Rockfall study

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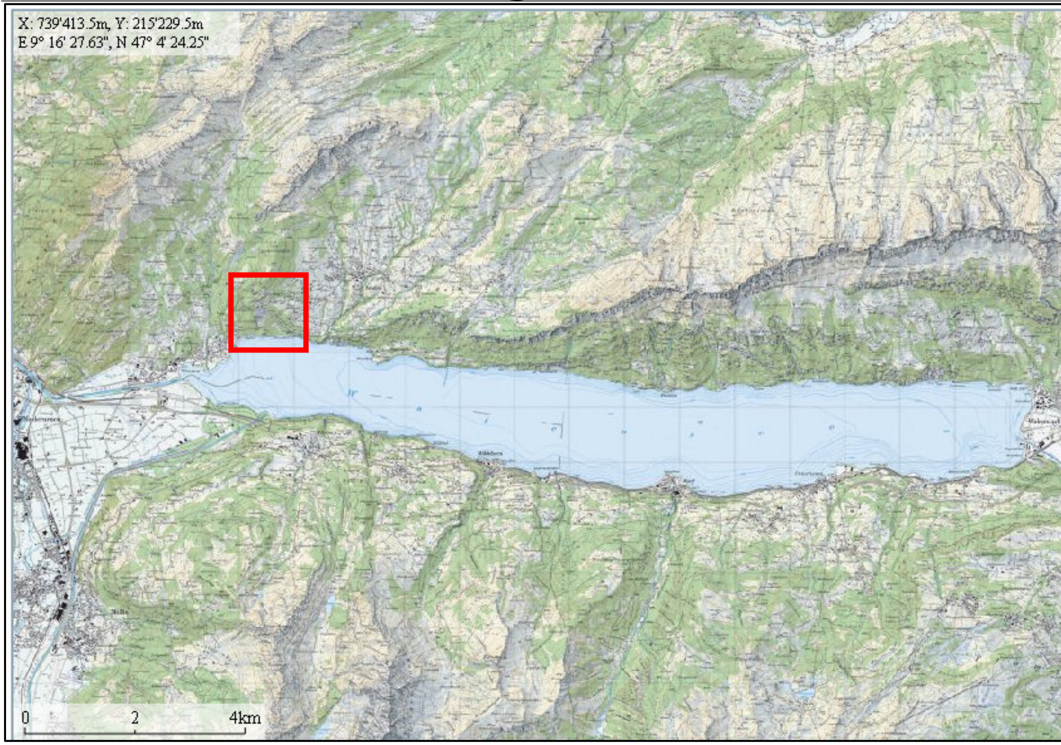
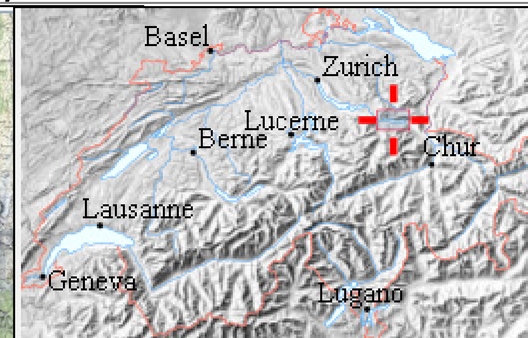
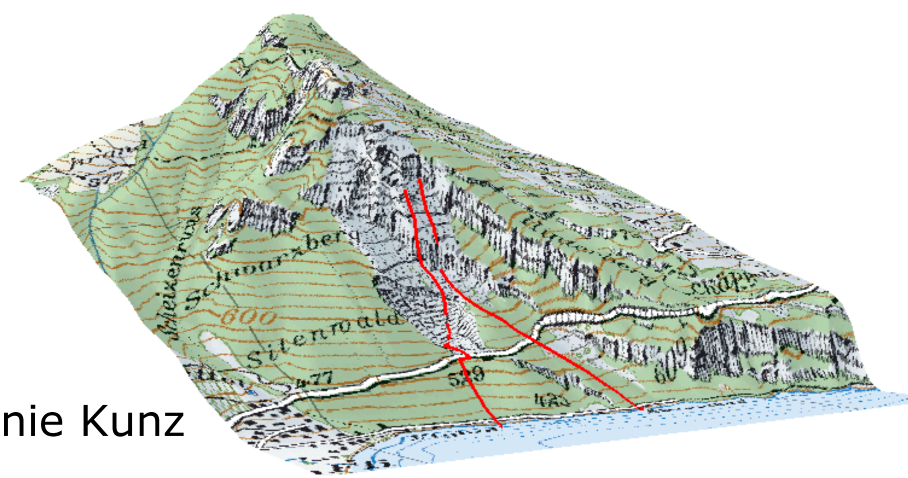
Test site: Durschlegi area near Weesen, SG

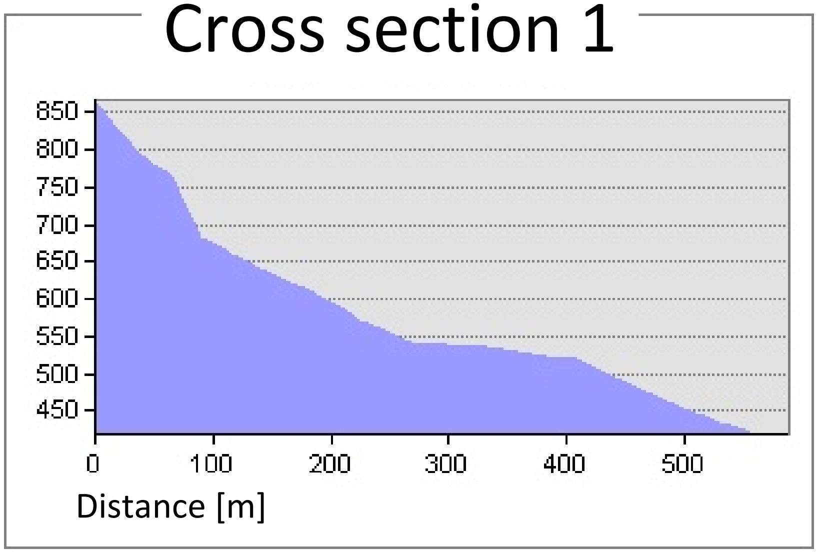


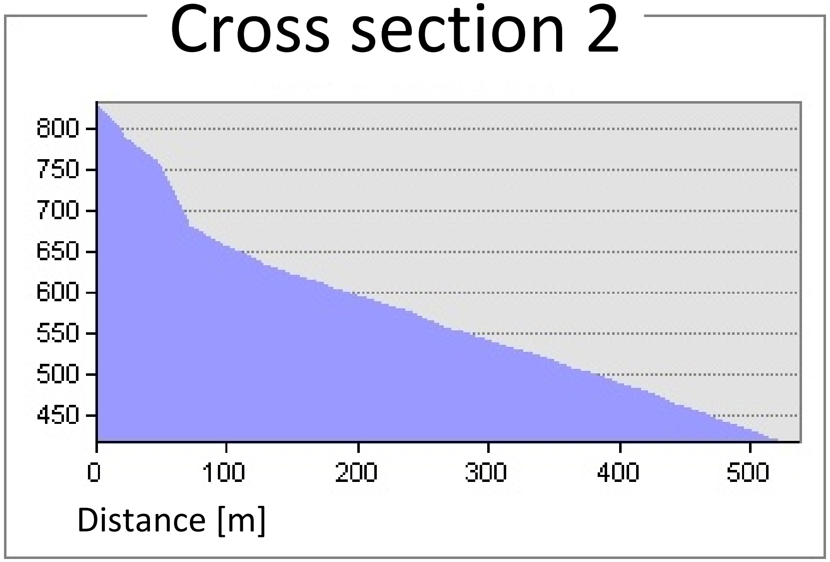




Melanie Kunz

Test site: Durschlegi area near Weesen, SG





Use and indicators for hazard maps

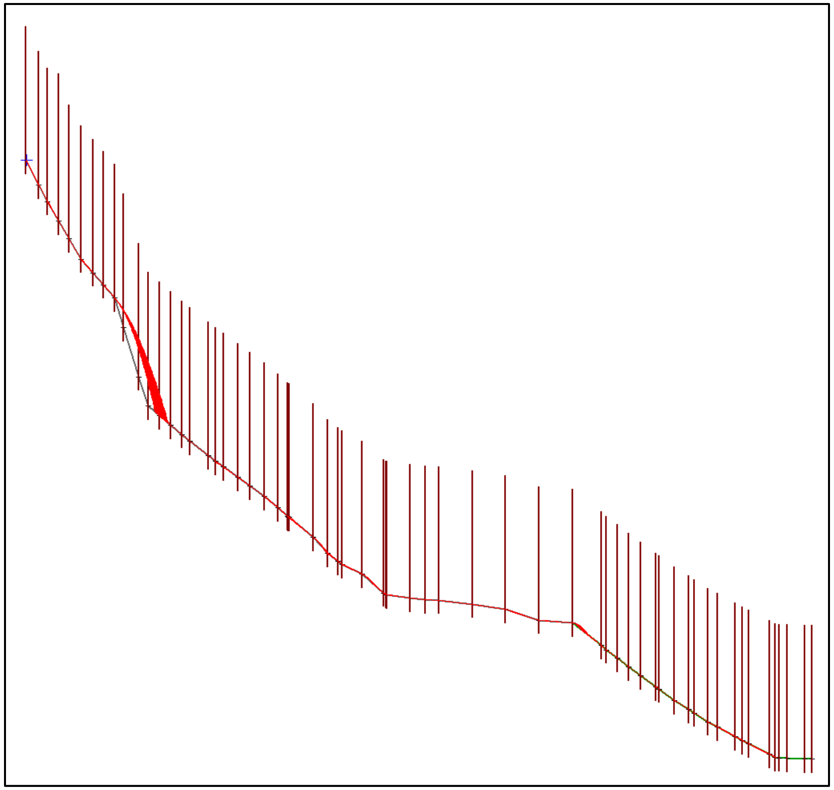
Use of hazard map	**Inclusion of existing protection measures**	**Human safety and/or economic loss**	**Indicators (energy, velocity or volume, etc.)**	**Way of representation (exceedance probability or physical value)**
Warning to hikers	Yes	Human safety	Any rockfall	Exceedance probability
Planning/installation/ maintenance of protection measures	No	Both	Energy	Physical value
Land use planning	Depending	Both	Energy	Physical value

Computation of the rock fall trajectories

- Using the program RocFall (Rocscience)
- One rock counter in each slope definition point
- Slope material:
  - Helveticum in the upper part & detachment zone
    - Coefficients of restitution:
      - Tangential $\mu = 0.615$; $\sigma = 0.092$
      - Normal $\mu = 0.303$; $\sigma = 0.045$
  - Vegetated soil in the lower part
    - Coefficients of restitution:
      - Tangential $\mu = 0.800$; $\sigma = 0.040$
      - Normal $\mu = 0.300$; $\sigma = 0.040$
- Point source on top of the slope, 10,000 runs
- Outcome: Rock fall count and velocity distribution
- Independent of stones volume/mass

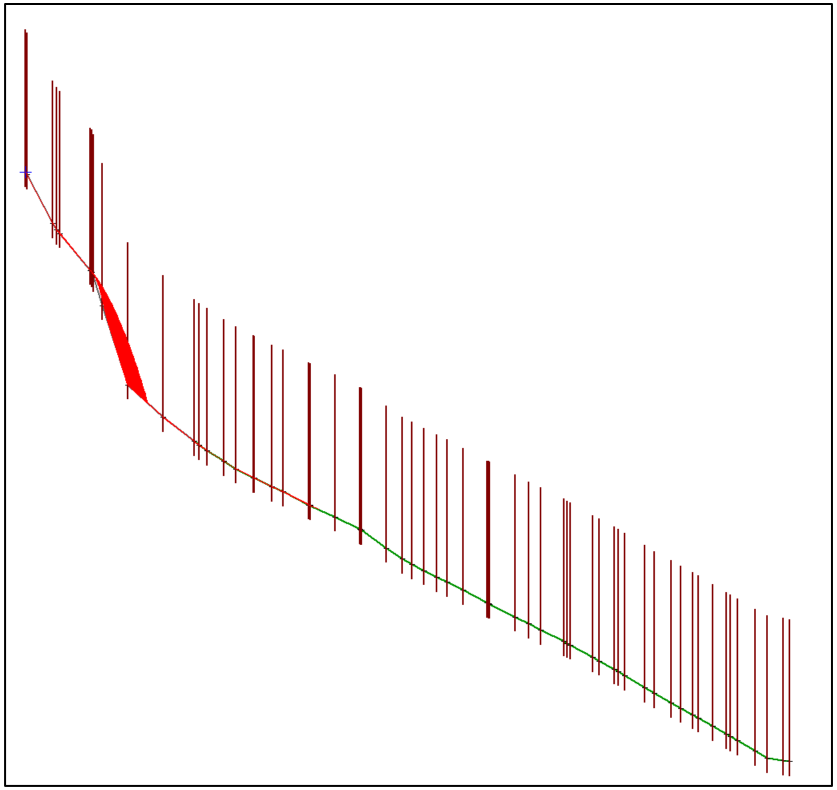
Computation of the rock fall trajectories

Cross section 1



584 rocks reach the bottom of the slope

Cross section 2



Rocks stop in the vegetated zone

Katharina Krämer

Detachment model

- The exceedance frequency can be described by , e.g.:

$$H_V(v|\theta) = a\, v^{-b}$$

- Include the epistemic uncertainties by modeling the parameters (A,B) as a random vector $\theta=[a,b]^T$

$$f_\Theta(\theta) \qquad \Theta \sim LN(\mu_a, \mu_b, \sigma_a, \sigma_b, \rho_{a,b})$$

- The unconditional exceedance frequency can be calculated:

$$H_V(v) = \int_\Theta H_V(v|\theta)\, f_\Theta(\theta)\, d\theta$$

- Derivation of the annual maximum rockfall event distribution function $f_V(v)$ from the exceedance frequency $H_V(v)$:

$$f_V(v) = \frac{d}{dv}(\exp(-H_V(v)))$$

Detachment model

- Estimation of exceedance frequency for volume classes by the 2.5% and 97.5% fractile
  - Constant mean of frequency
  - Coefficients of variation: 0.1 and 1.0

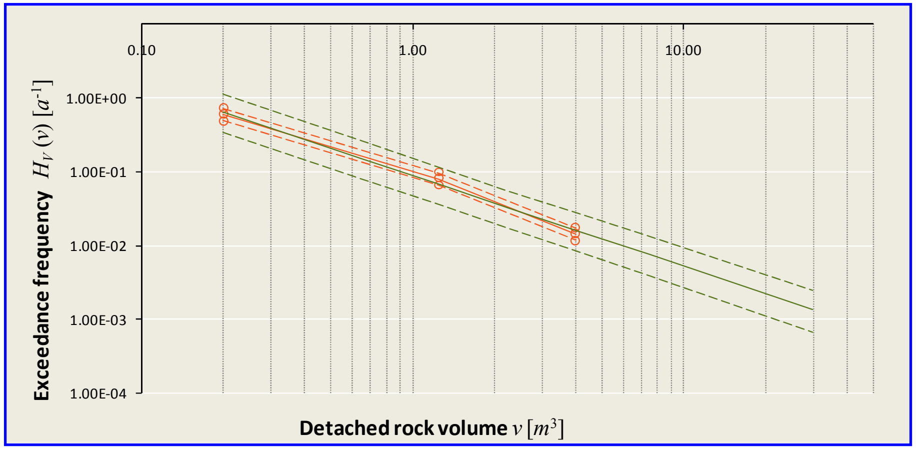
Range $[m^3]$		Rep.Value $[m^3]$	Exceedance Frequency $H_X(x_i)[a^{-1}]$				
			$Q_{0.025}$ $[a^{-1}]$		$Q_{97.5}$ $[a^{-1}]$		μ
			CoV 0.1	CoV 1.0	CoV 0.1	CoV 1.0	
0.1	0.3	0.20	$4.91\ 10^{-1}$	$7.259\ 10^{-1}$	$8.297\ 10^{-2}$	$2.169\ 10^{0}$	$6.00\ 10^{-1}$
0.3	1.0	0.65	N/A	N/A	N/A	N/A	N/A
1.0	1.5	1.25	$6.649\ 10^{-2}$	$9.830\ 10^{-2}$	$1.123\ 10^{-2}$	$2.937\ 10^{-1}$	$8.125\ 10^{-2}$
1.5	3.0	2.25	N/A	N/A	N/A	N/A	N/A
3.0	5.0	4.00	$1.175\ 10^{-2}$	$1.737\ 10^{-2}$	$1.986\ 10^{-3}$	$5.192\ 10^{-2}$	$1.436\ 10^{-2}$
5.0	10	7.50	N/A	N/A	N/A	N/A	N/A
10	50	30.0	N/A	N/A	N/A	N/A	N/A

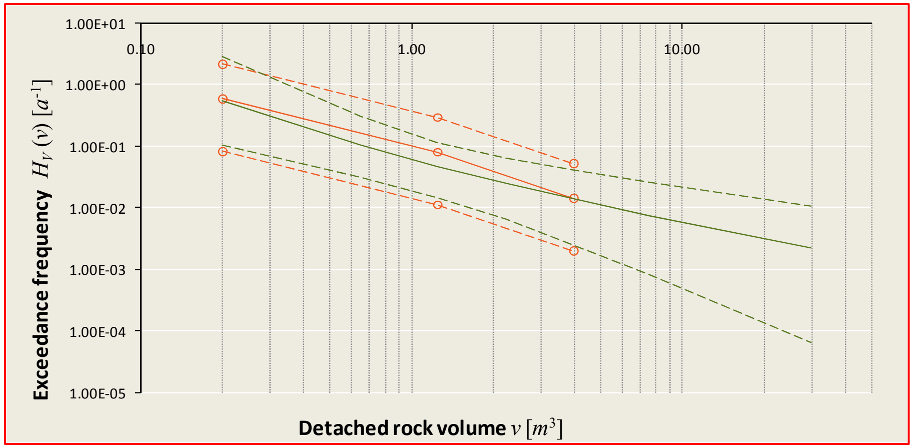
- Parameter estimation by method of maximum likelihood

	μ_a	μ_b	σ_a	σ_b	ρ_{ab}
CoV 0.1	$8.835\ 10^{-2}$	$1.232\ 10^{0}$	$5.089\ 10^{-3}$	$4.671\ 10^{-2}$	$4.849\ 10^{-5}$
CoV 1.0	$6.280\ 10^{-2}$	$1.232\ 10^{0}$	$3.010\ 10^{-2}$	$3.906\ 10^{-1}$	$-3.383\ 10^{-3}$

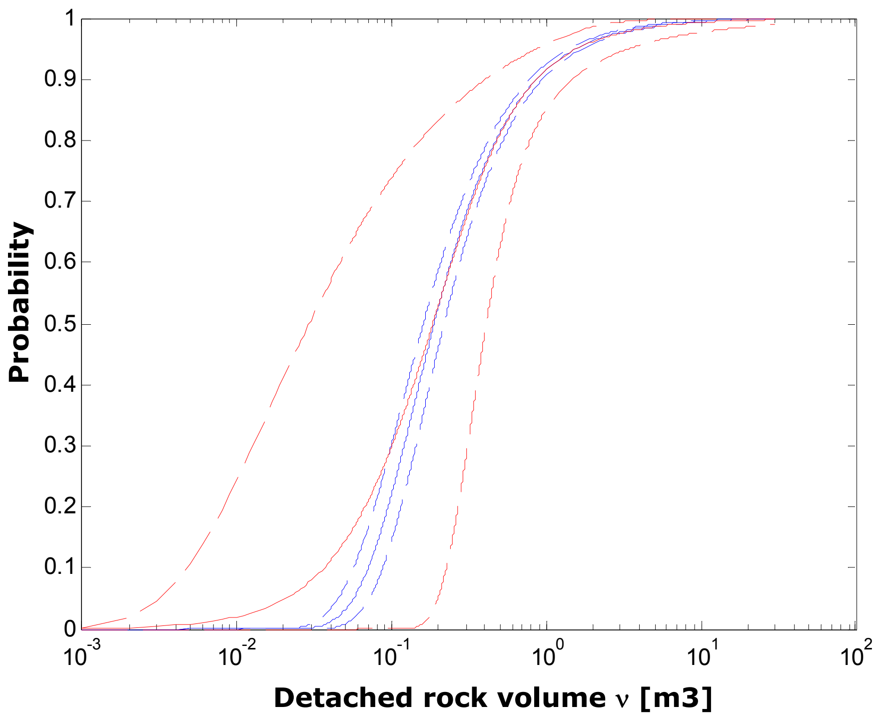
Detachment model

Exceedance frequency CoV=0.1 and CoV=1.0





CDF for annual maximum rockfall event



Matthias Schubert, Sebastian Thöns

Calculation of annual maximum energy

Annual Maximum Energy = 0.5 * Rock density * Annual Maximum Detachment Volume * $(\text{Velocity})^2$

Annual maximum detachment volume

- Calculated for the 2 sets of values/parameters for the detachment model (CoV=0.1 and CoV=10).
- A CDF curve is first randomly selected from the detachment model.
- A random probability value is then generated and the corresponding annual maximum detachment value is obtained.

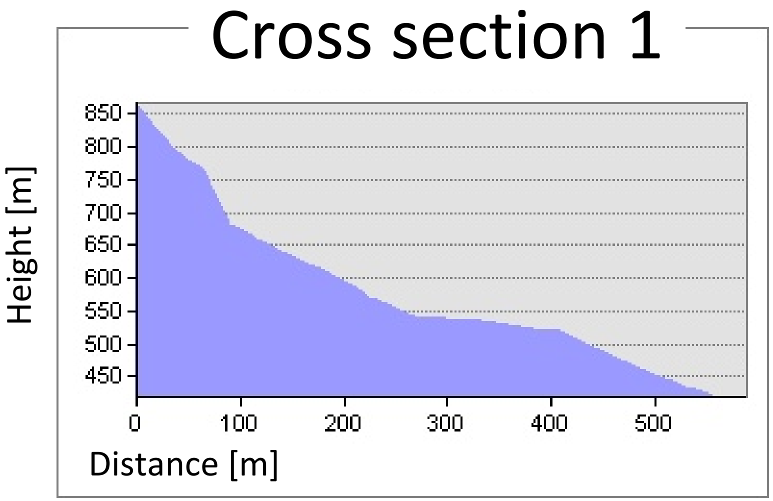
Calculation of annual maximum energy

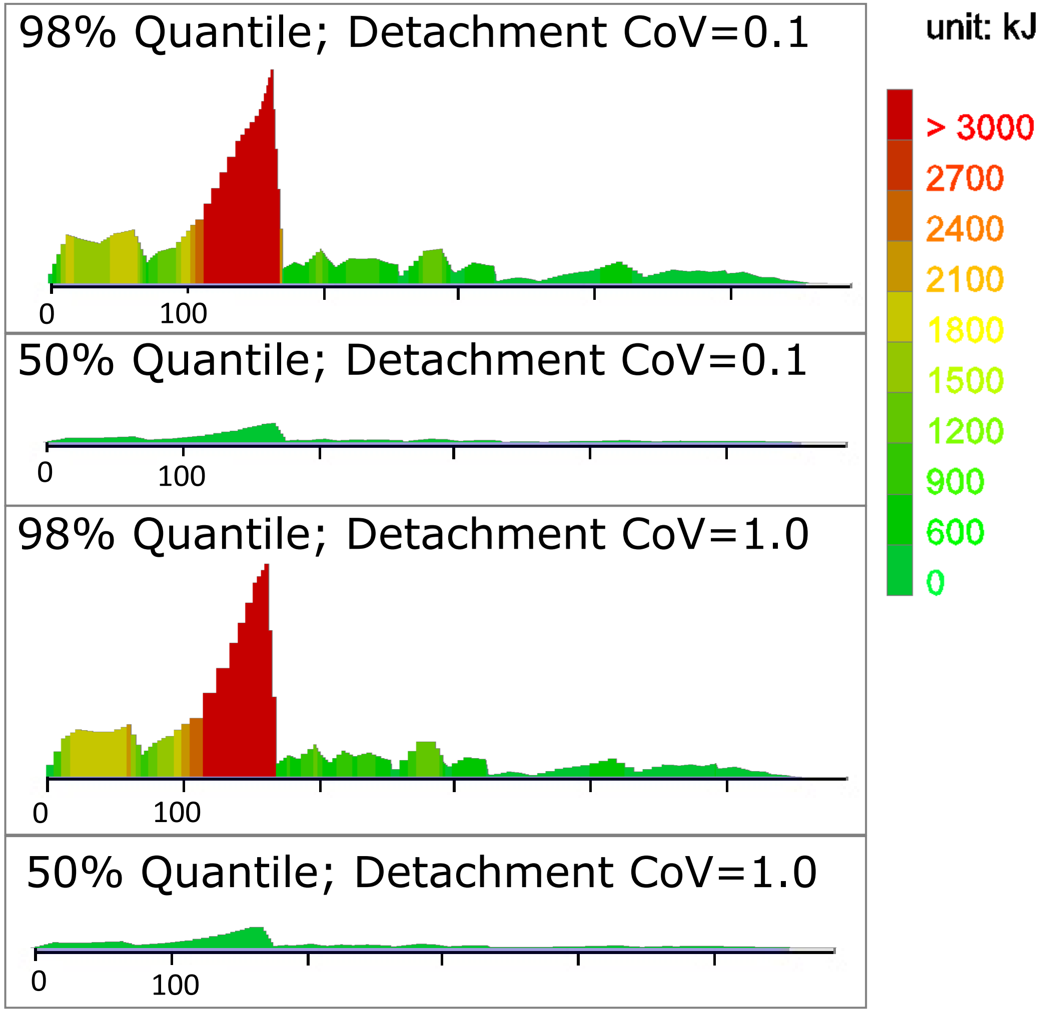
Annual Maximum Energy = 0.5 * Rock density * Annual Maximum Detachment Volume * $(\text{Velocity})^2$

Velocity

- A CDF is generated using the velocities obtained from the Roc-Fall program.
- A random probability value is then generated and the corresponding velocity is obtained.

Graphical representation of annual maximum energy





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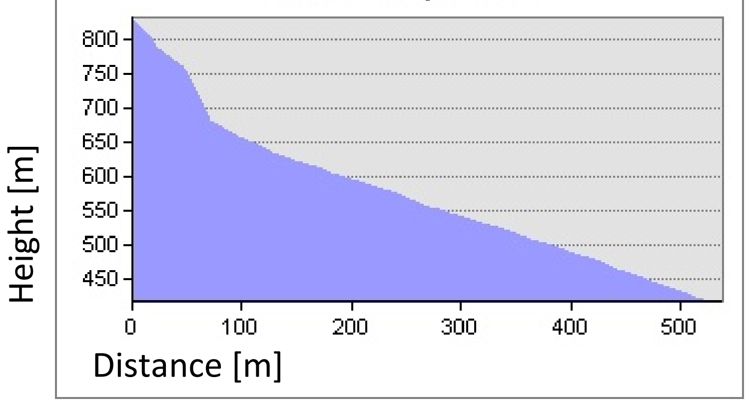
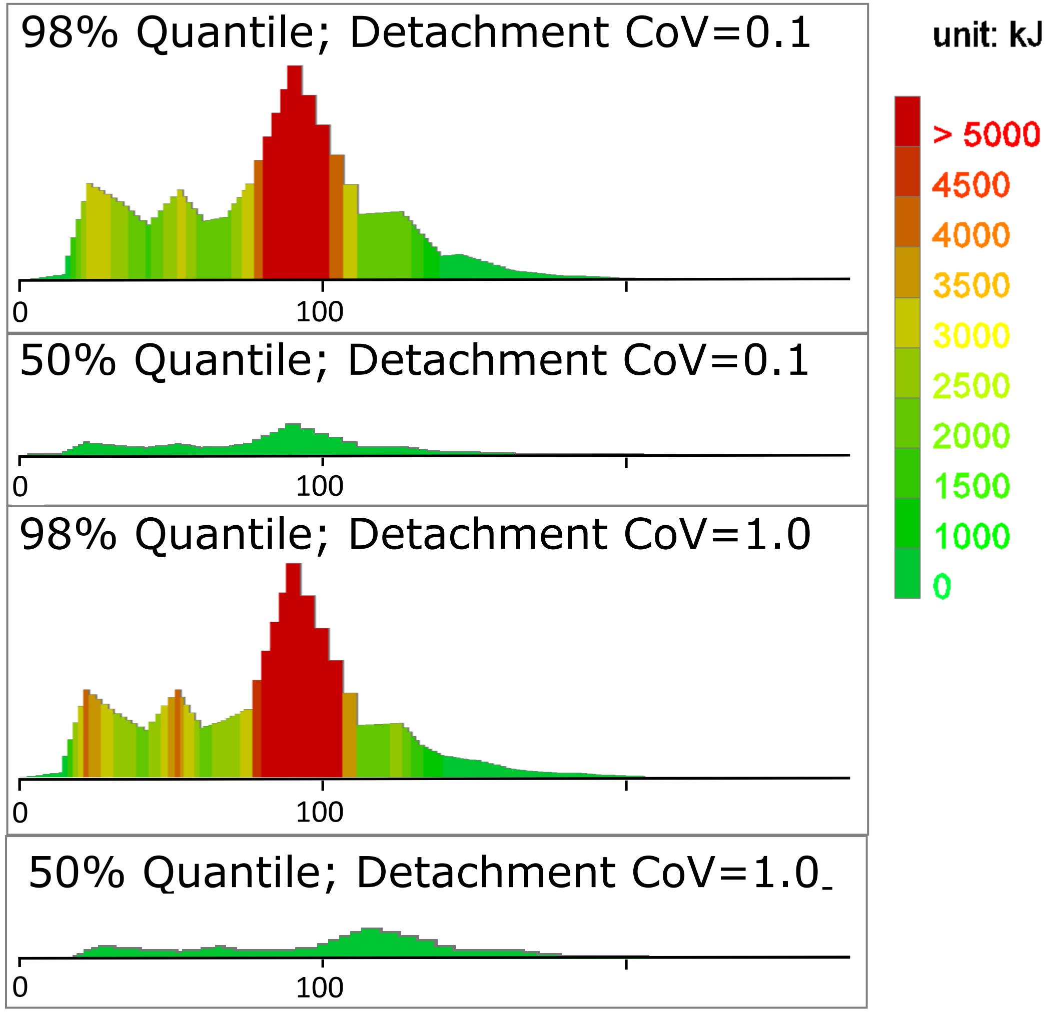
Graphical representation of annual maximum energy

Cross section 2





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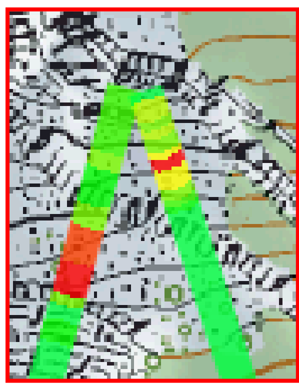
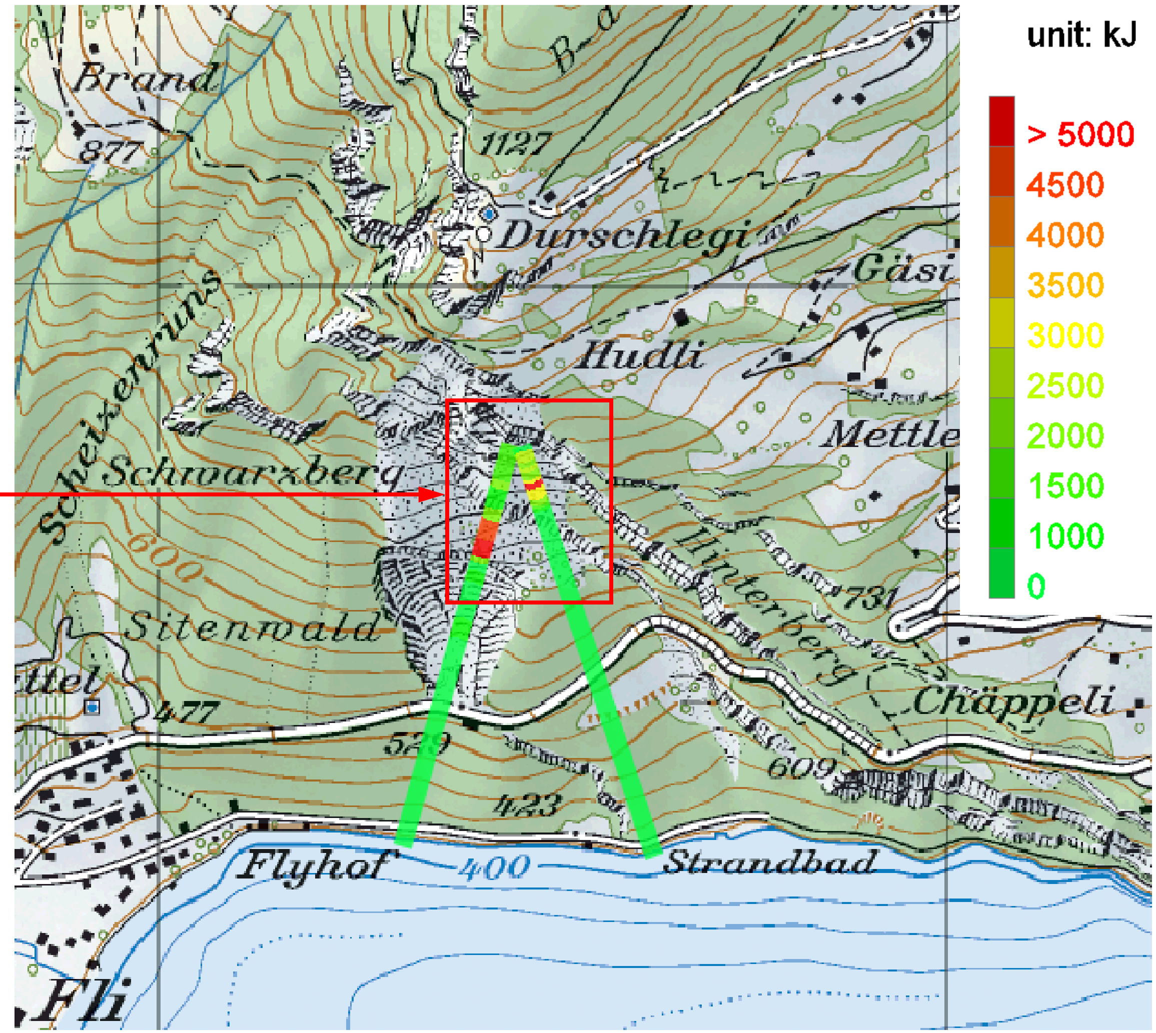
Graphical representation of annual maximum energy

- Hazard map for both slopes with Detachment CoV=0.1 using the 98% quantile





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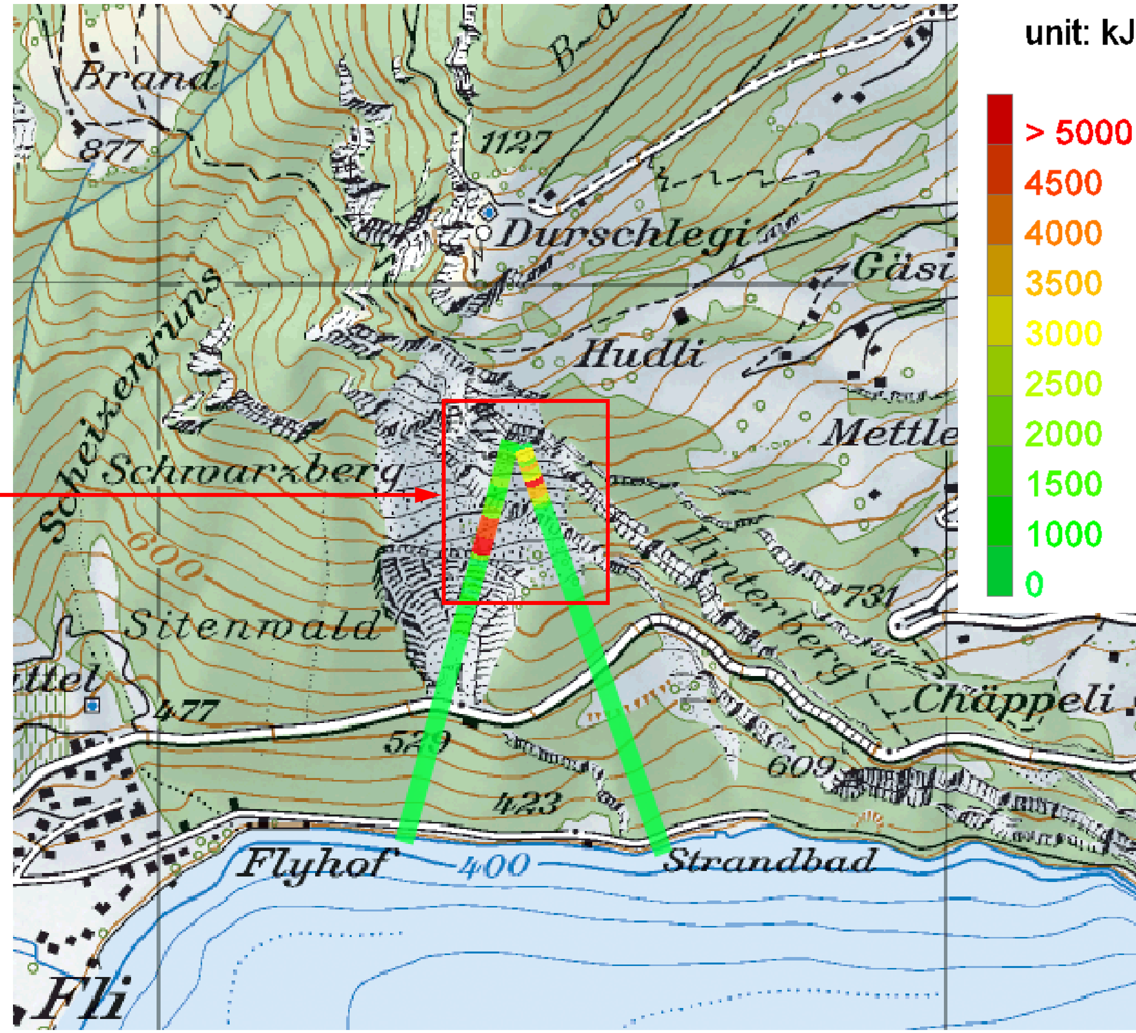
Graphical representation of annual maximum energy

- Hazard map for both slopes with Detachment CoV=1.0 using the 98% quantile



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Comments

- Combination of trajectory model and detachment model

$$f_V(\nu) = \frac{d}{d\nu}\left(exp(-H_V(\nu) \cdot h_T)\right)$$

  - Relative frequency of stones reaching a certain point on the slope: h_T
  - Assumption: The distribution function of the exceedance frequency per volume H_V does not change

- This combination was not considered
  - Only a small part of the slope is affected by the relative frequency of stones
  - For further refinement the trajectory model should include dependency on the volume of the stones

Summary

- Rockfall
  - Bottom of the slope 1 is reached for a small number of rocks
  - Slope 2: Rocks stop in the vegetated zone
- Detachment model
  - Geologist estimations and epistemic uncertainties have great influence on the detachment model
- Hazard map
  - Enlarging uncertainties of detachment frequency estimation enlarges quantile energies
  - Distribution of maximum annual energy along the slope is only minor influenced by different uncertainties in the detachment model