snow avalanches
measurement and back calculation

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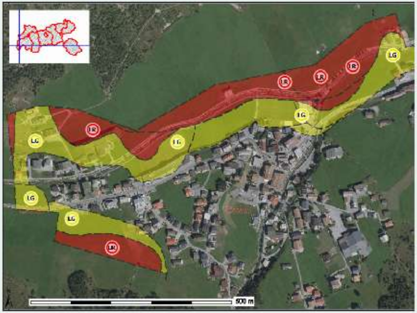
hazard mapping



how far?

→ **runout**

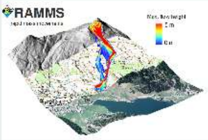
mitigation planning

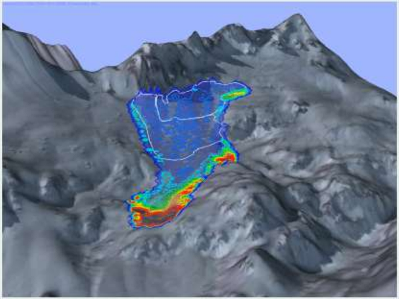
how destructive?

→ **pressure**

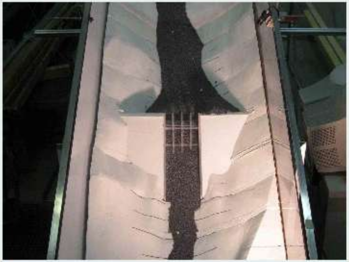
methods: computational and experimental avalanche dynamics

computational avalanche dynamics

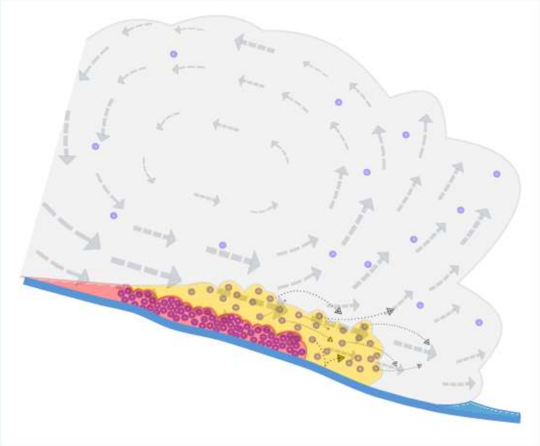




experimental avalanche dynamics



three layer structure



- powder cloud
- fluidized layer
- dense core

dense flow avalanche model

dfa - dense flow avalanche

- dense snow
- granular flow
- moderate velocity, high density

balance equations - SamosAT

- mass

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{\mathrm{d}(A\,\bar{h})}{\mathrm{d}t} = \dot{q}\,A$$

- momentum

$$\frac{\mathrm{d}\bar{u}_i}{\mathrm{d}t} = g_i + \frac{1}{A\,\bar{h}} \oint\limits_{\partial A} \left(\frac{\bar{h}\,\sigma^{(b)}}{2}\right) n_i\,\mathrm{d}l - \delta_{i1}\frac{\tau^{(b)}}{\bar{h}} - \frac{\bar{u}_i}{A\,\bar{h}}\frac{\mathrm{d}(A\,\bar{h})}{\mathrm{d}t}$$

Process parameters: friction and entrainment

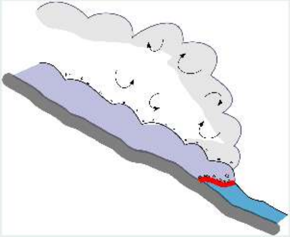
basal friction $\tau^{(b)}$ with Coulomb friction μ and turbulent drag ξ

$$\tau^{(b)} = \mu \, \sigma^{(b)} + \frac{g}{\xi} \, \bar{\mathbf{u}}^2$$

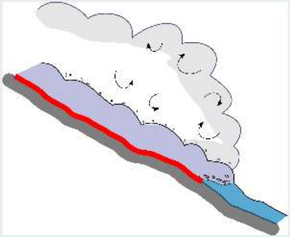
and entrainment $\dot{q}$

$$\dot{q} = \frac{\tau_b}{e_b} \, \|\bar{\mathbf{u}}\|$$

frontal ploughing: $e_b \to 0$



basal erosion: $e_b \to \infty$



model results and their interpretation

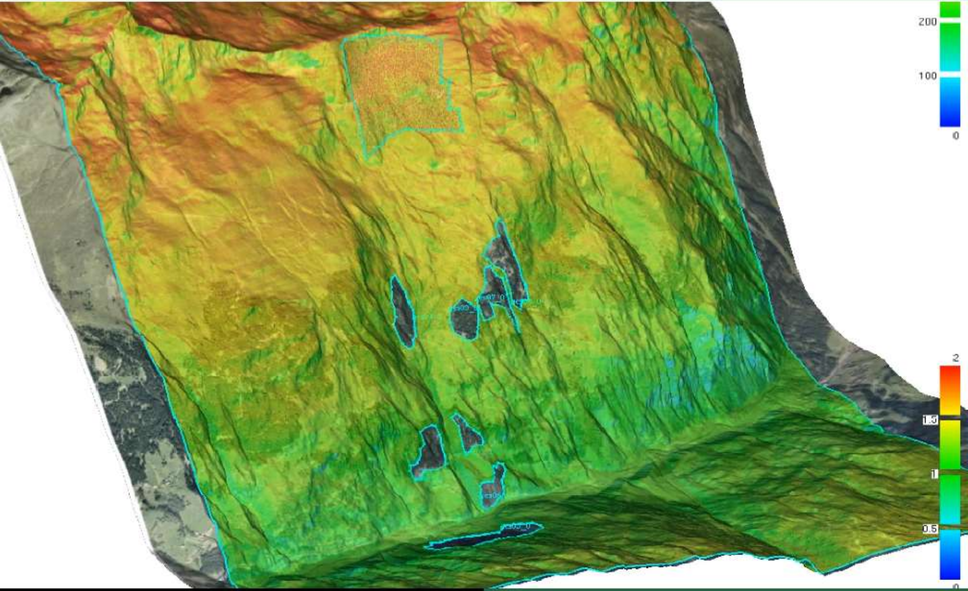
model results - spatiotemporal evolution of flow variables:

- $h(x, y, t)$ - flow depth
- $\mathbf{u}(x, y, t)$ - flow velocity

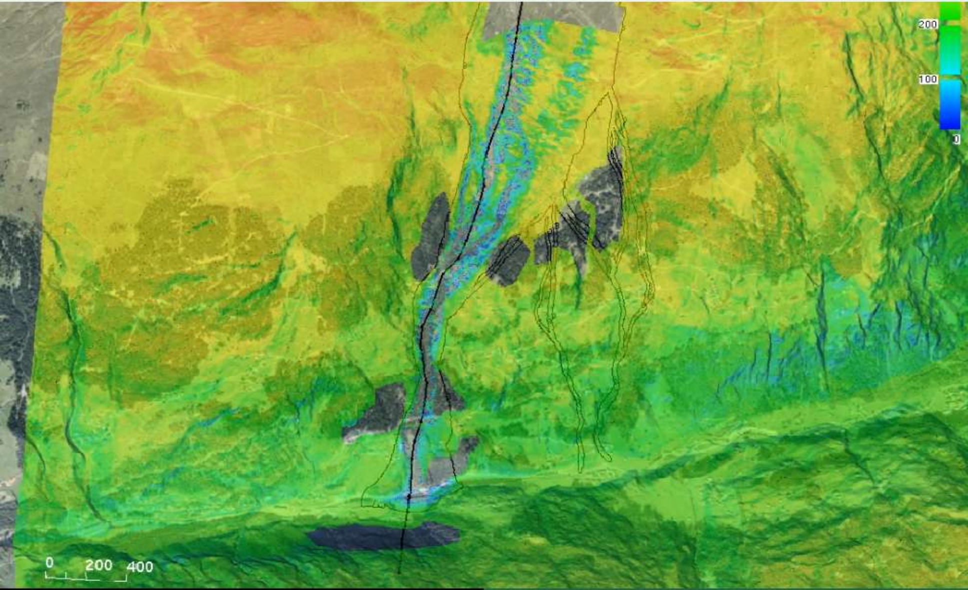
simulation results - maximum impact pressure

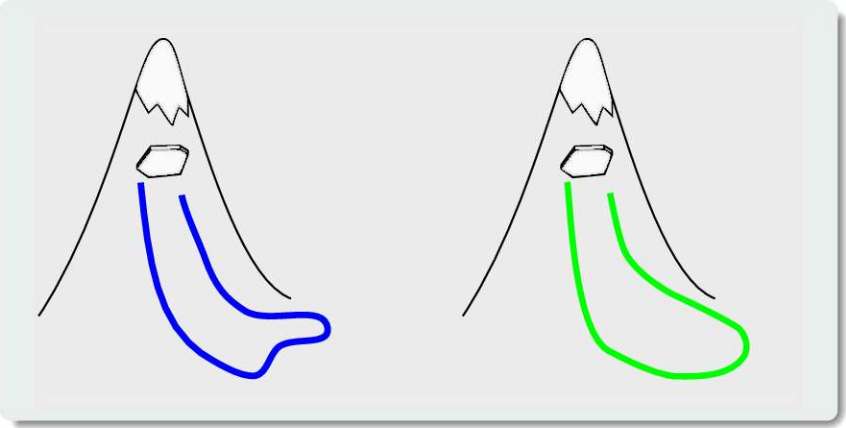
- $P(x, y, t) = \rho\, u^2$
- $\tilde{P}(x, y) = \max_t P(x, y, t)$

Example: Moosbach avalanche



Example: Moosbach avalanche





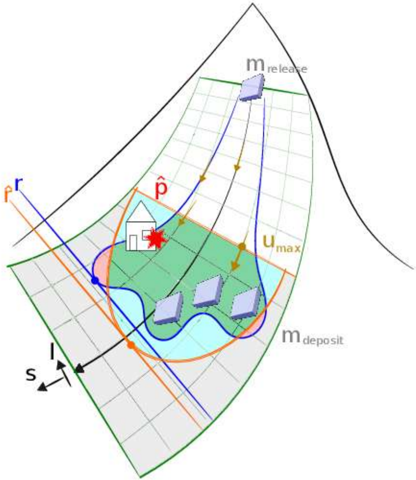
input: topography, information on release and snow distribution, model parameters

output: flow depth, velocity, ... maximum impact pressure - $\tilde{P}(x, y)$

- how to determine start and end point in a global framework?
- how would an avalanche see it?

- how would an avalanche see it - change of framework
- coordinate transformation along the avalanche path

Simulation results and optimization variables



flow depth and velocity → impact pressure, runout, *local risk*, ...

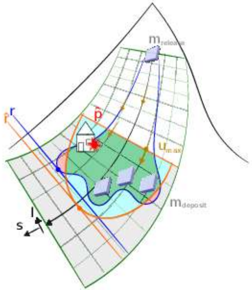
What is runout?

definition of optimization variables in terms of simulation and documentation

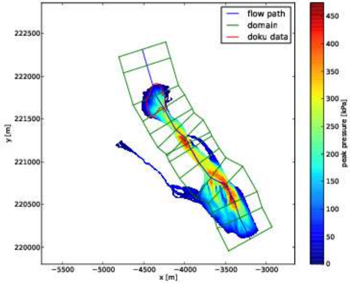
Optimization variables $X = \{r, t, f, p, u_{max}, d, V\}$

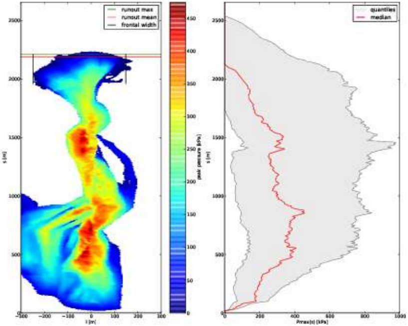
documentation $\hat{X} \pm \sigma_{\hat{X}}$ - **simulation** X

1. run out - r
2. matched affected area (true) - t
3. exceeded affected area (false) - f
4. damages - p
5. maximum velocity - u_{max}
6. deposition volume - V
7. average deposition depth - d



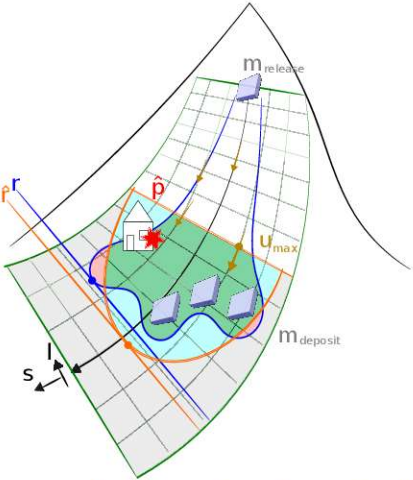
analysis and coordinate transformation





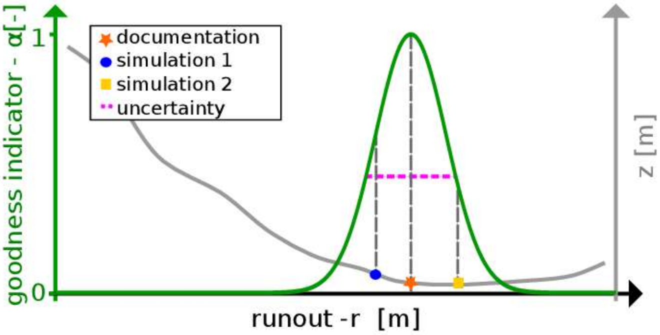
transformation of simulated peak pressure results in path dependent coordinate system: $p\,(x, y) \rightarrow p\,(s, l)$

Optimization variable runout



e.g. *runout* for documentation - $\hat{r}$ and simulation - r

Simulation-observation correspondence in one number: α

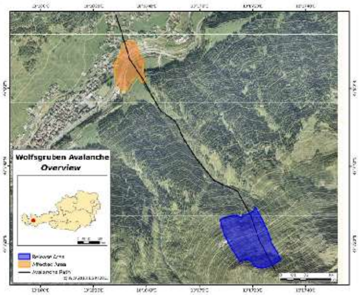


Comparison of simulated - r and documented - $\hat{r}$ runout

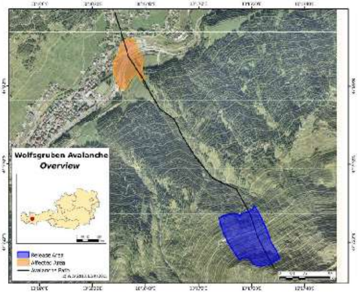
$\pm$ (observational) uncertainty yields correspondence measure $\alpha_r \rightarrow 0 - 1$

Example - Wolfsgrube 1988

- Monte Carlo simulation with 10000 runs $\rightarrow \mu, \xi, e_b$

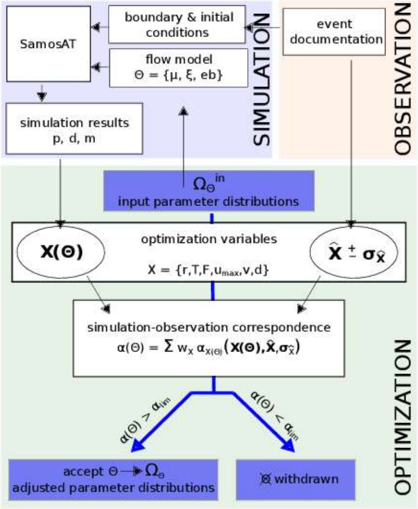


Example - Wolfsgrube 1988



documentation	value $\hat{X}$	uncertainty $\sigma_{\hat{X}}$
$\hat{r}$ - runout	2219 m	±50 m
$\hat{A}_{\text{affected}}$ $(\hat{t} = 1,\ \hat{f} = 0)$ - affected area	64153 m^2	±10 %
$\hat{u}_{\max}(\Delta z = 984\,\text{m})$ - maximum velocity	58.9 m s^{-1}	±2.5 m s^{-1}
$\hat{G} = \frac{m_{\text{deposit}}}{m_{\text{release}}}$ - growth index	1.45	±0.1
$\hat{d}$ - deposition depth	4	±0.5 m

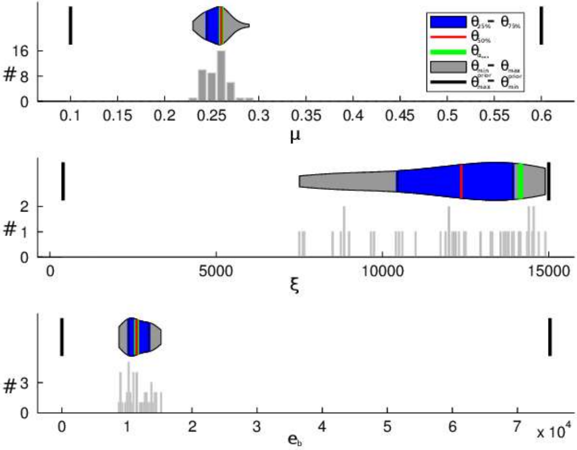
Simulation and optimization concept



Performing 10000 Monte Carlo simulation runs *picking* the most suitable

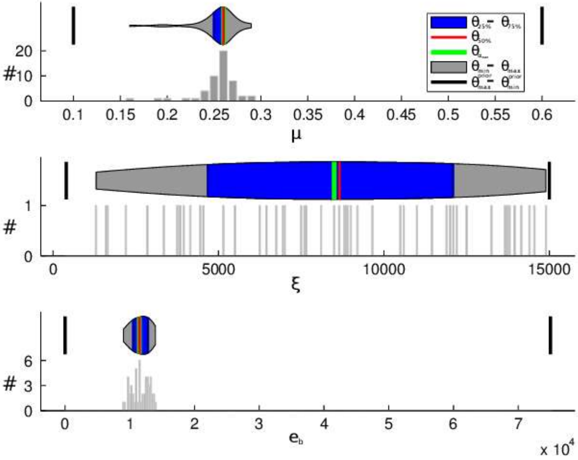
Optimized parameter distributions

- all optimization variables $X = \{r, t, f, u_{\max}, d, G\}$

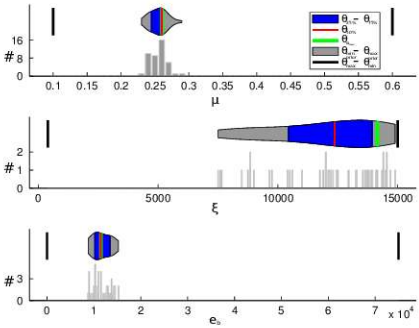


Optimized parameter distributions - without u_{max}

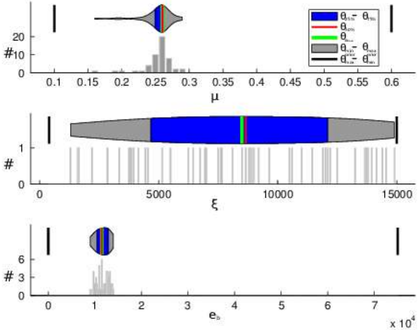
- reduced set of optimization variables $X = \{r, t, f, d, G, \cancel{u_{max}}\}$



Optimized parameter distributions - comparison

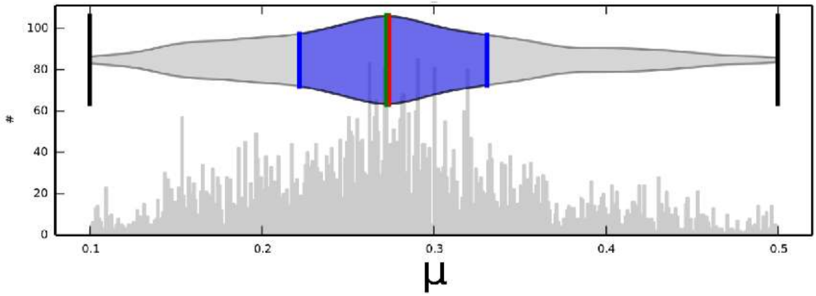


$X = \{r, t, f, u_{\max}, d, G\}$



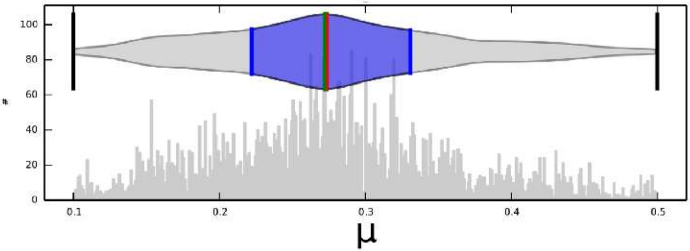
$X = \{r, t, f, d, G, \cancel{u_{\max}}\}$

Combination of 15 different avalanche paths

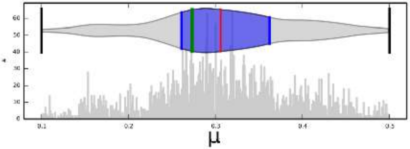


- common optimized parameter distribution for dry coulomb friction: μ = 0.10-0.50 → 0.10-0.35
- correlation analysis according to avalanche characteristics: volume, vertical drop, run out altitude, ...
  - correlation of μ and run out altitude $r = -0.47$
- multi-linear regression to find sub-distributions

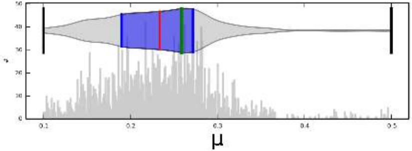
sub distributions according to correlation analysis



common distribution, $\bar{\mu} = 0.27$

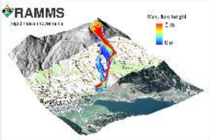


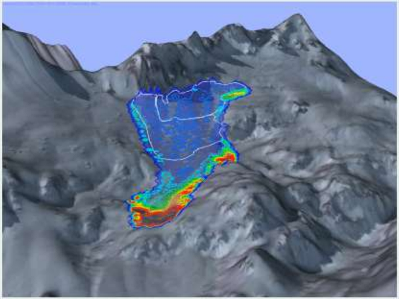
run out altitude $< 1245\,\text{m}$, $\bar{\mu} = 0.31$



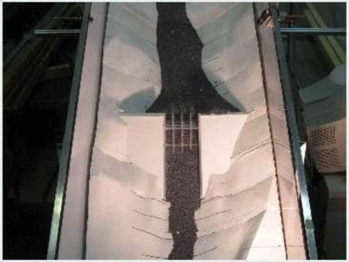
run out altitude $> 1245\,\text{m}$ $\bar{\mu} = 0.23$

computational avalanche dynamics

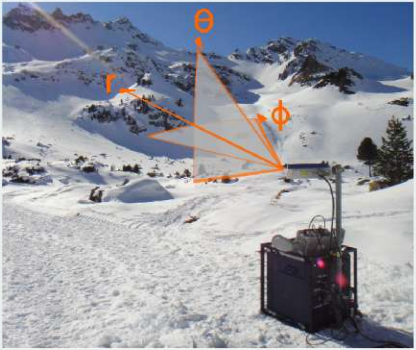




experimental avalanche dynamics

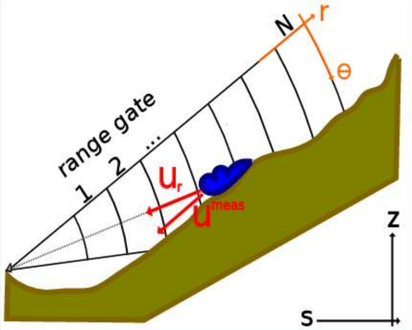


field measurement



pulsed Doppler radar measurements
5.8 GHz ≈ 5 cm snow clods

data processing



range gate width ≈ 25 − 100 m
topographic correction and projection

Ryggfonn

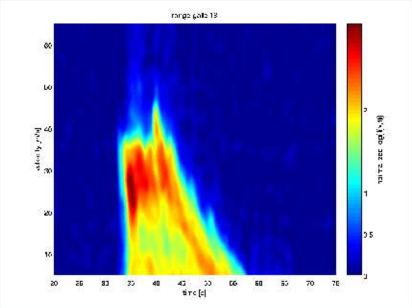
Vallée de la Sionne

Ryggfonn

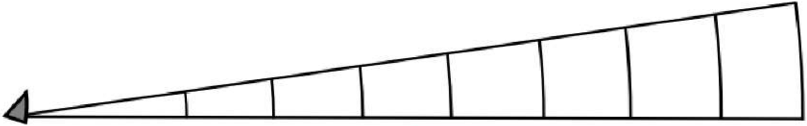
Vallée de la Sionne

VdIS 03.02.2015

525-550 m



- range gate intensity spectra $I(t, \Delta f) \rightarrow I(t, v)$
- lowpass and noise filtering
- normalizing with background sin-gnal



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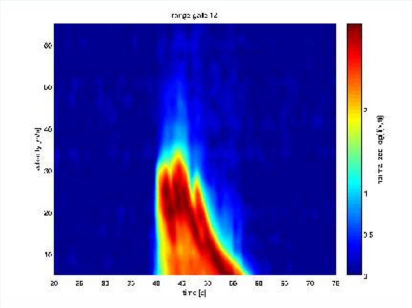
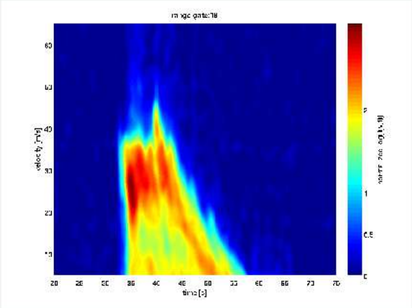
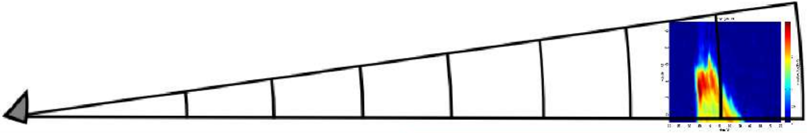
375-400 m



525-550 m





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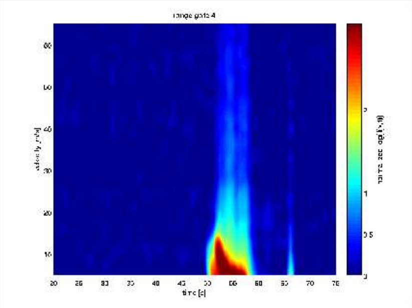
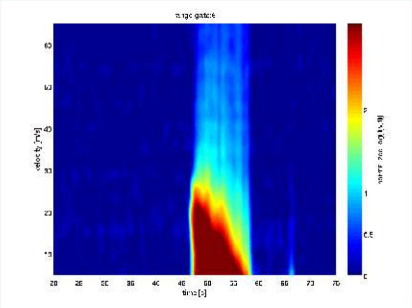
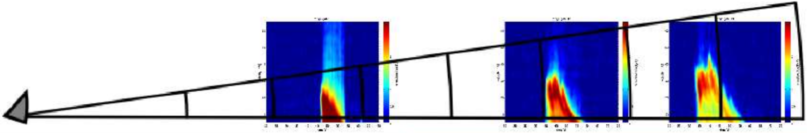
175-200 m



225-250 m



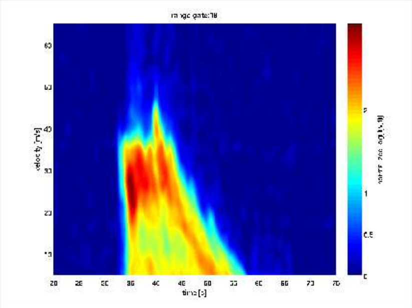


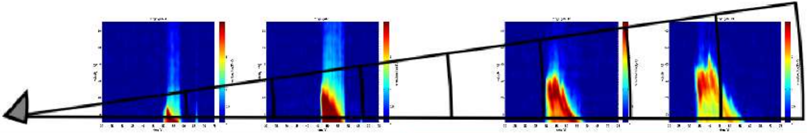
VdIS 03.02.2015

different velocity types

- velocity of maximum intensity
- front velocity
- velocity range
- ...

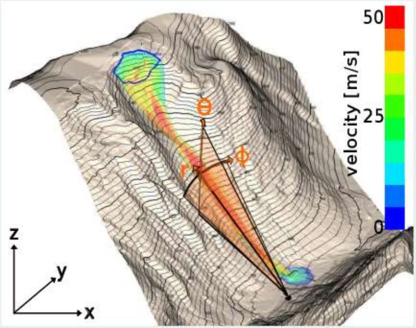
525-550 m



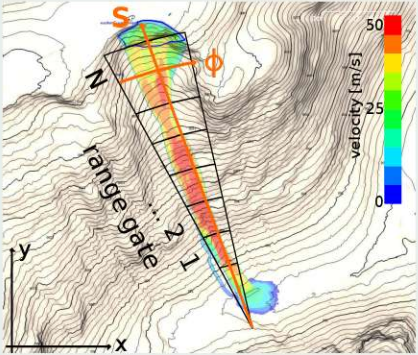


evaluation - Ryggfonn

simulation output

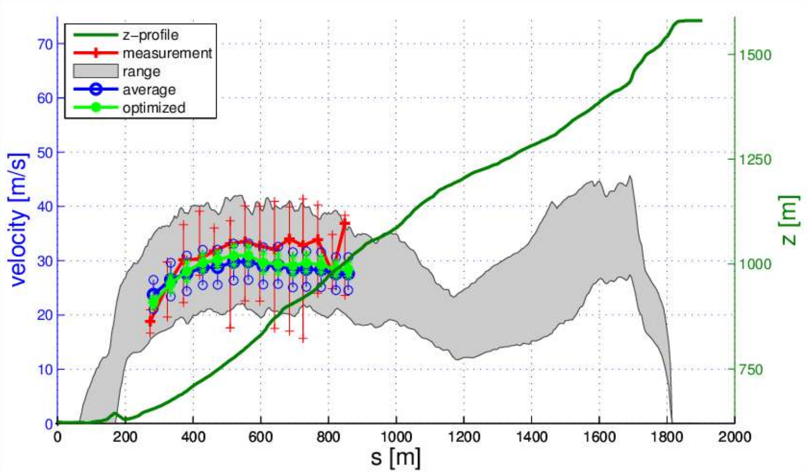


result processing



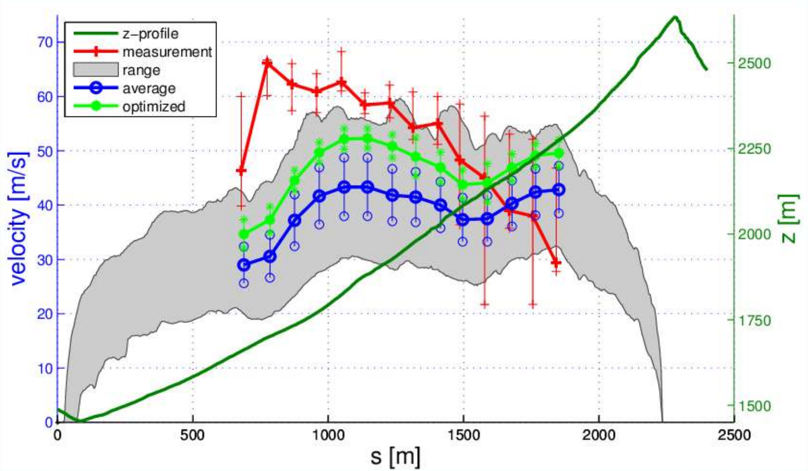
simulation input: topography, release height (measurement uncertainty), model parameters
transformation in measurement system,
comparison of multiple (10000) simulation runs.

Ryggfonn - avalanche simulation with release depth variations



velocity evaluation and uncertainty estimation with probabilistic methods

Vallée de la Sionne - avalanche simulation with release depth variations



velocity range, average and best fit... → parameter optimization

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