Geophysical Research Abstracts
Vol. 20, EGU2018-17575, 2018
EGU General Assembly 2018


# Coupling 3D rockfall propagation to the spatio-temporal frequency for a realistic rockfall hazard mapping

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Rockfall hazard is a major threat in mountainous area. To prevent from this natural hazard, it is necessary to estimate where and when a rockfall will occur, its magnitude and where it will propagate. Rockfall hazard is frequently divided into two domains analysed individually: failure hazard and propagation hazard. These hazard analyses are usually performed qualitatively or semi-quantitatively and therefore includes some subjectivity. In the case of extended cliffs, rockfall hazard is carried out in term of diffuse failure hazard: the cliff is assumed to be homogeneous and the rockfall sources are supposed to be uniformly dispatched throughout the cliff surface. Nevertheless, this is a rough approximation.

The proposed method aims to perform the whole rockfall hazard analysis, in a quantitative manner, as a single item. This has been achieved by integrating the parameters of the failure analysis (spatial-temporal rockfall frequency, block size distribution and spatial distribution of rockfalls) into the propagation analysis.

The method is performed on the study site of the Mont Saint-Eynard (Chartreuse massif, France). The site benefits of height years of annual grounded-based lidar monitoring carried out between 2009 and 2017.
The erosive dynamic of the cliff is measured with a lidar based method for rockfall detection. The volume distribution of the blocks is estimated from a field measurement.
Both the frequency-magnitude distribution of the rockfalls and the volume distribution of the blocks can be modelled with power laws. Based on the hypothesis of their temporal stability, the fitted power laws are used for diffused hazard assessment of future rockfalls event. Their use provides the failure frequencies of rockfalls of given size, the eroded volume of the cliff and the number of blocks of given size for a period considered.
With the method proposed, the spatial distribution of the sources is integrated in the propagation analysis. From the rockfall detection, density maps on 3D point cloud of each volume class are produced and are used to weight the 3D spatial distribution of the rockfall sources for the propagation simulation.
Propagation of distributed blocks are simulated to evaluate their path and stopped distance. Their varying size and spatial distribution are attributed with the block distribution and the density maps. The specific location of the sources is allowed using the Trajecto3D model. The Trajecto3D is a propagation model working on point cloud DEM. It allows a fine and detailed representation of the terrain and to get rid of the usual bias found on horizontally gridded data.
Finally, the resulting hazard map not only consider the obtained trajectories, but also consider the inhomogeneous spatial-temporal rockfall frequency and the rockfall and block volume distributions. This would help decision maker in rockfall hazard management by providing accurate hazard map that summarize information of interest.