Geophysical Research Abstracts
Vol. 16, EGU2014-5594, 2014
EGU General Assembly 2014

Estimation of rockfall frequency from simulated trajectories and observed tree impacts

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While significant progress has been achieved regarding the modeling 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 modeling difficult, so that estimations are generally based on expert knowledge regarding the rock structure of start zone 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 and a real-case example.

Consider a forest patch f located below a cliff with N_s potential rockfall start points. The expected value of the number of impacts in this forest patch during lapse T can be calculated as (1) :

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

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 (2):

$$Impact_{1\times N_f} = T \times Pstart_{1\times N_f} \times Ppropagation_{N_s\times N_f} \quad (2)$$

$Ppropagation$ 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 be 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 N_f coefficients of $Pstart$.

This framework was 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 solved with an optimization routine. Results show that the rockfall frequencies display high spatial variability and that 21% of starting points account for more than 50% of rockfall releases.

The coefficients of $Pstart$ can then be used to weight the simulated trajectories in order to map the spatial variability of rockfall trajectories and corresponding kinetic energies, which is an important step for a better identification of hazard areas. The proposed framework can thus lead to a numerical solution, but it relies on numerous assumptions. The spatial variations of rockfall volume are not taken into account and the forest stand is supposed time-invariant. This last point could be tackled by simulating trajectories during past stages of the stand evolution with growth simulation models.