Benchmarking the rockfall energy line method in hazard assessment

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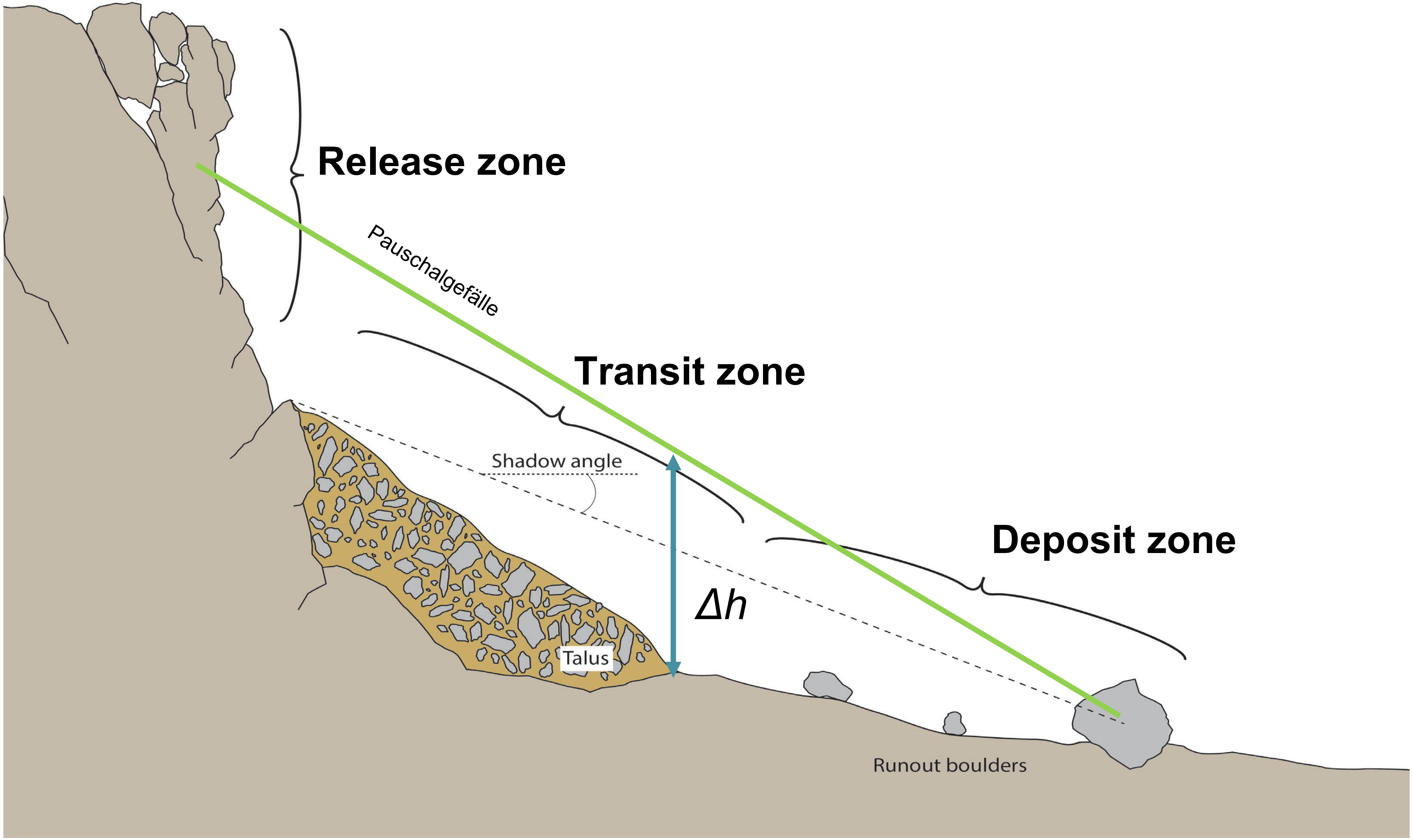
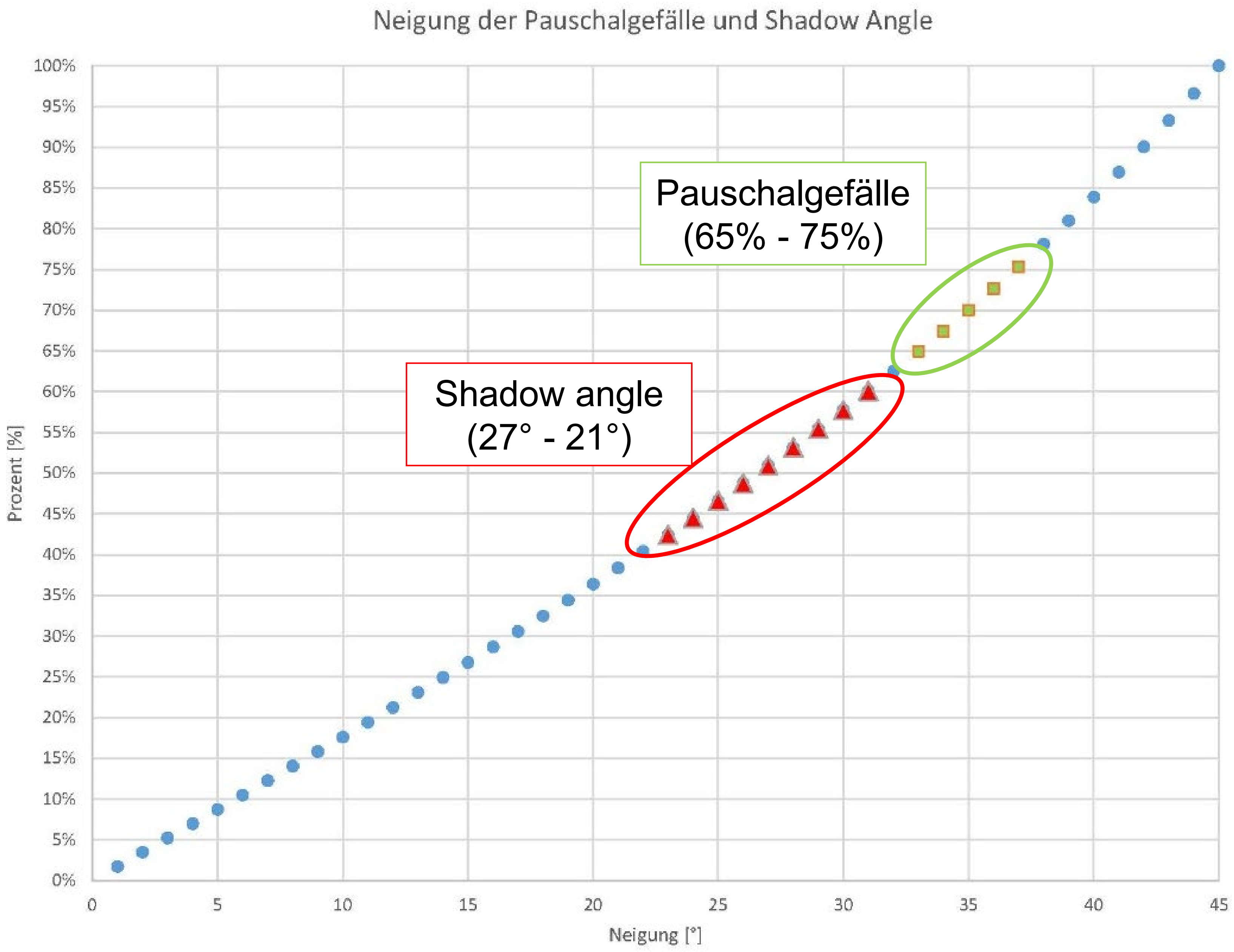
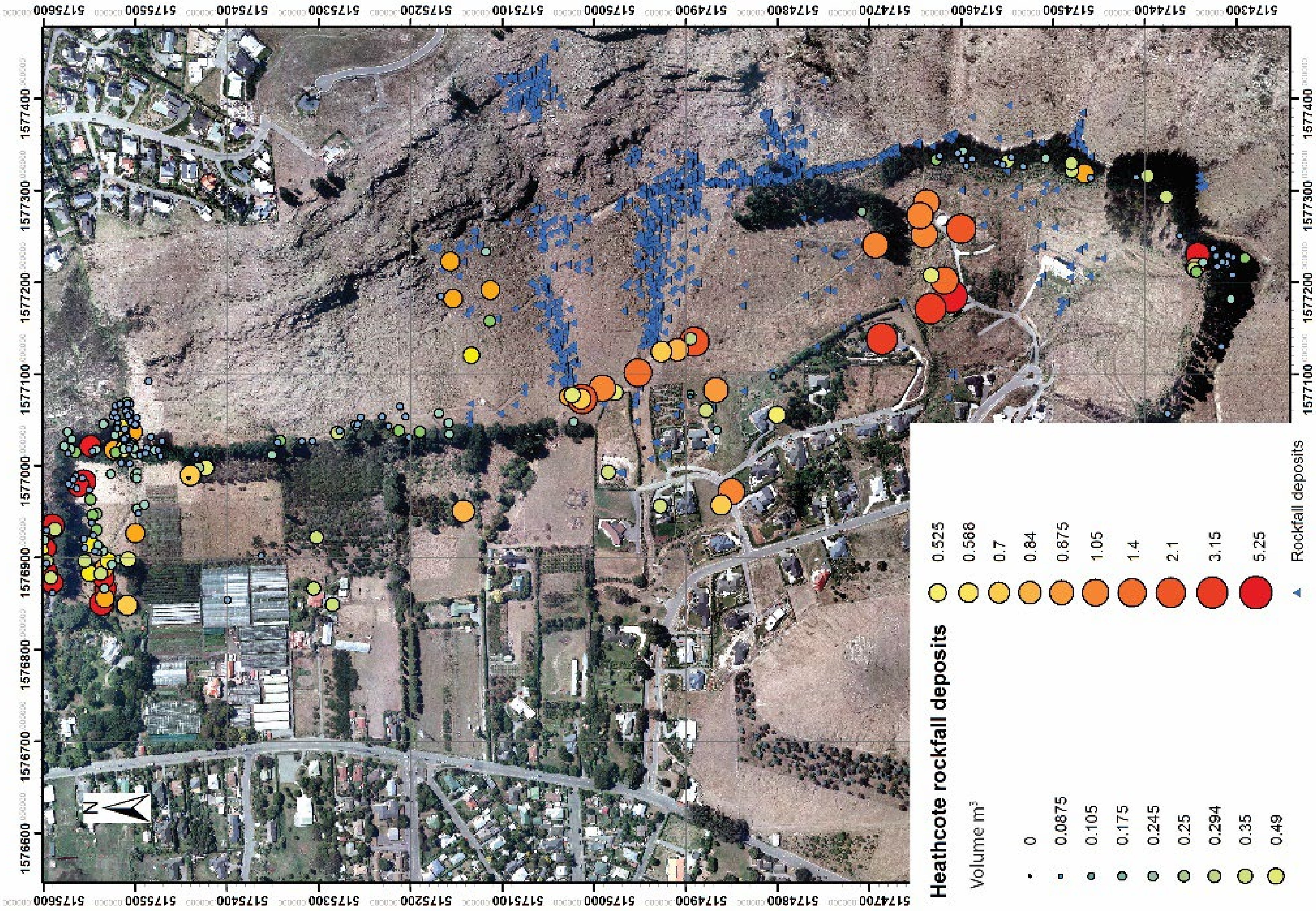
Shadow angle & Pauschalgefälle

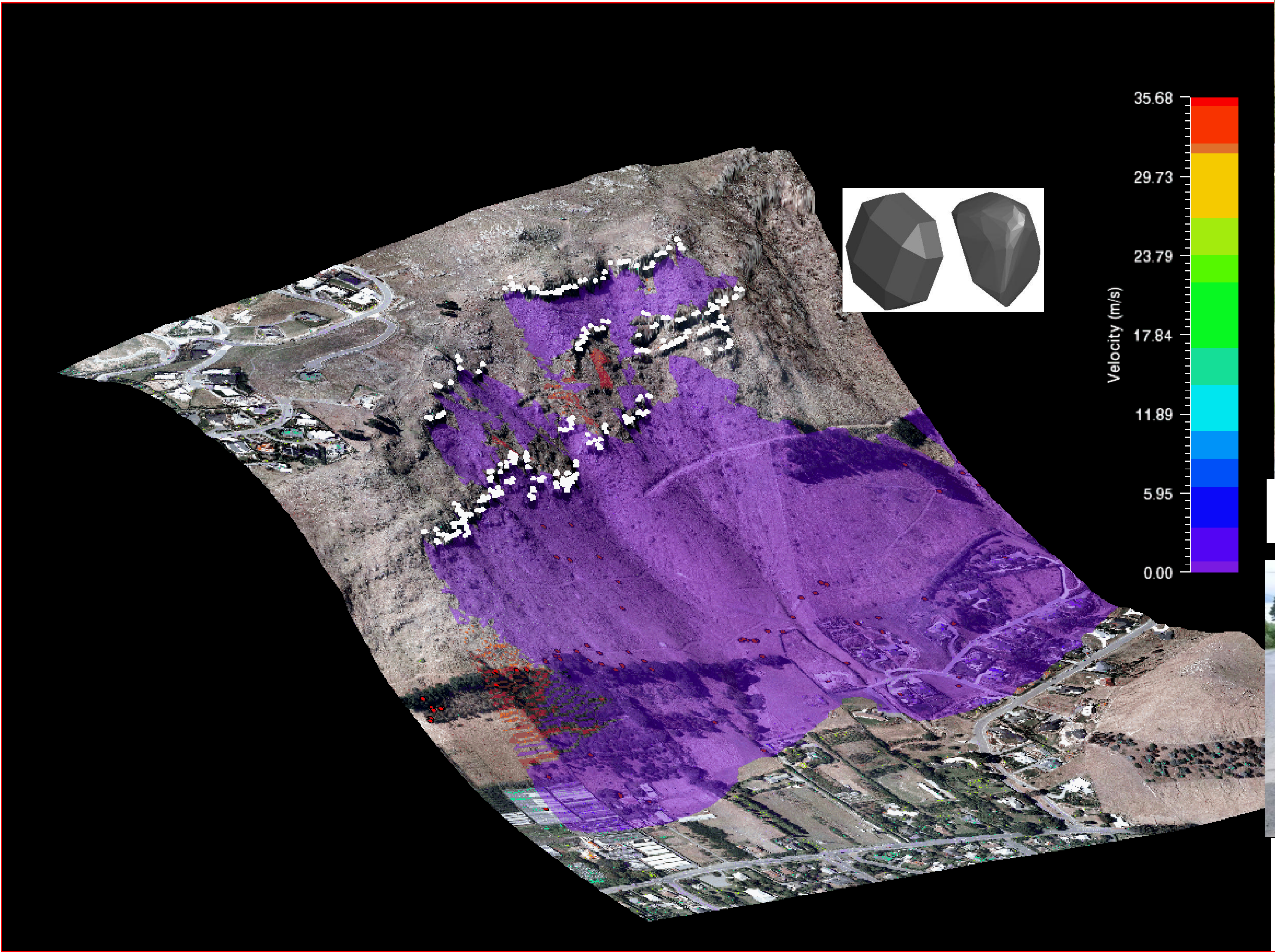


Shadow angle & Pauschalgefälle




Heathcote rockfall deposits
Volume m³
0
0.0875
0.105
0.175
0.245
0.25
0.294
0.35
0.49
0.525
0.588
0.7
0.84
0.875
1.05
1.4
2.1
3.15
5.25
Rockfall deposits
N
5175600
5175500
5175400
5175300
5175200
5175100
5175000
5174900
5174800
5174700
5174600
5174500
5174400
5174300
1576600
1576700
1576800
1576900
1577000
1577100
1577200
1577300
1577400

Shadow angle check



Observed **shadow angle** → 23°

Earthquake triggered Rockfalls, Christchurch, NZ (2011)

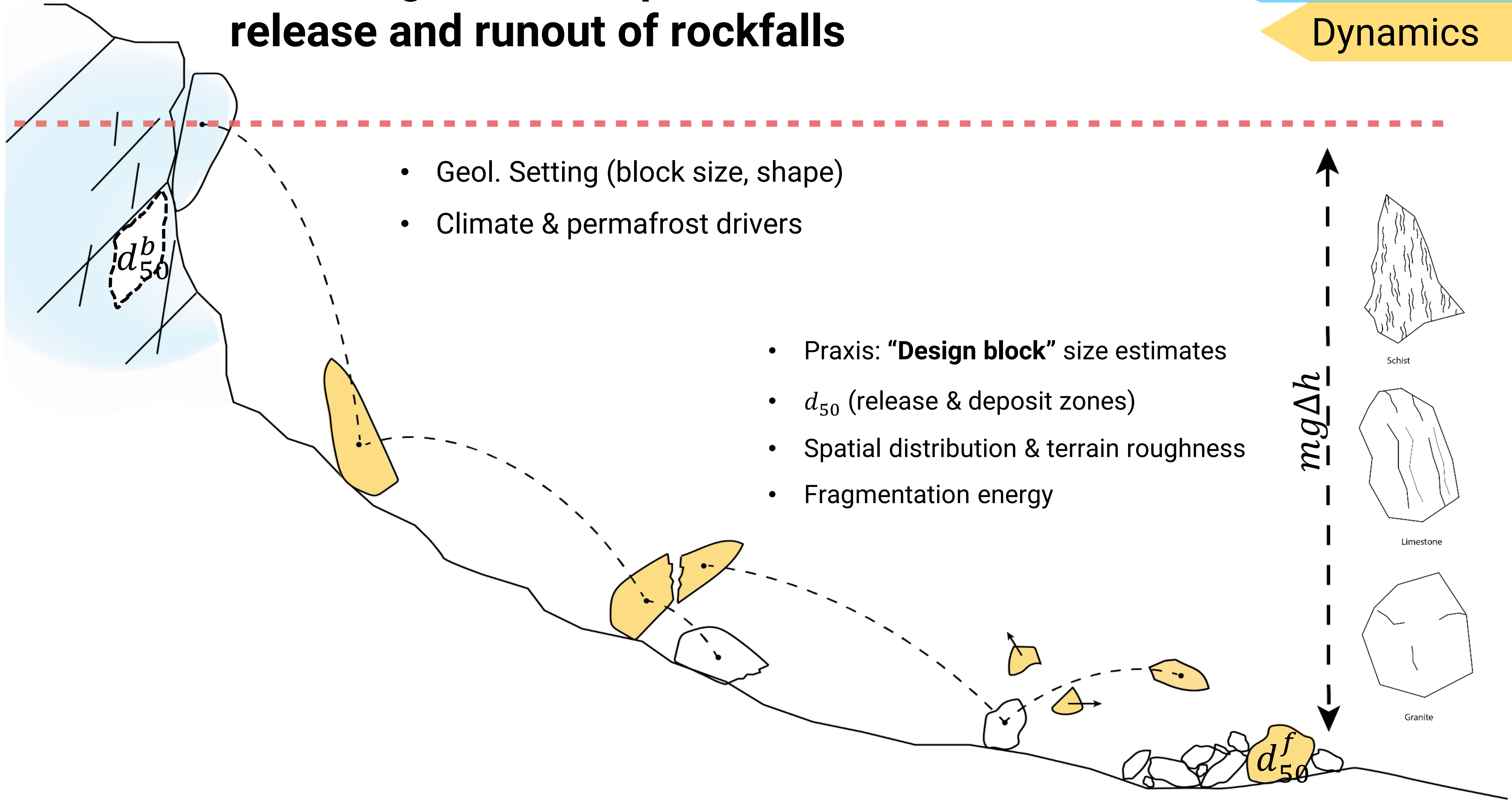
Rock fragmentation processes in release and runout of rockfalls

Release

Dynamics

- Geol. Setting (block size, shape)
- Climate & permafrost drivers

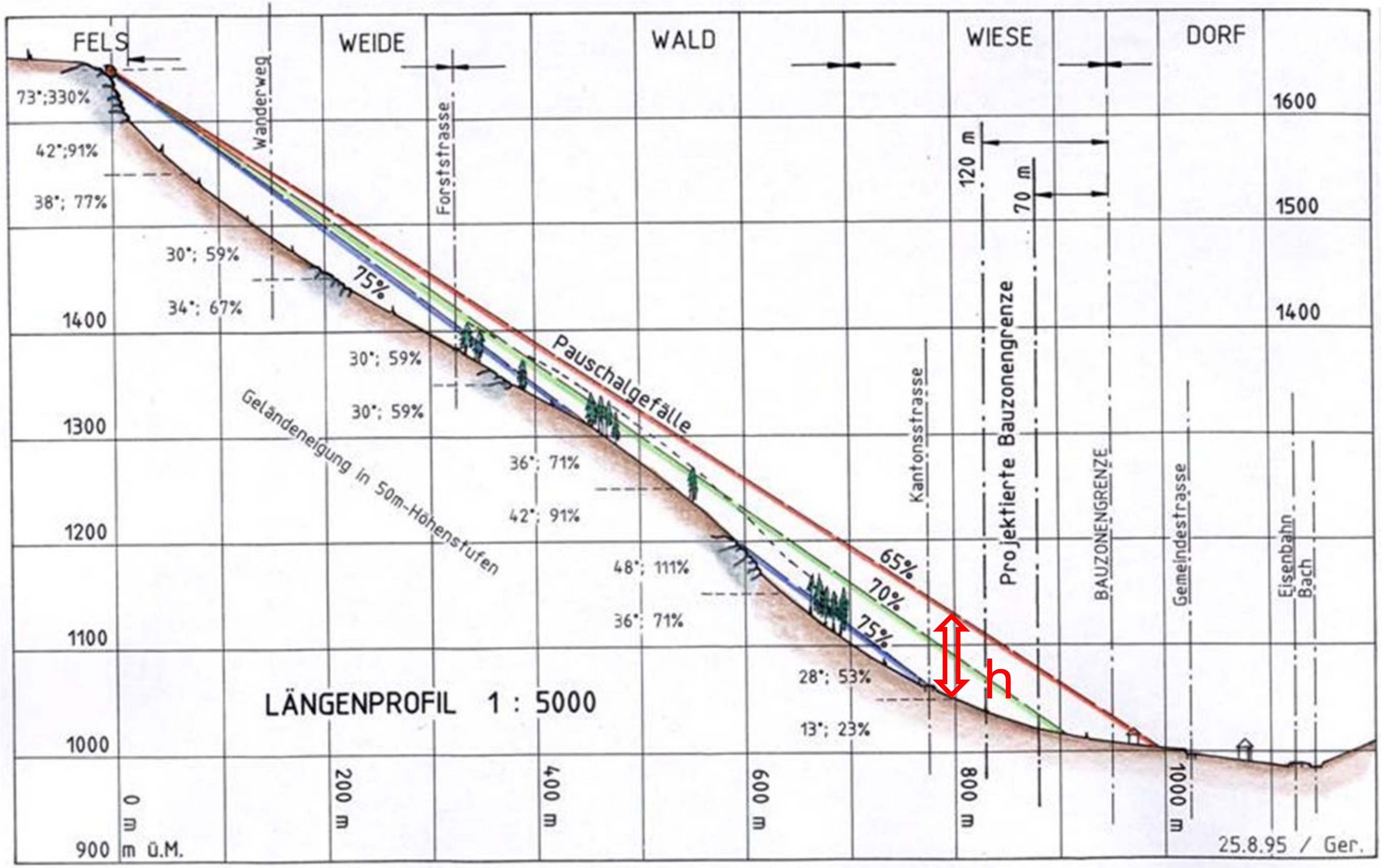
- Praxis: **“Design block”** size estimates
- d_{50} (release & deposit zones)
- Spatial distribution & terrain roughness
- Fragmentation energy



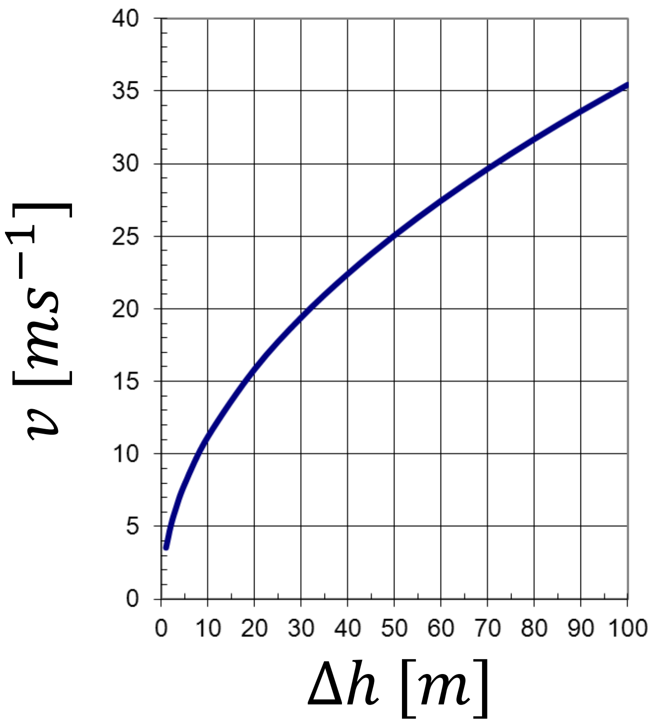
Rockfall energy-line / Pauschalgefälle

Gerber, W.,1994, Ganzheitliche Gefahrenbeurteilung, FAN Kursunterlagen 20 – 22.10.1994

Terrain Type	Suggested P_g value-
Smooth open terrain	65%
Moderate roughness or low brush	70%
Forested or blocky terrain	75%



$$v_{pg} = 0.8\sqrt{2g\Delta h}$$



Rockfall Calculator

Geological Engineering Tool

App Creator: James Glover, Ph.D. Geomechanics
Contact: mgh.james@protonmail.ch

Worked Example

Rockfall Velocity & Energy from a slope profile
Pauschalgefälle Methode (Gerber, 1994)
Gerber, W.,1994, Ganzheitliche Gefahrenbeurteilung, FAN Kursunterlagen 20 – 22.10.1994

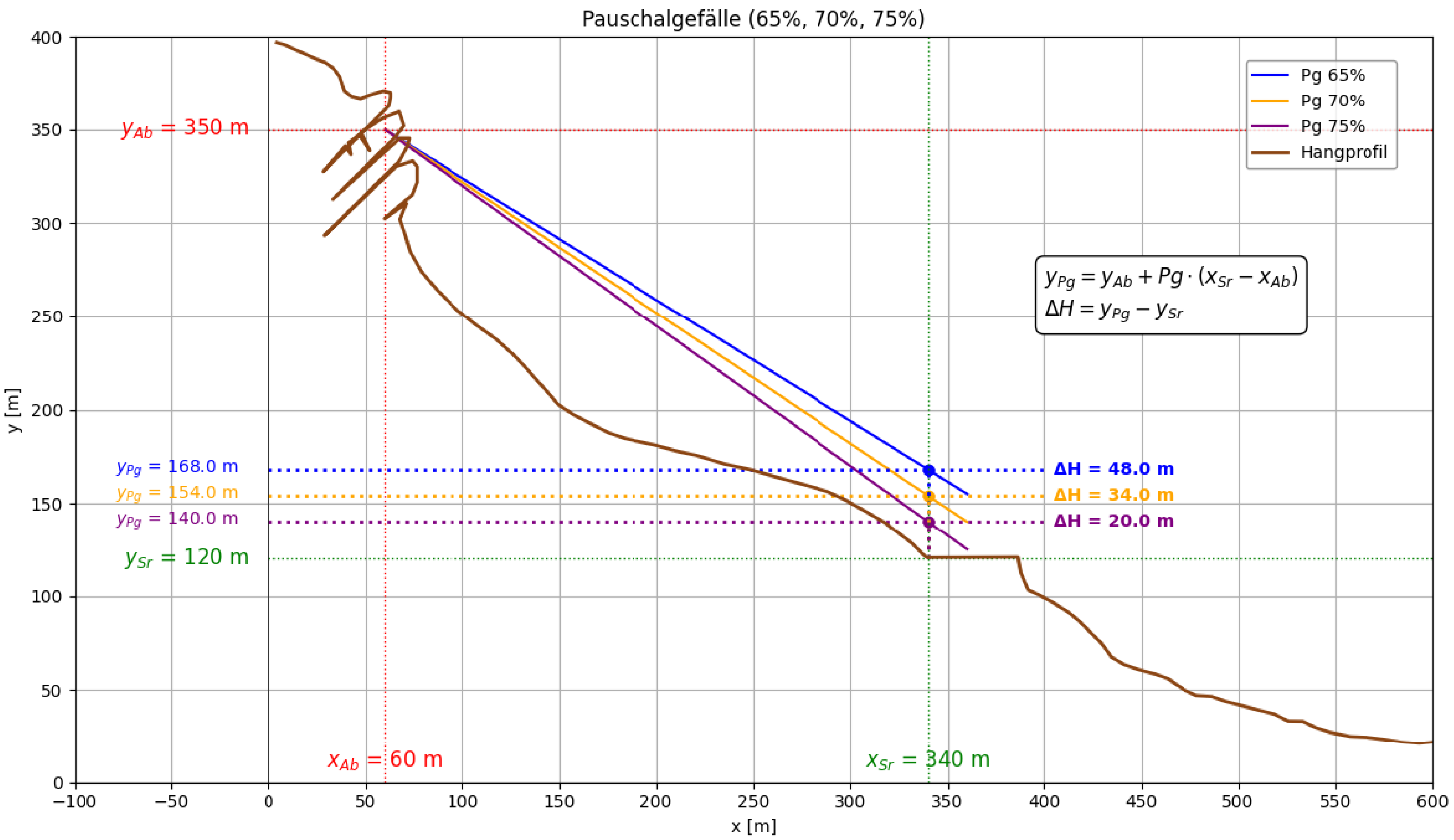
Documentation (EN)

Dokumentation (DE)

78 points loaded

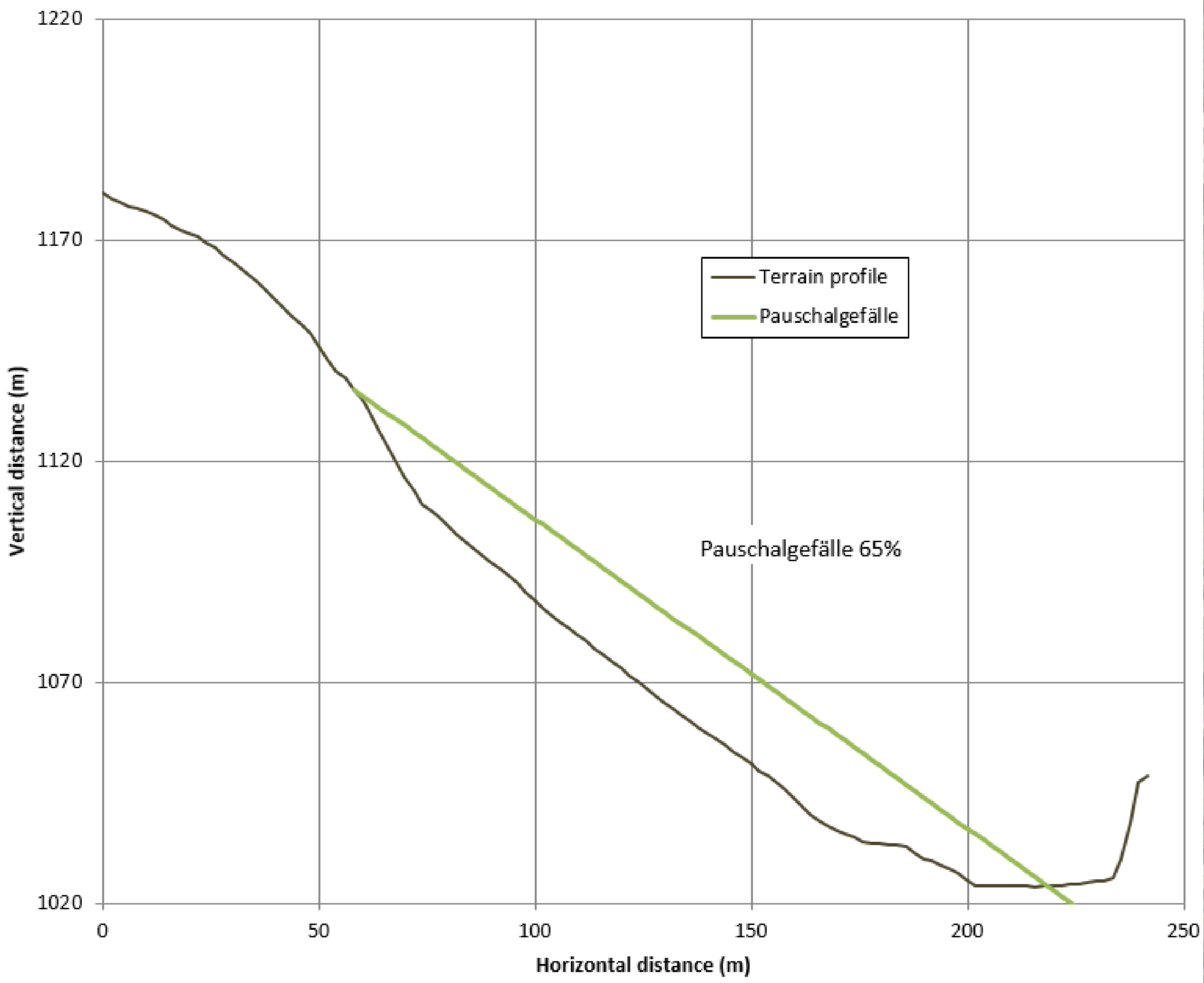
Import Terrain Data 78 points loaded

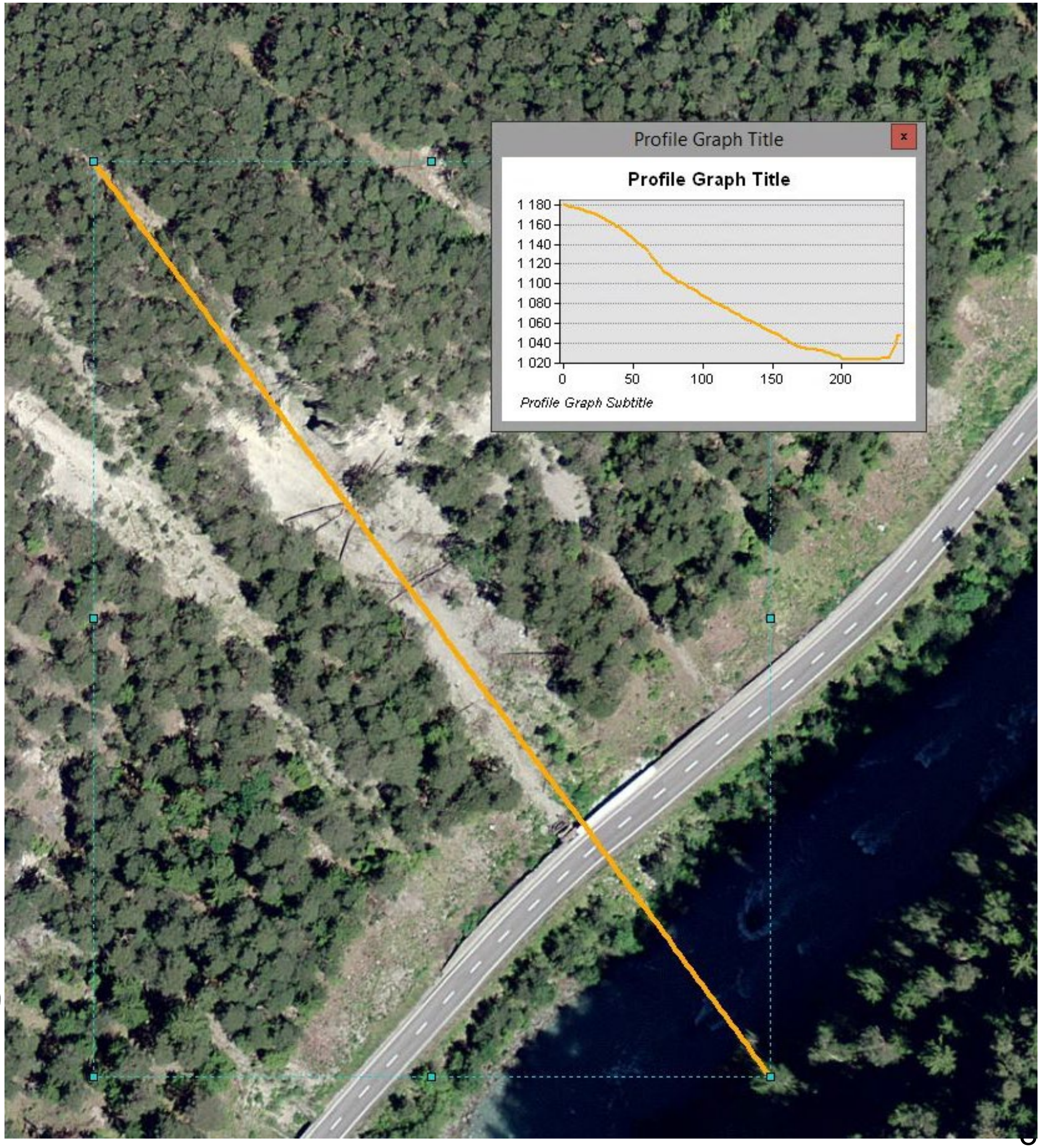
Upload CSV | Paste Data | Enter Text



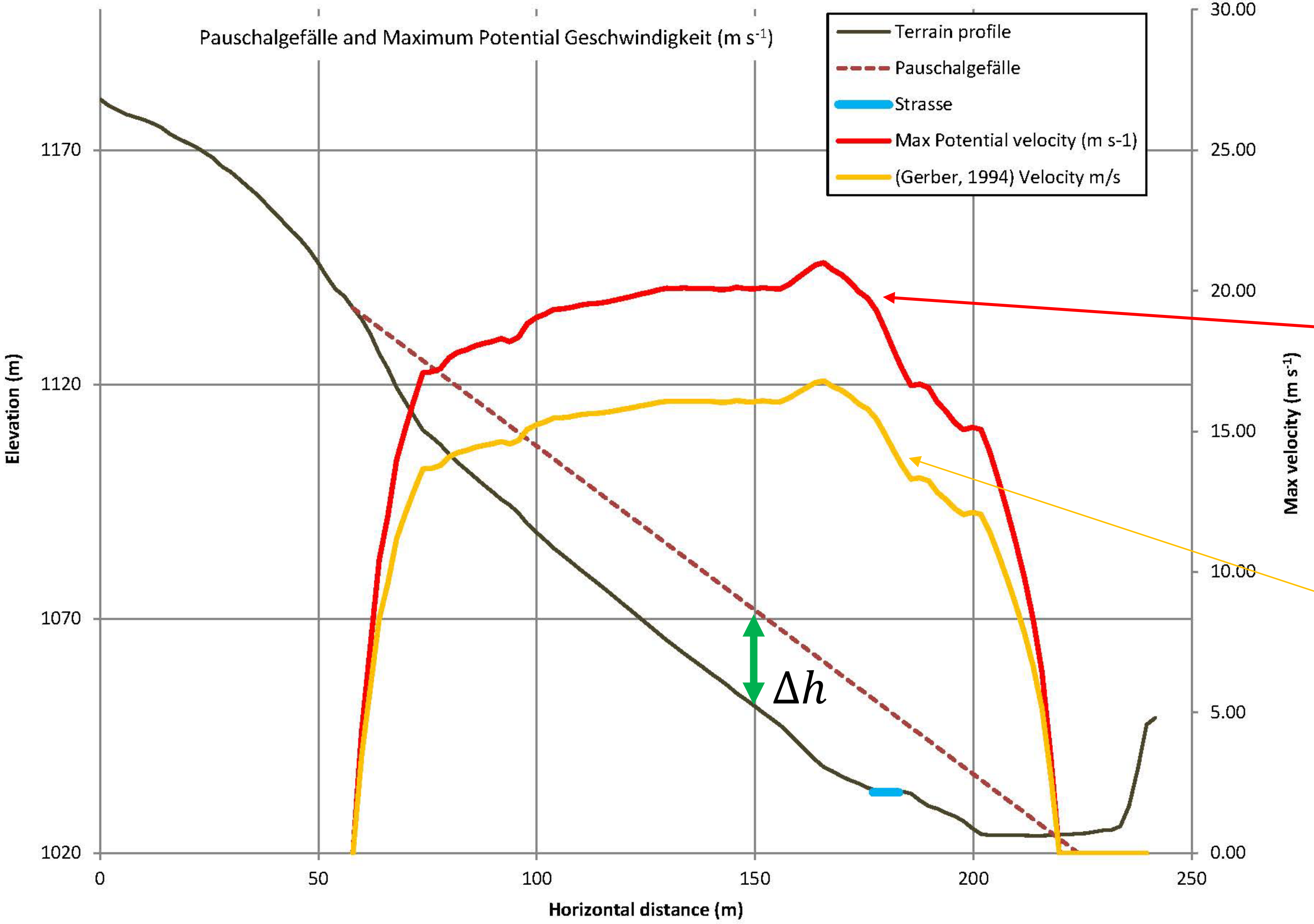
Web App

Praxis & Pauschalgefälle





Velocity estimates → rockfall energy line



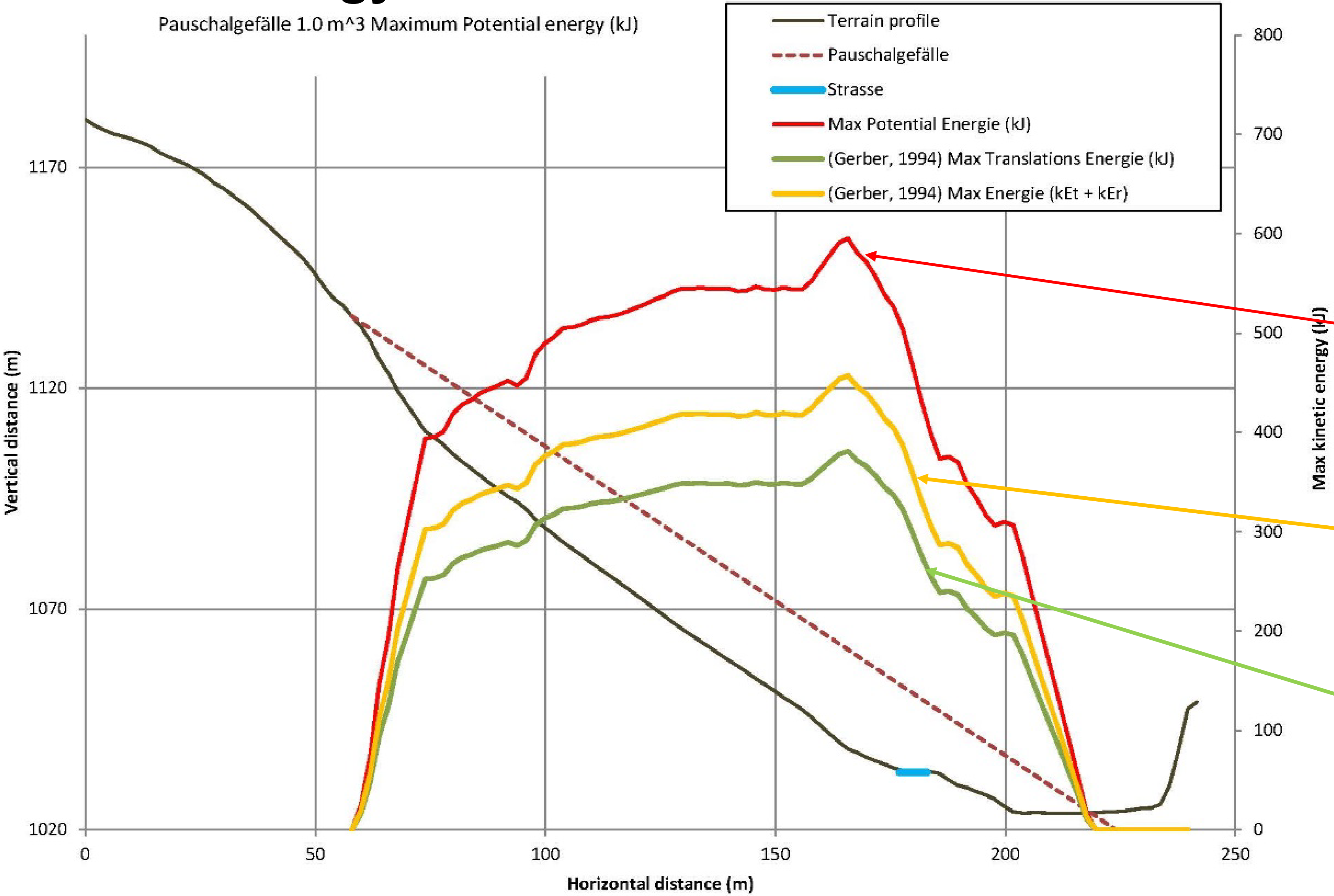
Velocity from Δh to energy line

$$v = (2*g*h)^{0.5}$$

Velocity with K factor 0.8 Pauschalgefälle

$$v_p = 0.8*(2*g*h)^{0.5}$$

Kinetic energy estimates



Design block
1.0 m^3
2700 kg m^{-3}

$$kEr = kEt * 0{\cdot}1$$

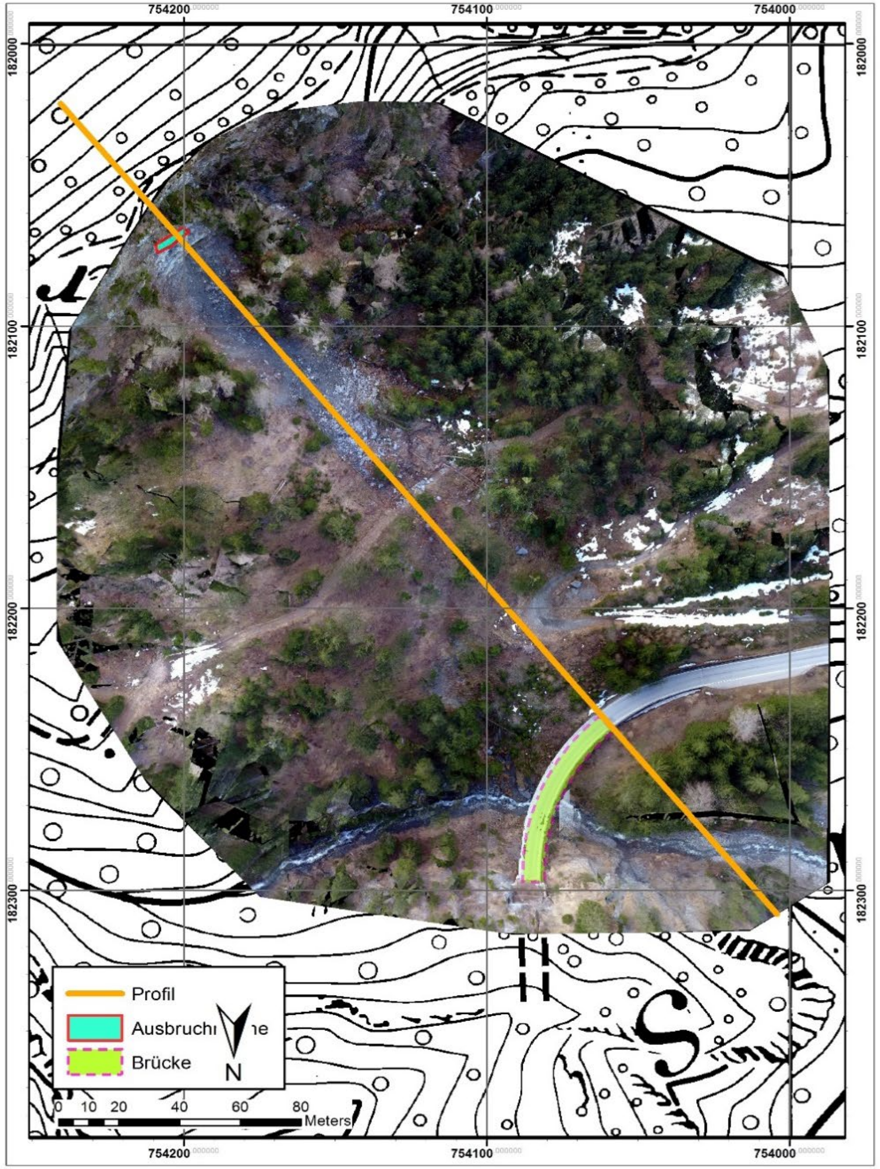
$kE = 0.5*m* v^2$

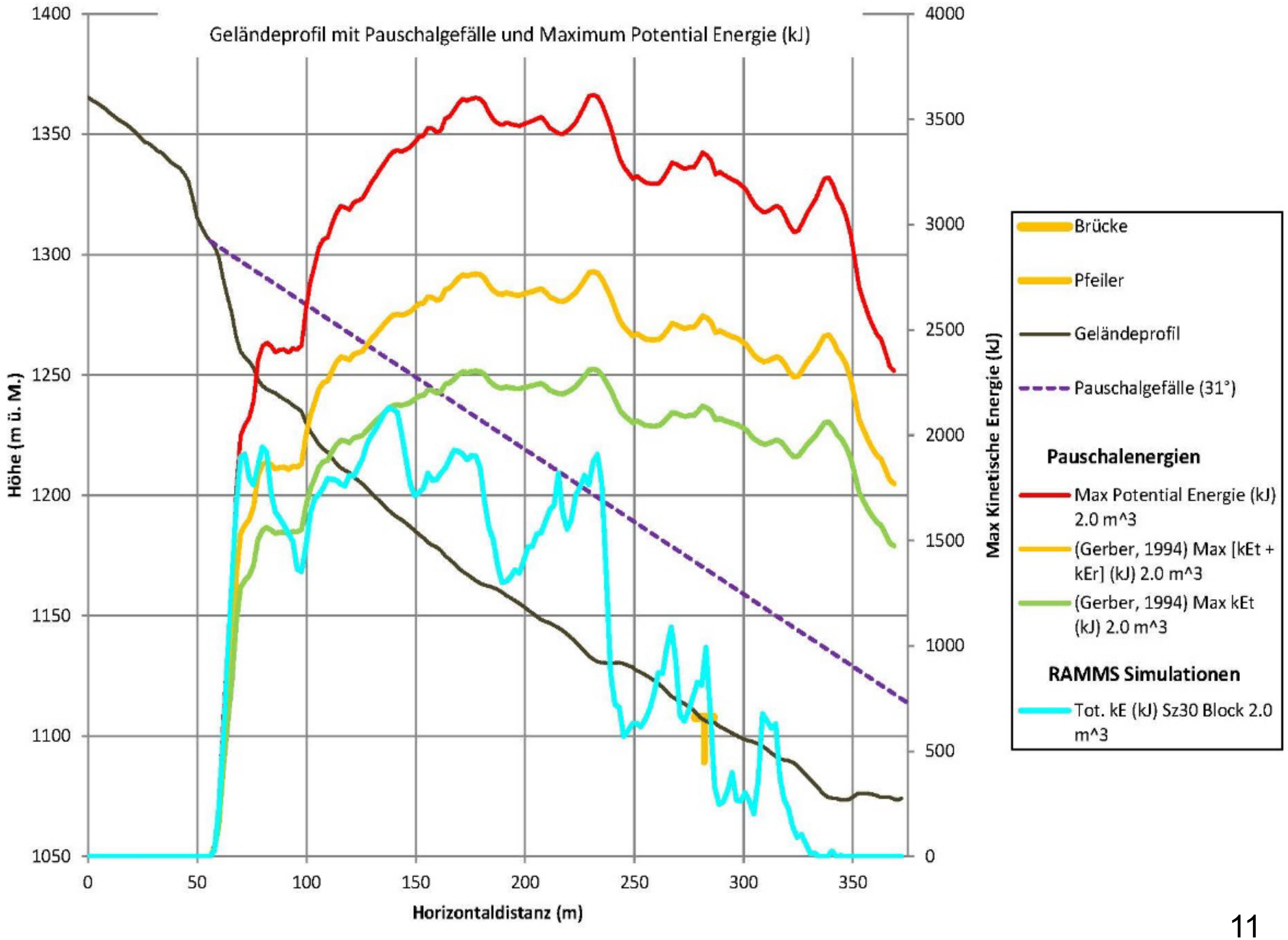
$kEtot = kEt + kEr$

$kEt = 0.5*m*v_p^2$

Validate simulation models

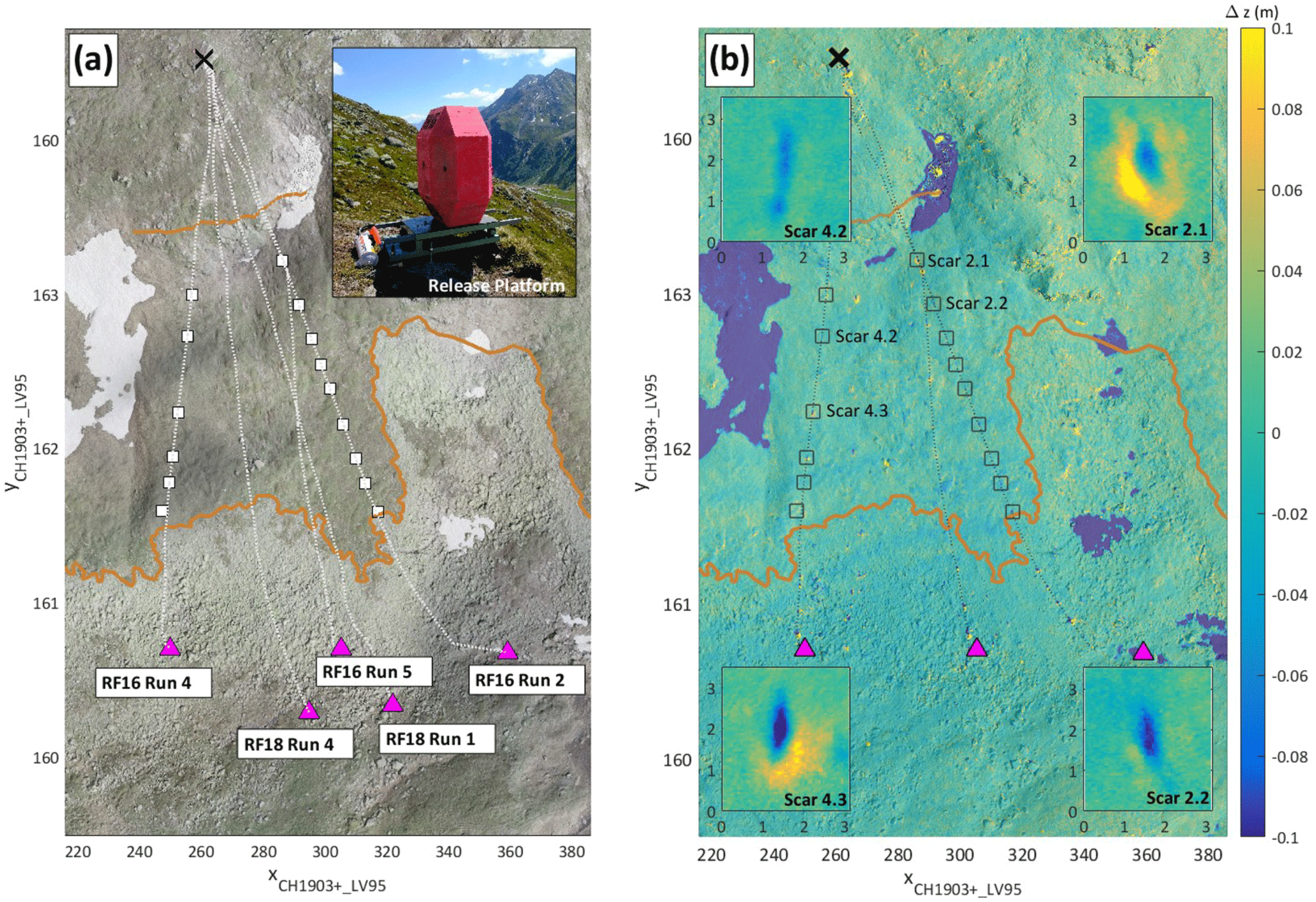
Beispiel Transerbachbrücke





Dataset: Rockfall Testing n = 82

Caviezel, et al., 2019, *Reconstruction of four-dimensional rockfall trajectories using remote sensing and rock-based accelerometers and gyroscopes*, Earth Surf. Dynam., 7, 199–210, https://doi.org/10.5194/esurf-7-199-2019

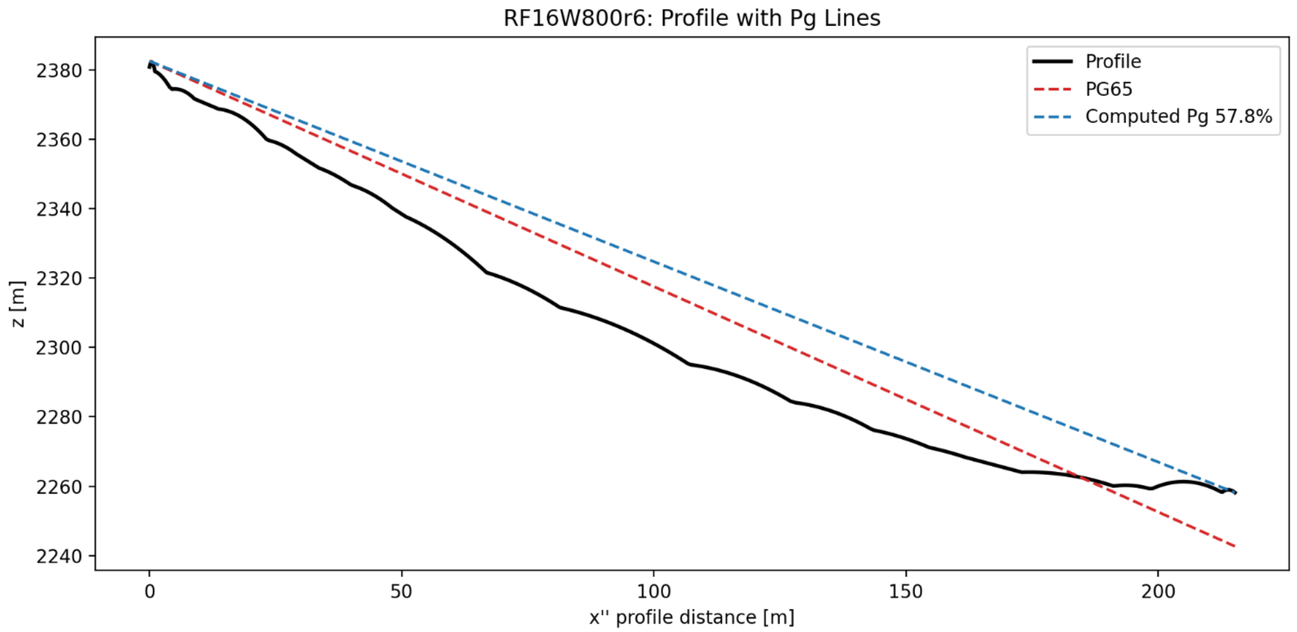


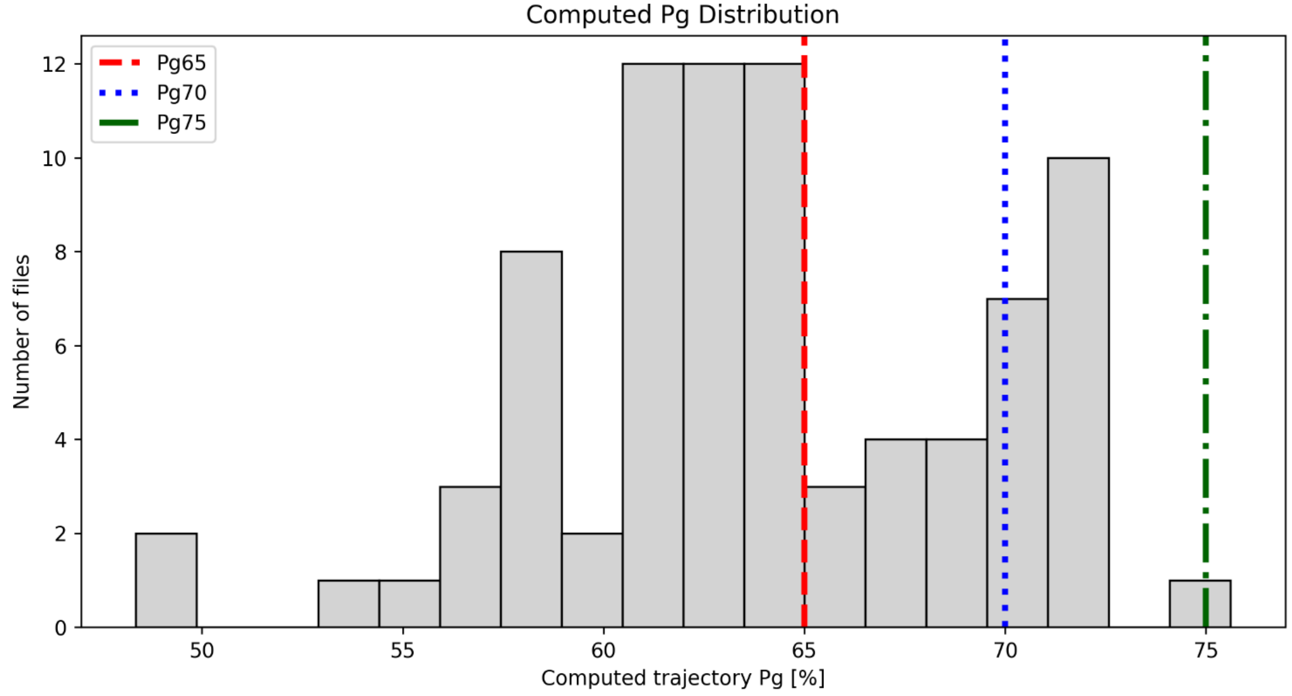
(Image: Caviezel, et al., 2019)

EnviDat
www.envidat.ch

Dataset

Video





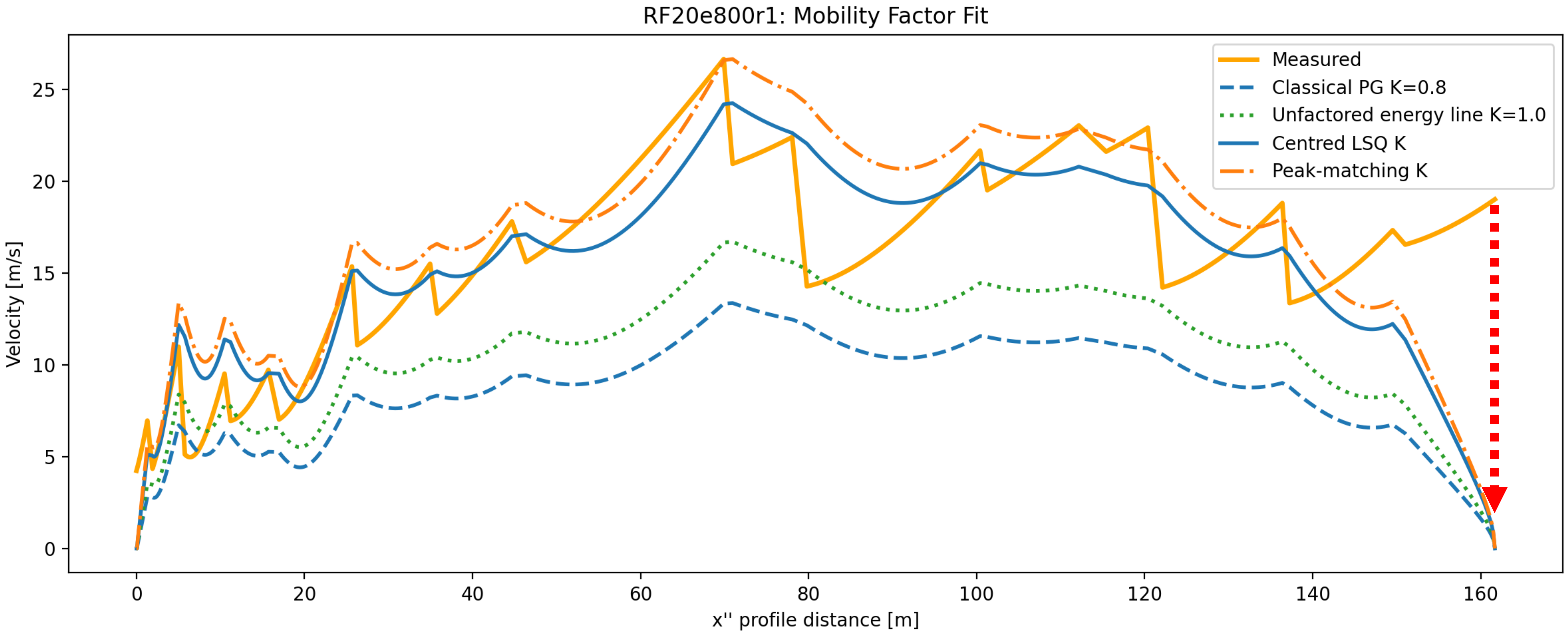
Runout Geometry

- Terrain alpine medow
- Idealised rock shape EOTA 1:1:1
- Extreeme runout possible
- Pg of 65% good estimate mean

Stat.	Computed Pg [%]
Mean	63.94
Median	63.44
Std. dev.	5.48
Minimum	48.35
Maximum	75.61

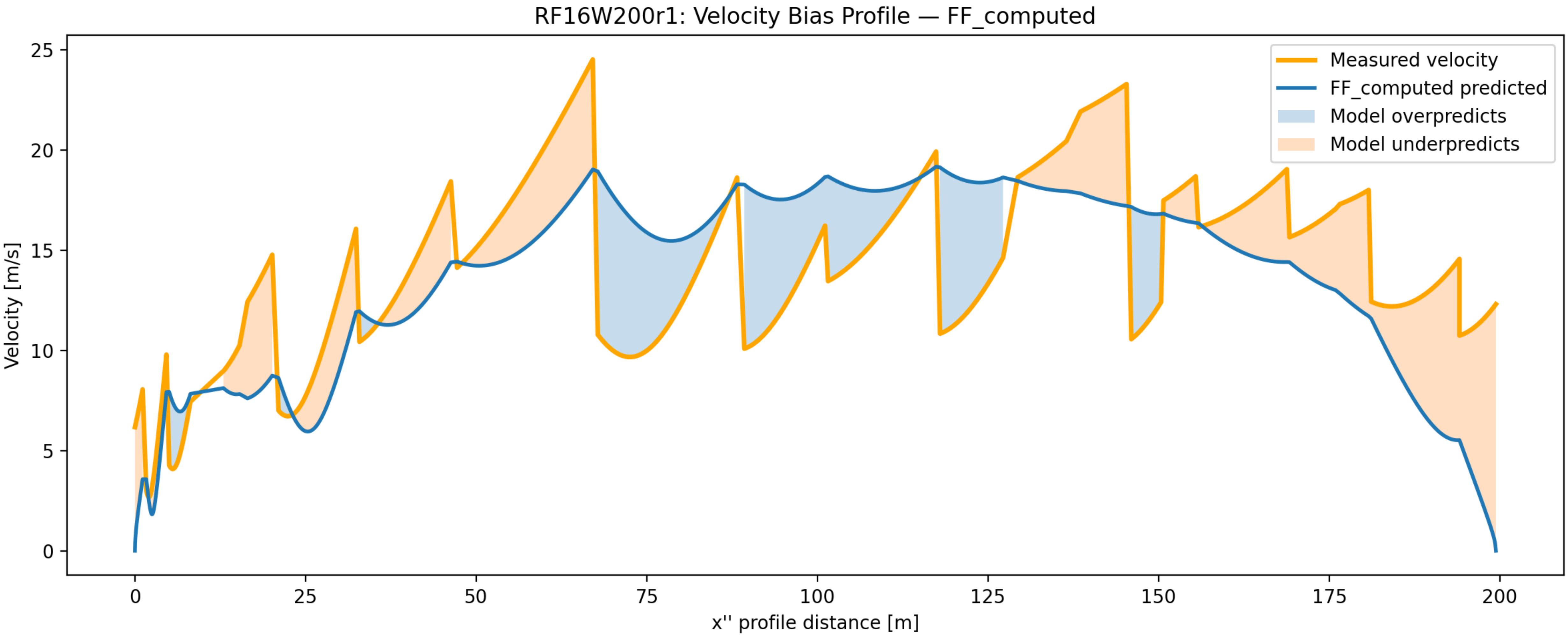
Velocity estimates → Mobility factor K

- Fitting **K** to predict velocity envelope
- K = 0.8 in Pg method underpredicts velocity in controlled experiments



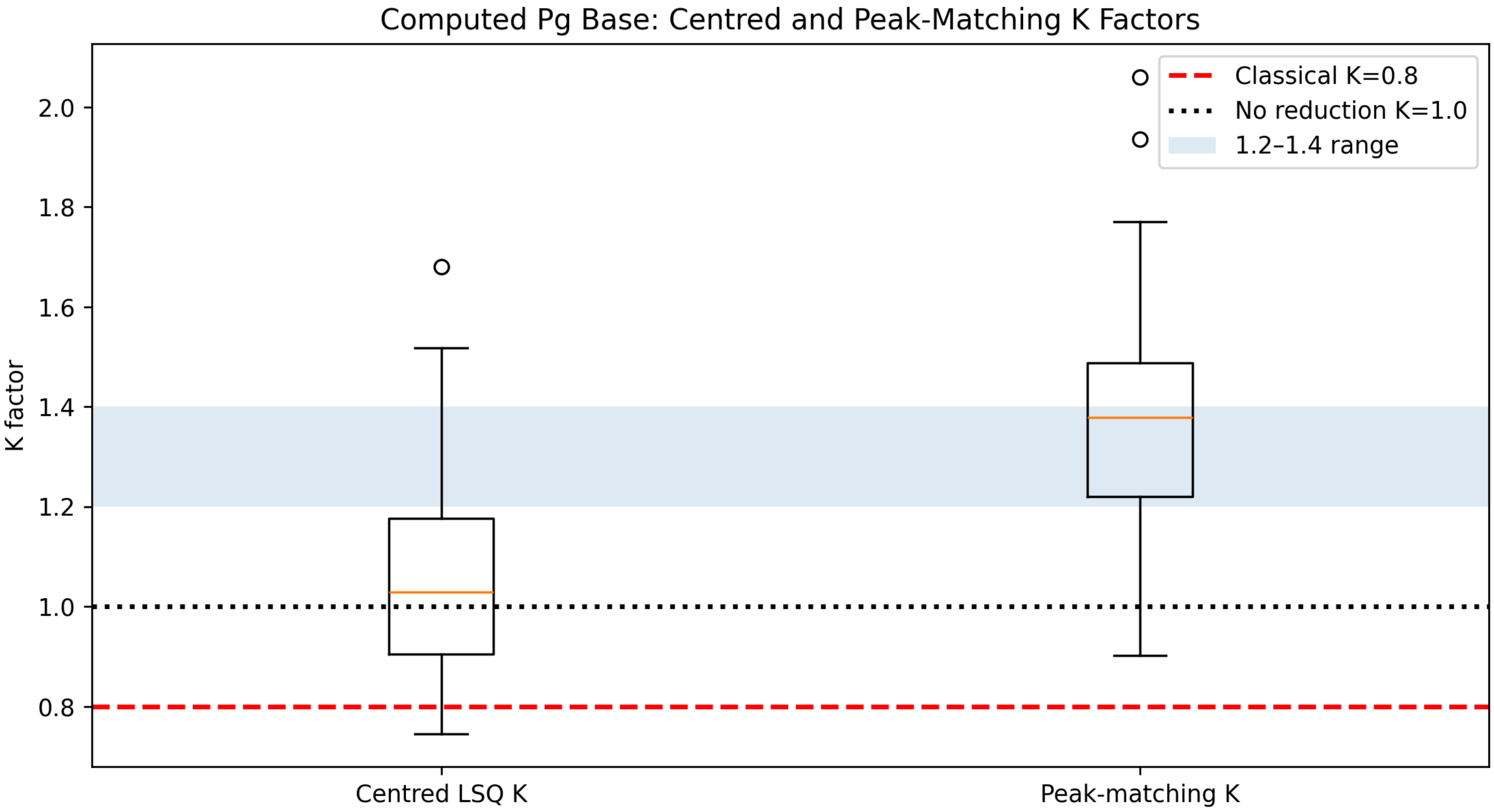
Velocity estimates → Mobility factor K = 1.0

Identifies regions of momentum gain and loss



Velocity estimates → Mobility factor K = 1.2 – 1.4

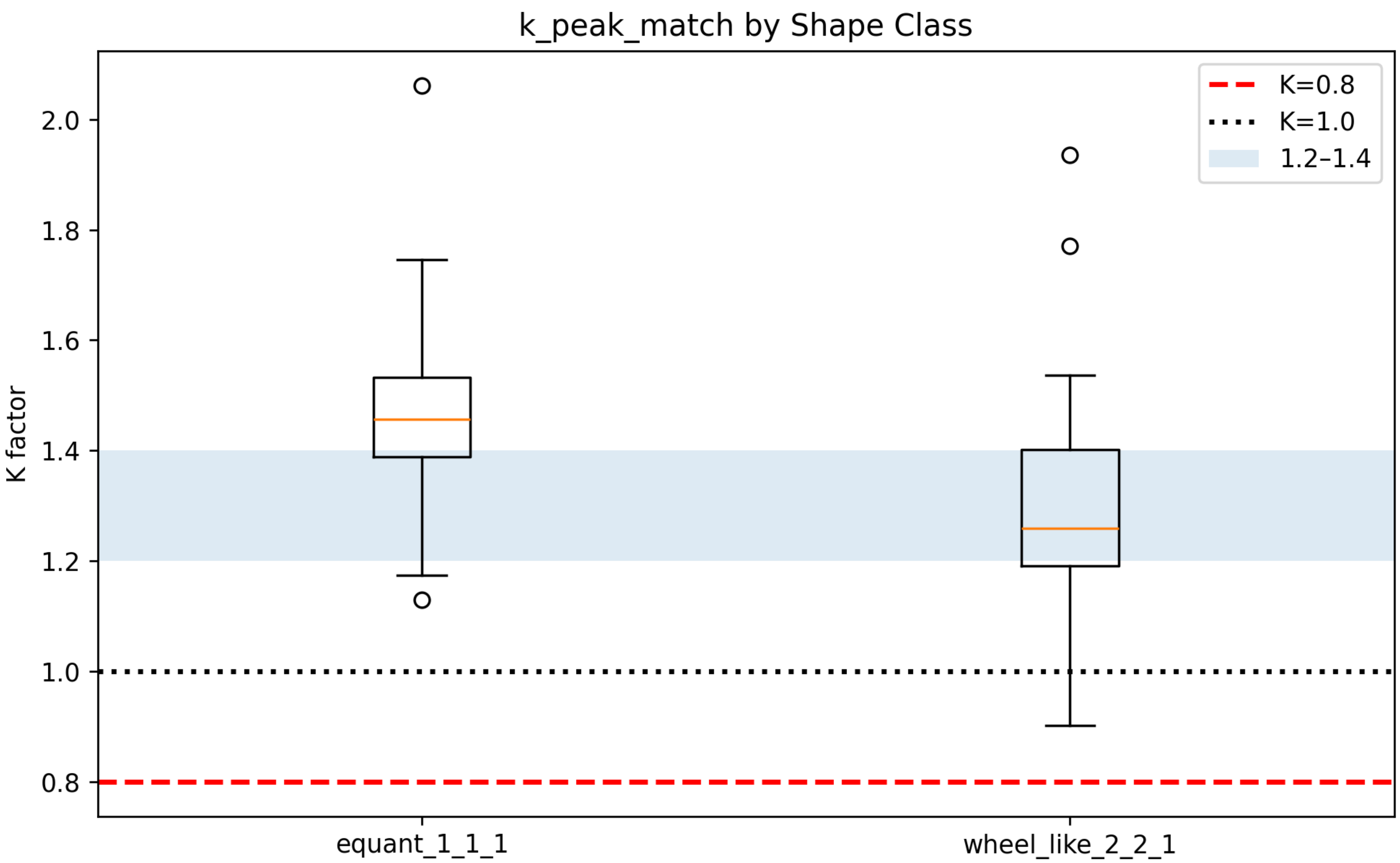
Capturing extreme velocities along slope profile



Velocity estimates → Rock shape K = 1.2 – 1.4

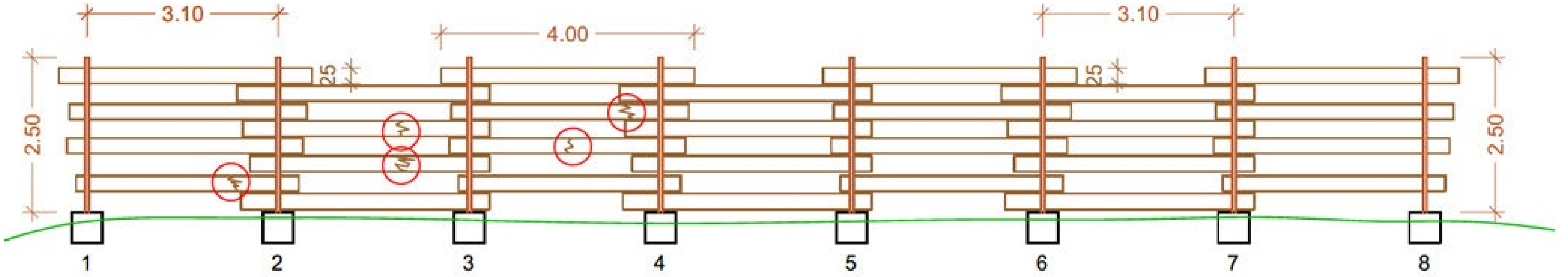
Rock shape clearly influences momentum retention

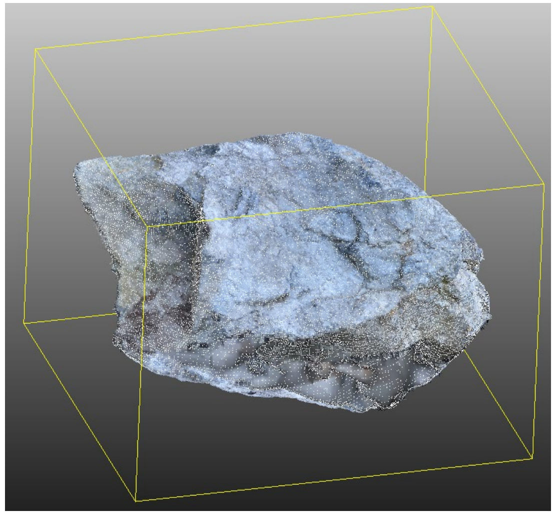
EOTA 2:2:1 better captures natural rockfall

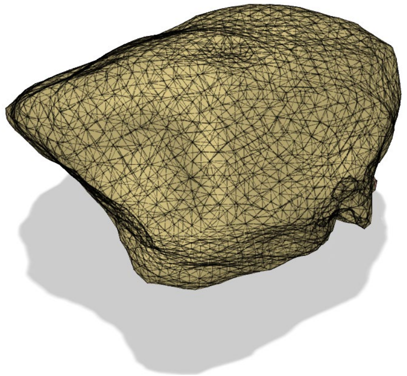


Case Studies → Rockfall impact wooden barrier Filisur, GR

- Construction year 1995
- Event 2021
- Oak beams
- Railway lines as posts







Event rock volume

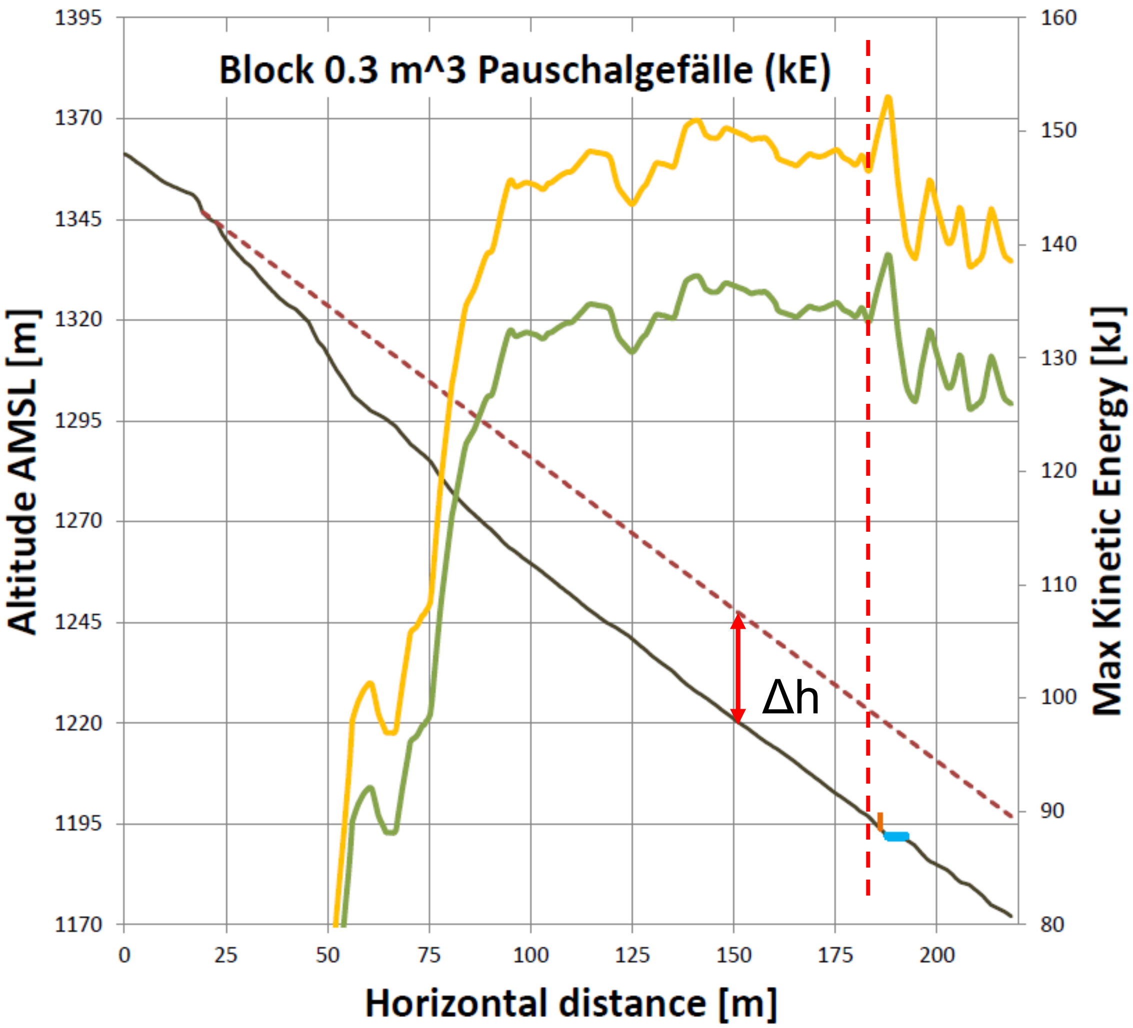
- Principal 3 axes + form factor* = **0.4 m^3**
- SFM (Pix4DCatch) scan volume = **0.3 m^3**

Mass = 810 – 1080 kg

ρ = 2700 kg m$^{-3$}

* Tendency to overestimate rock volume

Velocity & kinetic energy estimates



(Gerber, 1994)

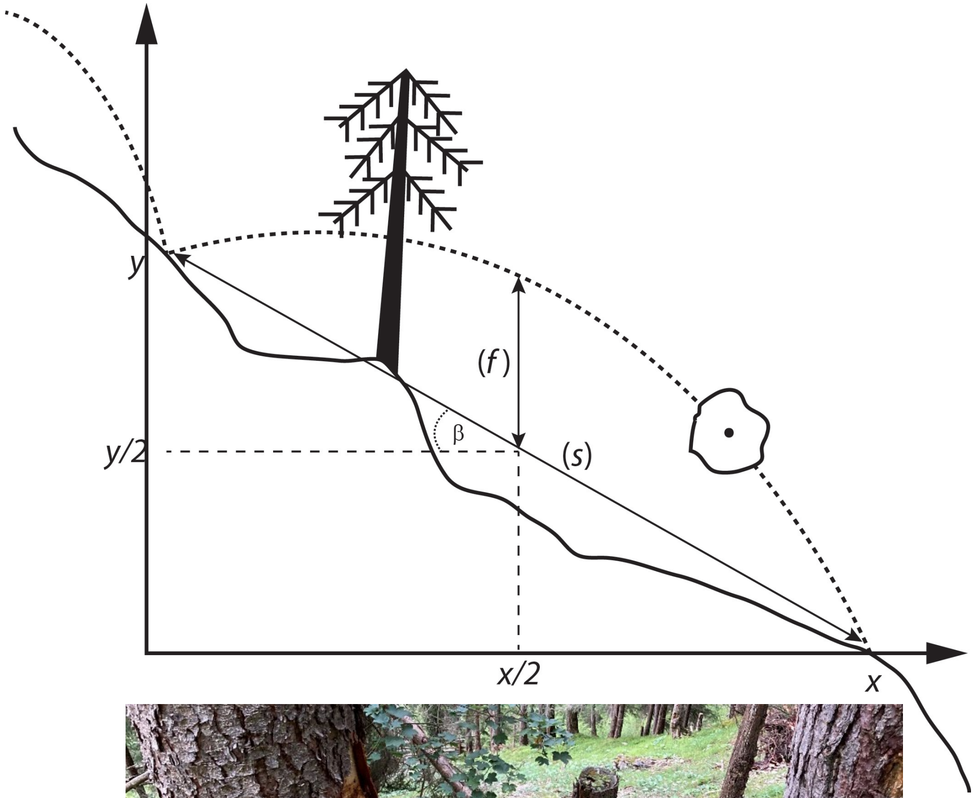
- [m/s] → $v = 0.8*(2*g*h)^{0.5}$
- [kJ] → $E_{tot} = E_t * 1.1 (E_r)$

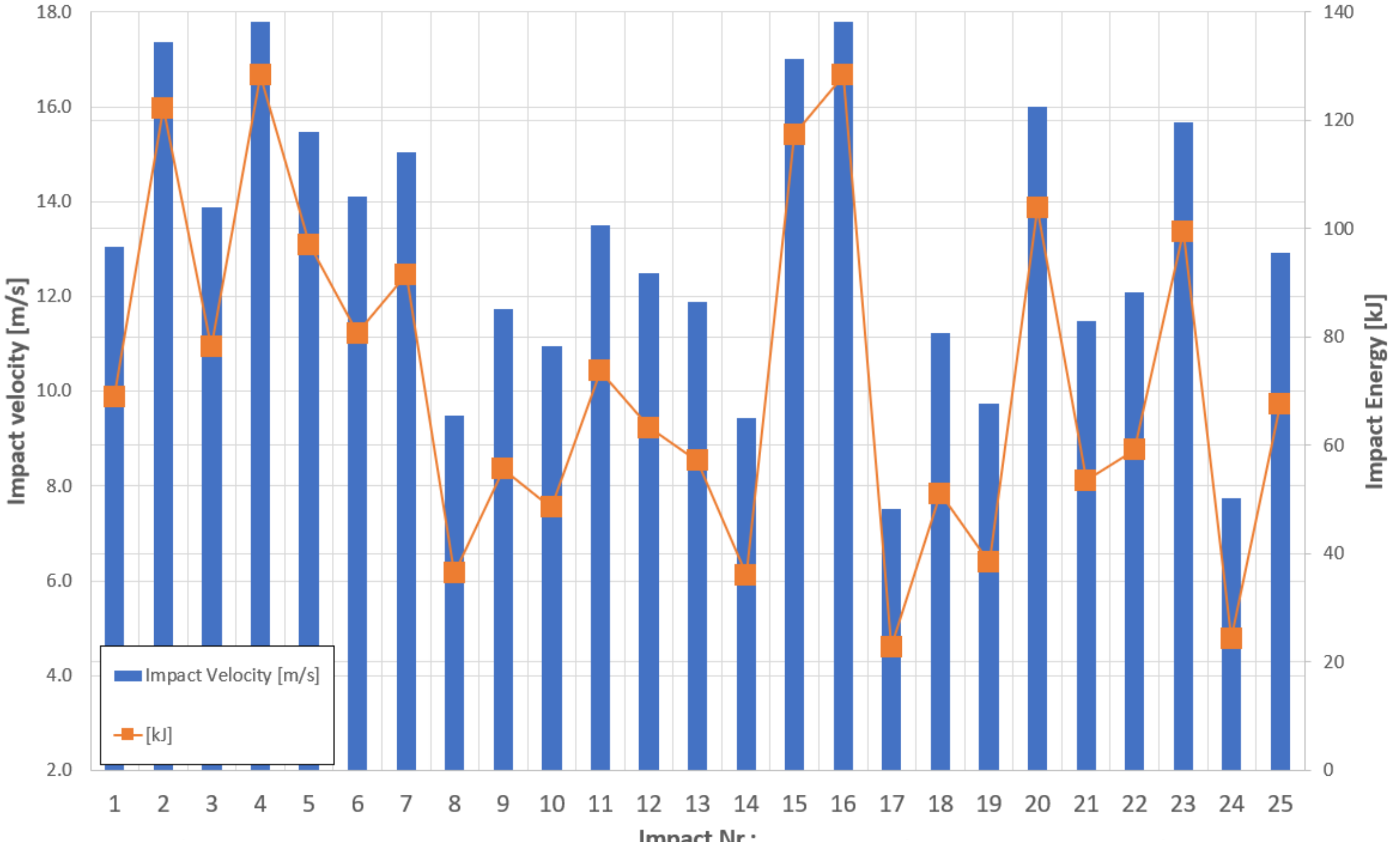
Filisur (GR) rockfall
Upper maxima for rock slope

Velocity at impact = **18.2 [m/s]**
E_t at impact = **134 [kJ]**
E_{tot} (E_t + E_r) = **147 [kJ]**

Velocity & kinetic energy estimates

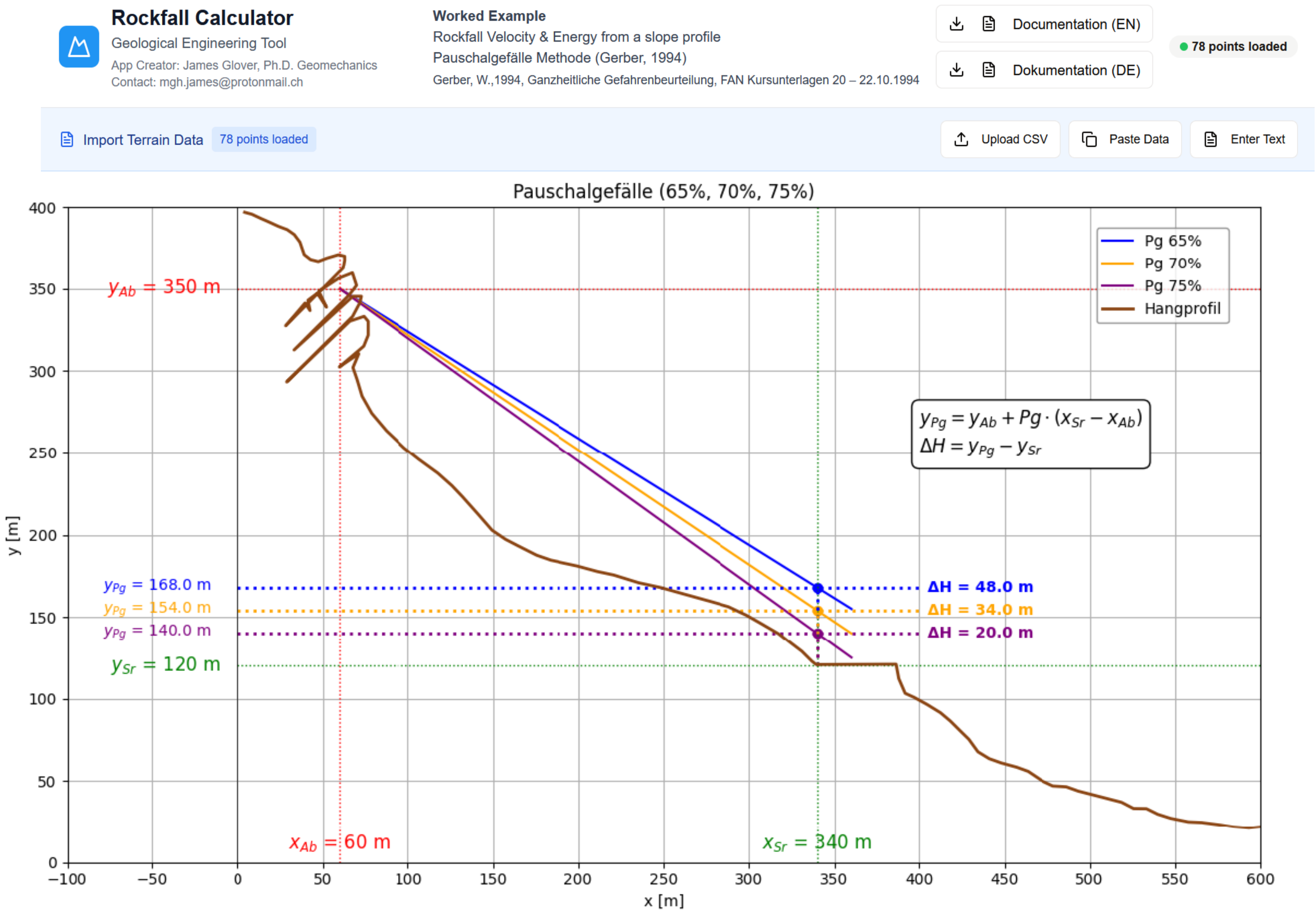
Jump distances between impact scars





		SFM	3 axes
Volume estimate		$0.3\ m^3$	$0.4\ m^3$
Mass estimate ρ = 2700 kg m^{-3}		810 kg	1080 kg
Impact velocity f/s = 1/8	13.0 m/s	68 - 75 kJ	91 - 100 kJ
Mean velocity f/s = 1/12	14.3 m/s	83 - 91 kJ	110 - 121 kJ

Many thanks for your attention!



Web App

Thanks to the canton of Grisons agencies for roads and forest and natural hazards for supporting this work.

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Ufficio foreste e pericoli naturali

Tiefbauamt Graubünden
Uffizi da construcziun bassa dal Grischun
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