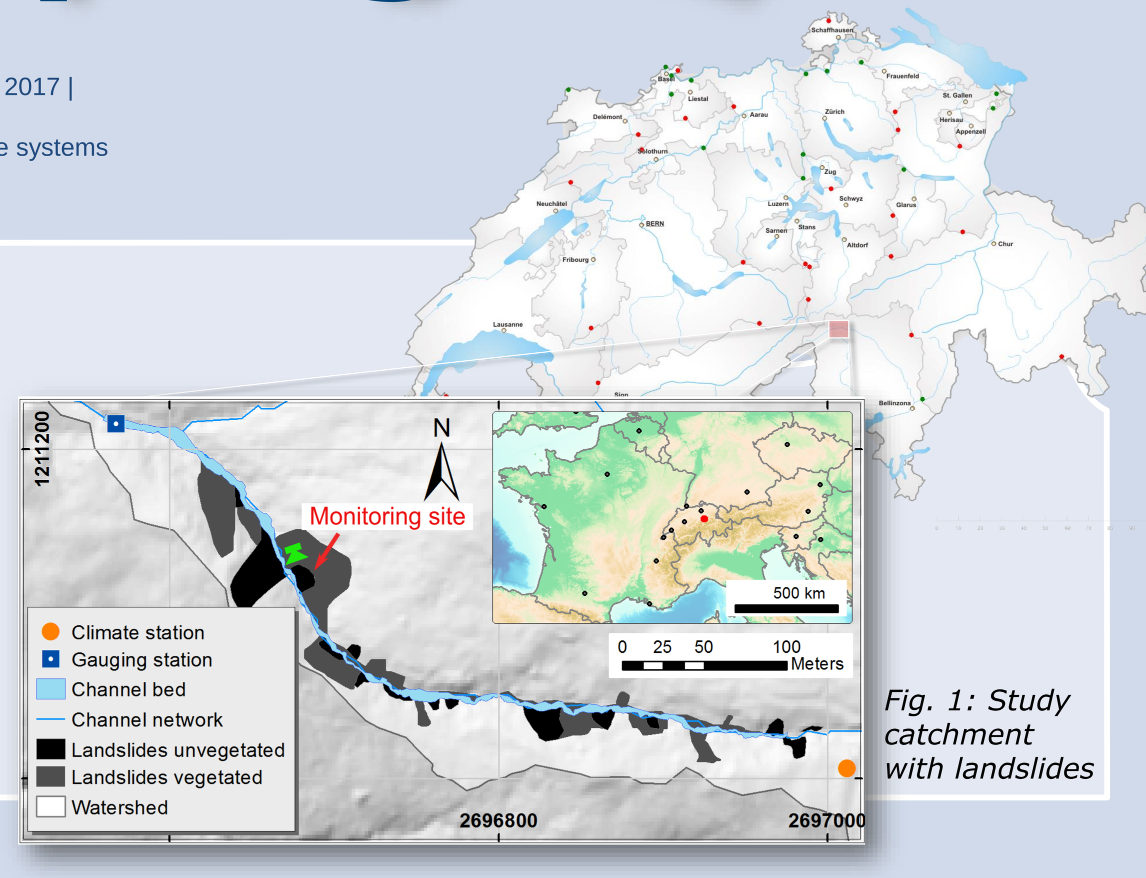

Fig. 1: Study catchment with landslides

Observations

Fig. 3A: The hillslope before 26 July 2014. It shows no measurable surface displacement for several months (**Fig. 4**), despite 55 precipitation events totaling 1073 mm of rain (10.1 mm/d on average).

Fig. 3B: A flood on 26 July with a 5-year return period. Although the magnitude of the discharge of this event was the highest on record, rainfall during previous events was higher (**Fig. 5**).

Fig. 3C: While previous events had not noticeably modified the monitored reach, this flood resulted in an ~4 m upstream migration of the alluvial step at the downstream end of the landslide.

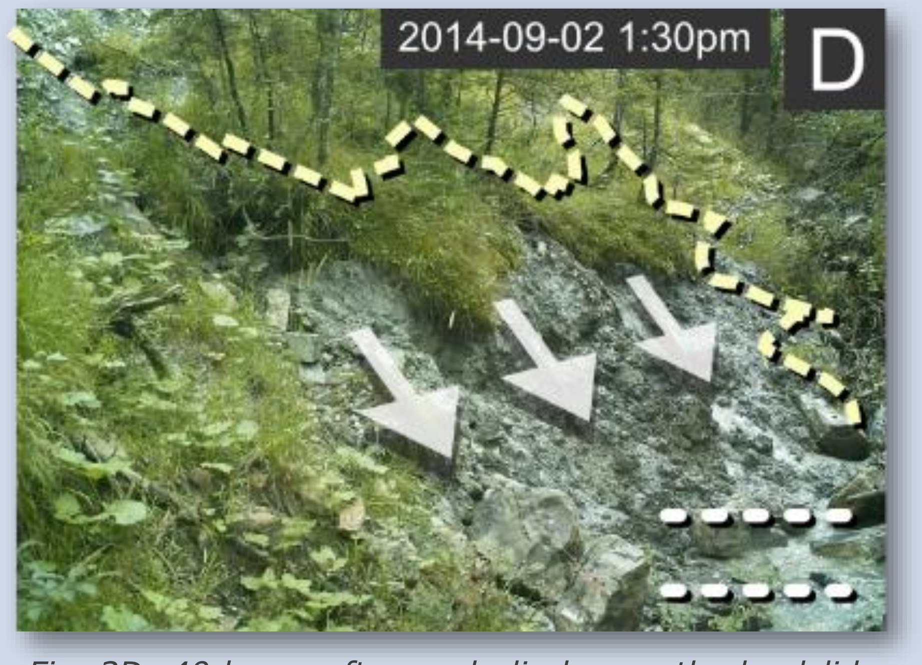

Fig. 3D: 40 hours after peak discharge, the landslide entered a 45 day phase of continuous integral motion (**Fig. 4**), during which precipitation averaged 10.8 mm/d.

Fig. 3E: Subsequent hillslope displacement narrows the channel so that boulders and large wood build a new ~1-m-high channel step at the landslide toe near the position of the original step.

Discussion

The monitored reach appears to have gone through a full channel-hillslope feedback cycle, which started and ended in a stable system state. To ascertain this, the dominant control on the hillslope's stability needs to be identified.

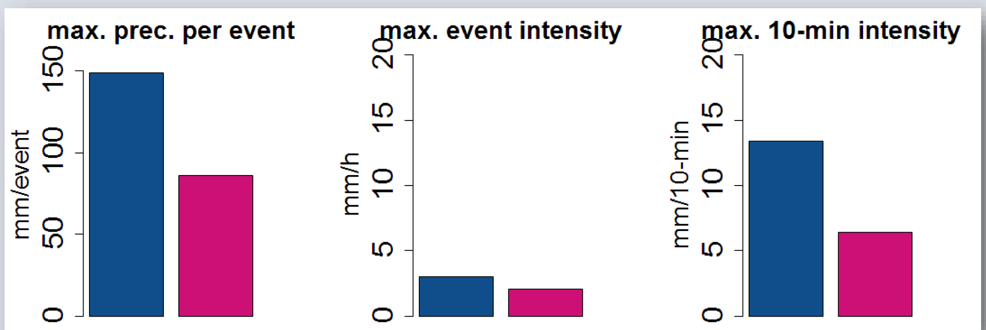

Fig. 5: Three rainfall characteristics are higher before the flood on 26 July (blue bars) than during the flood on 26 July (red bars)

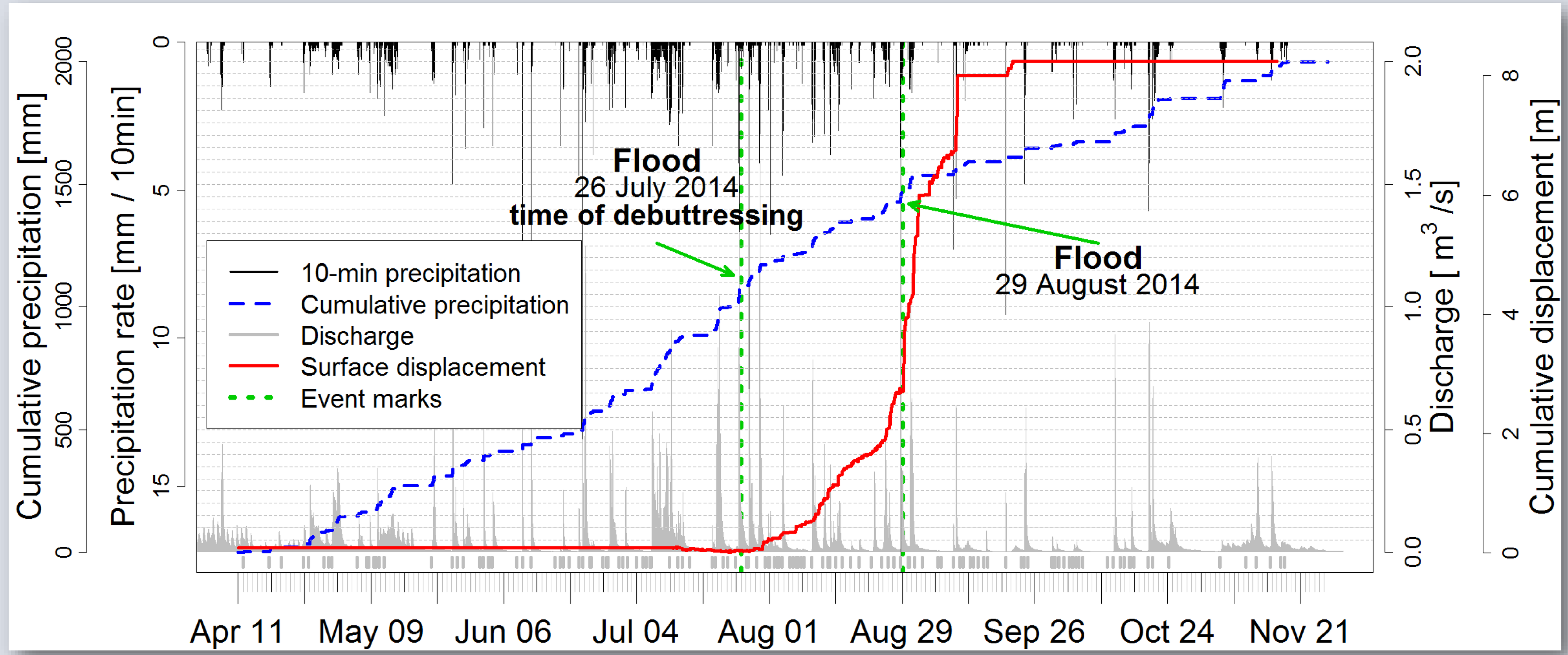

Fig. 4: Timeline of precipitation rates (black bars), cumulative precipitation (dashed blue line), discharge (gray graph), and hillslope surface displacement (red line) between April and November 2014 in the Erlenbach catchment. Vertical green lines indicate large flood events.

Rainstorms prior to the activation of landslide motion surpassed the triggering event in three categories (**Fig. 5**). Therefore, instead of hydraulic controls the debuttressing of the landslide front, due to erosion of the alluvia step, was the likely trigger of the hillslope failure.

"Hillslope activity was driven by the step erosion"

The hillslope stabilization was primarily due to rebuttressing of the landslide, closing the feedback loop in the Erlenbach channel-hillslope system.

Conceptual model

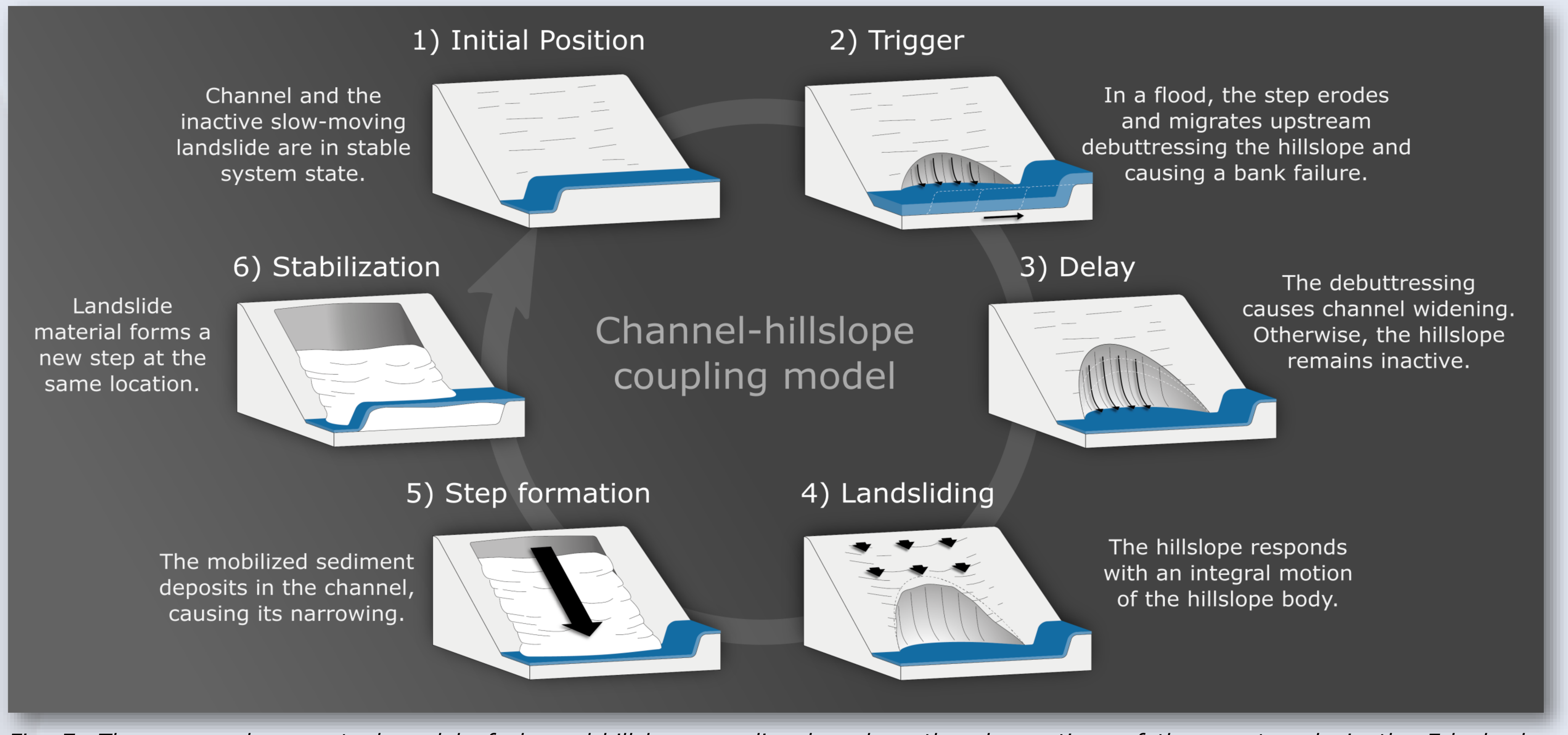

Fig. 7: The proposed conceptual model of channel-hillslope coupling based on the observations of the event cycle in the Erlenbach catchment. The cycle can be reinitiated (step 6 to 1) once hillslope sediment is refilled (all figures from Golly et al. 2017, GEOLOGY)

The entire feedback cycle of the channel-hillslope system can be described with a six-step conceptual model (**Fig. 7**). In the initial position (**1**) before the triggering flood, the hillslope was inactive and no hydraulic trigger was able to cause displacement. The trigger (**2**), causing hillslope movement, was the debuttressing of the landslide due to the erosion of an alluvial channel step at the landslide toe. This triggered, after a delay (**3**), deep-seated movement of the entire landslide body. Sustained landsliding accumulated material and formed a new channel step (**5**) at the landslide toe. Ultimately, step formation caused the end of hillslope movement and initiated a new phase of slope stability (**6**).