phd Seminar
Probabilistics in engineering

Presentation on the paper by
M. Jaboyedoff, J.P. Dudt, V. Labiouse (2005)

An attempt to refine rockfall hazard zoning based on the kinetic energy, frequency and fragmentation degree

Eva Sabiote

Objective of the research paper

- Explore influence of slope geometry and rockfall frequency on the hazard zoning
- Present a zoning method consistent with the Swiss codes

Approach:

- Examine 2D and 3D modells for their suitability for modelling different situations
- Examine dependency of zonation on slope geometry
- Examine extent of zones depending on different parameters

Rockfall hazard

$H(E,x) = \lambda_f \; P_p(E,x)$ Hazard at a given point, for a given energy

λ_f Mean frequency

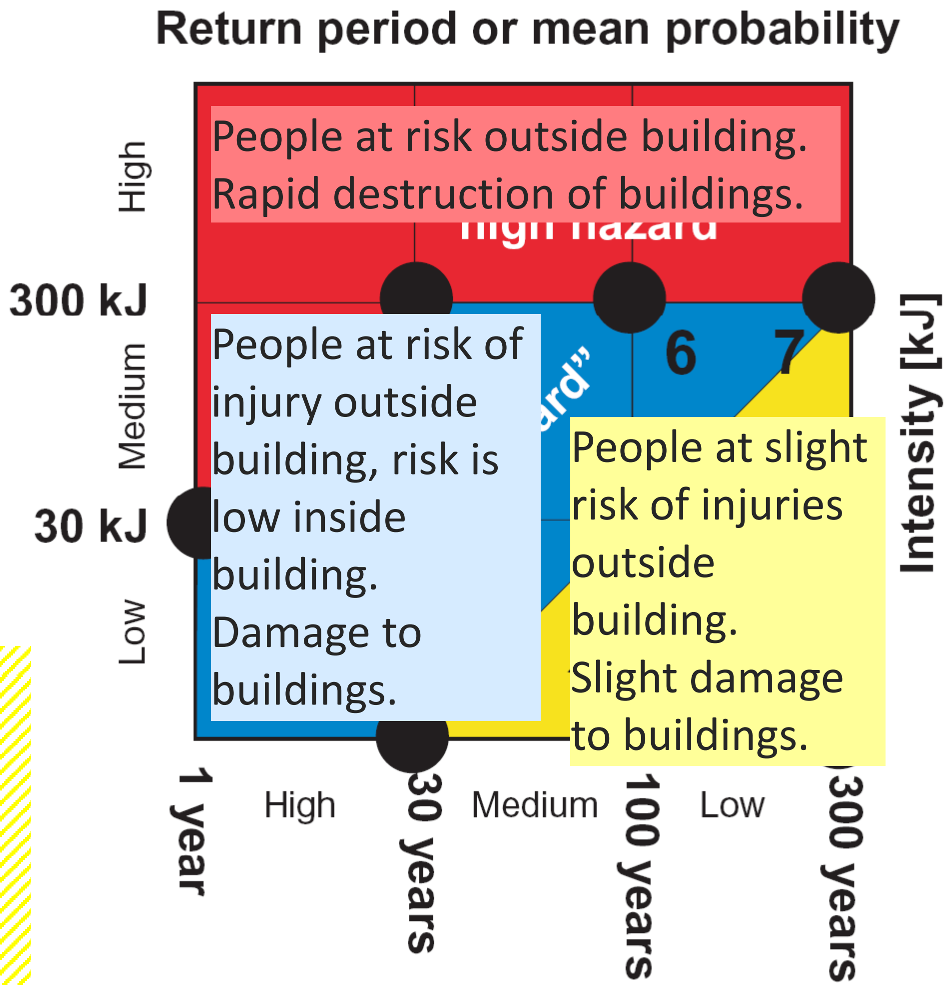
$P_p(E,x)$ Probability of propagation

- depends on: topography, lithology, block shape, material, mass
- estimated by: field observation, isopleths, rockfall simulation
- assessment: calculate percentage of trajectories crossing a point (2D), or area (3D)

Swiss codes: danger categories depending on objectives of land use planning

Resistance of reinforced concrete wall

Resistance of wood barrier



Yellow hatched zone: residual danger, where catastrophic landslides are supected

2D simulations

What is $P_p(x)$ for a certain reference period?

1. Inferre $P_p(x)$ from cumulative distribution,

   % of blocks that reached/travelled through a certain location x.

1. Consider $(x_{\lim}(t_{ref}))$ the location where $H(x_{\lim}) = 1/t_{ref}$

   being the definition of hazard $H(x) = \lambda_f N_b P_p(x)$

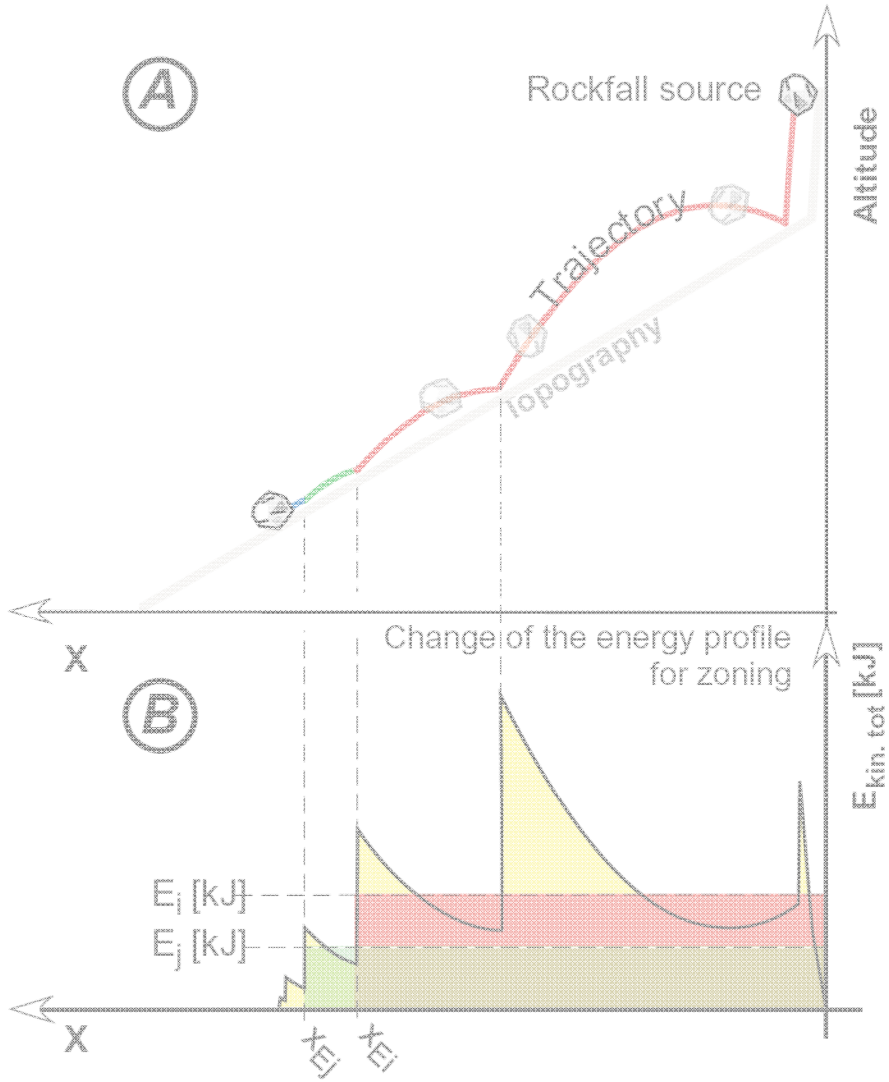
   then $P_p(x_{\lim}(t_{ref})) = 1 / \lambda_f \; t_{ref} \; N_b$

2D simulations

$$P_p(x_{\lim}(t_{ref})) = 1/\lambda_f t_{ref} N_b$$

Probability of a block exceeding an energy threshold E_i within a certain reference period

$$P_p(E_i, x_{Ei}(t_{ref})) = 1/\lambda_f t_{ref} N_b$$

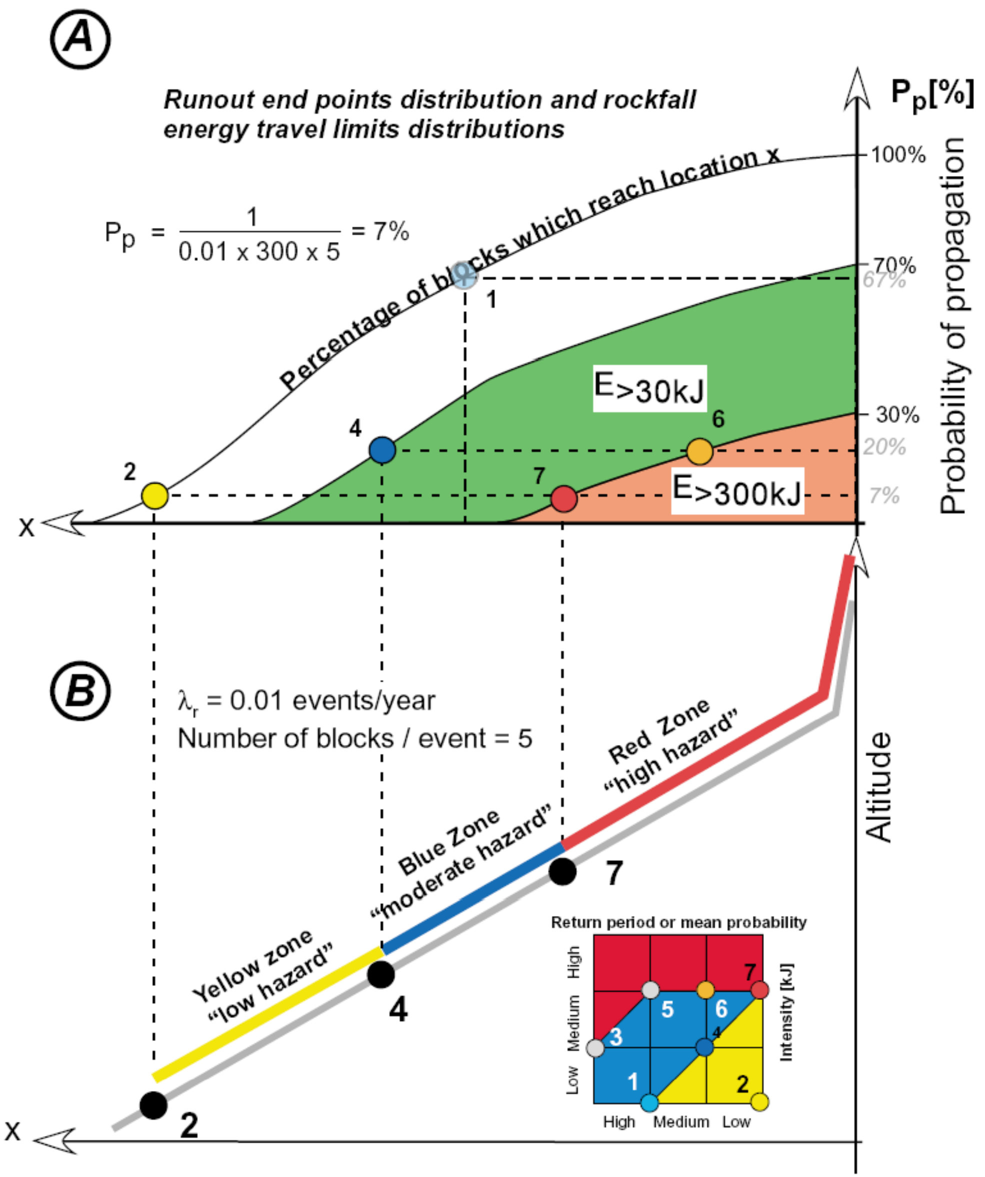


2D zoning

Use combinations of E and t_{ref} defined by the limits of the categories in order to estimate

$$P_p(x_{\lim}(t_{ref}))$$ and

$$P_p(E_i, x_{Ei}(t_{ref}))$$



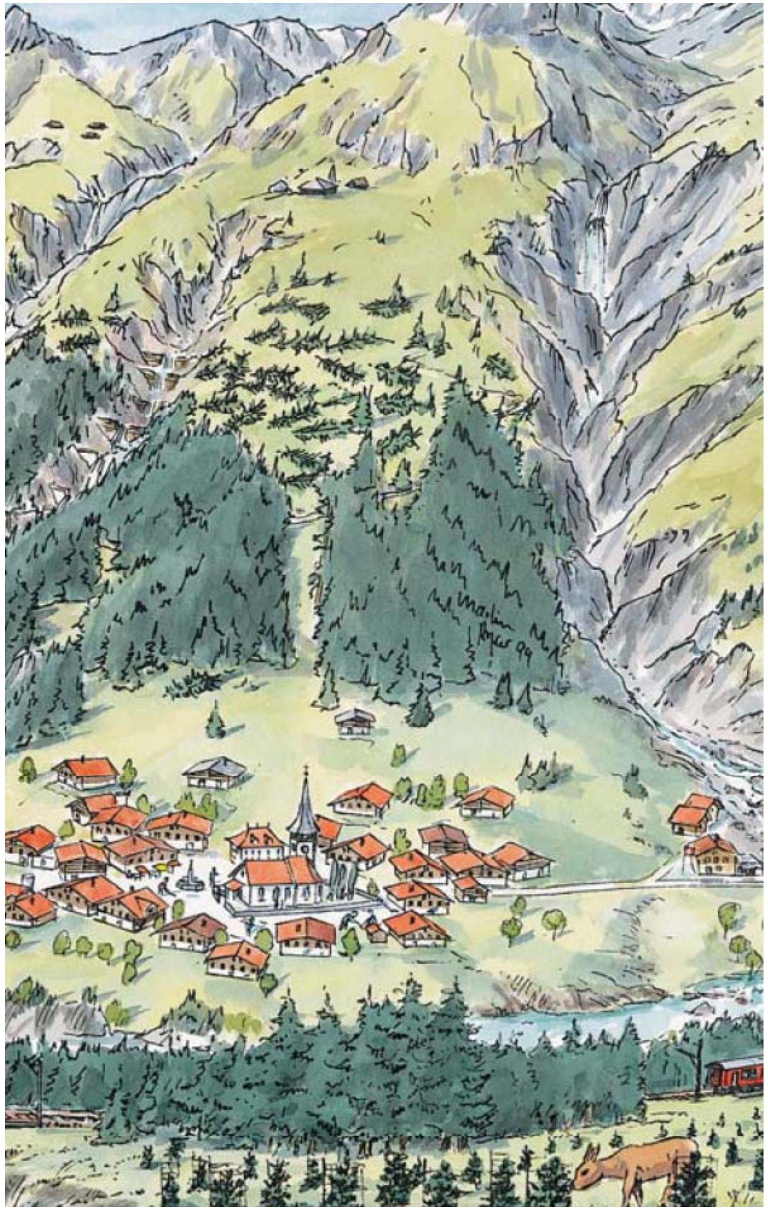
3D zoning

- Problem 2D zoning: Probability of a topographical point being reached by a block modelled by a point is almost 0; $P_p = 0$
  → P_p depends on size of block + target!

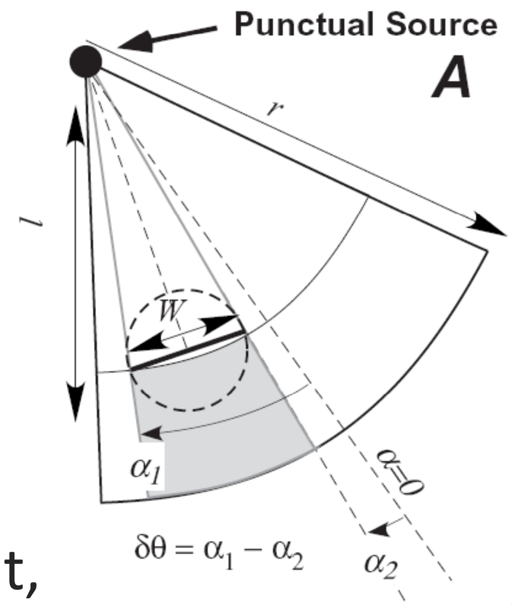
- Same procedure as in 2D could be applied but: How to calculate P_p in 3D?

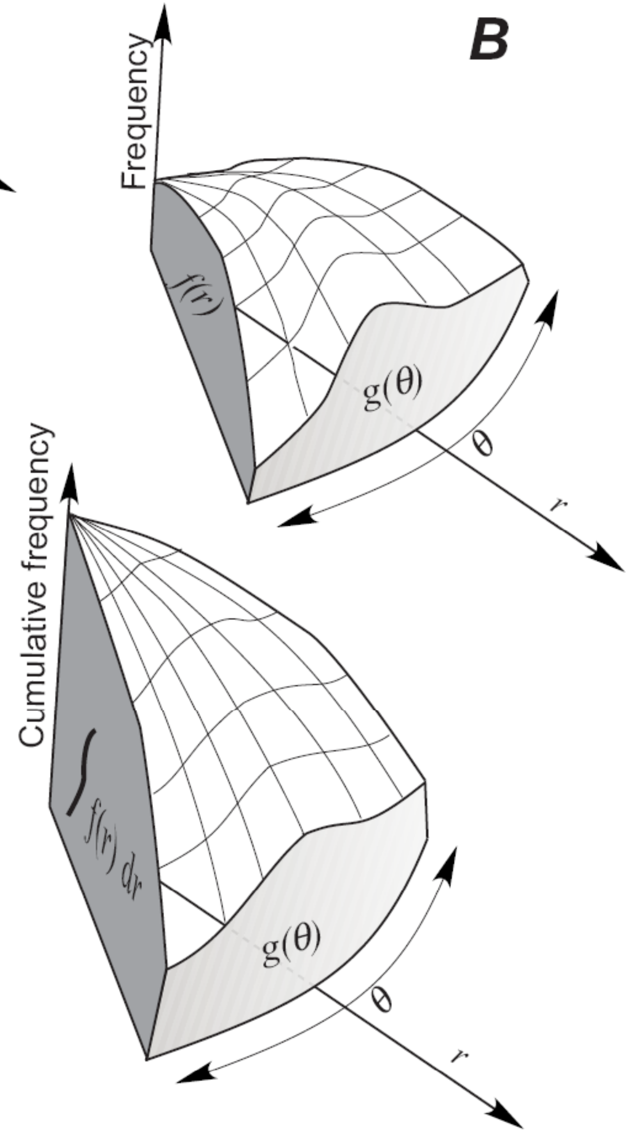
3D: Point sources and infinite linear cliffs

(Pseudozoning with
synthetic examples)



3D: Point sources





Assume target size constant,
block size added to it

$g(\theta)$ Angular distribution of trajectories

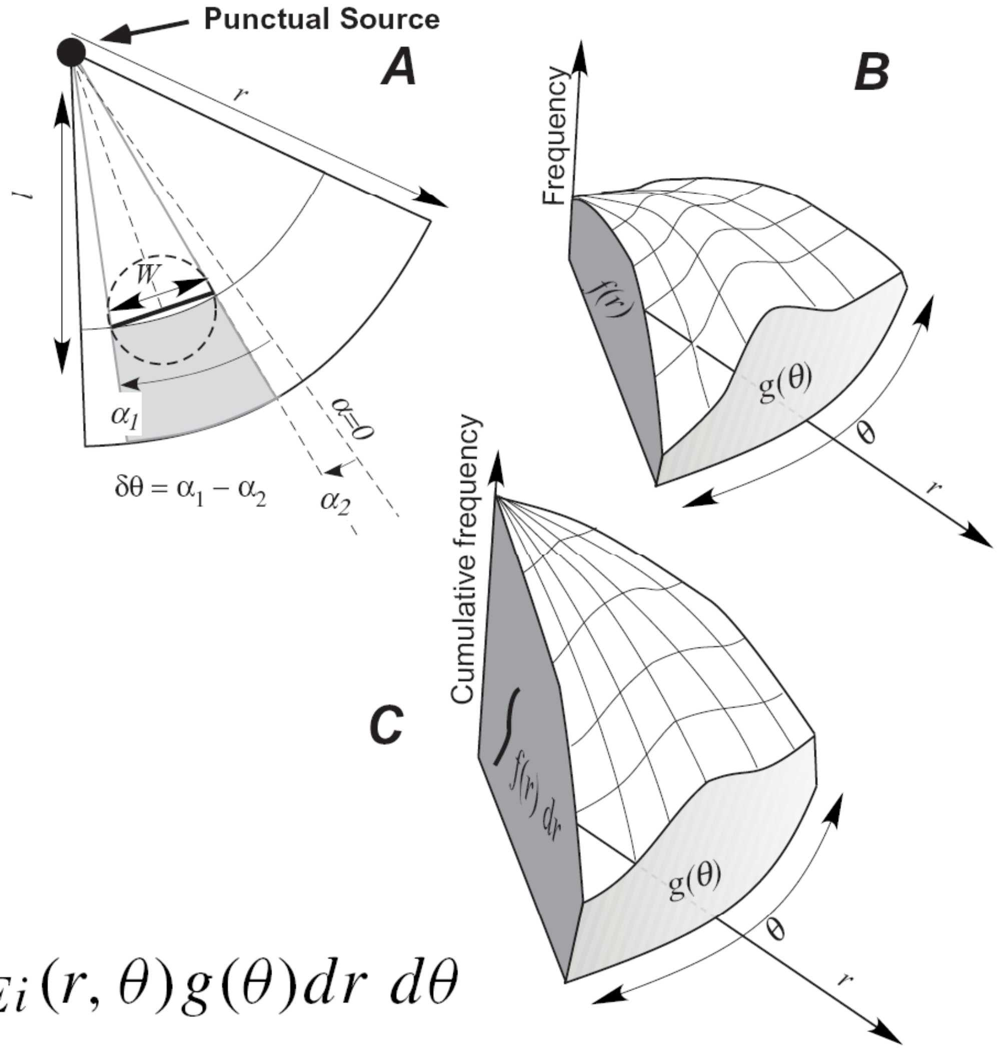
$f(r)$ Radial distribution of trajectories

$f_{Ei}(r,\theta)$ Distribution of energy travel limit

For simple topographic areas: $f_{Ei}(r,\theta) \approx f_{Ei}(r)$

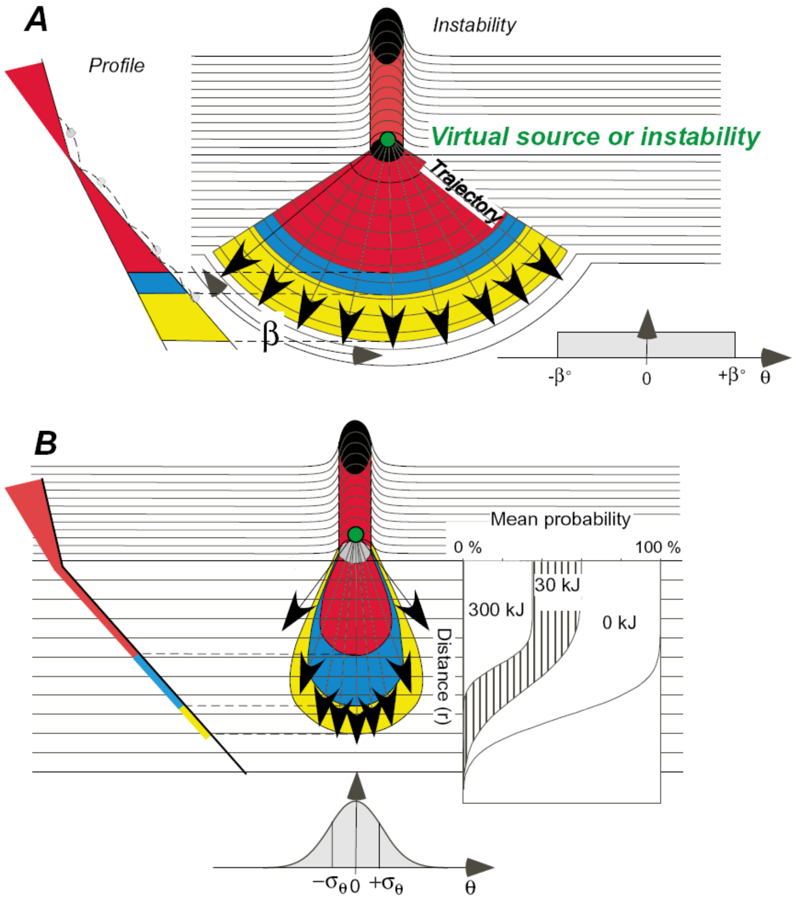
3D: Point sources

Probability to reach the target centred in
$r = l$ and
$\alpha = \theta$
with an energy higher or equal to E_i is



$$P_p(E_i, \alpha, \delta\theta, l) = \int_{\alpha-\delta\theta}^{\alpha+\delta\theta} \int_{l}^{\infty} f_{Ei}(r, \theta) g(\theta) dr \, d\theta$$

3D: Point sources



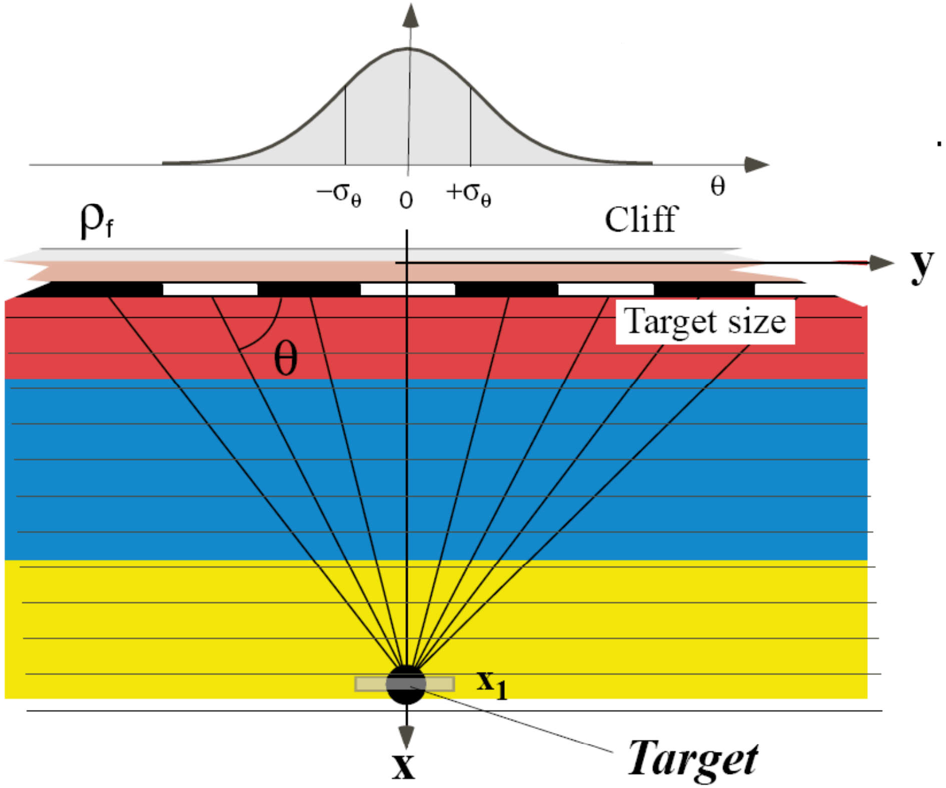
For defined
- distribution of energy travel limit $f(r)$
- mean frequency λ_f

and the assumption of topographic symmetry

A
- Circular scree fan
- No preferential orientation of trajectories
- $g(\theta)$ uniform

B
- Planar topography
- Trajectories distributed around the dip of the slope
- $g(\theta)$ normal distributed

3D: Infinite linear cliff



Mean frequency $\lambda_f = \omega \, \rho_f$

ω target size + block diameter

ρ_f events per unit of length of cliff

P_p to a point x_1: integration

- Theory: $\theta = [-\pi/2; +\pi/2]$
- Reality: trajectories close to dip direction, σ_θ small compared to π

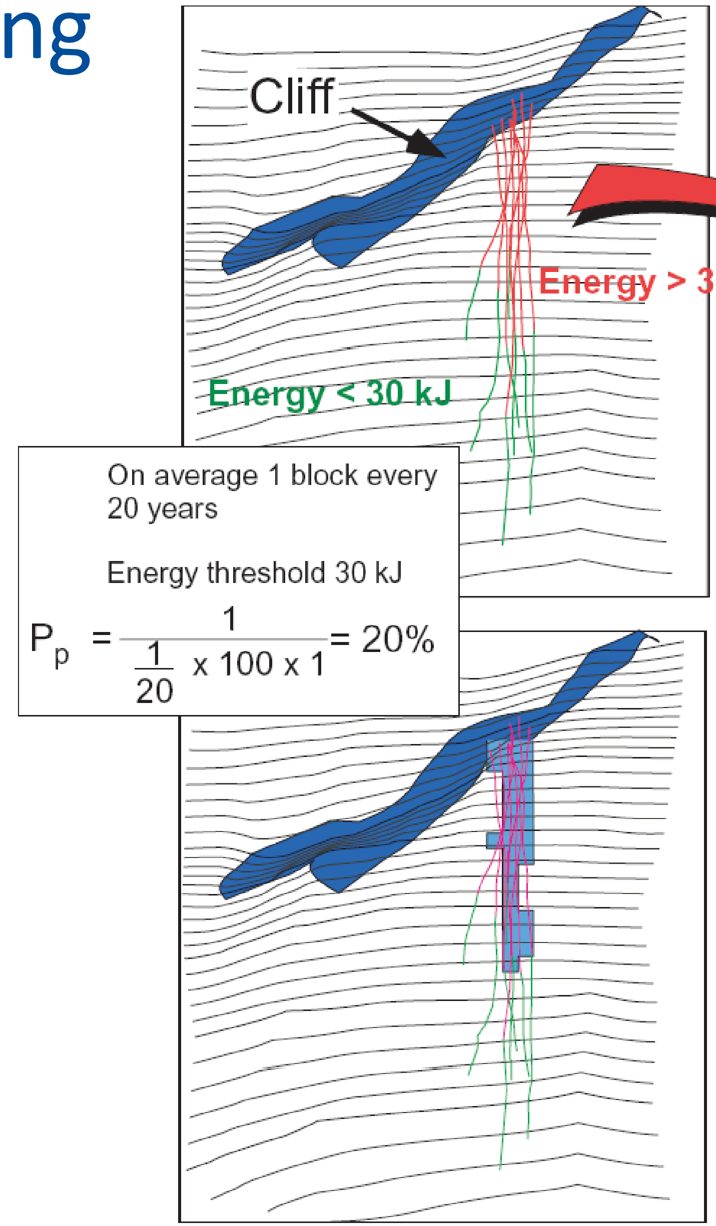
So the following simplification is done:

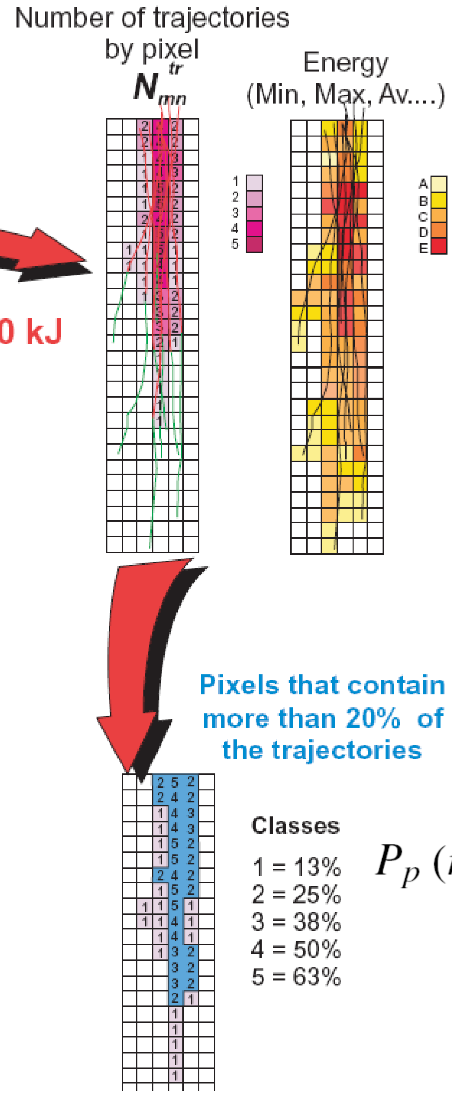
$$P_p(E_i, x_1) \approx f_{Ei}(x_1) \int_{-\pi/2}^{+\pi/2} g(\theta) d\theta = f_{Ei}(x_1)$$

3D zoning

- DEM – count number of trajectories N_{tr} crossing each cell; cells indexed m, n: $N_{tr}(m,n)$
- $P_p(m,n) = \dfrac{N_{tr}(m,n)}{N_{tr}^{tot}}$
- Cells having a mean probability verifying the condition:
  $$P_p(E_i, m, n, t_{ref}) \geq \frac{1}{\lambda_f \times t_{ref} \times N_b}$$
  belong to the degree of danger defined by $E_i - t_{ref}$

3D zoning





$$P_p(m,n) = \frac{N_{tr}(m,n)}{N_{tr}^{tot}}$$

$$P_p(E_i, m, n, t_{ref}) \geq \frac{1}{\lambda_f \times t_{ref} \times N_b}$$

Scenarios

- Unknown variables: λ_f, Vol

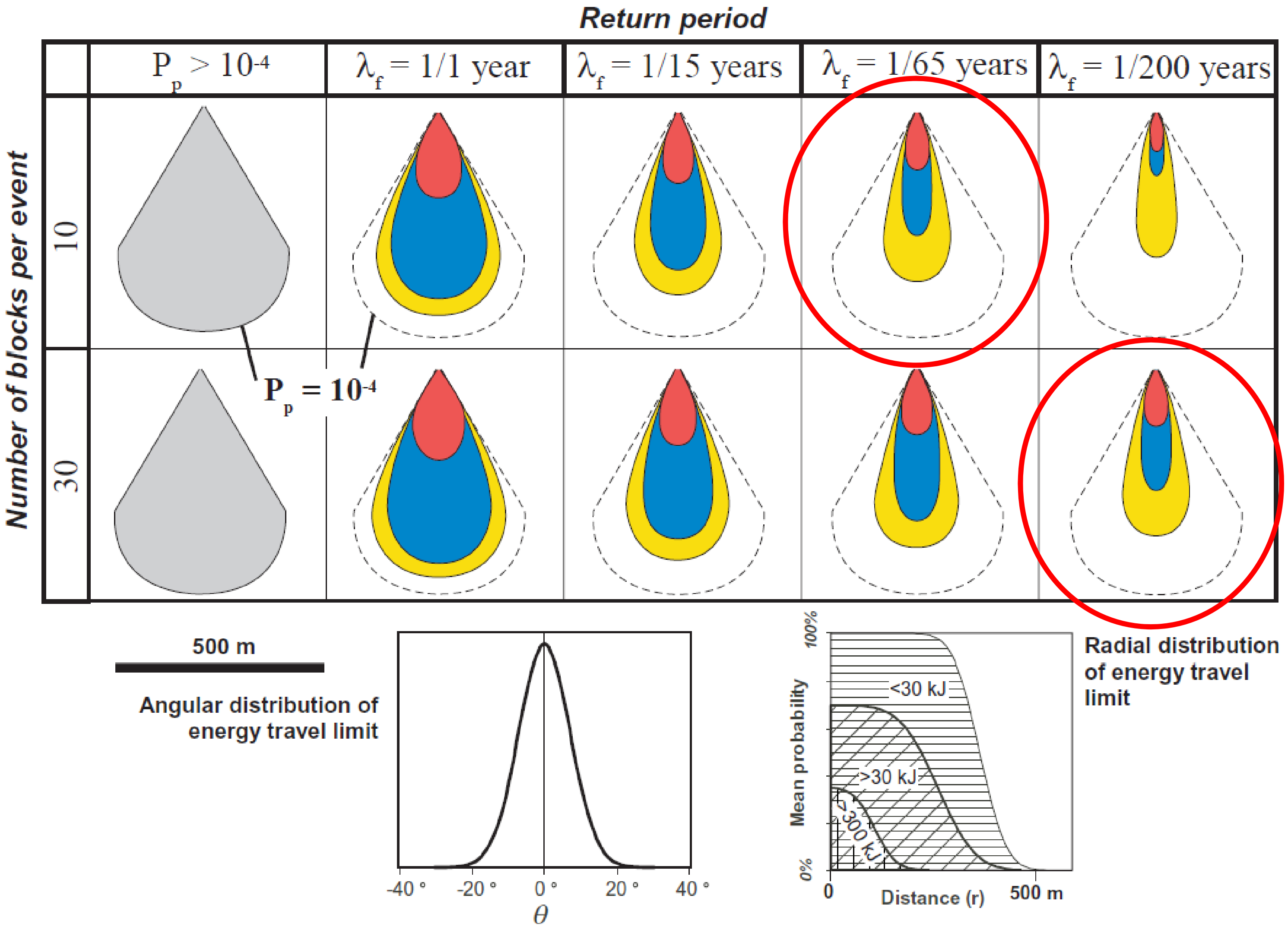
- Assess different scenarios with different

  - return periods
  - Volumes

  (e.g. with the exponential law: p_f depending on rockfall volume through an exponential function)

Scenarios

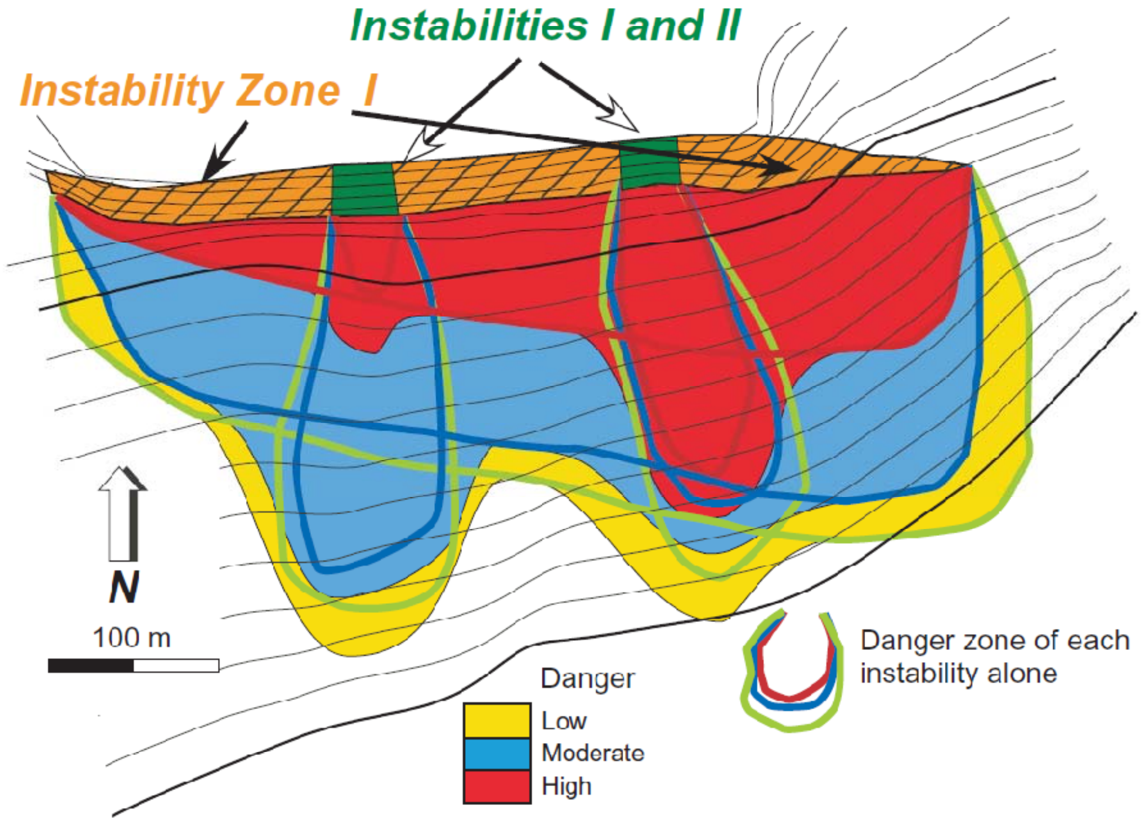
$$P_p = 1/\lambda_f t_{ref} N_b = const.$$



Multi zone problems

For n instabilities, the hazard is given by

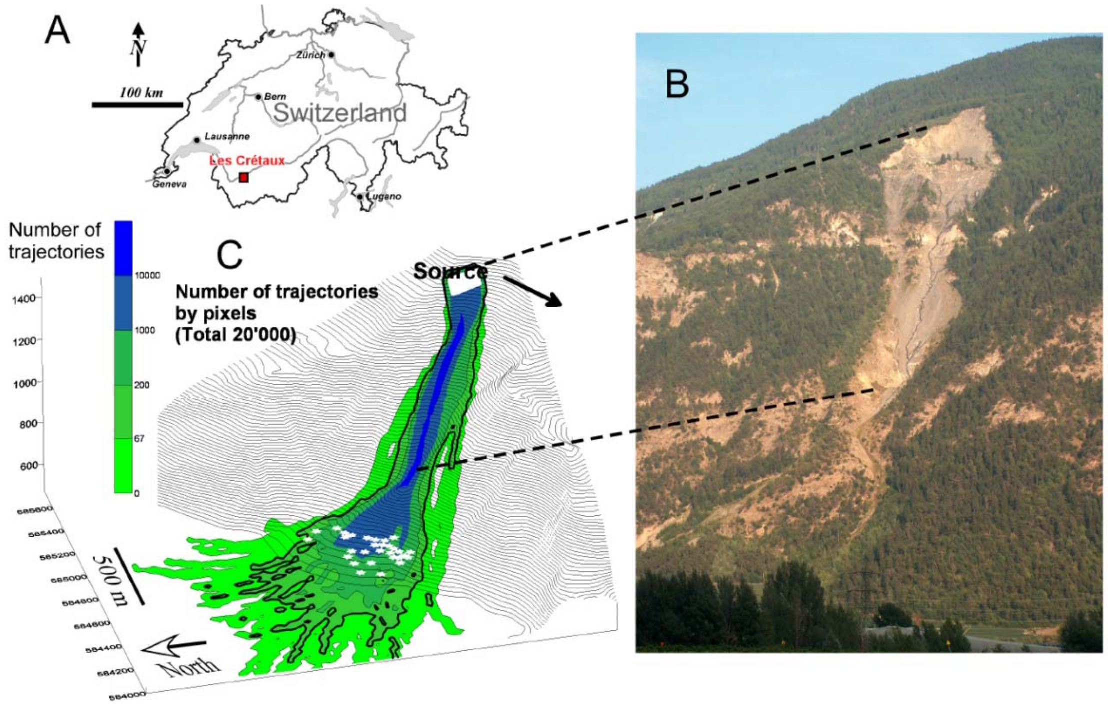
$$H(E_i, x, y) = \sum_{k=1}^{n} \lambda_f^k \cdot N_b^k \cdot P_f^k(E_i, x, y)$$



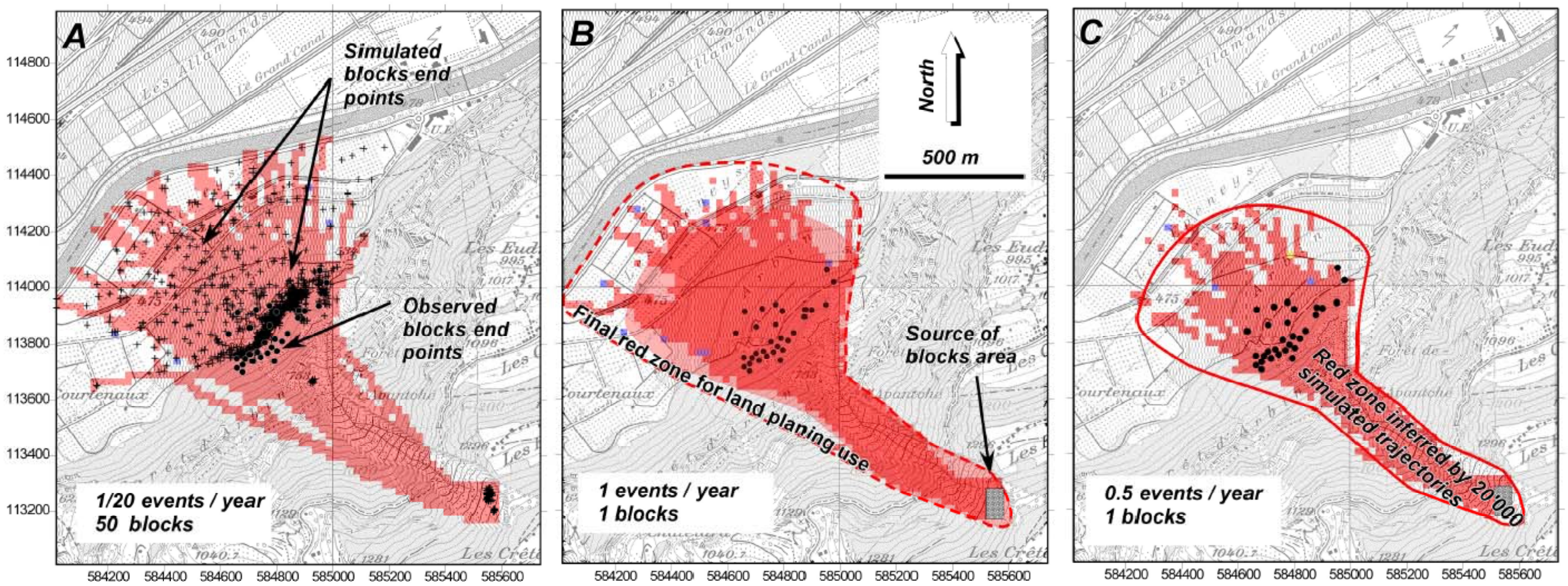
Case study: Crétaux (Switzerland)

- Source area 7200 m3, at 1400 m a.s.
- Deposition area 450 m a.s.
- 50 blocks of 100 kg -100 t

- Simulation: 20‘000 trajectories
- Results of simulation comparable to circular scree fan



Case study: Crétaux (Switzerland)



Discussion

- Rock-mass volume distribution has to be carefully chosen;   affects number, volume, energies → zoning limit
- Precision of DEM for 3D simulations → spreading of trajectories

Discussion and remarks for developing danger maps

- Rock-mass volume distribution has to be carefully chosen; affects number, volume, energies → zoning limit
- Precision of DEM for 3D simulations → spreading of trajectories
- Yellow zone not dependent on energy; based on distribution of runout limits and on t_{ref} = 300 years
- For the red zone, only points 7 and 3 have to be considered, as point 7 always leads to a larger red zone than points 5 or 6; choice between points 7 and 3 depends on the shape of the energy runout distribution.
- Blue zone can disappear for large blocks.
- Maximum extension of danger zone is often jagged; hand contouring.
- Target size has an effect on zoning; smaller cells diminuish P_p; improvement could be to normalize the results by unit of surface area.

Conclusions

- 2D zoning can be straightforward, as seen for infinite linear cliffs, where homogeneous slopes are assumed and taken into account the target dimension
- Zoning for point sources is more complicated, depends on target dimension and morphology (planar slopes / scree fan)
- Scenarios are sensitive to
  - Number of events
  - Blocks per event
  - P_p distribution in space

Merci!