Combined use of rockfall trajectory simulations and tree impacts observations for rockfall frequency assessment

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INTRODUCTION

While significant progress has been achieved regarding the modelling of rockfall propagation, including the interaction with forest cover, the estimation of the spatial distribution of rockfall frequency in release areas remains a challenging task. Indeed, the very low number of observed events makes any statistical modelling difficult, so that estimations are generally based on expert knowledge regarding the rock structure of start zones and a few recorded events. Meanwhile, recent dendrochronological studies have shown that trees, as silent witnesses of numerous events, bring information about the spatial distribution of rockfall trajectories. This data can be compared to simulated trajectories in order to reconstruct the most probable start zones. This study presents a methodological framework for the resolution of this problem on both virtual and real case studies.

METHODOLOGY

Consider a forest patch located below a cliff with N_s potential rockfall start points (Fig. 1).

The expected value of the number of impacts in this forest patch during lapse T can be calculated as (formula 1):

$$Impacts(f) = T \times \sum_{i=1}^{N_s} \left(p_{start}(i) \times p_{propagation}(i, f) \right)$$

with $P_{start}(i)$ the probability of rockfall for the start point i, $P_{propagation}(i,f)$ the probability that a rockfall from start point i impacts at least one tree in the forest patch f.

The matrix formulation for the whole forest divided in N_f forest patches is (formula 2):

$$\underset{1\times N_f}{Impact} = T \times \underset{1\times N_s}{Pstart} \times \underset{N_s\times N_f}{Ppropagation}$$

Propagation can be estimated with numerical simulations, by taking into account the current state of the forest stand if trees are measured and georeferenced, and if the volume of rockfall is known. Impact can also be observed on the field. Under the assumption that the forest stand and the start frequencies do not change during lapse T, the equation system (2) can be solved for the coefficients of P_{start}. The values of the coefficients of P_{start} correspond to the effective rockfall frequency related with all potential release points. The active release zones can be localized and graded from these coefficients.

RESULTS

This methodological framework was tested on a virtual case study consisting of a regular 35° slope. All the points located in the uppermost part of the site were considered as potential release points. Virtual tree impact observations were reconstructed from a limited amount of simulations (typically 10 to 100 events, in total) from selected release points. These virtual observations were used to characterize Impact while classical rockfall simulations from all potential release points allowed building $P_{propagation}$. The system (2) was solved with an optimization routine to assess the coefficients of P_{start}. Results show that both discrete and diffuse release areas can be identified. The influence of both forest (density, tree diameters) and release areas (rock volume, frequency, size, and distance between different release areas) characteristics was also analysed to assess the relevance and limitations of the approach.

The approach was also tested on a rockfall area located in Valdrôme, France, where more than 1000 trees were measured and geolocated in a one hectare stand located below a cliff with rockfall activity. The number of impacts on each tree was observed and starting points were determined based on a slope criterion applied to a digital terrain model. The rockfall trajectories were simulated with the RockyFor3D software. The system (2) was also solved with an optimization routine (Fig. 2). Results show that the rockfall frequencies display high spatial variability and that 21% of starting points account for more than 50% of rockfall releases.

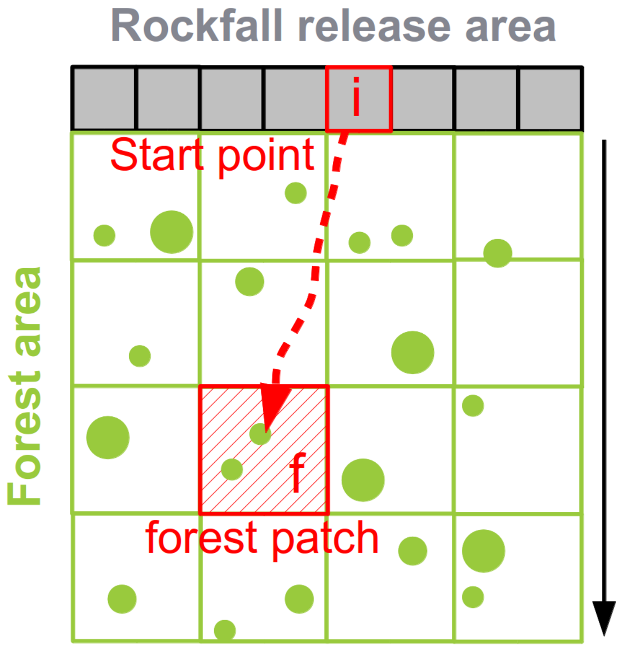

Figure 1. Conceptual scheme

CONCLUSION

Both case studies, virtual and real, show that the use of dendrochronology and rockfall simulations is a promising tool for a better evaluation of the spatial variability of rockfall hazard. Additional studies have yet to be realized in order to evaluate the methodology with respect to the errors in the input data.

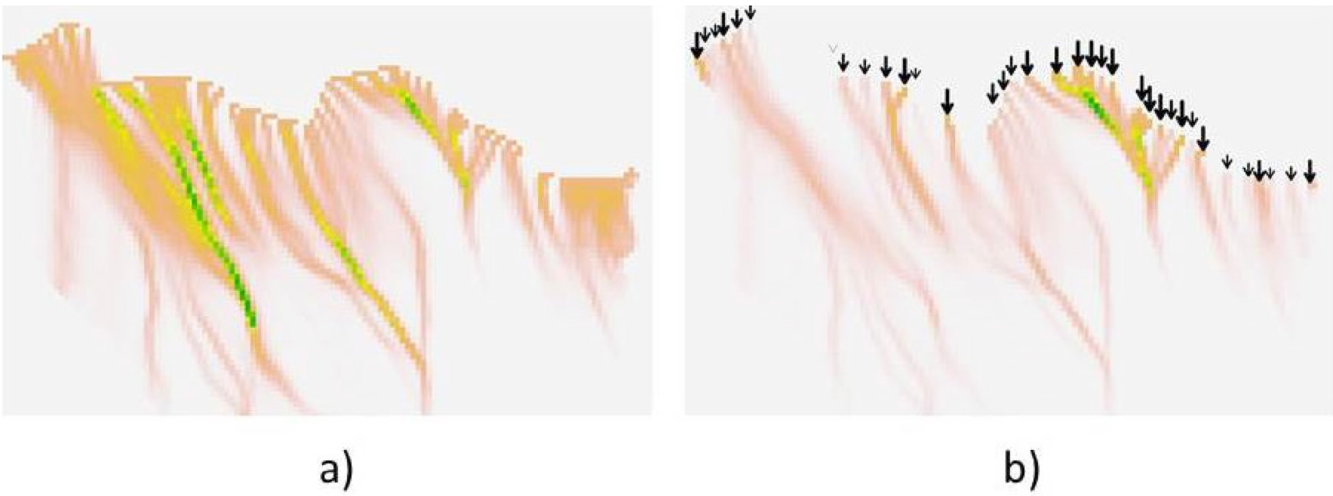

Figure 2. Equiprobable (a) or solved (b) rockfall frequencies

KEYWORDS

Dendrochronology; Rockfall; 3D simulation; Forest

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