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Research paper

How to improve dating quality and reduce noise in tree-ring based debris-flow reconstructions

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ABSTRACT

Tree rings have been used to reconstruct the occurrence of debris flows and other mass movements. Identification of past activity was typically based on the presence of growth anomalies in trees, with a focus on scars, stem tilting, trunk burial or apex decapitation. Clear guidelines have been missing so far and the dating of events has only rarely been based on thresholds so as to distinguish signal from noise. In a similar way, the spatial distribution of affected trees has not normally been considered in mass movement reconstructions, and was at best used as a subjective exclusion factor. This study therefore aims at improving dating quality of and reducing noise in debris-flow time series. Based on a dataset of 803 increment cores (385 trees) affected by debris flows, we reconstruct event histories using (i) a classical experts' approach, (ii) a weighted index (W_{it}) of responding trees as well as (iii) Moran's *I* and Getis–Ord Local Gi indices. We identify similarities and differences in results and then investigate subsets of the tree-ring sample to define ideal sampling positions on debris-flow cones and guidelines for sample depth.

1. Introduction

In recent decades, the occurrence of mass-wasting processes has repeatedly led to important economic losses and casualties (Jakob and Hungr, 2005). In an attempt to reduce disaster risk, enhanced knowledge on the occurrence and (spatial) behavior of past events is of crucial importance. As archival data is not usually very extensive or often completely missing, an urgent need exists for the creation of improved databases on past disasters (Ballesteros et al., 2011). Geochronological methods have been demonstrated in the past to have the potential to provide extensive time series of past disasters. However, several of the approaches applied in previous work (Schneuwly-Bollschweiler et al., 2012) have not been used for the assessment of hazards and risks in the first place, and thus need improvement so that more accurate and denser time series and more precise ages of mass-wasting activity can be obtained for the past decades up to centuries and for varying spatial scales.

In temperate regions, trees affected by mass movements typically record the evidence of past events in their growth-ring series and therefore provide a precise geochronological tool for the reconstruction of past mass-movement activity (Stoffel et al., 2010a). In the past, various procedures have been defined for the identification of characteristic growth disturbances (GD) and the definition of events (Alestalo, 1971; Shroder, 1978). However, the evidence left in trees and the nature and extent of damage in individual trees or entire forest stand will be dictated ultimately by the nature of the process investigated (Stoffel and Perret, 2006; Stoffel et al., 2013). Processes with a large spatial footprint (e.g., snow avalanches, landslides, floods) will tend to leave GD in a large number of trees, whereas only individual scars in one or a few trees will be found in the tree-ring record following rockfall activity (Perret et al., 2006; Schneuwly and Stoffel, 2008; Stoffel et al., 2005; Corona et al., 2013; Trappmann et al., 2013).

Different approaches and thresholds have thus been defined to reconstruct process activity. In snow avalanche research, for instance, a minimum of 10% (and up to 40%) of all sampled trees typically need to exhibit GD in the same year for an event to be accepted (Butler and Malanson, 1985; Butler and Sawyer, 2008; Dubé et al., 2004; Germain et al., 2009; Pederson et al., 2006). More recently, Corona et al. (2012) postulated that a flexible threshold is preferable over a fixed value and that this threshold should be adapted based on the number of GD and the number of trees available for analysis.

In landslide research, thresholds have less often been applied. Lopez Saez et al. (2012), for instance, demonstrated that

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simultaneous reactions in ≥10 trees and 5% of the sampled population are sufficient to date past events with high accuracy. While their threshold is comparable with those used in flash flood and debris flood research (Mayer et al., 2010; Ruiz-Villanueva et al., 2010), it differs quite substantially from values used in previous landslide research, where reactions in one single tree have been considered sufficient for the identification of past landsliding (Bégin and Filion, 2010; Fantucci and Sorriso-Valvo, 1999).

Debris flows generally affect more limited surfaces as compared to avalanches, landslides or floods (Stoffel et al., 2013) and cannot therefore be reconstructed with the same thresholds. As debris-flow surges tend to leave channels in only one or a few areas (Stoffel, 2010), they will not necessarily leave a large spatial footprint in the tree-ring record. As a consequence, quantitative thresholds have not been applied systematically so far nor have spatial patterns of affected trees been used as a criterion for the definition and reconstruction of past events.

This study therefore aims at providing a more objective means for the reconstruction of past debris flows and at improving dating quality of debris-flow time series. We present a systematic approach taking account of the intensity and number of GD and introduce geostatistical indices to account for the spatial distribution of affected trees. Based on the event chronology derived from a large set of trees affected by debris flows, we also test subsets of trees with different spatial distributions on the depositional cone to define an appropriate sampling strategy and to obtain optimal signal-noise ratios in the results.

2. Regional setting

The Wildibach torrent (46°07′N/7°47′E; Fig. 1) is located in the Zermatt valley (Valais, Swiss Alps), an inneralpine north–south oriented valley, ca. 8 km N of Zermatt. The catchment extends from 4545 m asl (Dom) to the confluence of the Wildibach torrent with the Vispa River at 1420 m asl. About 30% of the catchment is glaciated and periglacial processes and features (i.e. moraines, rock glaciers) dominate much of the remaining catchment area. Geology is composed of Permian gneisses (Labhart, 2004; Pfiffner, 2009). Mean annual air temperature in Zermatt (1638 m asl) is 3.9 °C and mean annual precipitation is 690 mm (1900–2008). High annual and day-time thermal ranges favor weathering processes which provide abundant material for matrix poor debris flows with block sizes of up to 2 m (Schneuwly-Bollschweiler and Stoffel, 2012; Stoffel et al., 2011). A large (31 ha), but relatively flat (mean slope angle: 13°) cone has formed at the outlet of the steep main channel (average 23°); it is covered with a forest composed of *Larix decidua* Mill. and some *Picea abies* (L.) Karst., but deposits of past debris flows remain clearly visible. The outermost segments of the cone are used for grazing and housing. The main road and the railway line intersect the cone in its lowermost part. The Wildibach torrent is known to produce debris-flow events; however, archival records are scarce and contain information on events in 1927, 1932, 1978, and 2000 (Valais, 2009; Zimmermann et al., 1997). The debris flow of 1978 caused extensive damage on the cone and led to the construction of deflection dams and a retention basin.

3. Material and methods

3.1. Field work and laboratory analysis

An area of 12 ha has been selected on the cone where debris flows have obviously affected trees in the past and where signs of anthropogenic influence are absent. All features related to past debris-flow activity (i.e. lobes, levees, abandoned flow paths) were

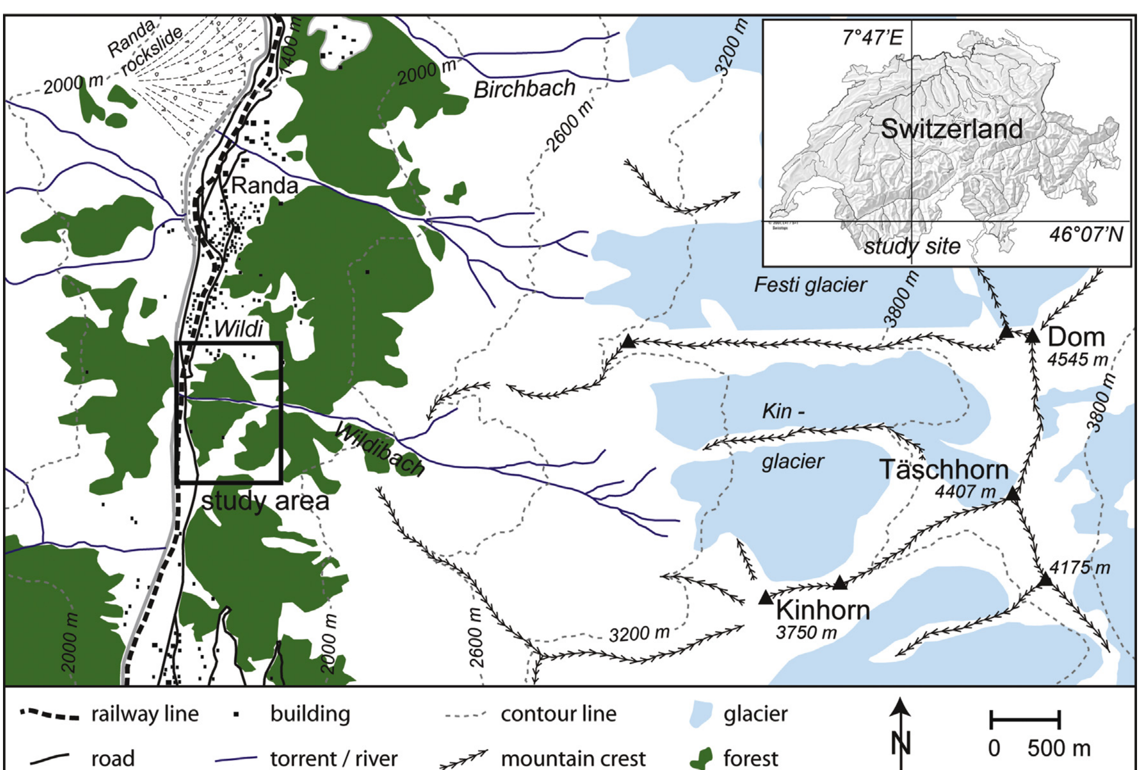

Fig. 1. The Wildibach cone is located in the Zermatt Valley, Swiss Alps. The upper parts of the catchment area are glaciated. The study area is focused on the debris-flow cone on the valley floor.