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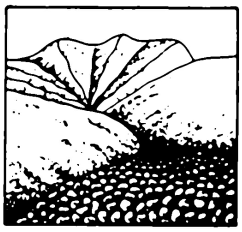
Пятигорск, Россия, 22-29 сентября 2008 г.



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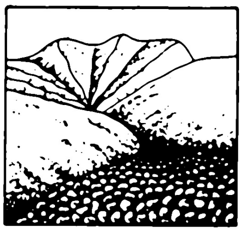

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On the evolution of debris-flow occurrence in space and time – results from tree-ring analyses

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Об эволюции селевых событий в пространстве и времени: результаты дендрохронологического анализа

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Селевая активность на залесенном селевом конусе р. Ритиграбен (Вале, Швейцарские Альпы) была оценена с точки зрения роста ежегодных колец вековых деревьев, обеспечивающих необычно полную запись прошлых событий и отложения материала. Изучение 2246 древесных колец, отобранных с 1102 хвойных деревьев, позволило реконструировать 123 события, начиная с 1566 г. Геоморфологическое картографирование позволило выявить 769 точек, в которых фиксируется связь с прошлой селевой активностью, на промежуточном конусе площадью 32 га. Кольца деревьев также показывают, что холодные летние периоды, с частыми снегопадами на больших высотах, регулярно блокировали сход селей в период между 1570-ми и 1860-ми гг. Тенденция потепления сочеталась с увеличением суммарного количества осадков летом и осенью в период между 1864 и 1895 гг., создавая все более благоприятные условия для формирования селей в очагах. Расширенная селевая активность достигла пика между 1916 и 1935 гг., когда теплые и влажные условия преобладали в Швейцарских Альпах в летние сезоны. Напротив, за последний 10-летний период (1996–2005 гг.) наблюдалась очень низкая активность, и было зафиксировано только одно селевое событие 27 августа 2002 г.

Debris-flow activity on a forested fan of the Ritigraben torrent (Valais, Swiss Alps) was assessed through growth disturbances in century-old trees, providing an unusually complete record of past events and deposition of material. The study of 2246 tree-ring sequences sampled from 1102 conifer trees allowed reconstruction of 123 events since AD 1566. Geomorphic mapping permitted identification of 769 features related to past debris-flow activity on the intermediate fan covering 32 ha. Tree-ring records also suggest that cool summers with frequent snowfalls at higher elevations regularly prevented the release of debris flows between the 1570s and 1860s; the warming trend combined with greater precipitation totals in summer and autumn between 1864 and 1895 provided conditions that were increasingly favourable for releasing events from the source zone. Enhanced debris-flow activity culminated between 1916 and 1935, when warm-wet conditions prevailed during summer in the Swiss Alps. In contrast, very low activity is observed for the last 10-year period (1996–2005) with only one debris-flow event recorded on August 27, 2002.

1 Introduction

Debris flows represent one of the most common and widespread of all natural hazards in mountain environments, where they repeatedly cause damage to infrastructure or even loss of life. With the projected greenhouse warming, there is much debate about changes in the frequency, magnitude and seasonality of precipitation events and related flooding or mass-wasting processes (Beniston, 2006). Before establishing any cause-and-effect relationship between global warming and the incidence of geomorphic processes, the natural variability of extreme weather events must be examined as well as detailed information obtained on past process dynamics on debris-flow fans. It is therefore the purpose of this paper to assess late Holocene debris-flow activity on a forested fan in the Swiss Alps using dendrogeomorphological methods. We investigate the frequency and timing of events, and discuss potential effects of projected climatic change upon the frequency and magnitude of events in a future greenhouse climate.

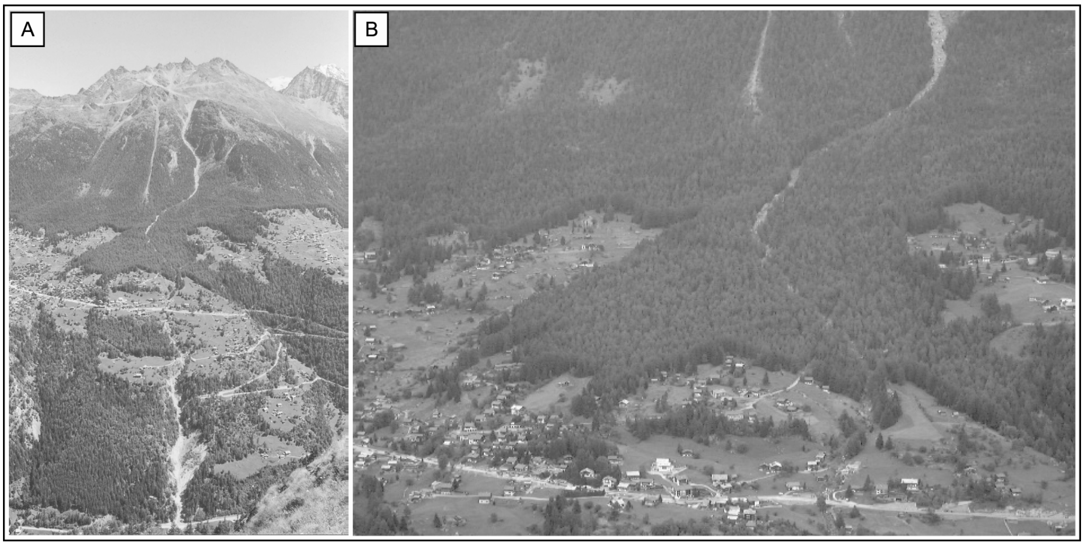

Figure 1. (A) Photo of the Ritigraben debris-flow system from its source to the confluence via (B) the intermediate fan (catchment area: 1.36 km^2, channel length: 3.5 km; photos by M. Stoffel).

2 Study area

The analysis of debris-flow dynamics was conducted around the Ritigraben torrent (Switzerland, 46° 11’ N, 7° 49’ E). Figure 1 shows the torrent originating in periglacial environments at 2600 m a.s.l. On its downward course to the Mattervispa river, the torrent passes a large forested fan (32 ha) on a structural terrace (1500–1800 m a.s.l.), where debris-flow material affects trees within an old-growth stand composed of larch (*Larix decidua* Mill.), spruce (*Picea abies* (L.) Karst.) and pine (*Pinus cembra* L.). At the confluence of the Ritigraben torrent with the Mattervispa river at 1,080 m a.s.l., deposits are lacking. Debris-flow material consists of metamorphic granites of Permian age originating from the steep source zone, where a rock glacier provides material for the initiation of debris flows. The high elevation of the source area restricts debris-flow activity in the torrent from June to September (Stoffel et al., 2005). The documentation of past events covers the last 20 years, with the “largest event ever” recorded in 1993, when eleven erosive surges transported 60,000 m^3 of debris.

3 Material and methods

Analysis of past debris-flow activity began with a detailed mapping of all features associated with past events, such as lobes, levees or abandoned flow paths using tape, compass and inclinometer. Thereafter, 1102 trees (2246 cores) were sampled that have obviously been disturbed by past debris flows and 102 trees (204 cores) of the same species selected from undisturbed reference sites.

Samples were analyzed and data processed following the standard procedures described in Stoffel and Bollschweiler (2008): We primarily focused on the initiation of abrupt growth reduction after apex loss or root denudation, the occurrence of reaction wood after stem tilting as well as on callus tissue and tangential rows of traumatic resin ducts formed after cambium damage (Bollschweiler et al., 2008, Stoffel, 2008). As conifers react immediately to damage, the intra-annual position of these disturbance was used to assess the timing of debris-flow activity in particular years with monthly precision (Stoffel and Beniston, 2006).

4 Results

Geomorphic mapping permitted identification of 769 features related to debris-flow activity on the intermediate fan of the Ritigraben torrent. The features and deposits inventoried in the study area included 291 lobes, 465 levees and 13 well-developed debris-flow channels. Dendrogeomorphological analysis of the increment cores allowed reconstruction of 123 debris-flow events covering the last 440 years. In Fig. 2, the reconstructed frequency is broken down into 10-year periods, with bars representing variations from the mean decadal frequency of debris flows for the period 1706–2005, when 3.26 events occurred every ten years. Results illustrate that the frequency generally remained well below average during most of the classical Little Ice Age (1570–1900). Periods with increased debris-flow activity only start to emerge after the last LIA glacier advance in the 1860s. This period of increased activity continued well into the early 20th century reaching a peak between 1916 and 1935, when 14 events could be dated from the tree-ring series. Results also illustrate that this major episode of activity was followed by a decrease in debris flows, with particularly low activity over the last 10 years (1996–2005), when only one debris flow was recorded on August 27, 2002.

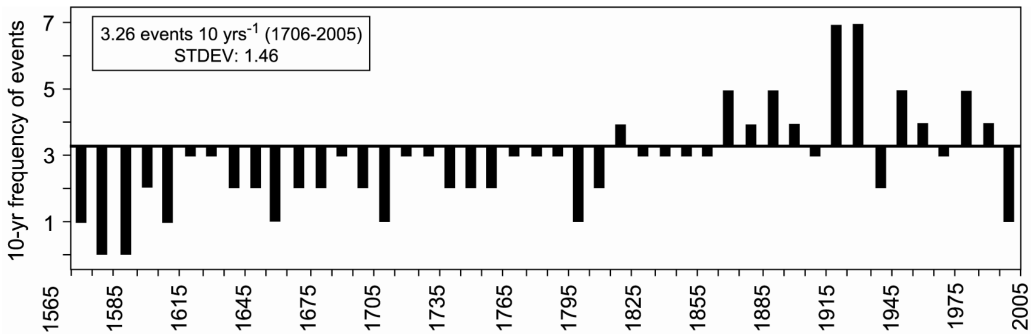

Fig. 2. Reconstructed 10-yr frequencies of debris-flow events between AD 1566 and 2005. Data are presented as variations from the mean decadal frequency of debris flows between AD 1706 and 2005.

The timing of past events indicates that events generally occurred much earlier in summer prior to 1900. This is especially true for the period 1850–1899, when >70% of the debris-flow events took place in June and July, with none in September. In the 20th century, activity clearly shifted to August and September, with not a single event registered in June after AD 1962. Our reconstructions suggest that snowfall and frozen ground has inhibited debris entrainment from the source zone (>2600 m a.s.l.) during precipitation events between October and May. The analysis of injured, buried or tilted survivor trees in deposits allowed dating of 249 out of the 291 lobes identified on the intermediate fan. A majority of lobes that are visible on the present-day surface of the fan were deposited during the last 80 years.

5 Discussion and conclusion

Increment cores extracted from 1102 living conifer trees allowed reconstruction of 123 debris-flow events since AD 1566. On the basis of the evidence presented above, it is possible to characterize climatological as well as meteorological factors driving debris-flow activity in the case-study area. Tree-ring based records of past debris-flow activity suggest that cool summers with frequent snowfalls at higher elevations regularly prevented the release of debris flows between the 1570s and 1860s. The warming trend combined with greater precipitation totals in summer and autumn between 1864 and 1895 produced an increase in conditions favourable for the release of debris flows. Enhanced debris-flow activity continued well into the

20th century and our reconstruction exhibits a clustering of events for the period 1916–1935, when warm-wet conditions prevailed during summer in the Swiss Alps (Pfister, 1999).

The timing of events also underwent changes over the period covered by the reconstruction. Based on the tree-ring record, we observe a shift in debris-flow activity from June and July to August and September over the 20th century, with not a single event registered in June after AD 1962 (Stoffel et al., 2008). Our findings are in agreement with data from Schmidli and Frei (2005), indicating a decrease in heavy summer rainfall and a slightly positive trend in heavy autumn precipitation intensities for the wider case-study area. Based on the IPCC A2 greenhouse-gas emissions scenario, RCMs suggest a similar shift in the occurrence of heavy precipitation events in the Swiss Alps from summer to autumn by 2100. Spring and autumn temperatures are projected to remain 4–7 °C degrees below current summer temperatures implying lower freezing levels in future springs and autumns as compared with current summers and therefore probably widespread buffering effects of snow on runoff and debris entrainment. Given that mean and extreme precipitation events are projected to occur less frequently in summer and that wet spells will become more common in spring and autumn, it is conceivable that debris flows will not necessarily occur as frequently in the future as they did in the past in the case-study area. However, even if the frequency of summer events decreases in a future greenhouse climate, the magnitude and related impacts of future summer debris flows could be greater than currently. This is because warmer temperatures and higher precipitation intensities could result in greater runoff, an increase in the transport capacity of surges leading to a greater erosive potential of debris flows.

The use of growth anomalies in tree rings for dating deposits on the intermediate fan introduces an additional tool to aid in our better understanding of the spatial patterns of past events and phases of aggradation or incision on the intermediate fan. Although our results clearly show that signs of pre-20th century events are recognizable in the tree-ring record of survivor trees, it should be noted that most of the lobes deposited by the 35 events reconstructed for the 19th century have been overridden or eroded by more recent activity. The equally small number of pre-20th century features does not therefore imply that these events have been of smaller magnitude than more recent ones. Based on the geomorphic map and the dendrogeomorphological dating of events, we conclude that debris-flow activity of the 20th century was characterized by sediment accumulation on the fan and that the high-magnitude event in September 1993 (60,000 m^3) is most likely to have been the largest event on the fan for at least the last century. Further investigations using stratigraphic analysis of debris-flow material and the dating of organic layers of exposed sediments in the current channel could be used on the intermediate Ritigraben fan to reveal more fully its development during the Holocene and to identify substantial changes in climatic conditions and sediment supply.

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