DENDROGEOMORPHOLOGICAL RECONSTRUCTION OF PAST DEBRIS-FLOW EVENTS ON THE MANIVAL TORRENT (FRENCH ALPS)

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ABSTRACT

Debris-flow risk analysis in mountainous terrains requires a better characterization of the frequency and the propagation area of debris-flow events. This characterization is generally based on the analysis of historical records, which are more or less incomplete and sometimes inexistent for small pristine catchments. To complete and enhance the historical record analysis, the dendrogeomorphological survey of alluvial fans has proved to be an efficient and attractive tool. The purposes of the study conducted on a torrent of the Northern French Prealps (Manival Torrent, drainage area: 7 km²) are: (i) to date the debris-flow events from dendrogeomorphological evidences on the wooded alluvial fan, and (ii) to analyze the evolution of debris-flow activity through time from the historical record completed with dendrogeomorphological surveys. From the study of the growth disturbances of 250 *Pinus sylvestris* located in abandoned channels and associated banks, we reconstructed the geomorphic activity of old debris-flow channels of the Manival. Ten events were identified by dendrogeomorphological survey. Only three of them were previously known from historical records

Key Words: Dendrogeomorphology, Debris-flow, Tree rings, Growth disturbances, Reaction wood

INTRODUCTION

Debris flows represent a major threat to infrastructure in many regions of the Alps. Numerous studies rely on the processes and forms related to debris-flow activity (Jakob and Hungr, 2005), the flow behavior and rheology (Bollschweiler *et al.*, 2007) or on the assessment of threshold values for the triggering of events. Nonetheless, the spatial behaviour of past debris-

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flow activity and the analysis of areas affected during particular events have been widely neglected in reconstructions.

Trees growing on cones can be repeatedly affected by debris flows and react to such disturbances with growth anomalies. As a consequence, more recently, on forested debris-flow cones, dendrogeomorphological analyses have repeatedly been conducted to identify the earlier occurrence of debris flows (Stoffel and Beniston, 2006), the magnitude of past events (Baumann and Kaiser, 1999), the spatial patterns (Bollschweiler *et al.*, 2007) and the triggering weather conditions of debris-flows (Stoffel *et al.* 2005). The aim of this study is to provide an overview of debris-flow activity in a French alpine torrent through (i) the assessment of growth disturbances in trees growing on the debris-flow cone, (ii) a determination of events in the torrent, (iii) the reconstruction of debris-flow frequencies and (iv) an illustration of the spatial activity during high magnitude events. In a final section, we compare the reconstructed events with archival data.

STUDY AREA

The study was conducted on the Manival torrent developed in an anticline on the east-facing side of the Chartreuse mountain range, about 10km north of the town of Grenoble (France) (Figure 1A, B). This torrent has received considerable attention since the end of the 19th century by the Restauration des Terrains de Montagne agency (RTM), the French national agency in charge of natural hazard mitigation in mountain areas, since it has produced many debris-flows in the past (Veyrat Charvillon and Memier, 2006). The total drainage area of this torrent has a size of 7.3 km^2 and extends from 1738 m a.s.l. at the Bec Charvet to 250 m a.s.l. near the Isere river in the Gresivaudan Valley. Debris-flows are commonly triggered from an unstable reception basin located in the upper part of the catchement which is an escarpment of interbedded limestone and Marl of Jurassic age, easily mobilized during heavy rainfall. Below 850 m a.s.l., sediment and water are collected by the torrent flow shifting channels essentially covered with an open forest built of Scots pine (*Pinus sylvestris* L.). In 1926, two long dykes running diagonally from the two sides of the channel to an open central deposit zone were built. This central deposit zone was enclosed by a large check dam in 1992 and a 25000-m^3 sediment trap was excavated behind the dam, which traps all the debris and allows only the water to move downstream (Veyrat-Charvillon and Memier, 2006). The sediment trap is located at about 600 m elevation on the upper part of the debris fan. At this point, the basin area covers about 3 km^2 and the cone, one of the largest in France, is mostly occupied by the village of Saint Nazaire les Eymes.

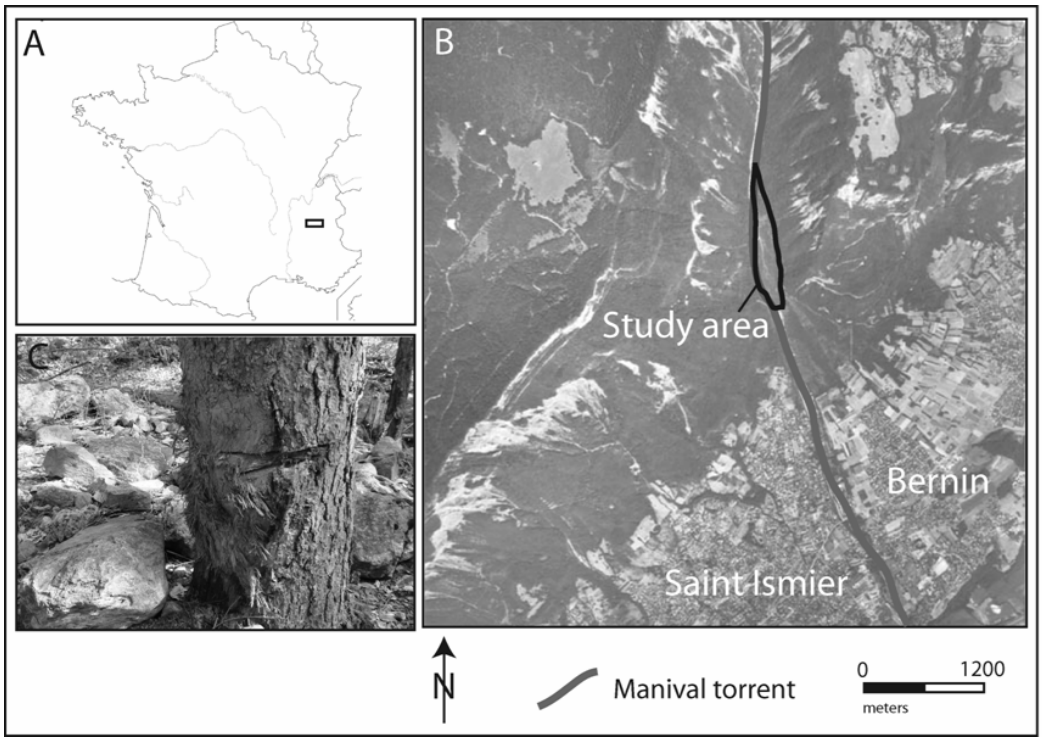

Fig.1: (A) The Manival torrent is located in the French Alps near the village of Saint Ismier (Department of Isère). (B) Aerial view of the Manival basin and localization of the study area. (C) View of debris flow impact.

MATERIAL AND METHODS

Depending on their volume, velocity or energy, debris flows can injure trees by scarring (i), tilting (ii) or breaking (iii) stems. The tree reacts to the abrasion caused by the flow with the formation of callues tissue at the edge of the injury (Perret *et al.*, 2006), (Figure 1C). The tilting and sometimes the S-shape of the stem is a sign of recovered straight stem after an unilateral pressure (Bollschweiler *et al.*, 2007) caused by the flow. Anatomically, it leads to the formation of compression wood on the downslope side of the trunk (Fantucci and Sorriso-Valvo, 1999). The loss of apex caused by rocks or boulders transported in the debris-flow mass induces candelabra growth and a distinct decrease in the growth the year following the event (Bollschweiler *et al.*, 2007). The elimination of neighboring trees can also result in a new environment with less competition, more light, nutrients and/or water that induces a growth release in the survivor trees (Strunk, 1997). These growth disturbances (GD), visible in tree-ring sequences have been analyzed to reconstruct past debris flow events.

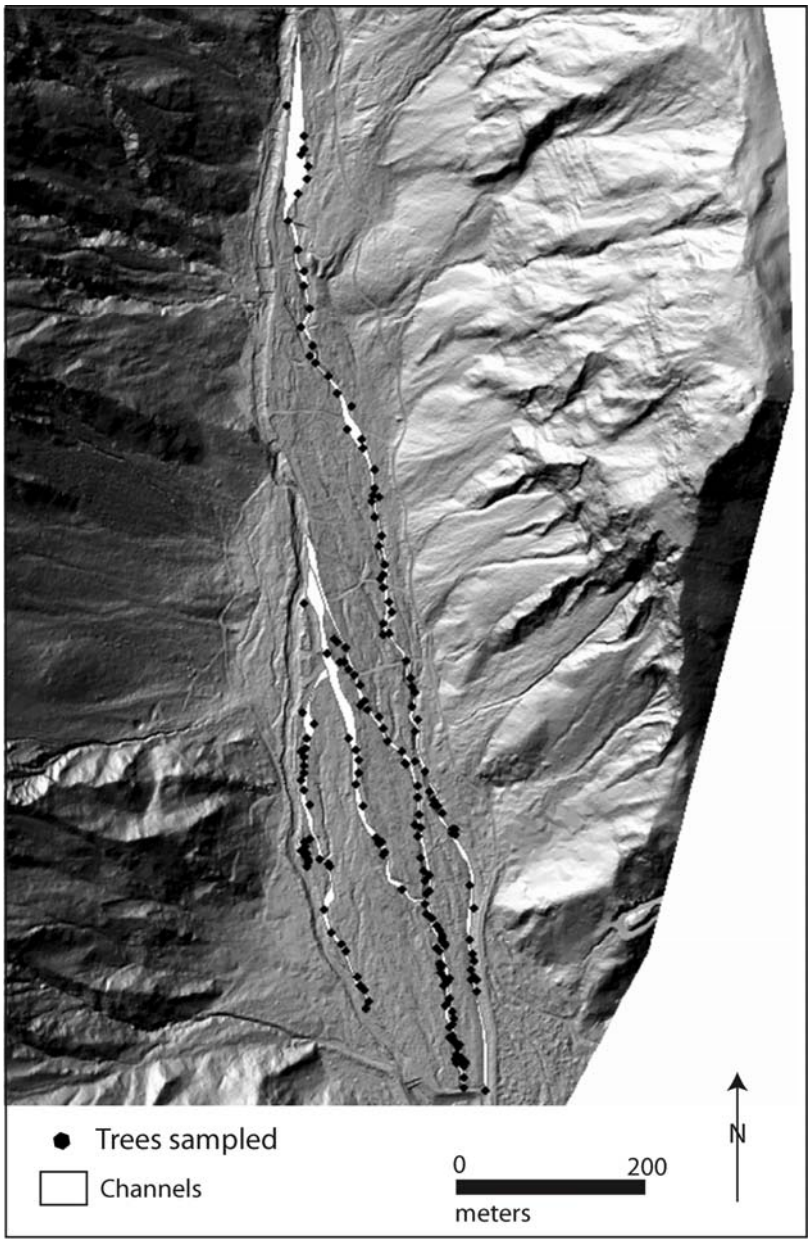

Fig.2: Digital Terrain Model of the Manival Torrent, the position of all sampled trees and the localization of the five channels.

In the field, we sampled trees along five channels, from the central deposit zone to the reception basin. 312 increment cores were sampled from 156 *Pinus sylvestris* trees (Figure 2). Two cores were removed from each tree in the flow direction. GPS coordinates with <1 m accuracy were recorded for each tree sample using a Trimble GeoExplorer. Sampling height was chosen according to the morphology of the stem: injured or tilted trees were sampled at the height of the disturbance; cores from decapitated trees were extracted next to the stem base so as to preserve as much tree-ring information as possible (Bollschweiler *et al.* 2008); cores from trees showing no visible growth disturbances were extracted at an average height of 130 cm. In addition to the trees sampled in the channels, fifteen undisturbed P. *sylvestris* trees showing no signs of geomorphic process were selected and used to build a reference chronology. Two cores were extracted per tree, perpendicularly to the slope, at breast height.

In the laboratory, the samples were analysed using dendrochronological standard methods: they were glued on wooden holders and finely sanded. Skeleton plots were made for visual crossdating of the samples and to trace missing or double rings (density variations). Afterwards tree-rings width was measured with a 0.001 mm accuracy using a digital LINTAB positioning table connected to a Leica microscope and TSAP 3·0 software (Time Series Analysis and Presentation). The reference chronology primarily served to compare general growth patterns of undisturbed trees with the tree-ring records of disturbed trees so as to allow distinction of predominant growth conditions (climate) from GDs induced by geomorphic processes. The comparison further allowed cross-dating of undisturbed with disturbed tree-ring records and, where applicable, correction of faulty tree-ring sequences derived from disturbed samples. The dated tree-ring series were statistically checked by using programme Cofecha (Holmes, 1983).

RESULTS

Age structure of the stand

Based on the pith age of the selected trees at breast height, the approximate age structure of the forest stand was assessed. We are aware that tree age at breast height provides neither germination nor inception dates. Nonetheless, it may furnishes valuable data on major disturbance events with reasonable precision. The mean age at sampling height of the trees cored at Manival is 62 years. While the oldest tree selected for analysis attained sampling height in AD 1875, the youngest sample only reached breast height in 1989. The spatial distribution within the stand is heterogeneous and the spatial distribution does not reveal any spatial patterns. This random distribution of tree ages through time and space suggests that even large debris flows were not able to eliminate large parts of the stand.

Dating of past debris-flow events

36 trees (23%) were sampled on channel 1, 79 (51%) on channel 2, 13 (8%) on channel 3, 21 (14%) on channel 4 and 7 (4%) on channel 5, the shortest one. 35 (22%) are trees with at least one visible scar, 21 (14%) are tilted trees and 100 (64%) exhibit any external defects. The 312 samples selected from the 156 P. sylvestris trees permitted identification of 375 growth disturbances (GD) of which 196 (52%) were the onset of reaction wood after tilting, 15 (4%) callus tissue and 164 (43%) abrupt growth releases or growth reductions. The earliest GD in the tree-ring series occurred in 1878. GD became more frequent after 1930, and nearly every year exhibited GD in a small number of trees. Most of these years were not classified as debris-flows years because only a few trees showed reactions. In total, GD allowed reconstruction of 10 event years between 1930 and 2008 in 1954, 1956, 1967, 1972, 1974, 1975, 1981, 1989, 1990, 2000. The years 1974 (24%), 1990 (40%) and 2000 (24%) are those exhibiting the highest frequency of appearance.

Spatial distribution of trees affected by debris flow

The spatial distribution of trees affected allowed approximation of the channels influenced by past activity by past debris flows. The reconstructed maps, provided in figure 3, illustrates the spatial distribution of characteristic Manival debris flows. They clearly indicate a lateral variation of the events. The debris flows are often limited to a single channel (1967, 1972, 1974, 1975, 1981). They concern two adjacent channels in 1954, 1956 and 1989 and they

affect trees located in the whole studied channels in only 1990 and 2000. The longitudinal extent also varies depending on the event. For example, in 1974 and 1975, the debris flows are restricted to a single channel but in 1974, the event extends to the central deposit zone while it was limited to the upper part of the channel in 1975 (Figure 3).

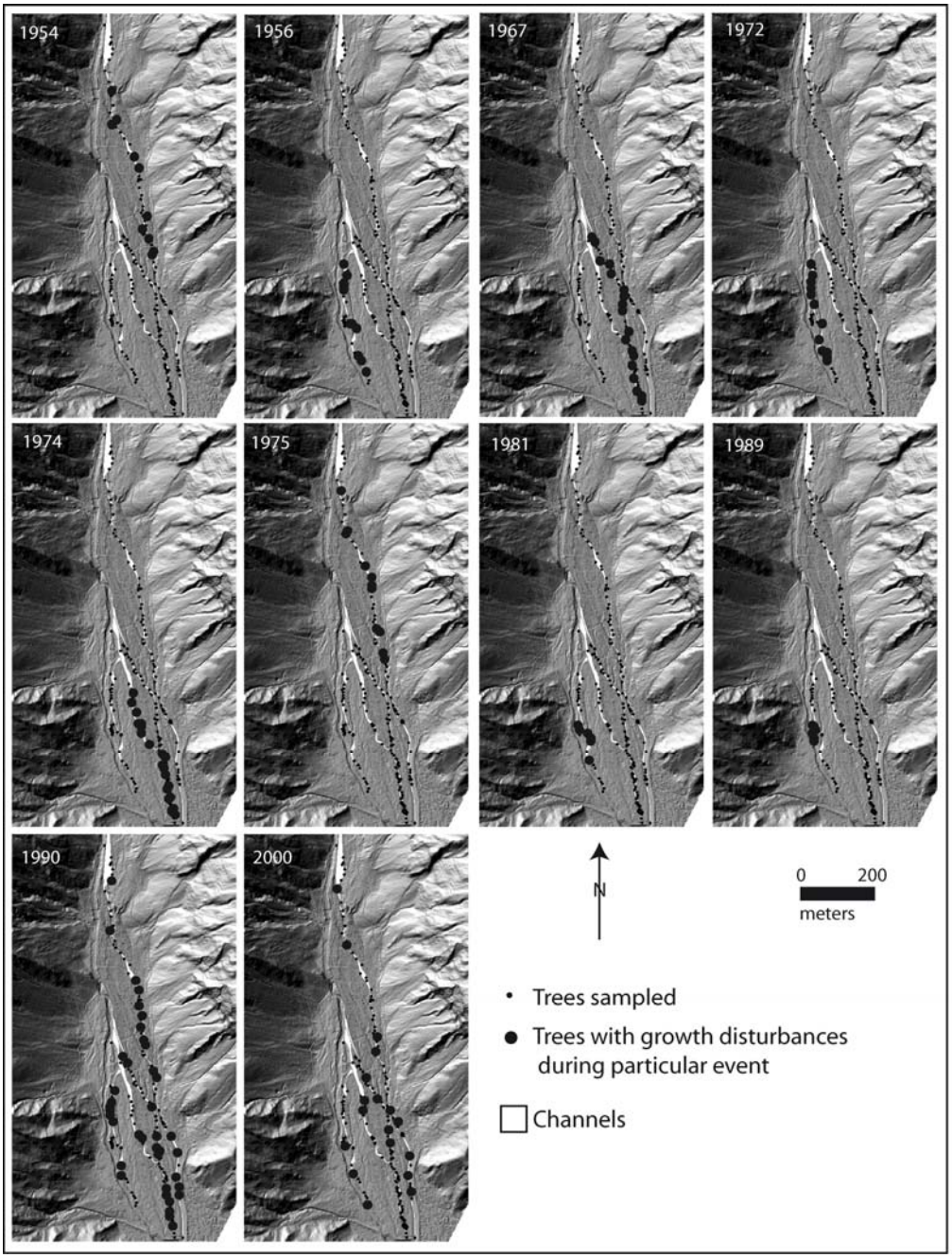

Fig.3: Spatial patterns of past debris-flow events for 1954, 1956, 1967, 1972, 1974, 1975, 1981, 1989, 1990 and 2000.

DISCUSSION AND CONCLUSION

The RTM have listed 18 debris-flow events since 1948 but the chronology do not seem to be complete (Brochot *et al.*, 2000). According to these historical archives, the last time that a debris-flow reached the bottom of the debris fan was in 1953. Since that event, urbanization has increased on the debris fan and the largest events with quantitative volume estimation are debris-flows, which occurred in 1968 (1990) and deposited about 60000 (12 000) m^3 of debris.

In this study, 312 increment cores from 156 living Scots pine (*Pinus sylvestris* L.) trees allowed recognition of 375 growth disturbances (GD) caused by 10 debris flow events. This reconstruction covers the period complemented the existing chronology. Amongst these ten events, three were pointed out in the historical dataset in 1956, 1990 and 2000 and 7 were not documented (Figure 4). However, the map confirms the extent of the event in 1990: the debris-flows overflowed the main channel and disturbed trees located in all studied channels. The dendrogeomorphological reconstruction does not enable to reconstruct the large events that occurred in 1968, 1984 and 1998 and filled the sediment trap check dam. It was, however, mainly limited by two factors. First of all, the study was limited to the upper part of the cone due to an important urbanization in its basal part leading to logging activity. In addition, only a limited number of trees heavily affected by debris-flow events can be found and the average age of these trees is relatively limited, especially the ones growing close to the channel. Furthermore, small debris-flow surges, recorded in the historical archives, may have remained in the incised channels and did not necessarily cause growth disturbance to any of the investigated trees. Therefore, the debris-flow frequency has to be seen as a minimum frequency for past events.

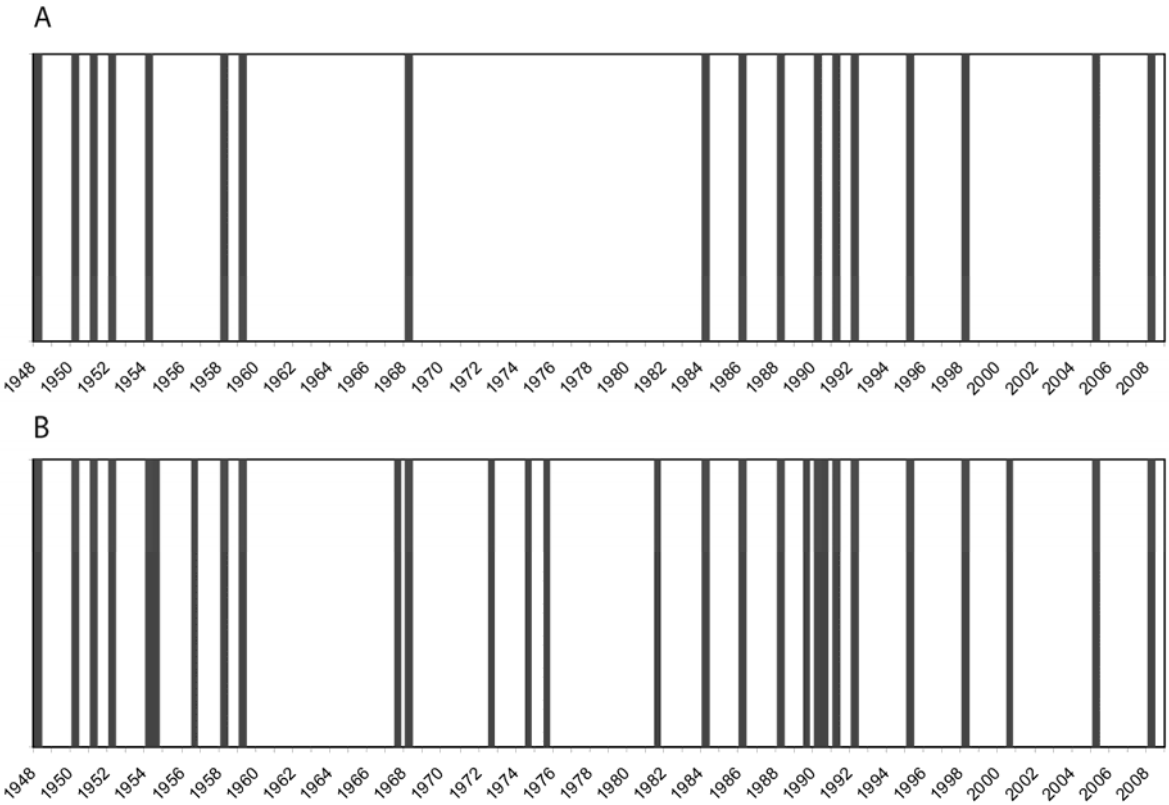

Fig.4: Reconstructed frequency of debris flows in the Manival torrent. (A) Archival data report 19 events since 1948. (B) Compilation of Tree-ring data and archival data.

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