Physically based rockfall hazard assessment

Crosta and Agliardi (2003)

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Introduction

Rockfall

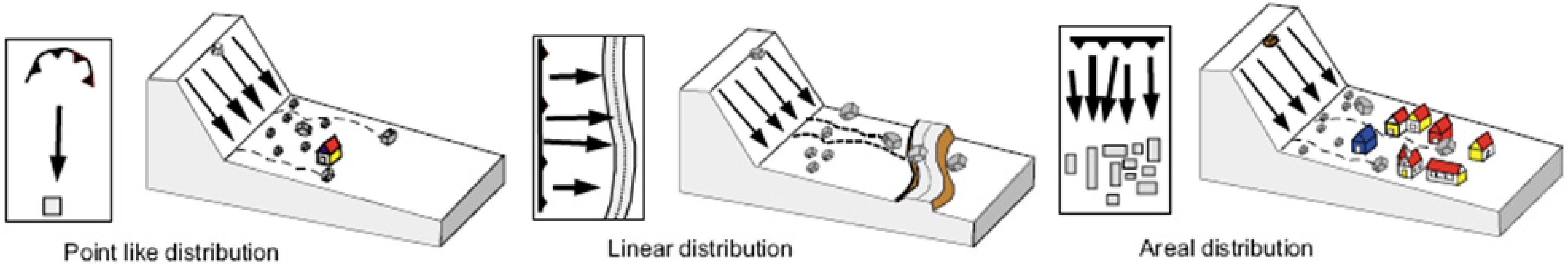
-characterized by high energy and mobility

-triggered by earthquakes, rainfall or freeze-and-thaw cycles or the progressive weathering of rock material and discontinuous in suitable climatic conditions

-originate from cliffs of different sizes and natures

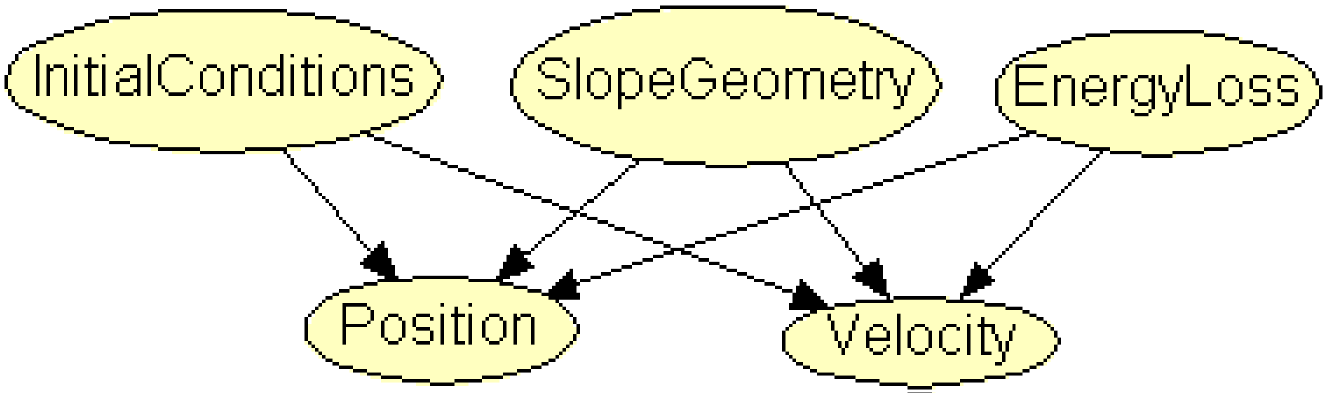
Introduction

1. A physically–based procedure to evaluate rockfall hazard using the results of 3-D numerical modelling



2. An objective approach based on 3-D matrixes providing both a “Rockfall Hazard Index” and a “Rockfall Hazard Vector”

Numerical modelling



Numerical modelling

An original rockfall simulation program, named STONE is developed.

- a raster grid containing elevation data (DEM);
- a grid of the source cells and of the number of boulders to be launched from each cell;
- three grids containing the values for the normal and tangential restitution coefficients and the rolling friction coefficient;
- a parameter file specifying the input filenames and the main controlling parameters and variability.

⇨

- raster maps which portray at each cell: the cumulative count of rockfall transits; the maximum computed velocity; and the largest flying height;
- vector outputs which provide instantaneous velocity and fly height at each sampled point of the computed fall paths.

Physically-based rockfall hazard assessment

Rockfall modelling aims to define

- fall path
- maximum runout distance
- envelop of trajectories
- velocity and energy distribution along trajectories

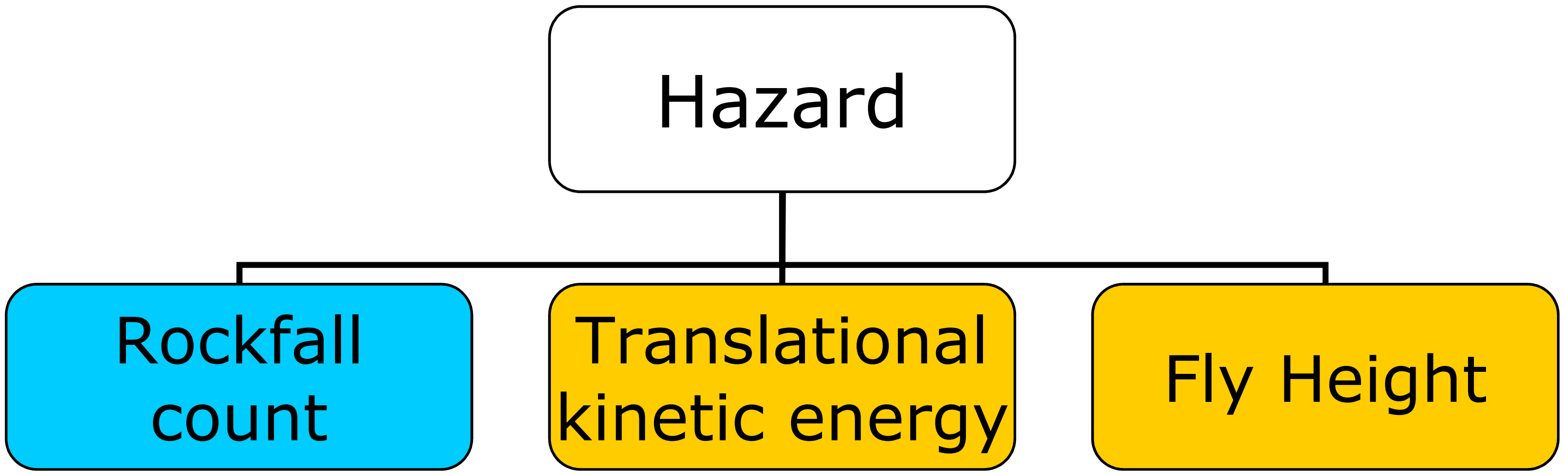
Landslide hazard is defined as:

the probability of occurrence of a landslide of given magnitude, in a pre-defined period of time, and within a given area

Physically-based rockfall hazard assessment

Two main questions arise.

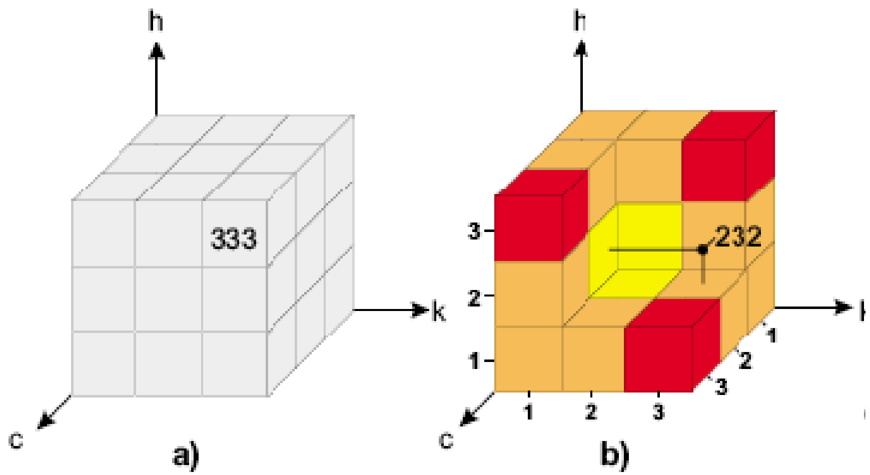
- What is the best way to compute and represent hazard?
- How can different hazard levels be ranked?



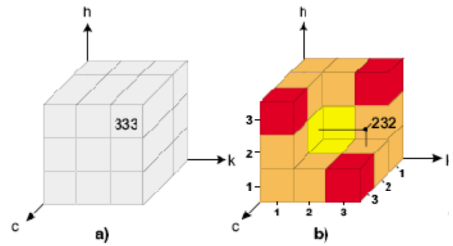
Physically-based rockfall hazard assessment

Rockfall Hazard Index (RHI) defined as RHI=(*ckh*)

- The digits are reclassified values of the adopted variables.
- Hazard is identified by a specific position in the hazard parameter space.



Physically-based rockfall hazard assessment



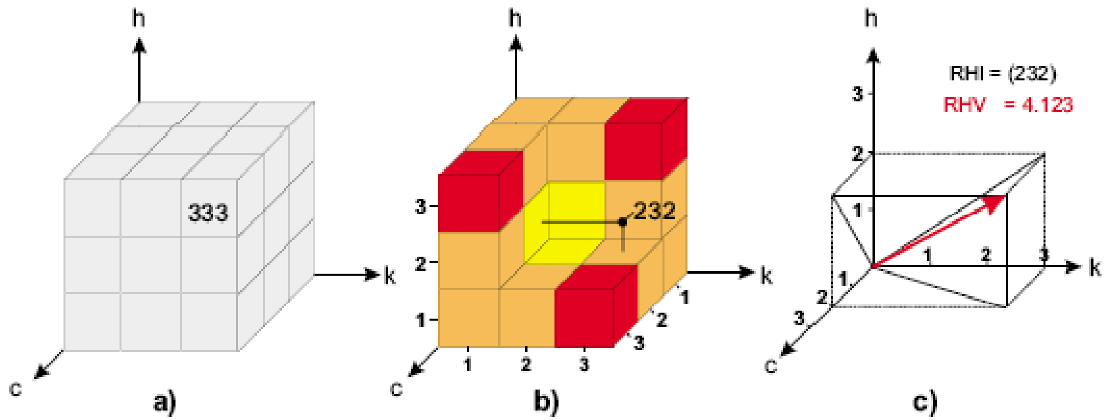
Rockfall Hazard Index (RHI)

- Are all the possible values of RHI realistic?
  RHI=(000)??
- How can RHI values be ranked to define the hazard level and perform zonation?
  Rockfall hazard increases at a maximum rate along the diagonal line that trisects the hazard space.

Physically-based rockfall hazard assessment

Rockfall Hazard Vector (**RHV**)

- It will be difficult to decide if RHI = (113) portrays a higher hazard than RHI = (311) or RHI = (121).
- The magnitude of **RHV** is used as hazard ranking criterion.



Physically-based rockfall hazard assessment

RHI/**RHV** procedure

The effectiveness of a hazard map relies on:

- An accurate description of rockfall phenomena and little required engineering judgement
- Accuracy of the input data
- Clarity on the fragmentation of the information provided

Physically-based rockfall hazard assessment

RHI/**RHV** procedure

The values of 3 parameters are reclassified in three classes according to standard criteria, established through the objective evaluation of the "potential destructiveness" of simulated rockfalls.

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
3	> 1	> 0.1	≥ 2500	≥ 10

Physically-based rockfall hazard assessment

class	c (normalised)		k	h
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1	< 0.2	< 0.01	≤ 700	≤ 4
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RHI/**RHV** procedure

The range of computed values of translational kinetic energy *k* (Class intervals correspond to the maximum energy absorption capacity of common types of rockfall barriers):

(1)700kJ—elastic catch nets

(2) 2500kJ—elasto-plastic barriers

Physically-based rockfall hazard assessment

RHI/**RHV** procedure

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
3	> 1	> 0.1	≥ 2500	≥ 10

The rockfall fly height *h* is reclassified according to the ability of a rockfall to overcome specific types of passive countermeasures:

(1)4m—catch nets

(2) 10m—retaining fills

Physically-based rockfall hazard assessment

RHI/**RHV** procedure

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
3	> 1	> 0.1	≥ 2500	≥ 10

The reclassification of the rockfall count *c*:

In fact, the number of blocks passing through a model cell depends on the topography and the number of launched blocks, and strongly varies on a case-by-case basis.

Physically-based rockfall hazard assessment

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
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RHI/**RHV** procedure

The reclassification of the rockfall count *c* (for *regional scale models*):

- Characterized by a very large number of launched blocks (>=1 million)
- Most hazardous areas are associated to the maximum probability of rockfall occurrence.
- Frequency on a channelled topography >> frequency on simply planar slopes
- "*c*" can be normalized with respect to standard values representing the transition from planar to channelled morphologies.

Physically-based rockfall hazard assessment

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
3	> 1	> 0.1	≥ 2500	≥ 10

RHI/**RHV** procedure

The reclassification of the rockfall count *c* (for *regional scale models*):

(1)<0.2: low rockfall frequency in unchannelled areas.

(2)0.2~1: increasing rockfall frequency on relatively simple slopes.

(3)>1: the most hazardous areas with respect to rockfall frequency.

Physically-based rockfall hazard assessment

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
3	> 1	> 0.1	≥ 2500	≥ 10

RHI/**RHV** procedure

The reclassification of the rockfall count *c* (for *local scale models*):

- The geomechanical features of localised source areas are better known
- "*c*" is normalized with respect to the total number of launched blocks from a single homogeneous area
- Proposed intervals: <0.01, 0.01~0.1, >0.1

Physically-based rockfall hazard assessment

RHI/**RHV** procedure

Once the input parameters have been reclassified, they are combined to obtain a value of the 3-digit positional Rockfall Hazard Index (RHI), portraying on the map a specific level of hazard and retaining in each digit the information about the contribution of each parameter.

class	c (normalised)		k	h
–	regional scale	local scale	(kJ)	(m)
1	< 0.2	< 0.01	≤ 700	≤ 4
2	$0.2 - 1$	$0.01 - 0.1$	$700 - 2500$	$4 - 10$
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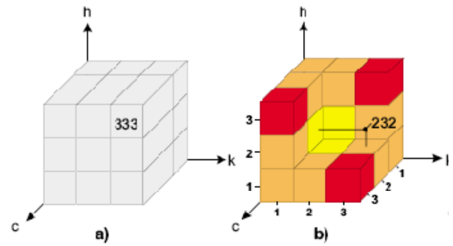
Physically-based rockfall hazard assessment

RHI/**RHV** procedure

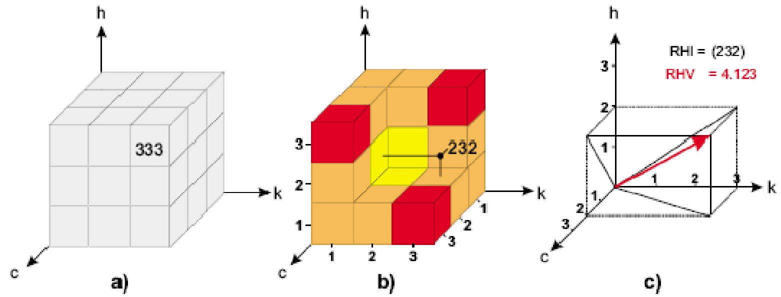


The resulting 27 classes are considered sufficient to represent hazard but they are not easily represented in a map. Then, further regrouping is performed to result in 3 hazard classes (low, intermediate and high).

This requires a ranking criterion allowing us to translate the positional index value into a sequential value.

Physically-based rockfall hazard assessment

RHI/**RHV** procedure

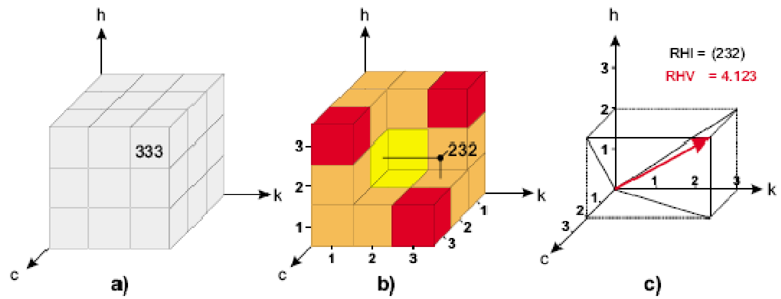


Such a criterion is provided by the magnitude of a Rockfall Hazard Vector (**RHV**) defined as:

$$\mathbf{RHV} = \begin{pmatrix} c \\ k \\ h \end{pmatrix}$$

Physically-based rockfall hazard assessment

RHI/**RHV** procedure



The **RHV** magnitude is:

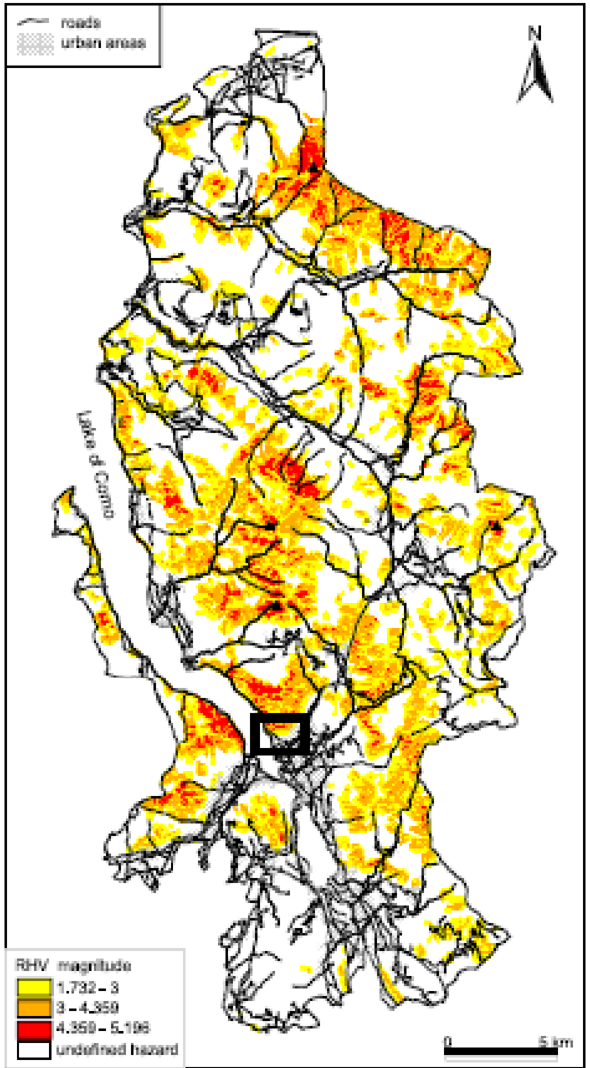
$$\left|\mathbf{RHV}\right| = \sqrt{c^2 + k^2 + h^2}$$

The magnitude is discrete. Nevertheless, it allows us to rank the hazard level in classes and to obtain an objective and clear hazard map.

Example applications

For the Lecco Province area, the results of low resolution modelling are employed to obtain a preliminary recognition hazard map.

The low resolution of the rockfall model allows for a preliminary recognition of hazard.



Regional rockfall hazard map for the Lecco Province.

Example applications

It must be noted that:

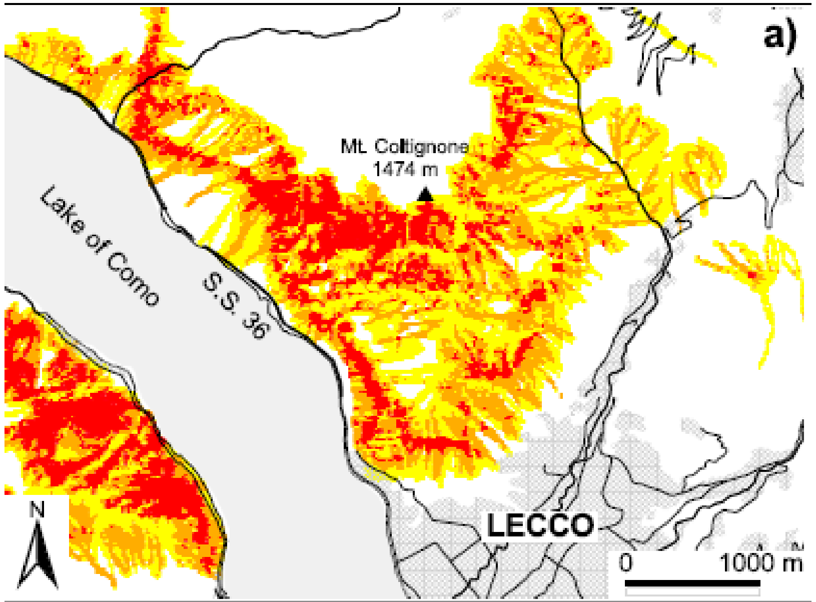
whereas the reclassification of the parameters contributing to hazard is performed according to objective criteria, a unique way to classify the level of hazard portrayed in the final map CANNOT be identified, since an objective definition of “low”, “moderate” or “high” hazard by means of the **RHV** magnitude does not exist.

Example applications

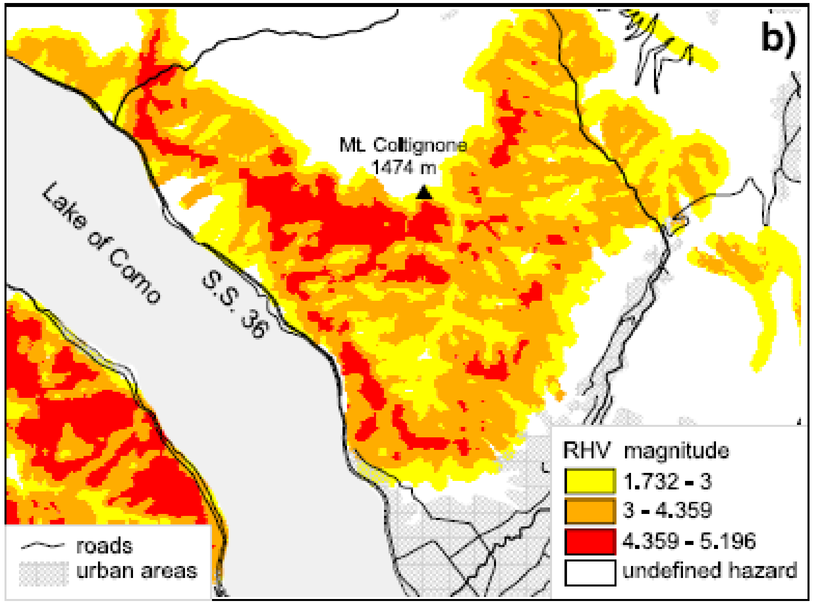
The hazard map obtained at a regional scale is useful to outline the areas more prone to rockfall.

These areas are then selected for further local scale analyses taking into account the distribution and types of different elements at risk.

Example applications



raw hazard map obtained by the application of the procedure, classified by the **RHV** magnitude



"smoothed" hazard map obtained by averaging neighbouring cells through spatial statistics techniques

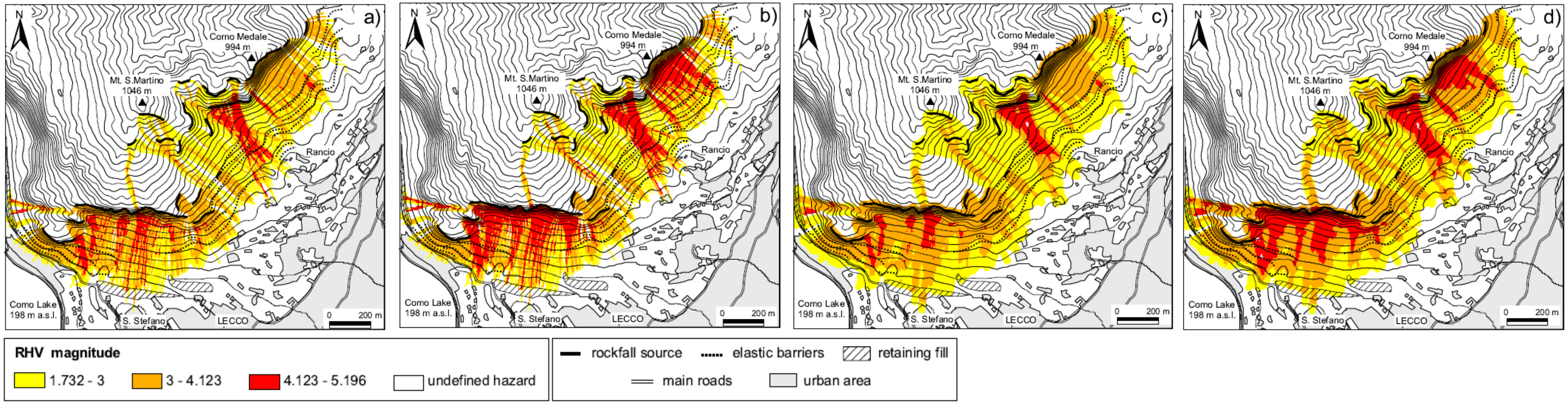
The "raw" hazard map has been smoothed by averaging the **RHV** magnitude value at each cell with respect to the neighbouring cells within a radius of 20 m.

The smoothed hazard map is much less fragmented than the "raw" one, resulting in a more effective zonation.

Example applications

For the Mt. S. Martino-Coltignone area, local scale rockfall models performed at a ground resolution of 5m on a small area (about 3 km^2) allowed us to obtain hazard maps suitable for planning and mitigation at the Lecco municipality scale.

Example applications



Hazard maps obtained from the local-scale Mt. S. Martino-Coltignone model (at 5m resolution). Hazard scenarios obtained by raster outputs using: **(a)** mean block mass, **(b)** maximum block mass. Smoothed maps by averaging **RHV** values through a 15m radius neighbourhood analysis for: **(c)** mean block mass, **(d)** maximum block mass. Hazard is classified according to the **RHV** magnitude.

The hazard maps have been classified according to the computed magnitude of **RHV**.

Class boundaries have been calibrated in detail using the record of historical events affecting the area in the last four decades.

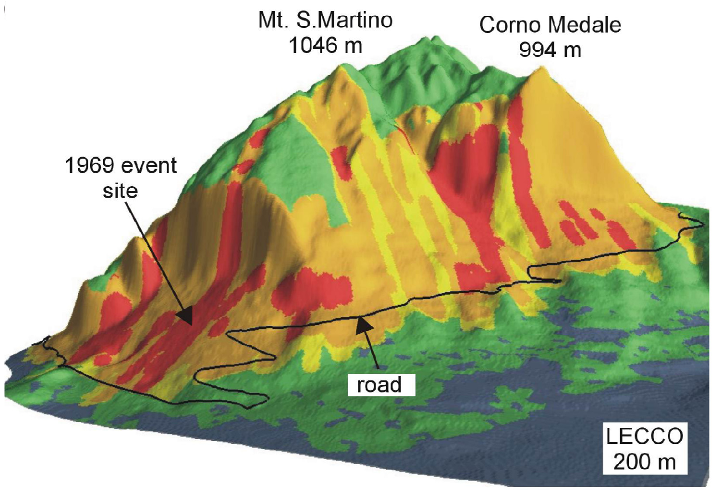
Smoothing was done by neighbourhood analysis within a radius of 15 m.

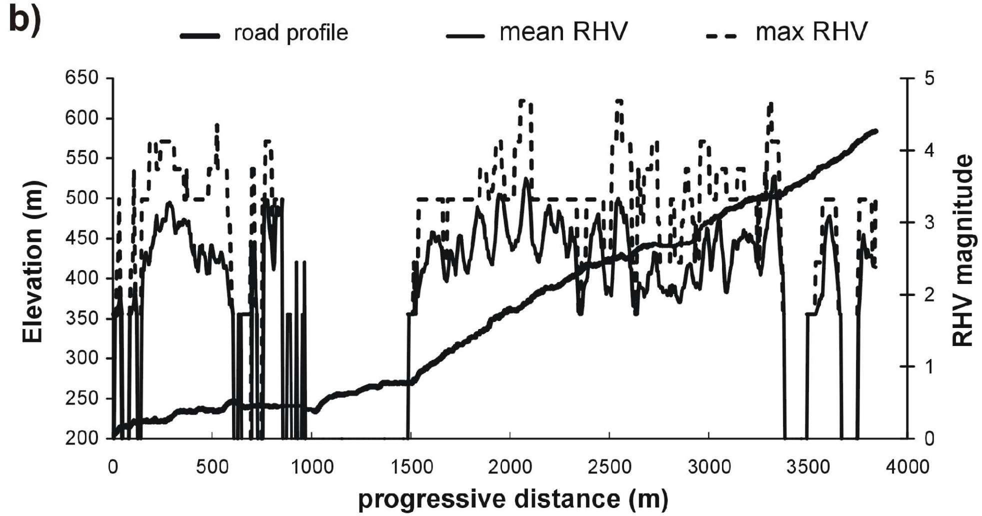
Example applications

Maps obtained through the proposed procedure can be employed for hazard assessment along linear features.

An example of hazard assessment for a road running along the toe of the Mt. S. Martino-Corno Medale slopes is reported.

Example applications





The **RHV** magnitude values have been sampled from the smoothed hazard maps along the road.

The values are plotted versus the progressive distance, from the lower to the maximum elevation.

The results could be useful to optimise maintenance and remediation works.

Take-home message

- What are uncertainties in rockfall hazard?
- How to model the rockfall hazard?
- How to represent the rockfall hazard?

Thank you! ☺