REPORT

# Applied Avalanche Research in Norway

FONNBU 50-YEAR CELEBRATION

DOC.NO. 20230100-02-R
REV.NO. 0 / 2023-11-10

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

# Project

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| Project title: | Applied Avalanche Research in Norway |
| Document title: | Fonnbu 50-year celebration |
| Document no.: | 20230100-02-R |
| Date: | 2023-11-10 |
| Revision no. /rev. date: | 0 / |

# Client

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| Client: | NVE |
| Client contact person: | Odd Are Jensen |
| Contract reference: | 20230100 |

# for NGI

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|---|---|
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# Summary

NGI's avalanche research station at Strynefjellet in western Norway was officially opened in October 1973, and in September 2023 NGI and the AARN project invited to a 3- day celebration in Stryn.

The aim of the celebration was networking, knowledge transfer between generations, and strengthening the collaboration both with national and international research institutes.

Forty-three Norwegian and international colleagues and contacts were gathered at Hjelle hotel. The event included a scientific seminar at the Jostedalsbreen National Park Centre, an anniversary dinner at Hjelle hotel, and a tour to Ryggfonn and Fonnbu. The event ended with a discussion on possibilities for future collaboration, research and networking, utilizing the facilities at Ryggfonn and Fonnbu.

This report summarizes the scientific contributions and discussions, as well as the discussion of future research and collaboration at Fonnbu.

# Contents



# Appendix



# Review and reference page

# 1 Introduction

NGI's avalanche research station at Strynefjellet in western Norway was officially opened in October 1973. The station has been at the centre of much of the avalanche research in Norway; with numerous field experiments conducted in the nearby valleys and the hosting of many national and international research partners as well as avalanche training courses and seminars since it opened.

A generation shift is ongoing in the snow avalanche group at NGI. Half a century after its initiation, all the group members who joined in the 20$^{th}$ century have partly or entirely retired. This is therefore a good occasion to wrap up and set a good starting position for the coming decade:

- What has been done during the past 50 years, what have we learned and how?
- What are the most important questions to solve in the coming decade?
- How can we, in collaboration with both Norwegian and international research partners, utilize the facilities in Fonnbu and Ryggfonn to solve these challenges?

These three main objectives were addressed through the 3-day program 6–9 September 2023, with social events at Hjelle hotel, a scientific seminar at the Jostedalsbreen National Park Centre, through a field visit to the avalanche test site Ryggfonn, and finally with discussions of future collaboration at the research station Fonnbu.

*Figure 1-1: 43 avalanche researchers from Norway, Switzerland, Austria, Iceland and Canada were gathered for scientific discussions in outstanding surroundings at the national park centre!*

## 1.1 General program

| **Wednesday 6th September** | | |
|---|---|---|
| 12:30 | Mountain hike | From Hjelle hotel |
| 6pm – 10 pm | Informal reception | Hjelle hotel |
| **Thursday 7th September** | | |
| 9am – 5 pm | Seminar: Where are we, and where should we be in 10 years? | Jostedalsbreen National Park Centre |
| 7pm – 11 pm | Anniversary dinner and party | Hjelle hotel |
| **Friday 8th September** | | |
| 10am – 12am | Visit to the full-scale avalanche test facilities | Ryggfonn |
| 1pm – 4pm | Lunch and discussions | Fonnbu research station |
| 4pm – 9 pm | Visit to Hoven skylift | Loen |

## 1.2 Participants

| **Name** | **Affiliation** |
|---|---|
| Stefan Margreth | SLF |
| Johan Gaume | SLF / ETH Zurich |
| Michaela Teich | BFW |
| Anselm Köhler | BFW |
| Dave McClung | UBC, NSERC |
| Mathias Granig | WLV |
| Gebhard Walter | WLV |
| Harpa Grimsdottir | IMO |
| Kristin Martha Haakonardottir | Verkis iceland |
| Stian Langeland | Wyssen Norge |
| Paul Vesland | Wyssen Norge |
| Walter Steinkogler | Wyssen |
| Odd Are Jensen | NVE |
| Odd-Arne Mikkelsen | NVE |
| Lars Harald Blikra | NVE |
| Rune Engeset | NVE, CARE, EAWS |
| Chris D'Ambroise | UiT |
| Albert Lunde | Nasjonalt kompetansesenter for fjellredning |
| Aanon Clausen | Forsvarets vinterskole |
| Henrik Langeland | SkredAS |
| Denise Christina Rüther | Sogndal |
| Heidi Hefre | NGI |
| Kjersti Gisnås | NGI |
| Peter Gauer | NGI |
| Sunniva Skuset | NGI |
| Anders Kleiven | NGI |

| | |
|---|---|
| Callum Tregaskis | NGI |
| Kate Robinson | NGI |
| Christian Jaedicke | NGI |
| Dieter Issler | NGI |
| Regula Frauenfelder | NGI |
| Sean Salazar | NGI |
| Elise Morken | NGI |
| Holt Hancock | NGI |
| Rosa M. Palau | NGI |
| Anders Solheim | NGI |
| Dominik Lang | NGI |
| Frode Sandersen | NGI – retired |
| Ulrik Domaas | NGI – retired |
| Krister Kristensen | NGI – retired |
| Steinar Bakkehøi | NGI – retired |
| Erik Hestnes | NGI – retired |

# 2 Scientific seminar: “Where are we, and where should we be in 10 years?”

A scientific seminar entitled “Where are we, and where should we be in 10 years?” was held at the Jostedalsbreen National Park Centre on 8th September.

## 2.1 Introduction

Since the 1970s, NGI has received funding from the Ministry of Petroleum and Energy via the Norwegian Directorate of Water Resources and Energy – NVE. This has allowed NGI to run the Fonnbu research station and full-scale experiments for avalanches in Ryggfonn in Strynefjellet and conduct applied avalanche research for the Norwegian society. Here we have unique opportunities to observe and study, among other things, the speeds and pressures in full-scale avalanches under relatively controlled conditions. Today, the entire original research team has passed retirement age. Luckily, new people have joined and are joining our team, and today we have a very promising avalanche research team with a good mix of age, gender, and research interests!

The research is organized in 3-year project periods, and the project is today called *AARN – Applied Avalanche Research in Norway*. AARN has just started a new period lasting from 2023 through 2025, and the first full reference group meeting was held on 7th September at Fonnbu. Our research is organized under three main topics:

1. Avalanche formation and release
2. Avalanche dynamics
3. Vulnerability and hazard zoning

The seminar and celebration mark the start of the new project period, and the topics reflect the main work packages in AARN. The aims of this seminar were to

1. strengthen the knowledge transfer between generations by discussing
    - where are we today?
    - what should be solved in the coming decade?
2. ensure our research is relevant and novel by
    - strengthening our European research network to increase collaboration
    - gathering national stakeholders and research institutions to intensify our collaboration with them.

Six invited speakers, two for each main research topic, tried to answer the following questions: *What have we achieved in avalanche research, what is the state-of-the-art, and what are the main challenges to solve in the coming 10–20 years?* The speakers were selected to represent the Norwegian perspective and the more international/ European (here Swiss/Austrian) perspectives for each of the topics. Each session was ended with a discussion. Two of the speakers—Johan Gaume and Michaela Teich—are members of the AARN reference group, while Odd Are Jensen is the project owner of AARN in NVE.

| **TOPIC 1: FOREST EFFECTS ON RELEASE AREAS AND PROBABILITY** | **9:15 AM** |
|---|---|
| Peter Gauer (NGI) | 20 min |
| Michaela Teich (BFW) | 20 min |
| Discussions - where are we, and where should we be in 10 years? | 30 min |
| Break (coffee and snacks) | 30 min |
| **TOPIC 2: AVALANCHE DYNAMICS** | **11:00** |
| Dieter Issler (NGI) | 20 min |
| Johan Gaume (SLF/ETH) | 20 min |
| Discussions - where are we, and where should we be in 10 years? | 30 min |
| *Lunch and tour at the national park centre* | *12:30-14:30* |
| **TOPIC 3: VULNERABILITY AND HAZARD ZONING** | **14:30** |
| Odd-Are Jensen (NVE) | 20 min |
| Stefan Margreth (SLF) | 20 min |
| Discussions - where are we, and where should we be in 10 years? | 30 min |
| In memory of Sam Wyssen - Stian Langeland (Wyssen) | **16:00** |

## 2.2 Topic 1 – Forest effects on release areas and probability

**Short summary of the presentation by Peter Gauer, NGI (attached):**

The effect of forest avalanche danger or in hazard mapping is twofold:

1. The effect on release probability
    a. Tree trunks support the snowpack.
    b. The loading rate is reduced due to snow interception.
    c. The snowpack properties are modified.
2. The effect on the runout
    a. Braking effect – trees act as obstacles retarding the flow.
    b. Tree debris may, however, also increase the risk.

NGI is currently trying to incorporate the different effects mentioned above in models, both for the release probability and the runout. In the release probability model, support from tree trunks and reduced loading intensity are already included. However, more work is needed on how the forest influences the snowpack and its stability. In the runout model, trees contribute to the friction and drag coefficients, but there are open questions regarding non-linear effects. More research and validation data are needed.

We have seen many examples of rare, very destructive avalanches in which the forest played a minor or no role. Protection forest may be able to stop or significantly decelerate small, frequent avalanches – when a really big, rare avalanche occurs, the forest is destroyed and has little effect on the extreme runouts.

**Short summary of the presentation by Michaela Teich, BFW (attached):**

*"Avalanche protective forests: what do we know and where do we grow from here?"*

Protective forests play an important role but are often poorly maintained – why?

BFW developed FlowPy to map the protective function of forest
→ result: 16% of the forest area in Austria has a direct protective effect.

FlowPy: Open-access decision support tool for identifying protective forest -

- data-based runout and intensity model for regional modelling of snow avalanches, rockfall and shallow landslides
- easily adaptable, requires few input parameters.
- Seeks to estimate the effect of forest on avalanche runout.
- Currently being implemented in AvaFrame

The primary protective effect of forests is on avalanche formation and release in potential avalanche starting zones. Two ways to address this:

- process-based approaches
- observation-based approaches

Most important parameters in the release area:

- Gap width, crown cover, density of evergreen trees, slope angle
- Shrub forest layer and surface roughness are also important.
- These parameters are included in the method by Bebi et al. (2021), now widely used for protection forest mapping.

Climate change: the past is not always representative for future conditions! Process-based approaches are needed to quantify future protective effects on avalanche release:

- Disturbed forest and post-disturbance management
  → What is the protective effect of dead timber in a windthrown area?

**Discussion points:**

There is a current lack of observational data – in terms of forestry parameters, snowpack processes and their effect on avalanche release in forested areas, and the direct braking effect of forests on avalanches. Collaboration potential for augmenting existing and developing new observational datasets addressing this topic emerged as a theme from the discussion.

## 2.3 Topic 2 – Avalanche dynamics

**Short summary of the presentation by Dieter Issler, NGI (attached):**

*"A Tour of Avalanche Dynamics Along Overgrown Paths"*

*From statistical to dynamical models:*

Compared to the models with fixed runout angle α in the early 1900s, NGI's α-β model (1980), accounting for path steepness, brought a significant improvement. However, it should be calibrated for each climate zone!

*Block models:*

- Underestimate the velocity in large avalanche paths – a generic problem of PCM and Voellmy-type models
- 1D and 2D continuum models like RAMMS have the same problem.
- Practitioners counter this deficiency with size-dependent friction parameters.
- This shortcoming has practical consequences:
  - Avalanches may choose different paths in winding gullies.
  - Many protection dams dimensioned too low because of this!

*What do we learn from real avalanches?*

- Deposition area of fluidized layer extends several hundred meters longer in many cases – moderate pressure, but still considerable damage.
- Powder-snow cloud may run significantly longer.
- The intermediate layer is not captured in current models!

*The modern approach: μ(I) rheology – the future?*

- Effective friction coefficient μ grows sublinearly with shear rate I
- ⇒ Higher velocity along the path than in Voellmy models with same runout
- Must be extended to μ(I)-ϕ(I) rheology with variable density to correctly capture the deposit depth at and beyond the dam in Ryggfonn.

*The forgotten alternative: an extension (eNIS, 2007) of NGI's NIS model (1987):*

- Key idea: combine the granular/viscoplastic rheology of NIS with the density dependence of sheared granular flows.
- Density adjusts itself to balance bed-normal dispersive pressure with weight.
- ⇒ Striking increase of runout distance and velocity compared to NIS model with constant density.

*Is air the missing piece in the puzzle?*

- Density of the fluidized layer in eNIS is still significantly larger than observed.
- Avalanche front compresses snow cover, creating excess pore pressure.
- Compressed air escapes through the avalanche and fluidizes it.
- Snow properties determine degree of fluidization, density, velocity, front length.
- Striking qualitative agreement with observations, but the theory must be incorporated in a numerical model and tested against measurements!

**Short summary of the presentation by Johan Gaume, SLF (attached):**

- Past century: continual increase in mathematical complexity of gravity mass flow models. Moderate increase in needed computational resources (1D and 2D depth-averaged continuum codes). Presently, transition from 2D depth-averaged models to fully 3D models *reduces mathematical complexity but increases computational demands sharply*.
- Development effort at SLF along two axes: 1) Material Point Method (MPM) code to be introduced in practice ~2026. 2) Commercial Discrete Element Method (DEM) code allows studying processes at the particle level.
- An MPM code developed at SLF is able to simulate both fracture propagation and avalanche flow using a cohesive viscoplastic critical-state rheology.
- Depending on the assumed snow properties (friction coefficient and cohesion), the MPM code exhibits different erosion and entrainment modes (ploughing, basal erosion with/without entrainment. Efficient entrainment only in limited parameter domain. Net effect of entrainment can be deceleration or acceleration.
- Similar results obtained with DEM. Very useful for improving entrainment law in depth-averaged models!
- MPM code shows the emergence of roll waves and erosion/deposition waves depending on slope angle, curvature, snow properties and avalanche size/speed. Such waves may be decisive for destructive effect of avalanches.
- MPM and DEM particularly suited for avalanche impact on structures.
- With suitable computer resources, 3D simulation of large avalanches is possible.

**Discussion points:**

There was general agreement on several points:

- Traditional depth-averaged models are still useful and needed, particularly in large-area hazard mapping and quantitative risk analysis.
- There is considerable scope for improving the depth-averaged models so that they describe different flow regimes and entrainment/deposition.
- The new modelling techniques presented by Johan Gaume can be used to great effect to study basic flow processes in detail to inform the development of better depth-averaged models.
- In the medium-to-long-term perspective, 3D codes simulating particles directly (DEM) or as a discretization technique for continuum models (SPH, MPM), or combinations of both techniques (e.g., DEM+CFDe) may replace the traditional depth-averaged models.

## 2.4 Topic 3 – Vulnerability and hazard zoning

**Short summary of the presentation by Odd Are Jensen, NVE (attached):**

- Large parts of the areas most exposed to avalanches in Norway have been mapped in the last years (56 municipalities). NVE has had an ongoing program for this.
- Done by different consultants.
- NVE also developed a guideline for hazard mapping – best practice.
- Houses susceptible to avalanches:
  - With current forest: 144 000
  - Without forest: 304 000
- Need for large investments in mitigation measures in the coming years
- Most urgent research needs:
  - Avalanches with long return periods (realistic fracture depth and release area, wind drift, etc.)
  - Climatic / regional variances
  - Forest effect both on release and runout
  - Powder-snow cloud effect on runout
  - Pressure/intensity criteria
  - Effects of climate change
- Develop better tools for contingency planning and site-specific forecasting.
- Improve education of natural-hazards consultants.

**Short summary of the presentation by Stefan Margareth, SLF (attached):**

The Swiss criteria for hazard zoning with 3 return periods (30/100/300 y) and pressure limits of 30/3/(1) kPa have heuristic origin but have been found to be useful. Other countries have adopted significantly different criteria.

The procedure for elaborating hazard maps is well established, with field work and simulations typically amounting to ~15% of the total effort while analysis, map generation and reporting comprise ~50%.

Evaluating the pressure from rare powder-snow avalanches is still difficult. Comparison of SAMOS-AT and RAMMS::E show large divergences. A robust, easy-to-use and reliable model is sorely needed.

Assessment of an avalanche path by different experienced experts diverged massively because of the uncertainty in the delineation of release areas for different return periods. A methodology/model for estimating release probability is needed, the Swiss rules for selecting the fracture depth are useful but snowfall probability differs from release probability. The uncertainty of the assessments should be quantified with a probabilistic approach.

Extreme scenarios going beyond the 300-years scenario of the guidelines might be considered in the future, particularly where the risk can be large. Generally, risk considerations must be incorporated to a much larger degree than hitherto.

Accounting for climate change is challenging because its effects can mitigate or exacerbate the hazard, depending on the altitude zone, the probability of slushflows and the topographic effects of glacier melting.

*Executive summary:*

- Hazard maps and elaboration procedures (30/100/300 y + pressure limits) **have generally been successful**, as demonstrated in the extreme winters of 1999 and 2018 (event analyses).
- Hazard matrices of dense flow and powder snow avalanches will be combined; **structural and organizational requirements** can also be imposed in the yellow zone.
- Future: **risk-based land-use planning** that considers not only the hazard level but also the utilization.
- **Probabilistic simulation models** to capture uncertainties of hazard assessments
- Try to develop **objective rules** for defining release areas and release probability.
- Need for guidelines for handling **extreme scenarios** (return period 1000 years?)
- Improved **assessment of the effect of mitigation measures** (simulations?): catching dams, retarding structures
- Rules for systematic consideration of **climate change** in hazard assessments

- **Discussion points:** How do we best incorporate uncertainty related to climatic changes – both in terms of past changes and future projections – into the delineation of hazard zones?
- More generally, handling and visualization of uncertainty came up with regards to most discussion points including effects of structural mitigation measures,

extreme scenarios, probabilistic simulation models, climate changes etc. on vulnerability analyses and hazard zonation.

# 3 Visit to the full-scale test-site Ryggfonn

The full-scale test site Ryggfonn was established in 1981, with the possibility of artificially triggering avalanches, recording speeds and forces in the avalanche, and also to evaluate the effect of a 15 m high catching dam in the valley floor. The avalanche path has a drop height of 900 m and a length of about 2100 m. The size of the avalanches usually varies from 2 ($10^2$ t) to 5 ($10^5$ t), measured in the Canadian avalanche classification system (McClung and Schaerer, 1993), and the speed can reach up to 60 m/s.

An overview of the instrumentation history in Ryggfonn was given by Peter Gauer during the dinner Thursday evening. On Friday morning, the group went on a field tour to Ryggfonn, and an overview of the installations in addition to some results was given by Peter Gauer.

Today the main instrumentation consists of:

- Wyssen tower for avalanche release
- Weather station above the release area with temperature and wind observations
- Weather station in the valley floor with snow height, wind, temperature.

- Towers measuring velocity and pressure profiles in front of and on top of the catching dam.
- Doppler radar to detect avalanches and record velocity profiles
- Thermal camera to measure snow temperature of the snow cover and the avalanche, detect entrainment and estimate avalanche sizes (to be installed in 2023)

# 4 The way forward – discussions at Fonnbu

After the visit to Ryggfonn, we held a plenum discussion at Fonnbu, focused on research ideas in connection with the Ryggfonn test site and general ideas for future collaboration. There were many ideas, both for increased collaboration and networking, increased use of data, and new elements to the test facilities in Ryggfonn. It was also stated both by Swiss, Austrian as well as the Norwegian participants and NVE that the test facilities in Ryggfonn are unique, still generate highly relevant new knowledge and have the potential for increased research interest.

The main outcomes and ideas of the discussions are grouped and summarized in three main topics below:

**International collaboration and networking**

1. Increased network activity on avalanche dynamics
    a. Workshop hosted at Fonnbu

b. Search for funding to organize a European network for avalanche dynamics, with workshops etc.
c. Framework for avalanche test collaboration
d. Establish a database for model validation
e. Staff and student exchange
2. EU-proposal on avalanche or gravitational mass flows?
    a. Build on a similar structure as AARN: release area, run-out and vulnerability.
    b. Also include other gravitational mass movements in steep terrain to make it more overarching / suitable for EU-calls?
    c. SLF, NGI, BFW, WLV are all very interested in participating in a consortium.

**Ideas for future research in Ryggfonn and Fonnbu**

1. Use Ryggfonn more extensively for testing dam design and novel mitigation methods:
    a. Modify the dam on half of its length to test more modern dam designs with steeper upstream side
    b. Test additional mitigation structures (fences, nets, etc.) on the dam crown against the fluidized front
    c. Study degradation and maintenance needs of different dam structures, e.g. types of geotextiles, dry rock…
    d. Reach out to mitigation structure producers, railway and road authorities for funding (both Norwegian, Swiss and Austrian)
2. Study the fluidized layer in more detail:
    a. How to deal with it?
    b. Workshop on this topic?
    c. What can we do with the already gathered data in Ryggfonn?
    d. Install mitigation structure for the fluidized layer at the dam in Ryggfonn? Steel fences on top of the dam?
    e. Combine with lab experiments?
3. More studies on snow drift and release probability
    a. Use Ryggfonn to test models of avalanche release probability for avalanche warning (frequent surveys of snow depth in release area, modelling of snow properties).
    b. Testing snow drift models at Ryggfonn and Sætreskarsfjellet – also compare with data from other locations in Norway, e.g., Tyin.
4. Snow pressure measurements at Fonnbu
    a. Still need better knowledge of snow pressure from maritime areas with relatively high density snow masses – Fonnbu is ideal for this kind of studies
5. Slush flows and snowpack/avalanche release

   a. Snow profiles → calibration of SNOWPACK and/or Crocus → towards automatic forecasting tools?

**Data collection and sharing**

1. Common database for avalanche dynamics with open datasets
   a. Ryggfonn, Vallée de la Sionne, Col du Lautaret, Canada?, Austria?
   b. Not too many sites but focus on high quality and comprehensive measurements that allow to test all relevant aspects of the models.
   c. Standardized format of data sets from several test sites for model validation
2. Common international database for avalanches hitting dams
   a. Guidelines for measurements in the future
   b. Collect well-documented past events.
3. Collect and utilize data from other sites in Norway for snow drift and perhaps avalanche size and speed?
   a. 500 avalanches from avalanche control at Tyin (Wyssen/Skred AS).
   b. Data from other avalanche control sites, e.g. Grøtfjorden for release probability and size of release area?
4. Opportunities connected to the new national transport plan (NTP) in Norway:
   a. 2 billion NOK for landslide and avalanche mitigation per year. Suggest some more funding also for research and testing?
   b. Lobbying towards the Ministry of Transport
5. Make Fonnbu-data more easily available.

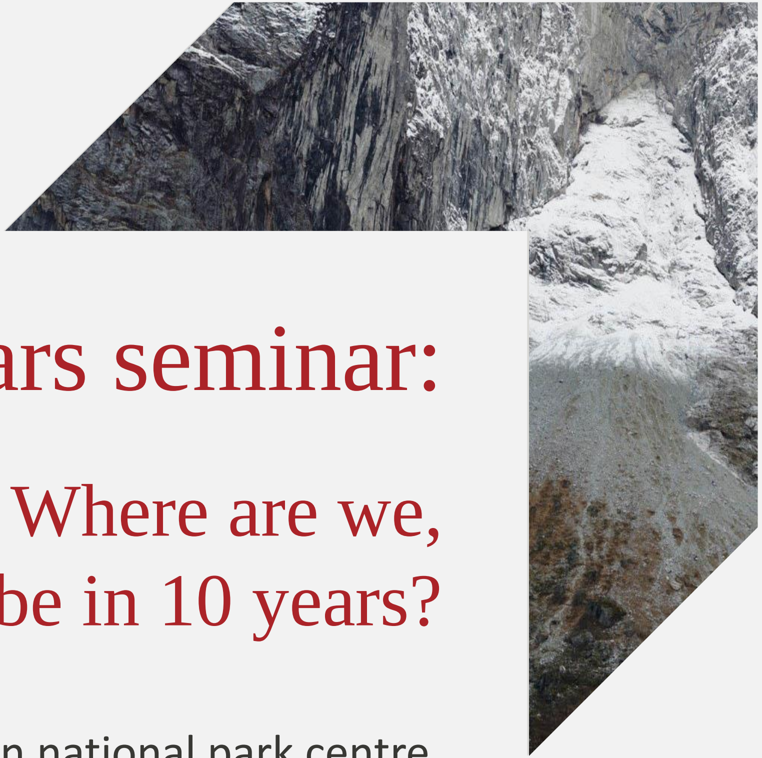
We highly appreciate all the ideas and comments made at Fonnbu and will build on these to increase collaboration both nationally and internationally, as well as plan new and exciting research plans in Fonnbu and Ryggfonn in the years to come.

*Figure 4-1: Discussions on future research possibilities at Fonnbu.*

# Appendix A

SEMINAR PRESENTATIONS

NGI



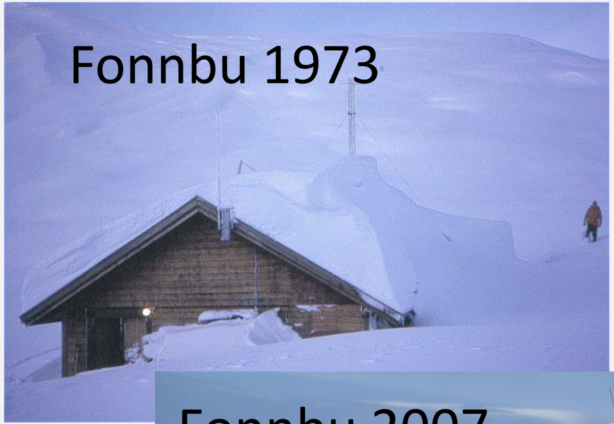
# Fonnbu 50 years seminar:

## Where are we, and where should we be in 10 years?

Jostedalsbreen national park centre

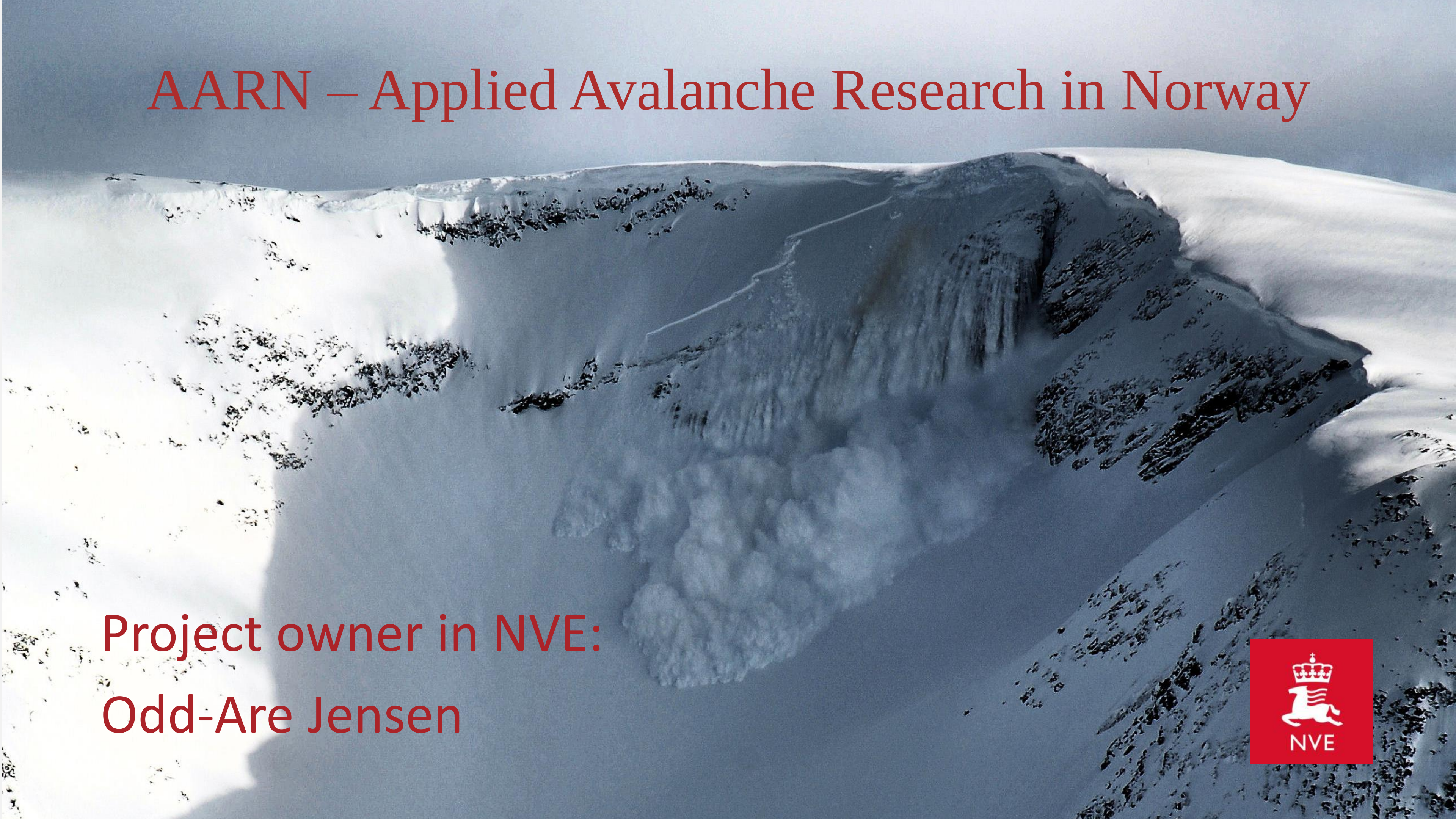
7th September 2023

# Research activities through 50 years





# AARN – Applied Avalanche Research in Norway



Project owner in NVE:
Odd-Are Jensen

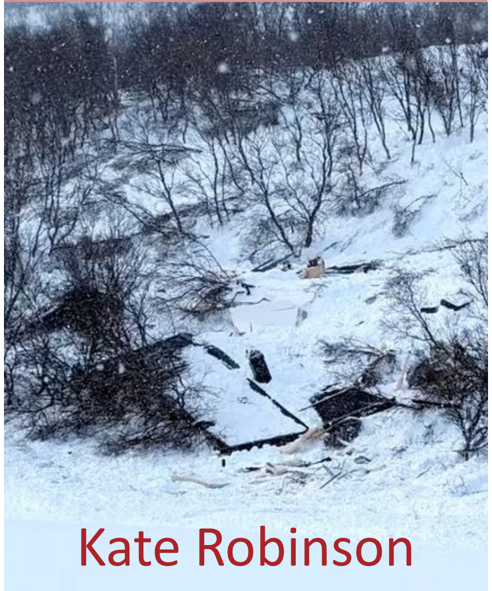
# AARN 2023-2025

WP0: Management and Dissemination

Kjersti Gisnås & Callum Tregaskis

WP1: Avalanche Formation and Release → WP2: Avalanche Dynamics → WP3: Avalanche Interaction






+ the rest of the AARN-team! (10+ researchers!)

# AARN – Applied Avalanche Research in Norway

<u>Reference group:</u>

- Michaela Teich, BFW
- Johan Gaume, SLF/ETH
- Odd-Arne Mikkelsen, NVE
- Tore Humstad, NPRA
- Henrik Langeland, Skred AS
- Nicolas Eckert, INRAE
- Tómas Jóhannesson, IMO
- Andrew Hogg, University of Bristol

# Aim of today's seminar and gathering

- Generation change
  - Where are we today?
  - What should be solved in the coming decade?
- How can we make our research relevant but also novel?
  - Strengthen European research network to increase collaboration
  - Gather and strengthen the collaboration with national stakeholders and research institutions

NGI

| | |
|---|---|
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| Break (coffee and snacks) | 30 min |
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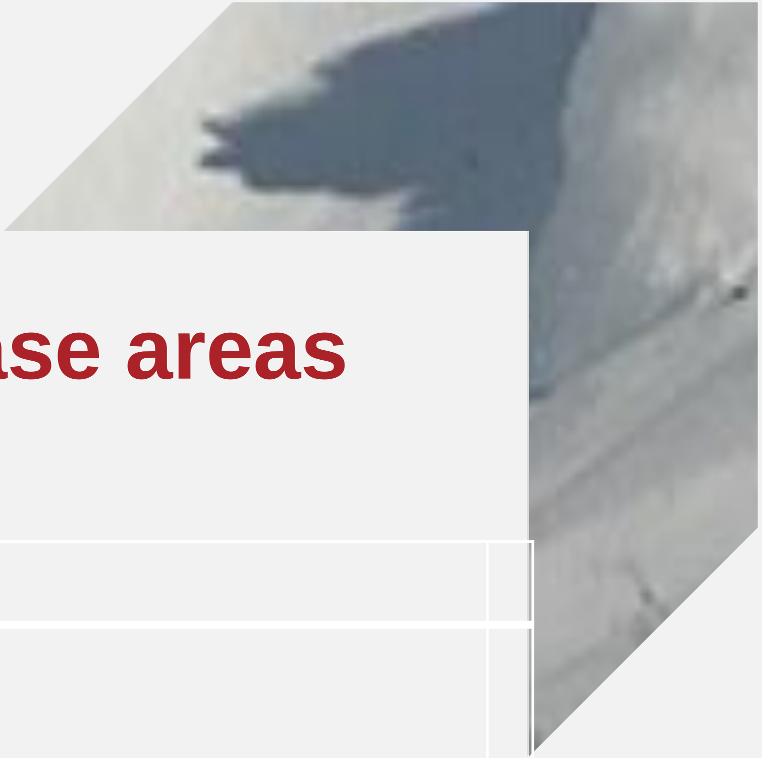
| In memory of Sam Wyssen - Stian Langeland (Wyssen) | **16:00** |

NGI

# Forest effects on release areas and probability



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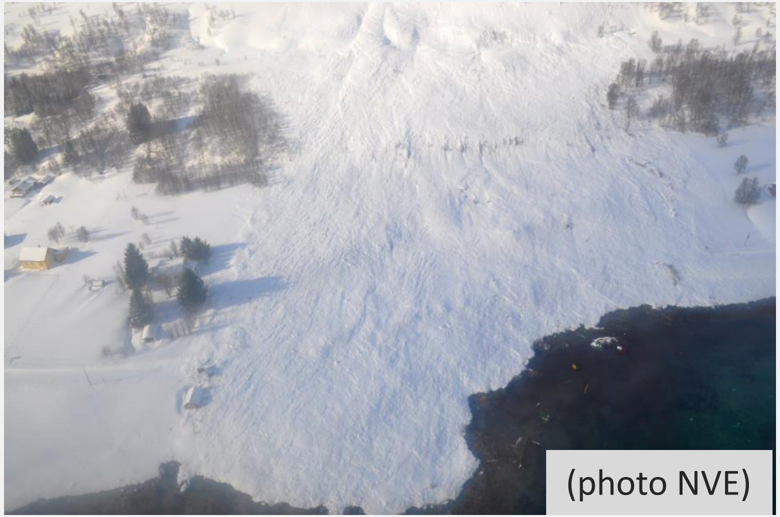
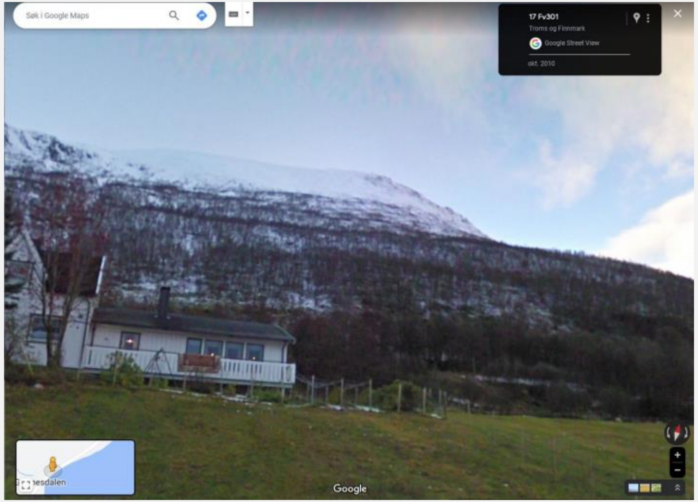
# Reinøya: 2023-03-31 15:00

(photo NVE)



(photo NVE)

- Total drop height was about 500 m.
- Lower half of the slope was covered by open birch forest.

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(photos from google street view, October 2010)

- Two fatalities
- 140 goats
- 20 sheep
- Several buildings obliterated
- Some of the buildings are said to have stood there for more than 150 years

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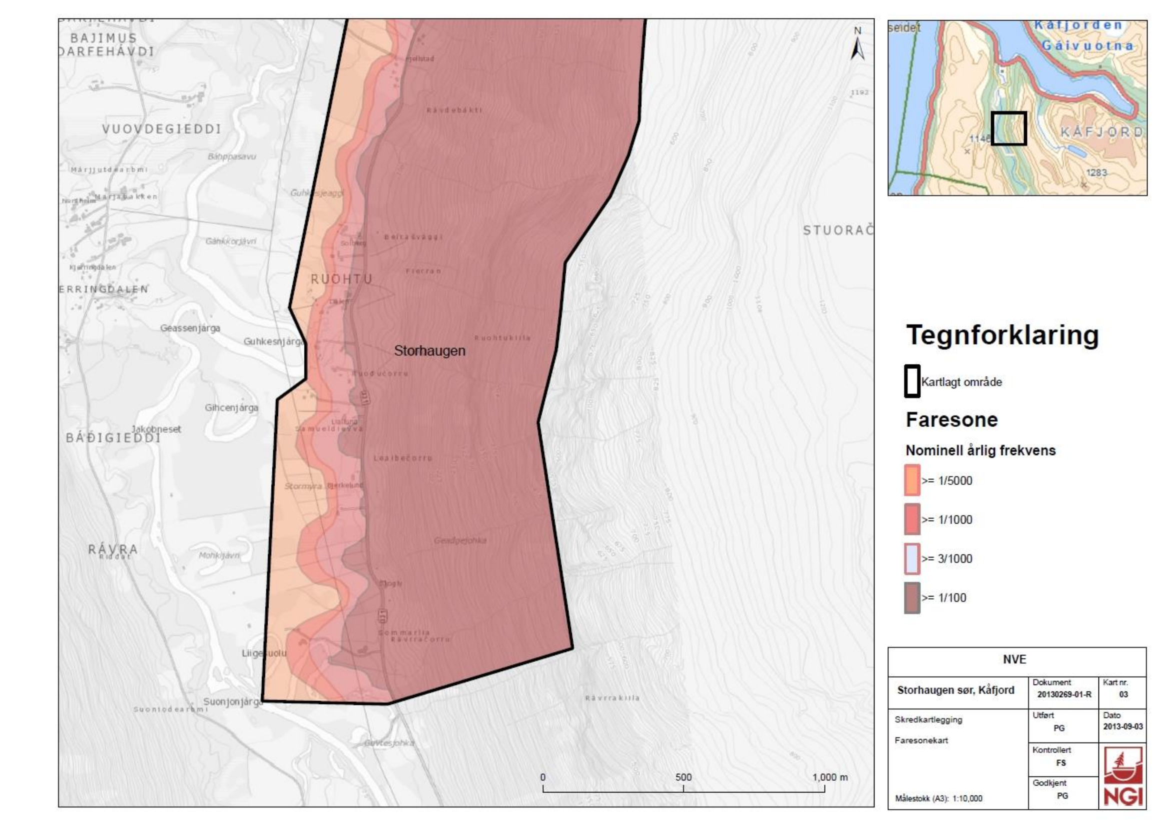
# Hazard mapping

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# What is the effect of forests regarding hazard mapping?

Tell: That's how it is, and the avalanches would
have buried the Altdorf under their weight long ago
if the forest up there didn't stand up to it as a militia.

F. Schiller: Wilhelm Tell III,3

- Bannwald
- Forest protection propagate by Foresters like J. W. F. Coaz
- Most cost-effective mitigation measure
- Natural based solution

Gruschenwald above Andermatt / Bannwald Andermatt
Bannbrief von 1397

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| Avalanche events in Blons | |
|---|---|
| Mont-Calv-Lawine | 1954 |
| Eschtobel-Lawine | 1946, 1954 |
| Falvkopf-Lawine | 1497, 1526, 1689, 1896, 1954, (2013) |
| Nova-Lawine | 1954 |
| Mura-Lawine | 1954 |
| Stutz-Lawine | 1954 |
| Walkenbach-Lawine | 1982 |

Blons: 56 fatalities and 2 still missing

Falvkopf

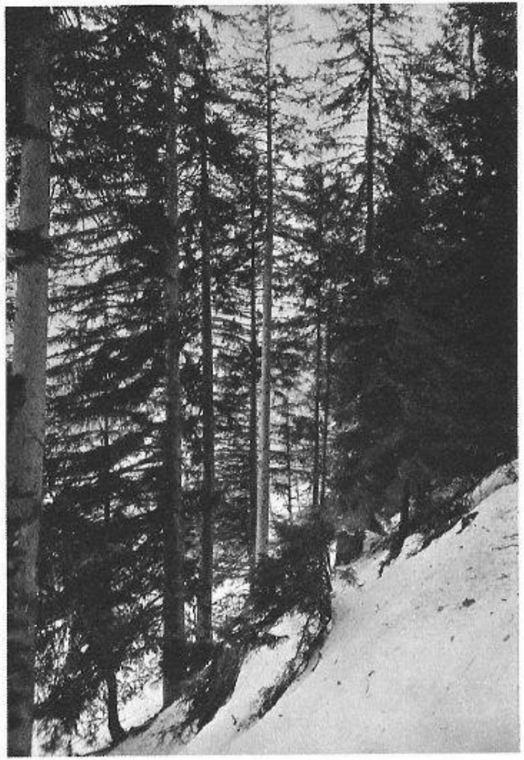
RT = $91 \pm 67$

Phot. E. Heß, Bern

Hockmatten
Grengiols, Rütiwald (oben) und Gastwald (unten), durch welche die Wildschneelawine vom 21. Februar hindurchging

Phot. E. Eugster, Brig

Ablagerung der Wildschneelawine von Hockmatten, 20. Februar 1931
Schnee von geringer Kohäsion



Phot. E. Eugster, Brig

Ried, Grengiols
Dichter Wald, der von der Wildschneelawine vom 21. Februar durchquert wurde

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Hess, E. (1931) **Wildschneelawinen**
*Die Alpen* SAC p. 321-334

# Gugelberg (SZ) 1987-01-22

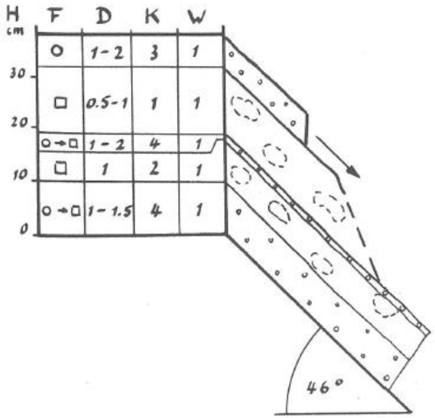


*Abbildung 2:* Schneeprofil beim Anriss A 1 am Gugelberg, 23. Januar 1987, 11.00 Uhr. Die oberste Schicht war am Vortag, zum Zeitpunkt des Lawinenanbruches, feucht und weich, gefror jedoch in der Nacht.

F: Kristallform
D: Korndurchmesser
K: Härte
W: freies Wasser

(Erläuterungen zum Schichtprofil siehe *Salm* 1982)

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*Tabelle 1.* Charakteristik der drei Bestände, in denen Waldlawinen anbrachen.

| *Anbruchort in Abbildung 1* | *A 1* | *A 2* | *B* |
|---|---|---|---|
| *Grösse der Aufnahmefläche* | *175 m²* | *340 m²* | *265 m²* |
| Stammzahl pro ha | | | |
| – Durchmesser 1–15 cm | 450 | 2560 | 1360 |
| – ab 16 cm Durchmesser | 630 | 760 | 530 |
| Mitteldurchmesser | | | |
| – ab 1 cm Durchmesser | 24,2 cm | 12,3 cm | 12,1 cm |
| – ab 16 cm Durchmesser | 37,6 cm | 23,1 cm | 26,4 cm |
| Grundfläche pro ha | | | |
| – Durchmesser 1–15 cm | 2 m² | 18 m² | 6 m² |
| – ab 16 cm Durchmesser | 75 m² | 35 m² | 33 m² |
| Baumartenanteil in % von der Grundfläche | 97 Bu<br>2 Fi<br>1 Ta | 61 Bu<br>18 BUl<br>11 BAh<br>10 Fi | 55 Bu<br>25 Fi<br>12 Es<br>5 BAh<br>3 SAh |
| Bestandesoberhöhe | 22 m | 15 m | 15 m |
| Deckungsgrad | 90 % | 90 % | 90 % |
| Schlussgrad | gedrängt | gedrängt | gedrängt |

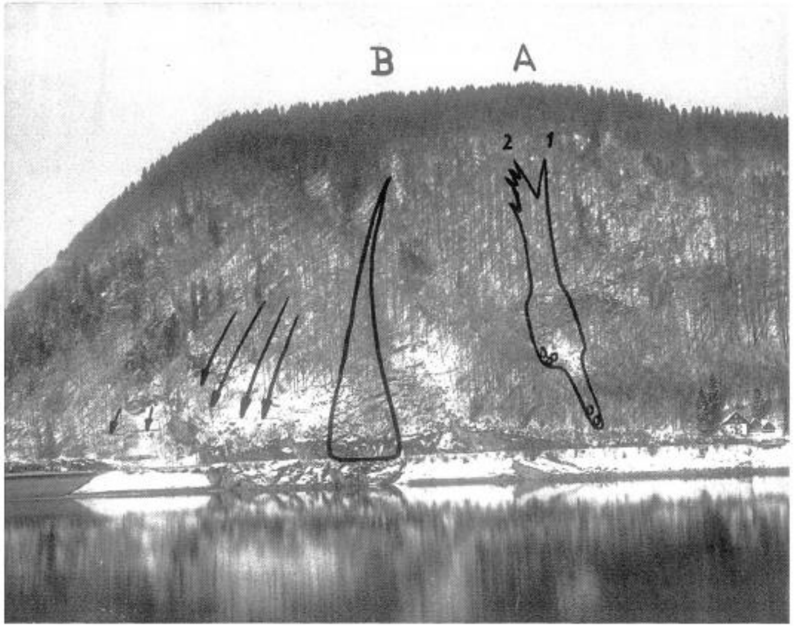


*Abbildung 1:* Gugelberg im Wägital mit den eingezeichneten Lawinen vom 22. Januar 1987. Am rechten Bildrand das Wärterhaus.

Imbeck, H. / Meyer-Grass, M. **Waldlawinen am Gugelberg**
1988 *Schweizerische Zeitschrift für Forstwesen* , Vol. 139, No. 2
p. 145-152

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# The technical regulations in Norway TEK17

**Table: Safety classes when building structures are placed in landslide or avalanche endangered areas**

| Safety class | Consequences | Nominal annual probability |
|---|---|---|
| S1 | Slight | < 1/100 |
| S2 | Moderate | < 1/1000 |
| S3 | Severe | < 1/5000 |

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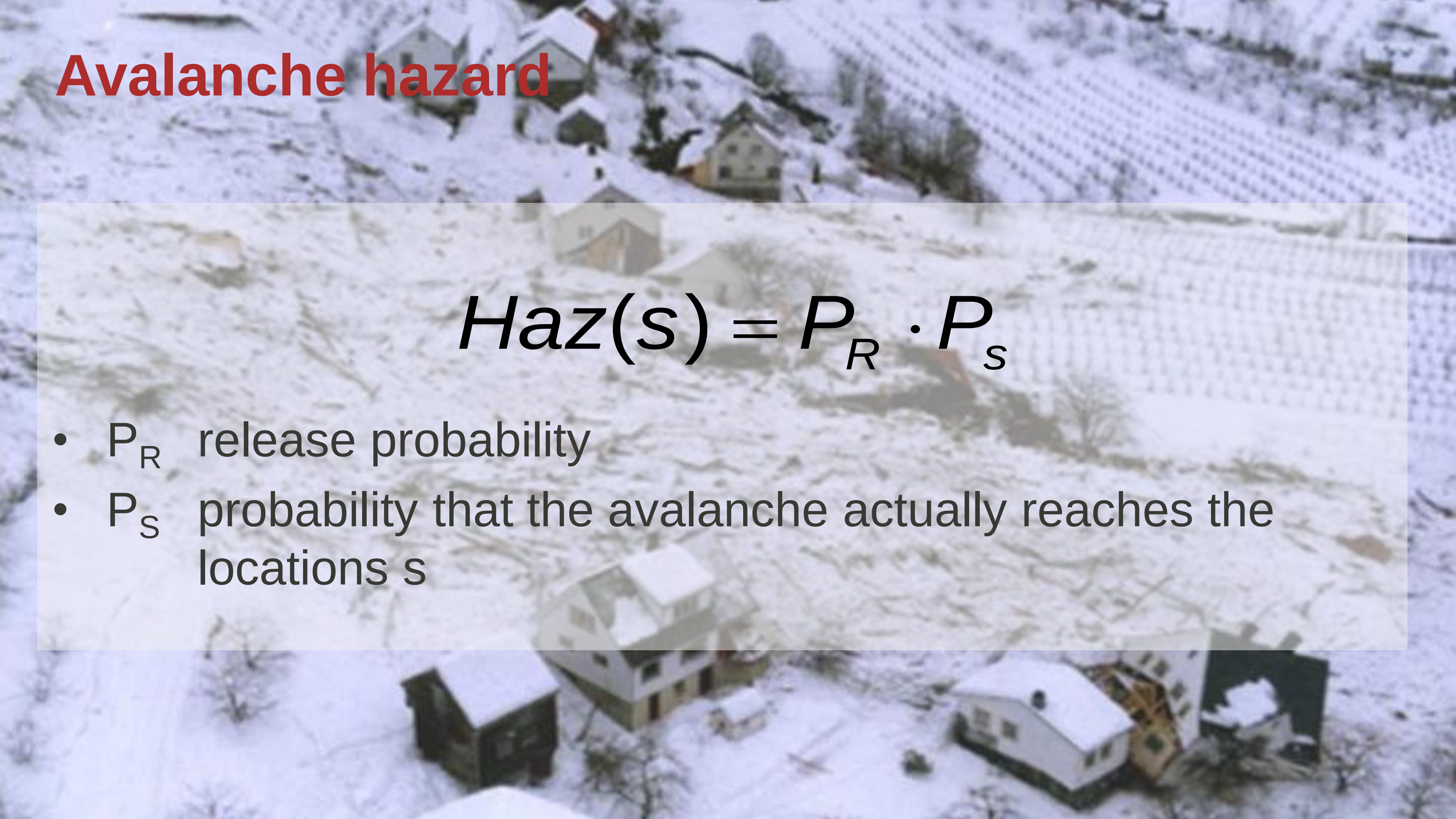
# Avalanche hazard

- Avalanche hazard is a combination of
  - terrain and vegetation
  - precipitation (snow or rain) and wind
  - snowpack conditions (probability of avalanche release)
  - runout of the avalanche

# Avalanche hazard



$$Haz(s) = P_R \cdot P_s$$

- $P_R$ release probability
- $P_S$ probability that the avalanche actually reaches the locations s

# The influence of forest on avalanche hazard

- One needs to distinguish between effect:
  - on release probability
  - on runout

# Avalanche in forests

South of Livingston (2019-01-26)

(photos GNFAC)

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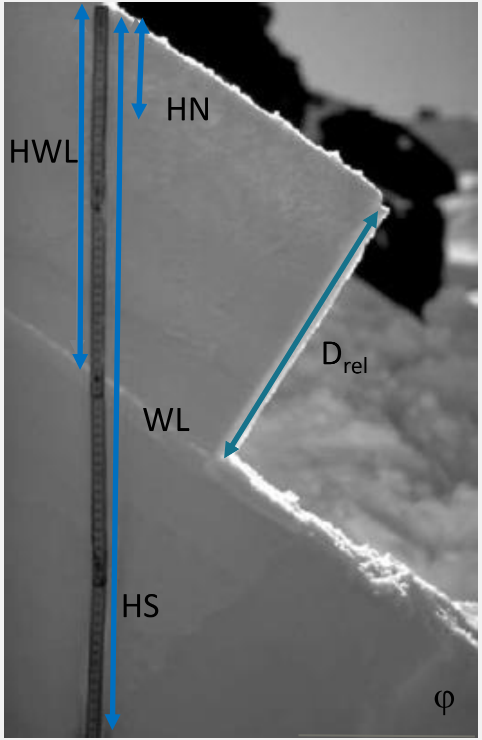
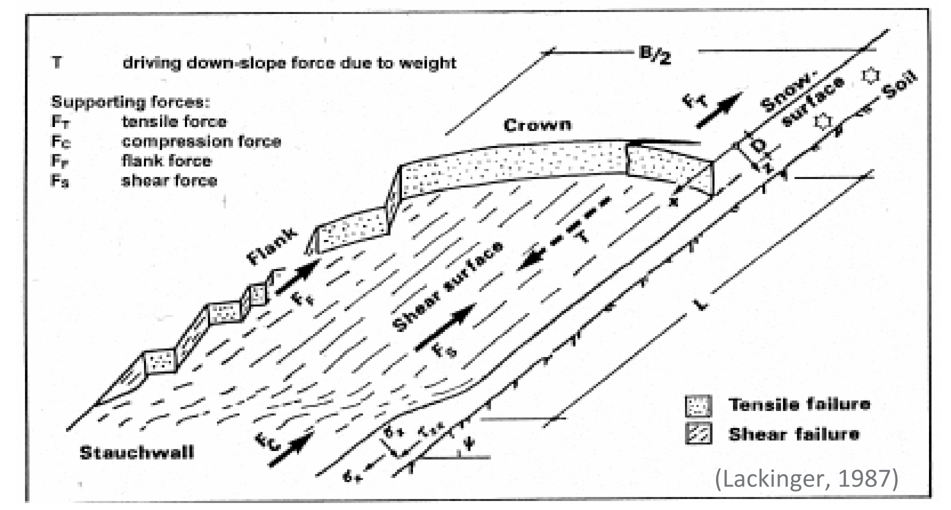
1. What are the parameters influencing natural avalanches releases?

2. How are they effected by forests and its stand properties?

# Probability of avalanche release




(Photo J. Schweizer)




(Lackinger, 1987)

**Performance function**

$$G = \text{Resistance} - \text{Load}$$

**< 0 => release**

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# Avalanche release

Simple snowpack stability aspects:

## Performance functions G

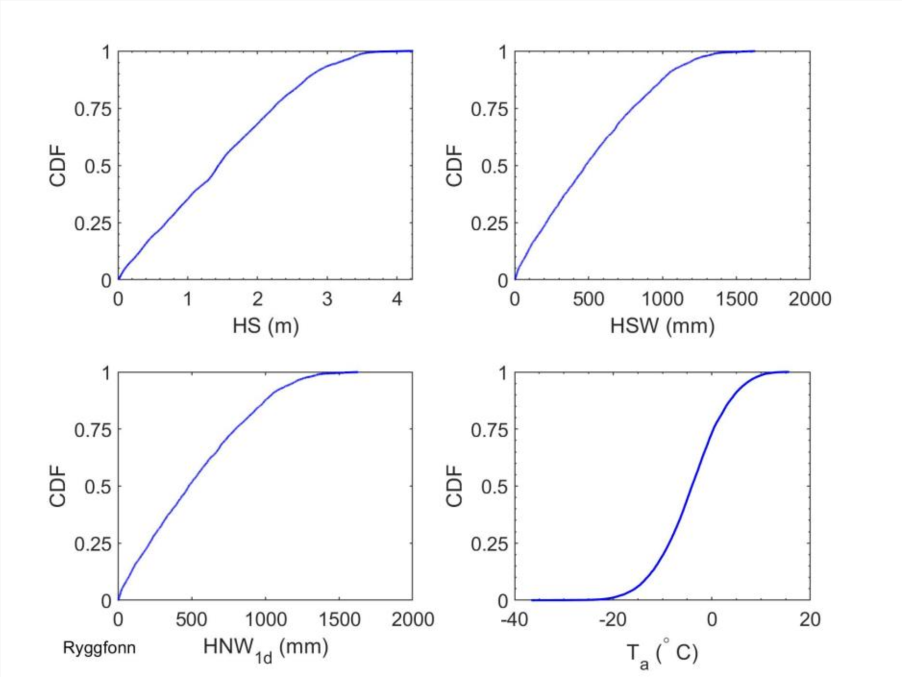
$$G_{nd} = -1 + \left( \underbrace{\frac{C}{g\,\rho H S \cos\varphi \sin\varphi}}_{O\approx 0.1-1} + \underbrace{\mu_s \cot\varphi}_{O\approx 0.3-1} \right)$$

snowpack stability

where G < 0 implies failure

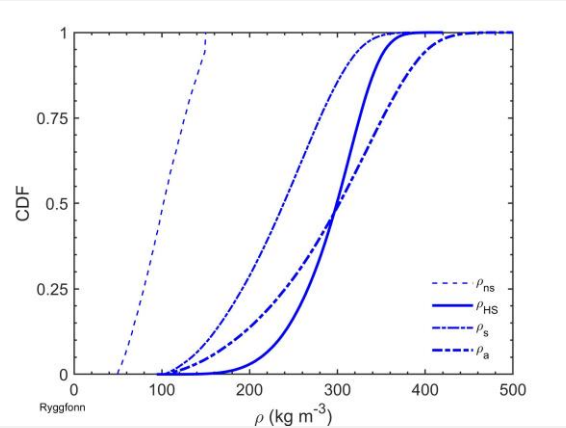
# CLIMATE INPUT

SeNorge data period between 1957 - 2017




HS, HSW, Ta

derived snow density data

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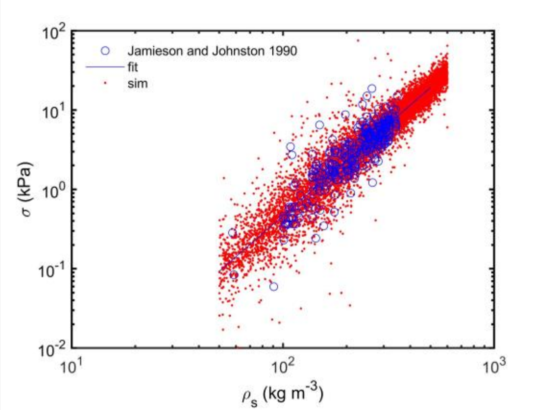
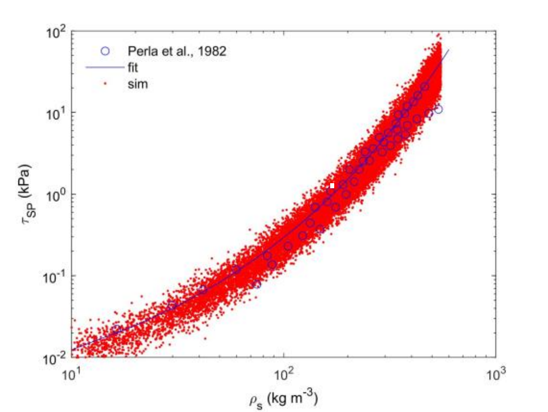
# Snowpack properties

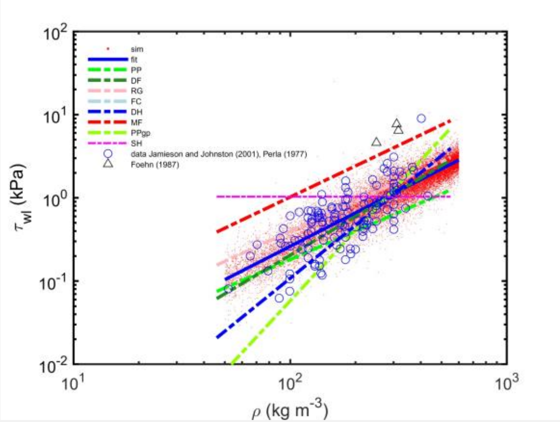
## Tensile strength




## Shear strength




## Weak-layer shear strength

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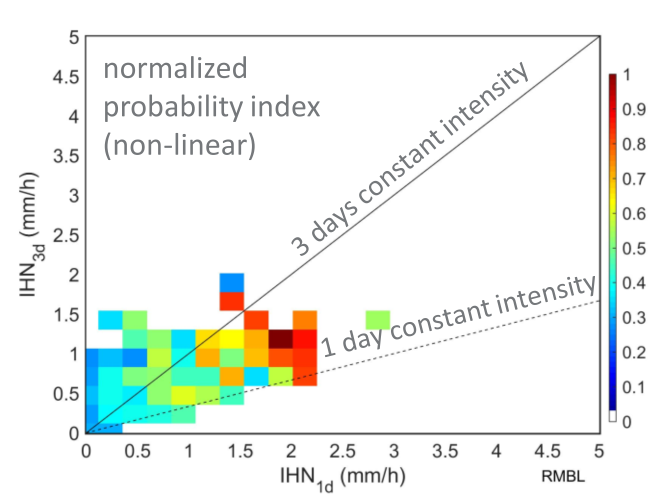
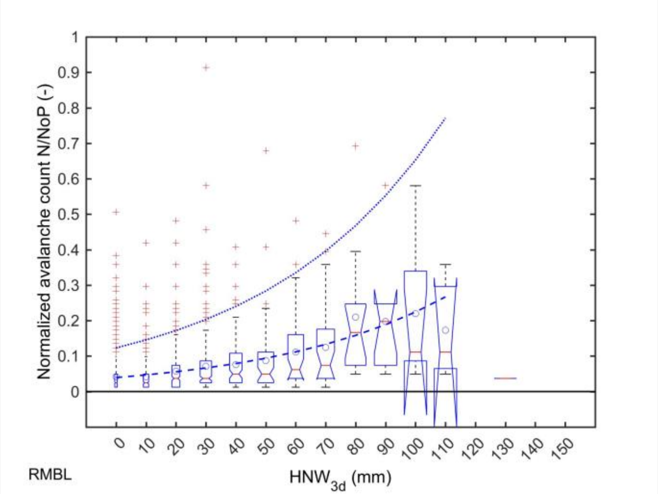
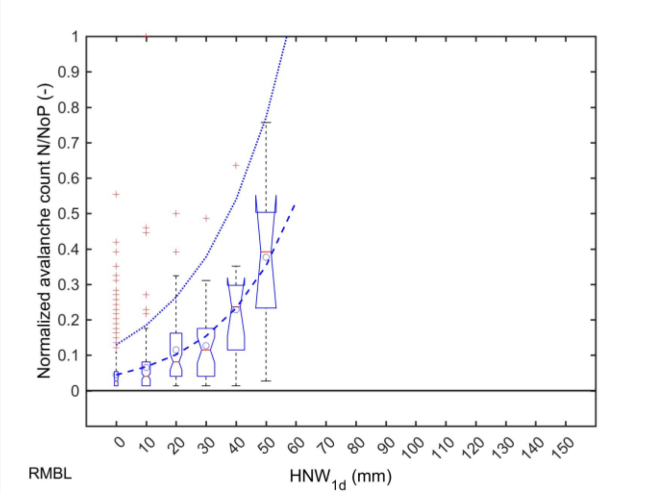
# Trigger for natural release

- “Precipitation” intensity; rate of loading

Probability to observe an avalanche

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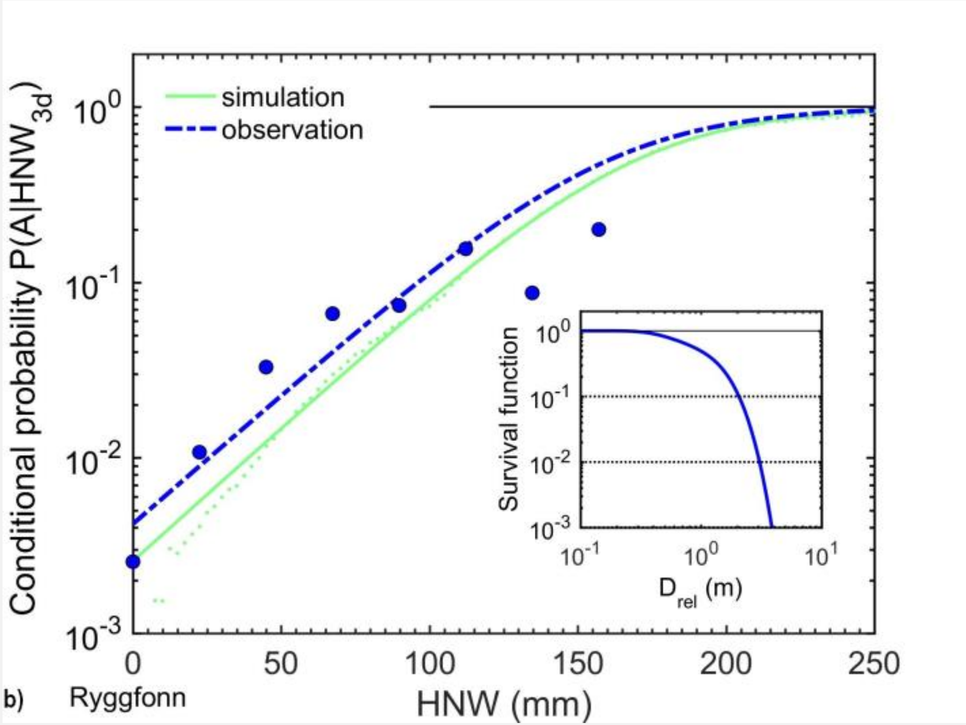
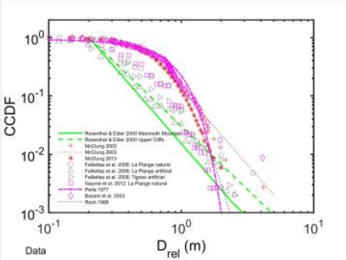
Data: Rocky Mountain Biological Laboratory (RMBL), Gothic, Colorado (an area of approx. 60 km$^2$, 81 paths) during a period 37 years.

# Comparison between observed and simulated $P(A|HNW_{3d})$ for the Ryggfonn path.




NGI

# What might be different in a forest

- There might be some support due to stems

# Direct support of the snowpack by tree stems

Simple snowpack stability aspects:

parameter describing stand structure

## Performance functions G

$$G = -1 + \left( \underbrace{\frac{C}{g\rho HS\cos\varphi\sin\varphi}}_{O\approx 0.1-1} + \underbrace{\mu_s \cot\varphi}_{O\approx 0.3-1} \right) + \frac{1}{2}\frac{N_{ha}}{10^4}\frac{d_t HS\eta_f K N_g}{\cos\varphi\sin\varphi}$$

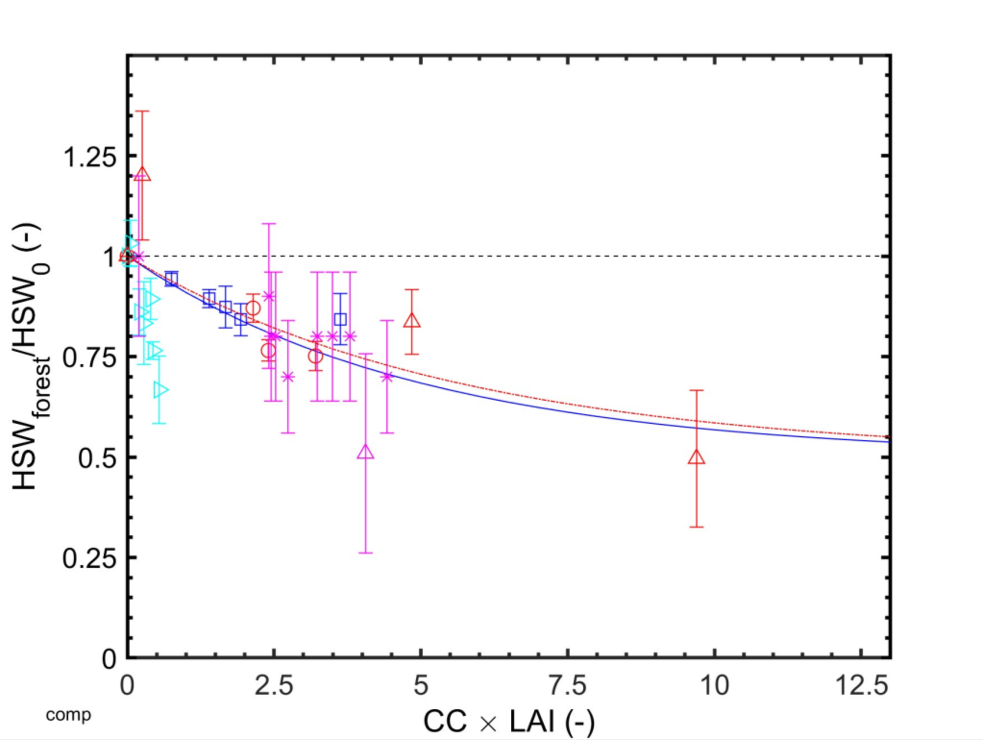
snowpack stability

mechanical stabilization due to tree support

where G < 0 implies failure

NGI

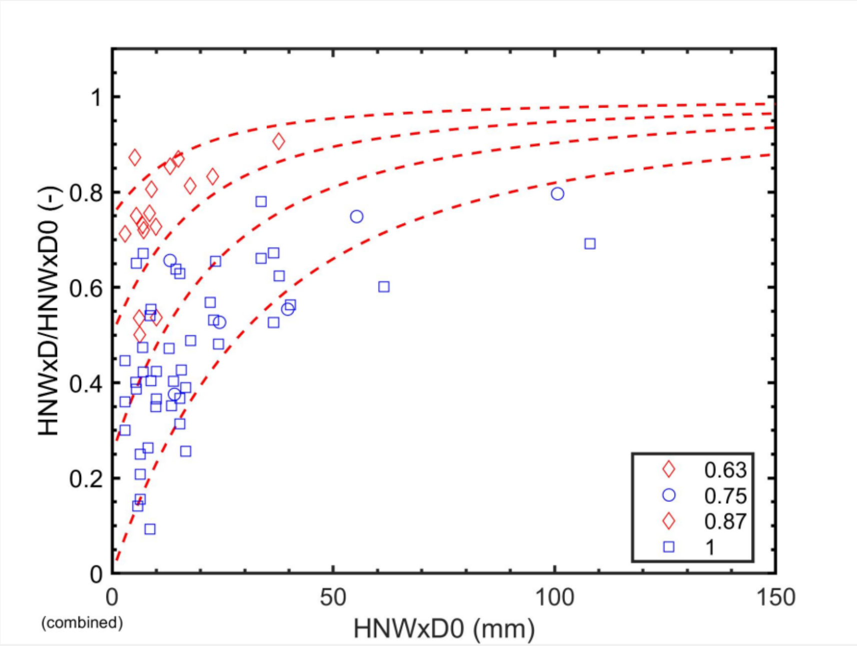
# Forest and snowpack




- Comparison of the measured HSW in a forest versus the open depending on the forest closer

NGI

# Forest and snowpack




- Comparison of the measured HNW in a forest versus the open depending on the crown cover
- To a certain degree a reduction in loading intensity

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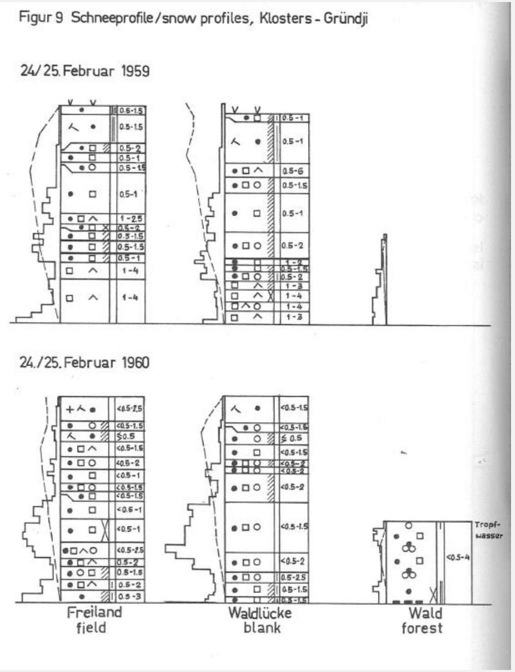
# Forest and snowpack

- Change of snowpack properties




in der Gand, H. R. and Zupancic, M. (1966) Snow gliding and avalanches, Tison, L. J. (Ed.) International Symposium on Scientific Aspects of Snow and Ice Avalanches , Vol. 69 IAHS Publ. Int. Assoc. Hydrol. Sci.: Gentbrugge, Belgin, p. 230-242

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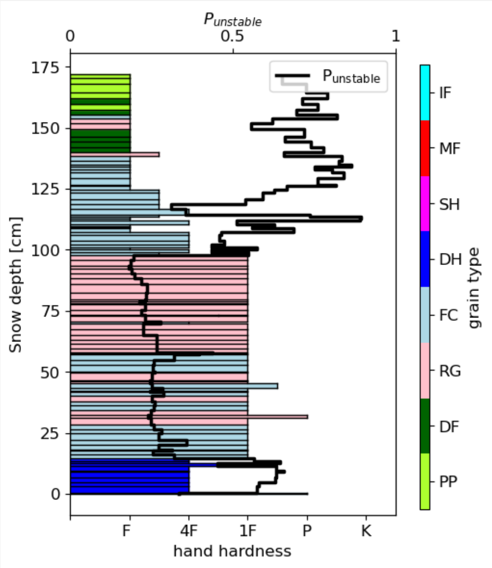
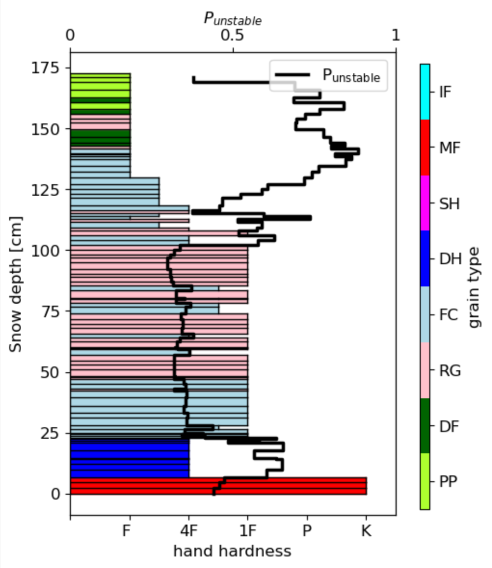
# Simulation tests with Snowpack (using ref data set WFJ2 for 2016, slope = 38°, Az = 270°)

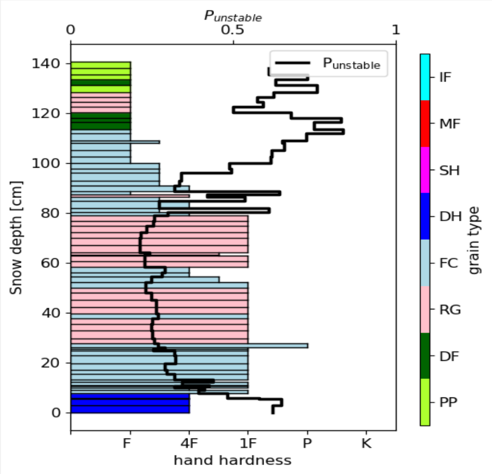
- P_unstable for 2016-03-04 15:00




SDI = 0 N/ha (no forest)




SDI = 500 N/ha




SDI = 1000 N/ha

Stability index P_unstable according to

Mayer, Stephanie / van Herwijnen, Alec / Techel, Frank / Schweizer, Jürg

**A random forest model to assess snow instability from simulated snow stratigraphy** 2022 *The Cryosphere* , Vol. 16, No. 11 p. 4593-4615

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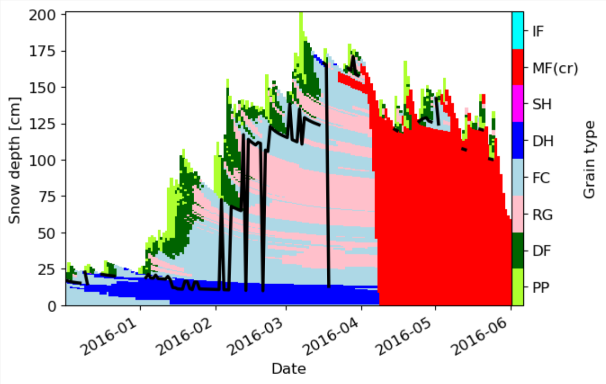
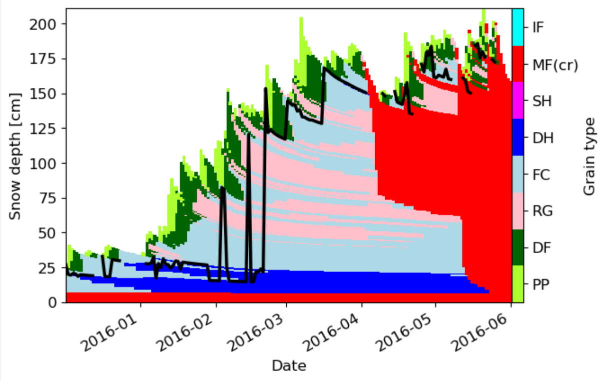
# Simulation tests with Snowpack (using ref data set WFJ2 for 2016, slope = 38°, Az = 270°)

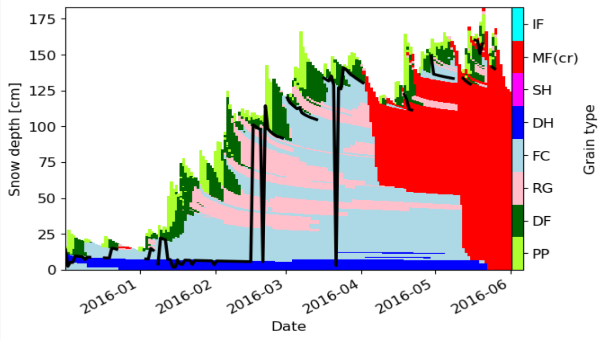
- max(P_unstable) with P_unstable > 0.5




SDI = 0 N/ha (no forest)




SDI = 500 N/ha

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Stability index P_unstable according to

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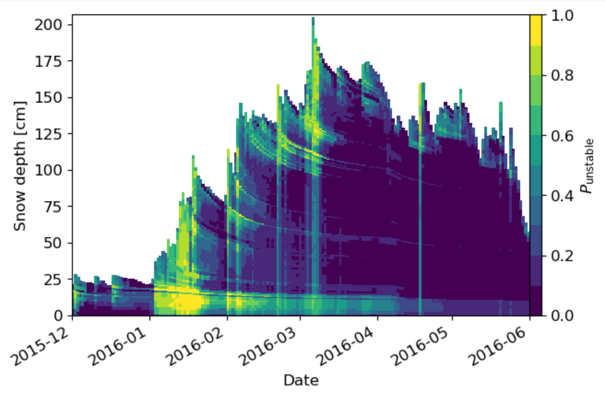
**A random forest model to assess snow instability from simulated snow stratigraphy** 2022 *The Cryosphere* , Vol. 16, No. 11 p. 4593-4615

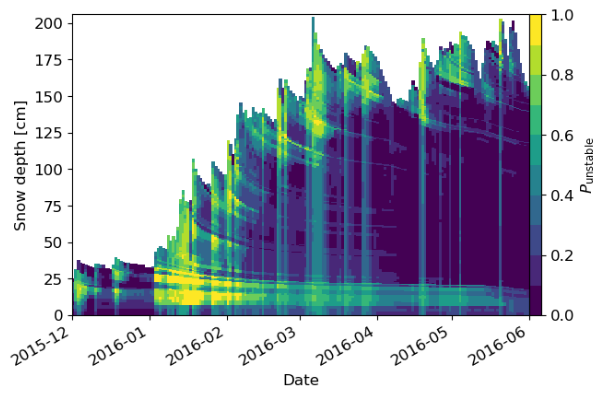
NGI

# Simulation tests with Snowpack (using ref. data-set WFJ2 for 2016, slope = 38°, Az = 270°)

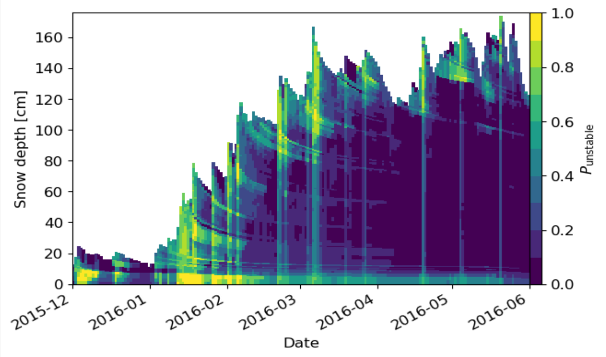
## P_unstable




SDI = 0 N/ha (no forest)




SDI = 500 N/ha




SDI = 1000 N/ha

Stability index P_unstable according to

Mayer, Stephanie / van Herwijnen, Alec / Techel, Frank / Schweizer, Jürg

**A random forest model to assess snow instability from simulated snow stratigraphy** 2022 *The Cryosphere* , Vol. 16, No. 11 p. 4593-4615

# Need of Validation

- Mechanical disturbance especially during warm-ups not included

# Effect of forest in the track



(Photo Torgeir Åsheim-Olsen)

- Definitely, a forest will have a braking effect
- However, this effect is still hard to quantify
- **Debris may increase the risk**


Reinen School, Tromsø, 2013-04-02
(Photo Torgeir Åsheim-Olsen)

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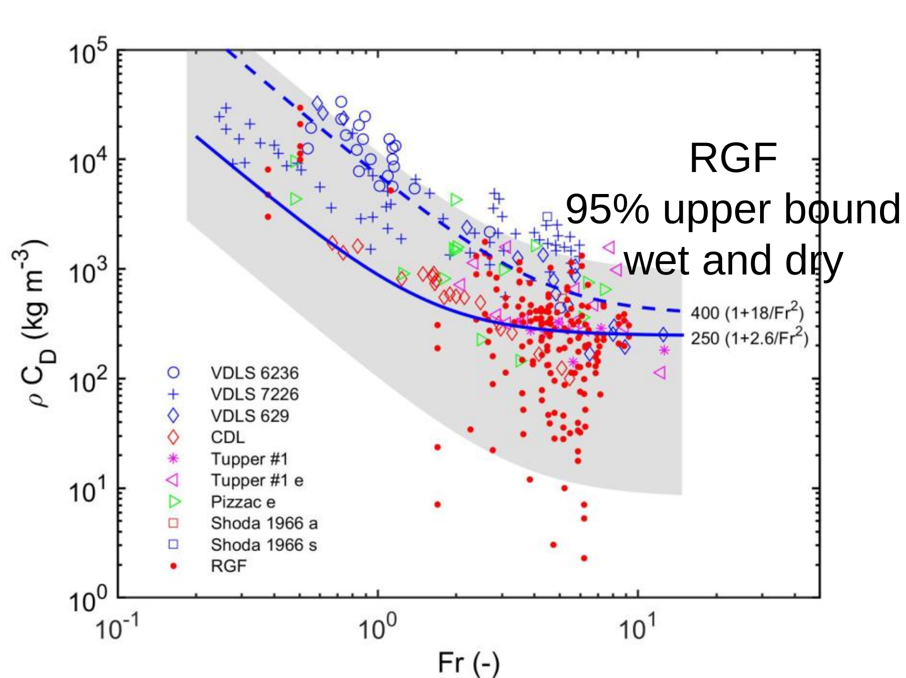
- How to account in our models

# Impact pressure on mast like obstacles

$$F = \rho C_D(u) A \frac{U^2}{2}$$

- $C_D$ is the so-called drag factor
- A is the project area (d x $h_f$)




- In addition, there might be some detrainment

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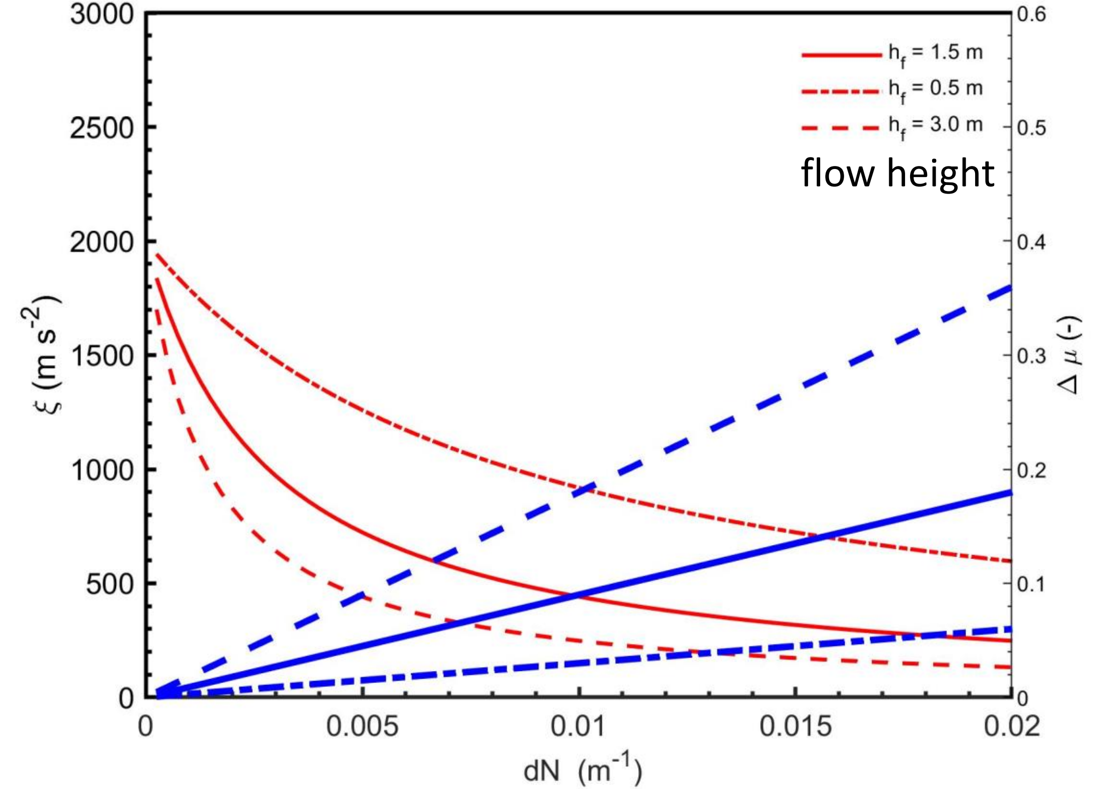
# Contribution to friction and drag coefficients from trees




Example, parameter estimates for RAMMS

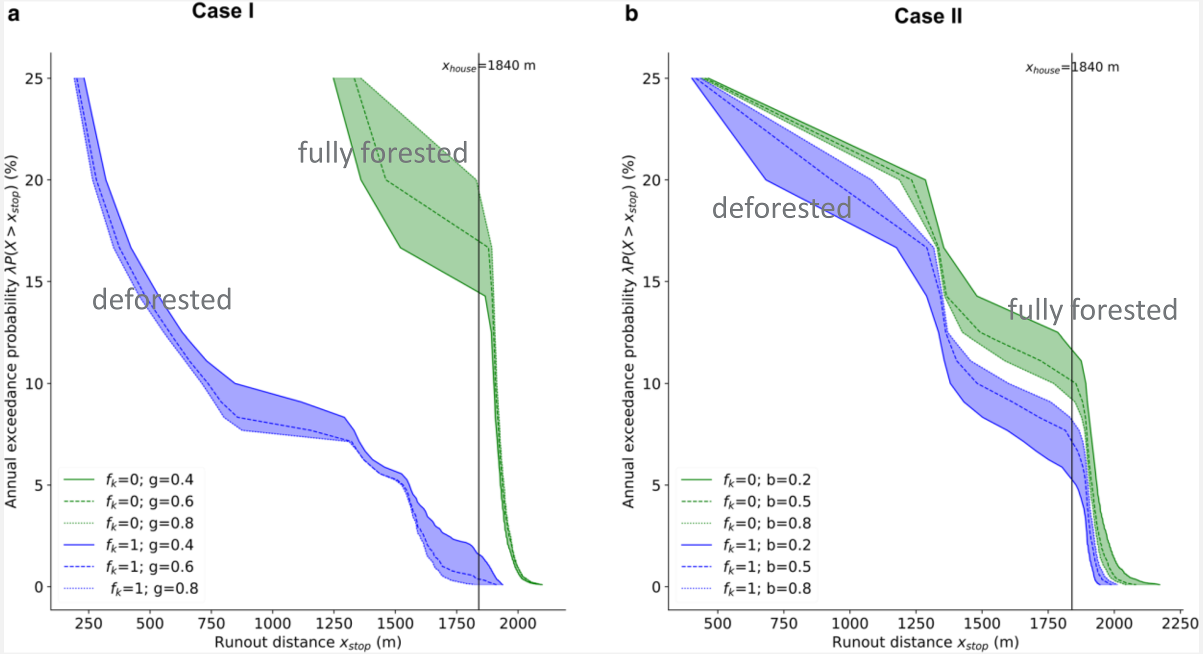
$$\Delta\mu \approx d_t N_\perp \frac{C_{D0} f_{CD}}{2} h_f$$

parameter describing forest stand structure

$$\frac{1}{\xi_f} \approx d_t N_\perp \cos\phi \frac{C_{D0}}{2} \frac{h_f}{g}$$

$$\frac{1}{\xi} \approx \frac{1}{\xi_f} + \frac{1}{\xi_0}$$

# Runout simulation




varying $\mu = F(..,g\cdot(f_k-f))$ varying $\xi = F(..,b^{(f_k-f)})$

(Zgheib, Taline / Giacona, Florie / Morin, Samuel / Granet-Abisset, Anne-Marie / Favier, Philoméne / Eckert, Nicolas (2012) **Diachronic quantitative snow avalanche risk assessment as a function of forest cover changes,** *Journal of Glaciology* p. 1-19, Fig. 9)

# Some recent examples from Norway

All theory is gray, my friend,
but forever green is the tree of life
J. W. Goethe Faust I

NGI

# Reisadalen, Friday 31st March 12:00

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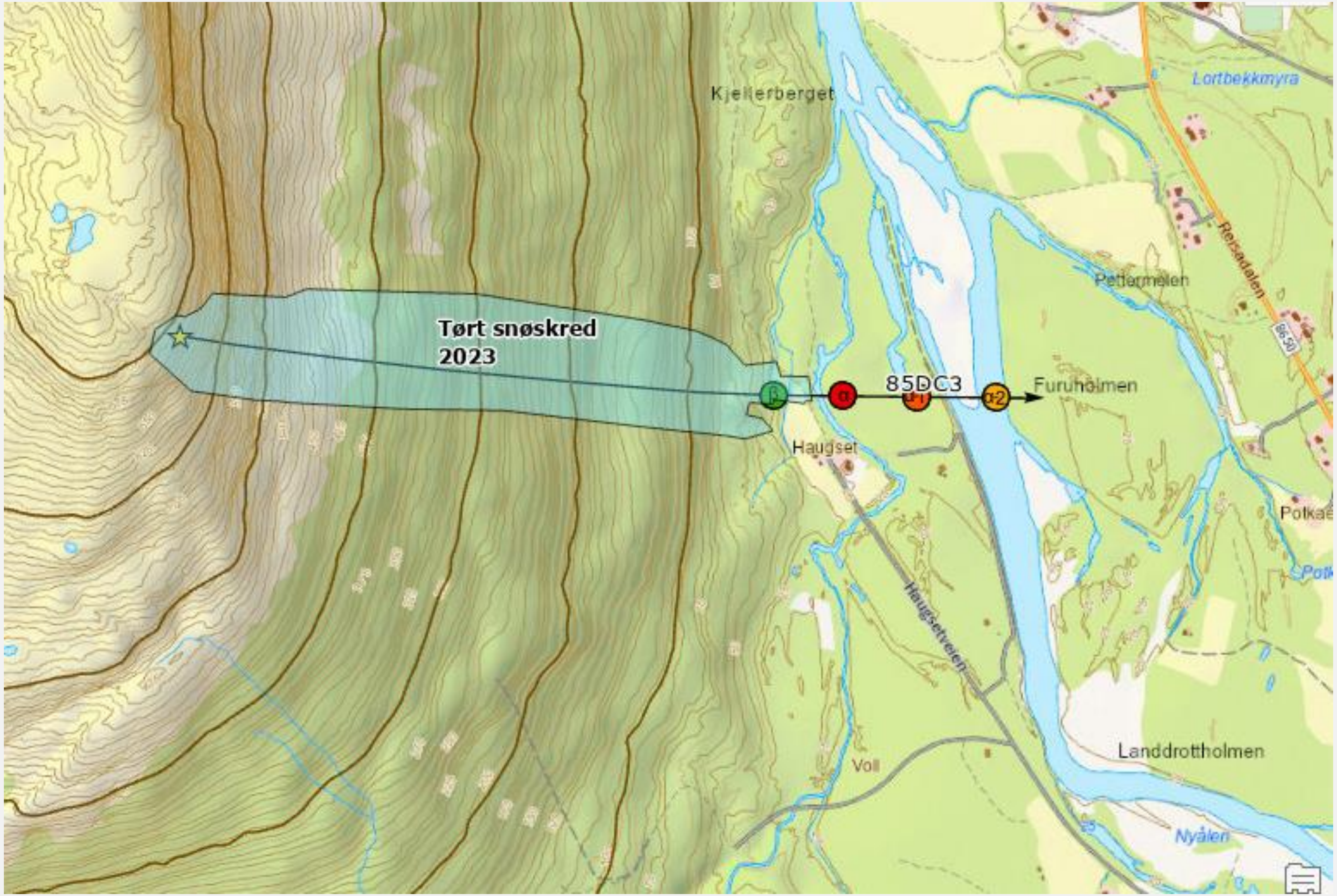
# Reisadalen, Friday 31st March 12:00

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# Kildal, Nordreisa 2023-04-01

- Existing hazard zone S2 heavily based on existing forest

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# Store Strandvatnet, Repvåg 2023-03-31

How much more was needed to cause considerable damage

NGI

# 2023-01-25 Vatnadalen, Mo I Rana

- Slushflow

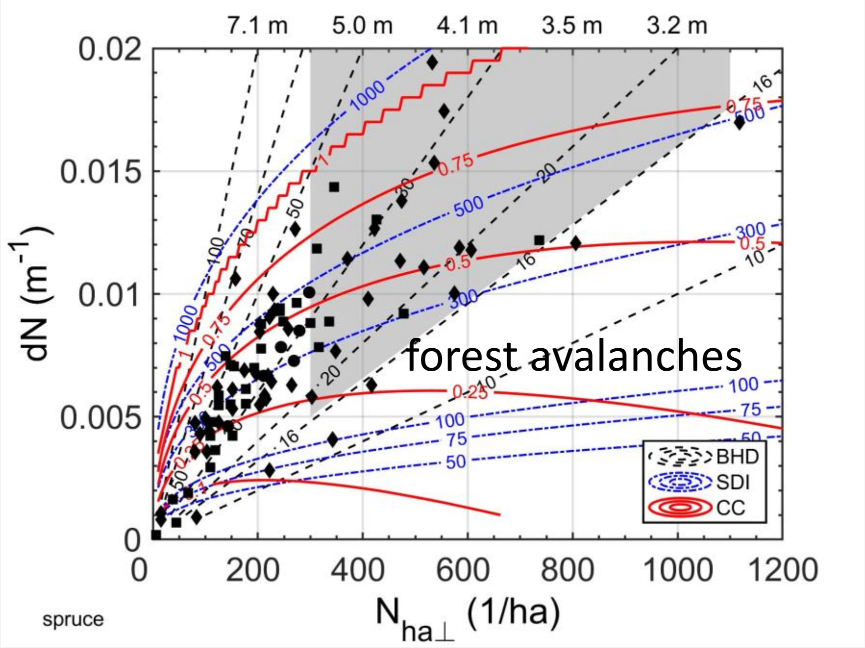
# Avalanches in forests

- How can we best characterize the forest stand regarding avalanche hazard

(photos GNFAC)

# Forest parameters that might influence its effect

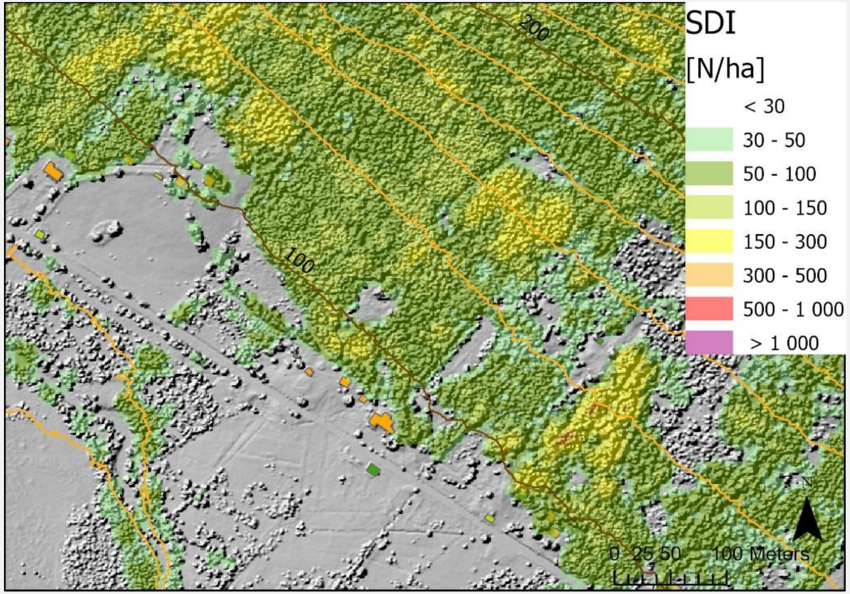
- BHD breast height diameter
- $N_{ha}$ number of trees per ha
- Derived parameters
  - SDI stand density index
  - CC crown cover
  - BDS basal area




One needs to distinguish between effect

- on release probability
- on runout

# Example of the stand density index SDI



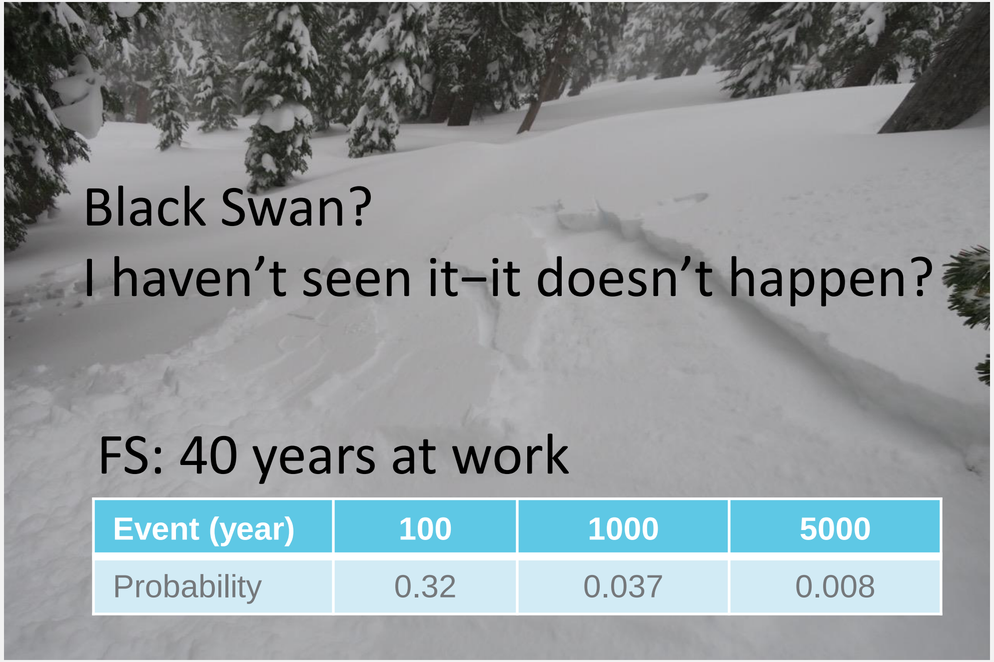

# Conclusion

- Forest is certainly an important factor regarding avalanche hazard
- However, little work is done to really quantify its effect on the snowpack and its stability
- What are the best stand parameters to simple describe the efficiency of a forest in respect to avalanche mitigation and are easy applied by the practitioner in the field
- One needs, however, keep  the time perspectives in mind

# Avalanche release probability

- “Natural avalanche in a forest”, what is the Trigger?

Tree bombs



Black Swan?

I haven’t seen it–it doesn’t happen?

FS: 40 years at work

| Event (year) | 100 | 1000 | 5000 |
|---|---|---|---|
| Probability | 0.32 | 0.037 | 0.008 |

(Photos: Sierra Nevada Avalanche Center)

# Future development?


Thank you

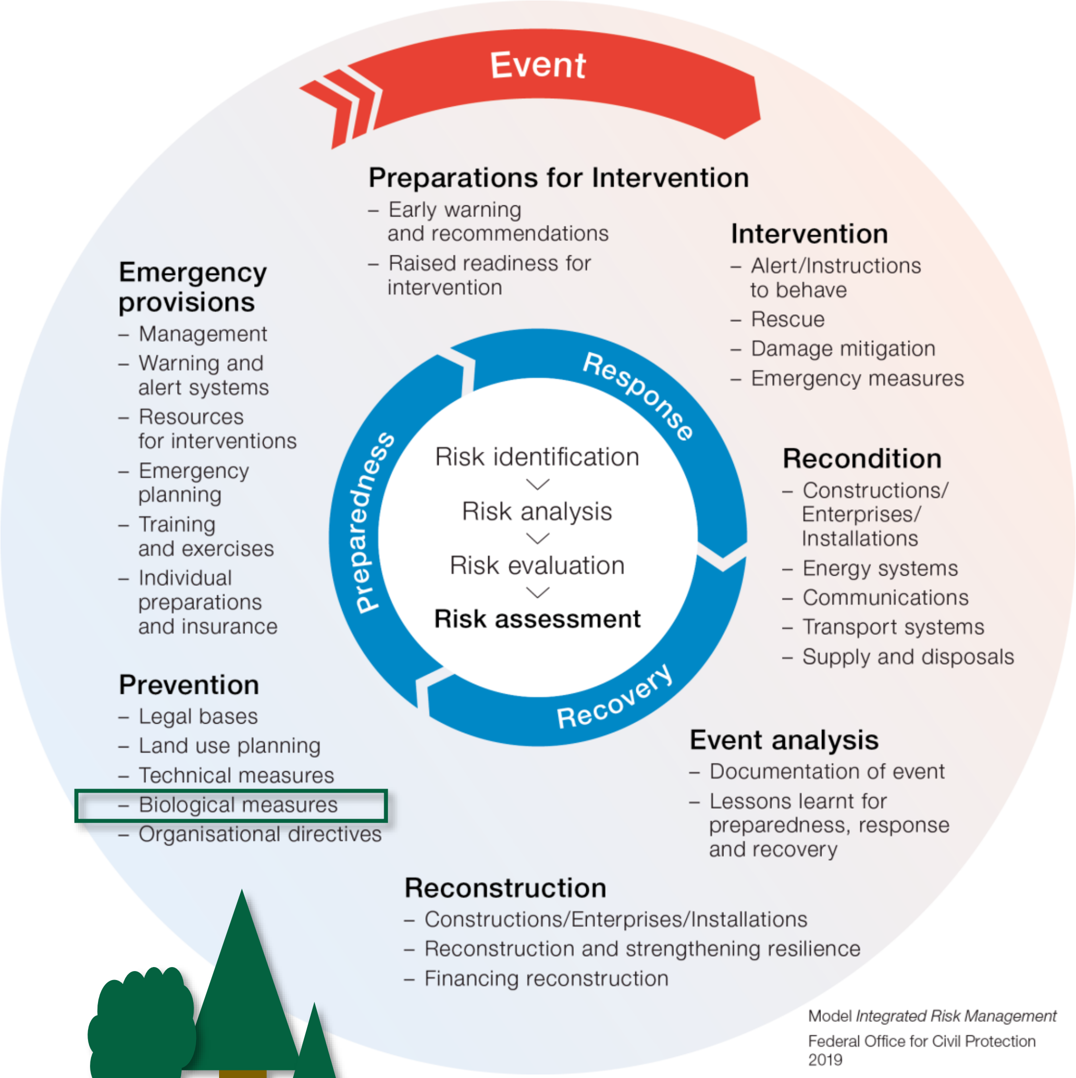

# Avalanche protective forests: what do we know and where do we grow from here?

Michaela Teich

50-year anniversary of Fonnbu avalanche research station

7 September 2023

# Protective forests within an integrated risk management (IRM)




Model *Integrated Risk Management*
Federal Office for Civil Protection
2019

"A [protective] forest is a forest that has as its primary function the protection of people or assets against the impacts of natural hazards [...]."

Brang et al. 2001

(Protective) forests, however, are often underutilized.

Teich et al. 2021

HOW COME?

# Protective forests within an IRM


Brang et al. 2001

Photo: N. Wever/SLF

# Modeling of forests with a (direct) object protective function

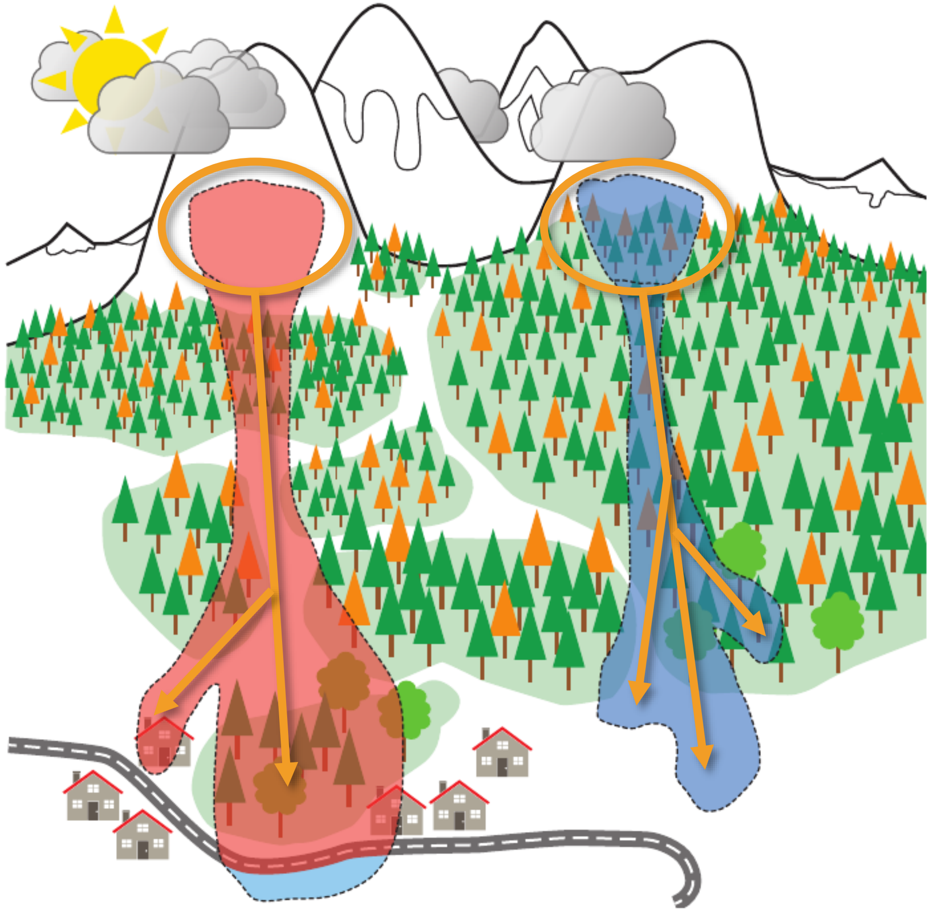
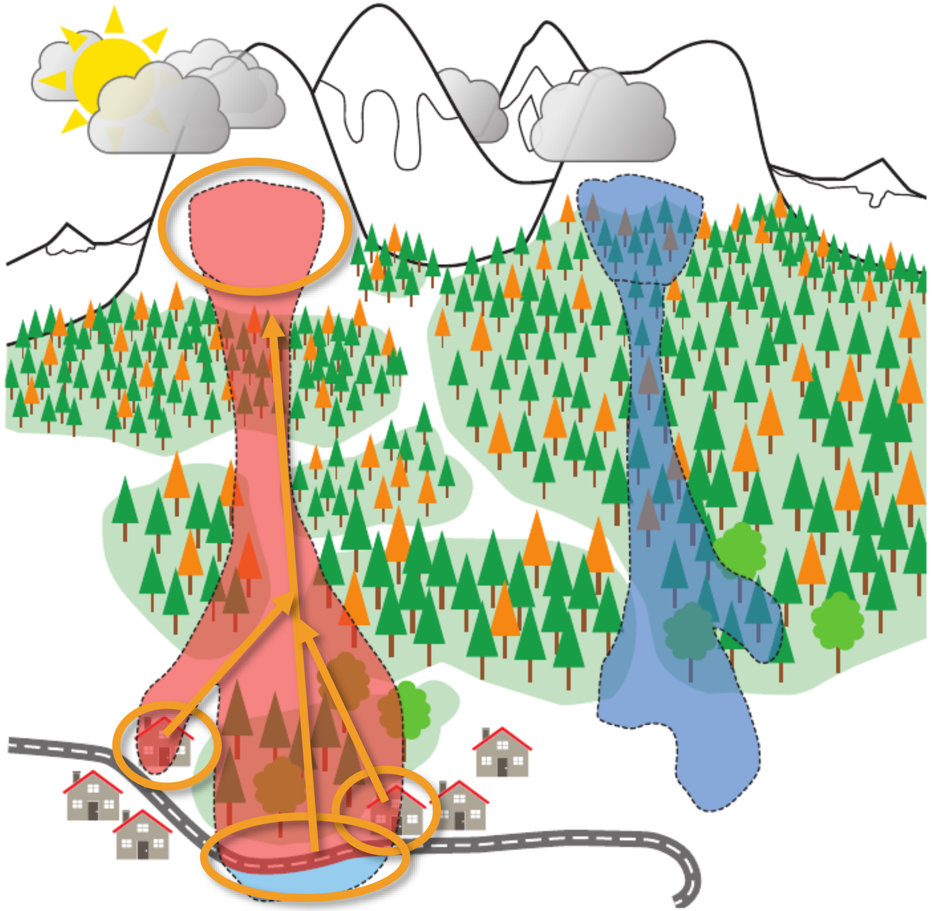


Illustration: A. Huber

I. Where are the potential release areas?
   - Without considering forest (effects)!
II. Where does the process go?
   - Process modeling of gravitational natural hazards (snow avalanches, rockfall, landslides)

Perzl et al. 2019

# Modeling of forests with a (direct) object protective function



I. Where are the potential release areas?
   - Without considering forest (effects)!

II. Where does the process go?
   - Process modeling of gravitational natural hazards (snow avalanches, rockfall, landslides)

III. Where are the objects to be protected?
   - Could they be hit?

IV. Which process paths are potentially damaging?
   - Back-tracking from affected objects

Illustration: A. Huber

Perzl et al. 2019

# Modeling of forests with a (direct) object protective function

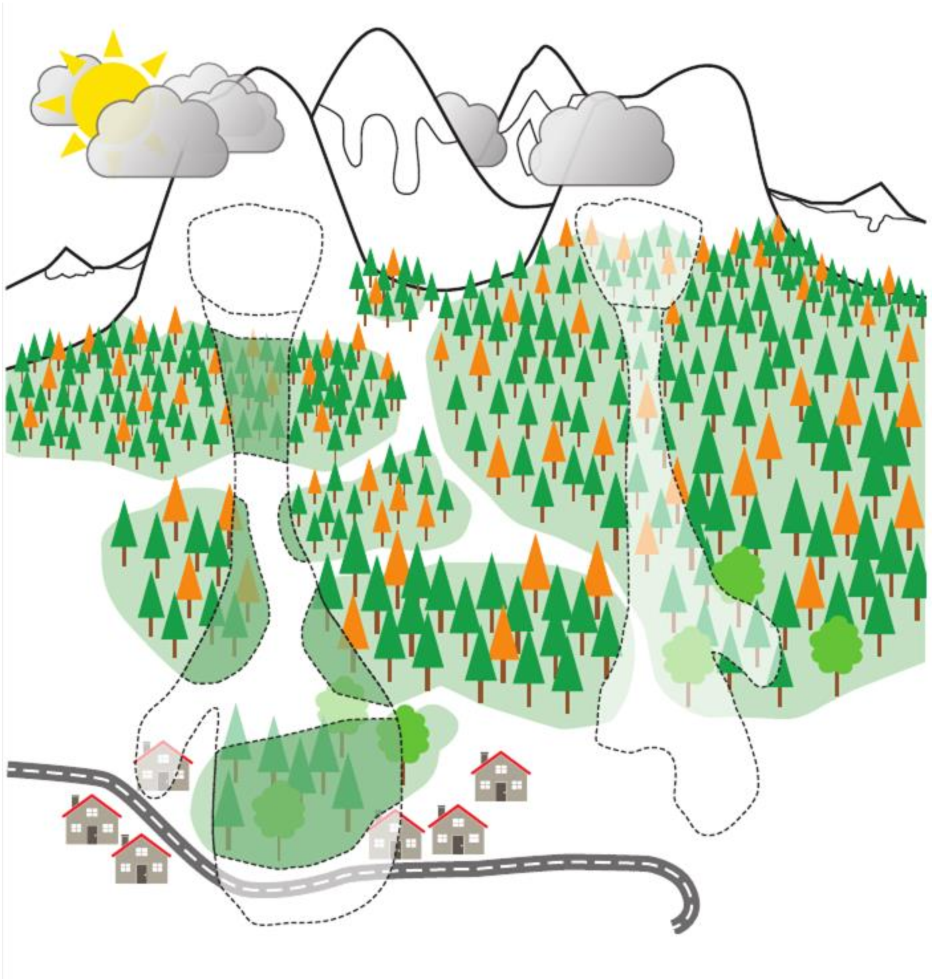


Illustration: A. Huber

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III. Where are the objects to be protected?
   - Could they be hit?

IV. Which process paths are potentially damaging?
   - Back-tracking from affected objects

V. Which are the potentially damaging process paths in forest?
   - Intersection with the forest area

Perzl et al. 2019

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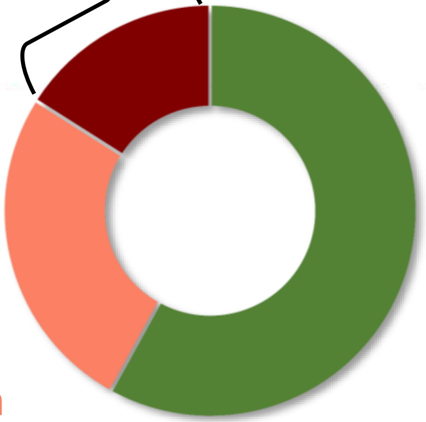
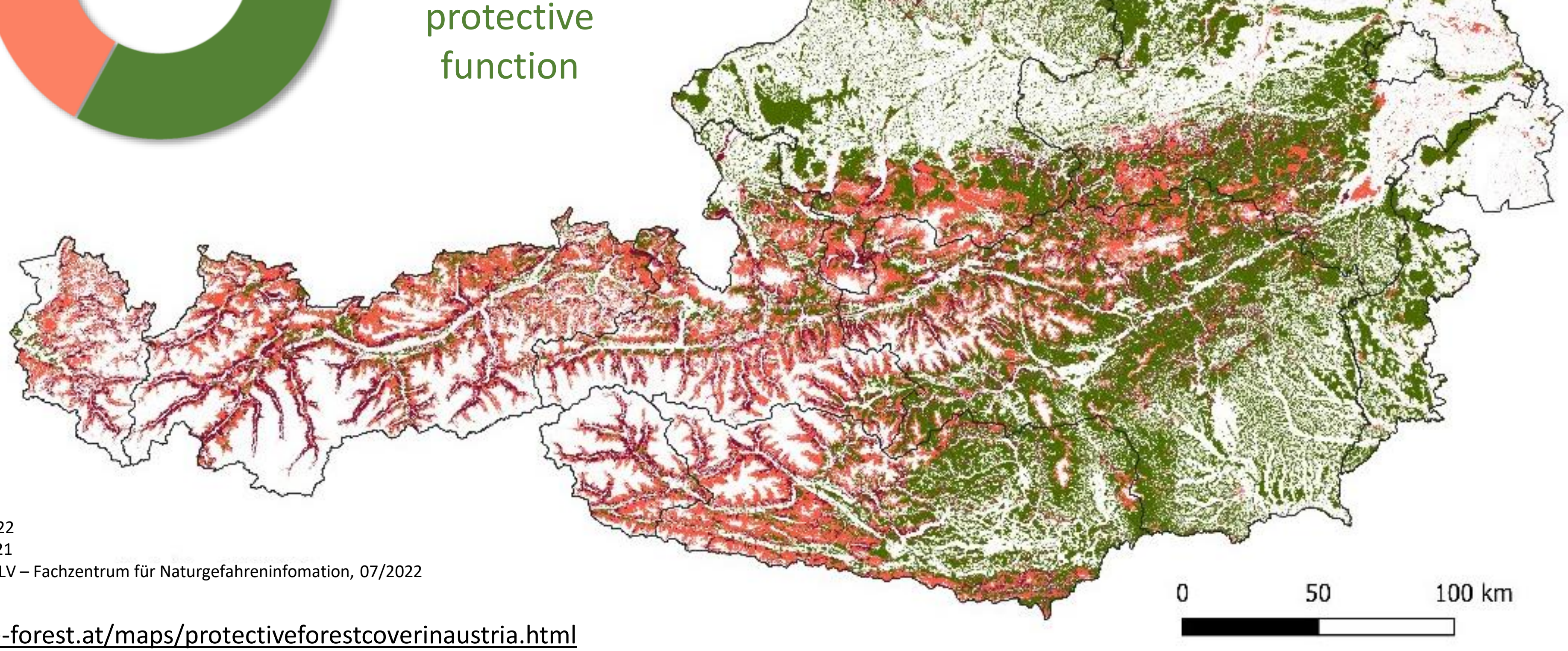
# Protective forest cover in Austria




...potential protective forest area in Austria based on scientifically defined criteria.




Federal Ministry
Republic of Austria
Agriculture, Forestry, Regions
and Water Management

Basic data: ©BEV, 2022
Technical data: BFW, LFD, BML – Abt. III/4, 2022
Layout & design of base map: LFRZ GmbH, 2021
Data evaluation & design of technical data: WLV – Fachzentrum für Naturgefahreninfomation, 07/2022

Source: https://www.protective-forest.at/maps/protectiveforestcoverinaustria.html

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Austrian Research Centre for Forests

# Open-access decision support tools for utilizing protective forests in IRM

Interreg Alpine Space
GREEN RISK 4 ALPS
European Regional Development Fund

AvaFrame
THE OPEN AVALANCHE FRAMEWORK

## The simulation tool Flow-Py (Neuhauser et al. 2021, D'Amboise et al. 2022) is...

- open-access & open-source software, containing...
- a data-based runout and intensity model for...
- ...regional modeling of snow avalanches, rockfall and shallow landslides.
- easily adaptable requiring few input parameters.

- a tool to identify forests with a direct object protective function and...
- to estimate the protective effects of forest on hazard runout (D'Amboise et al. 2021).
- currently being implemented in the open avalanche framework AvaFrame (Oesterle et al. 2022): https://avaframe.org/

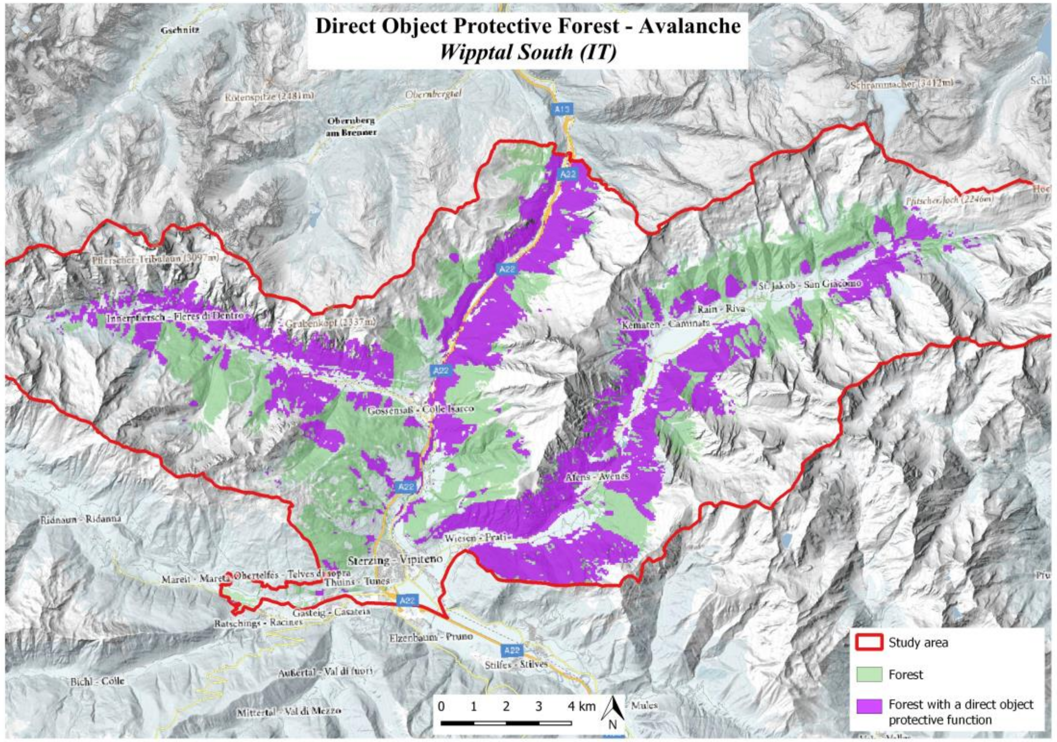



Figure: Accastello et al. 2022

# Protective forests within an IRM

How does the forest protect?

PROTECTIVE EFFECT

Where, What and Whom should the forest protect?

PROTECTIVE FUNCTION

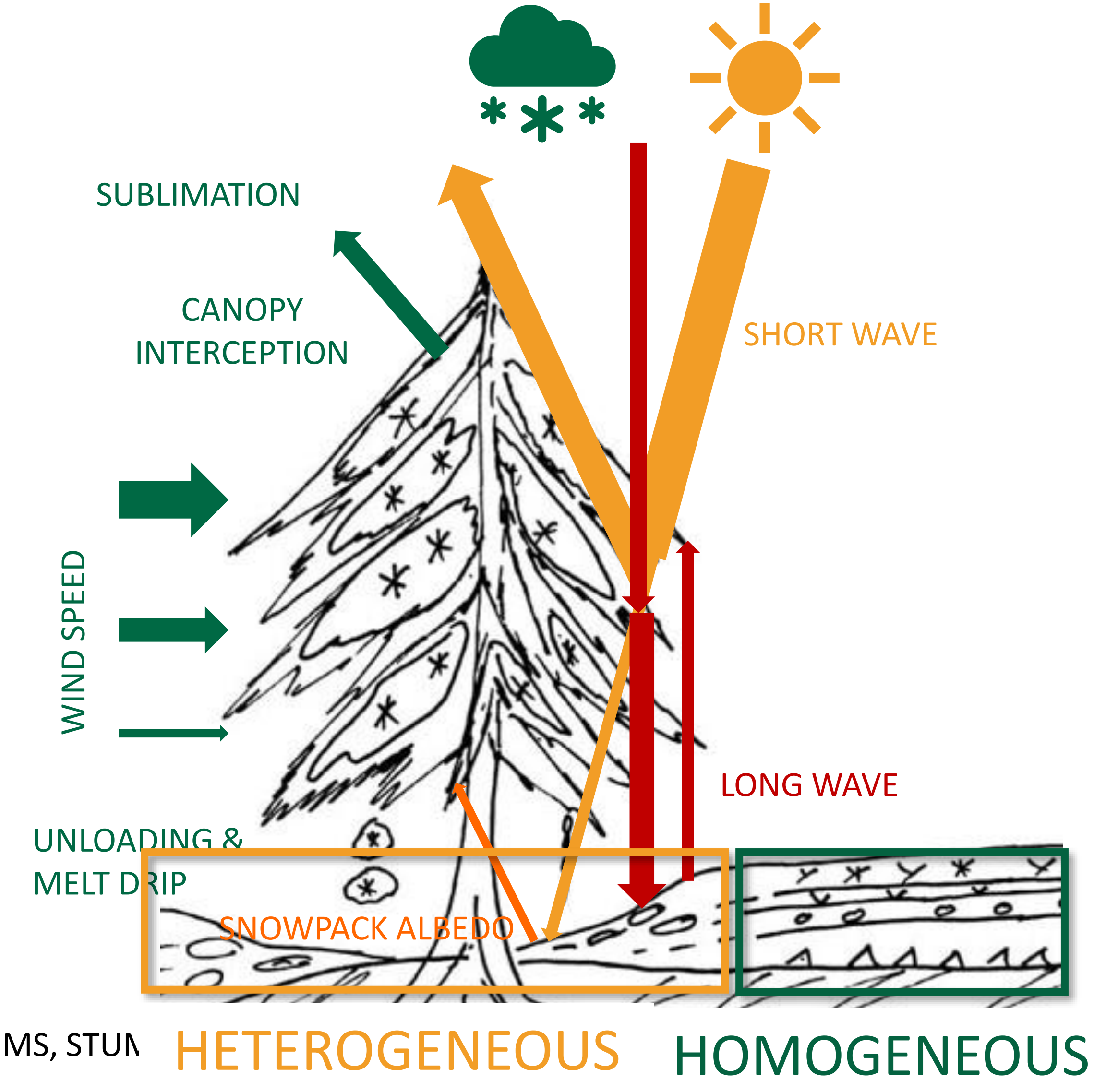
Brang et al. 2001

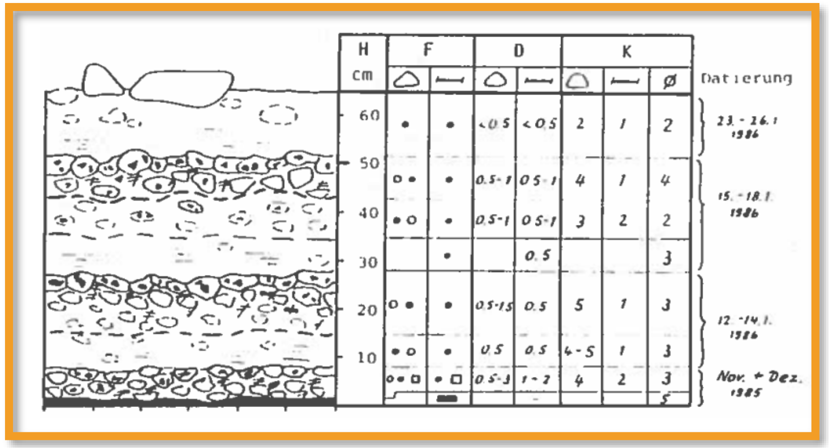
Photo: N. Wever/SLF


# Protective effects of forests…

…on avalanche formation and release probability

# Protective effects of forests on avalanche formation and release



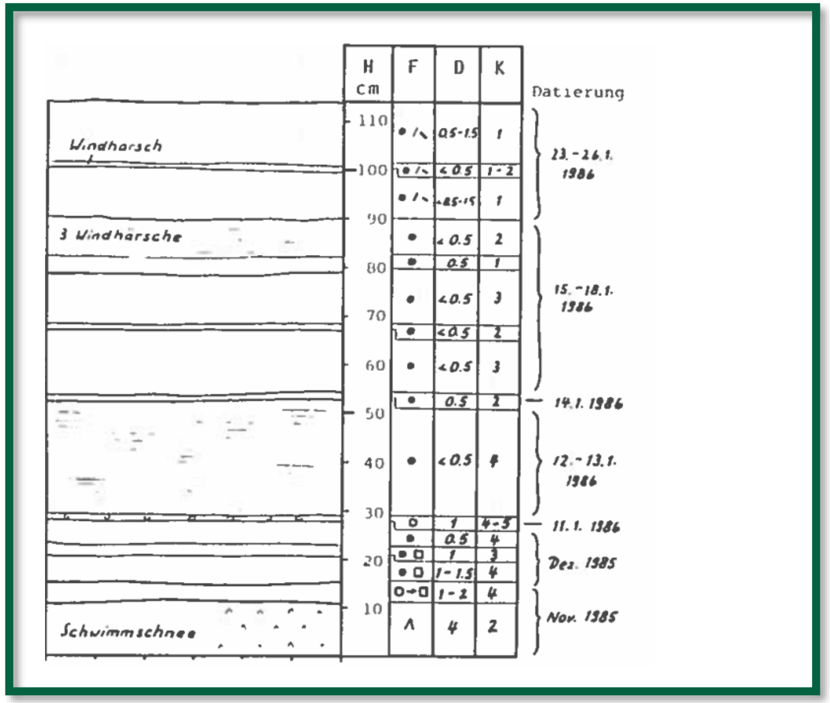




Illustration adapted from: Schneebeli & Bebi 2004

Source: Imbeck 1987

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# Protective effects of forests…


…on avalanche formation and release probability

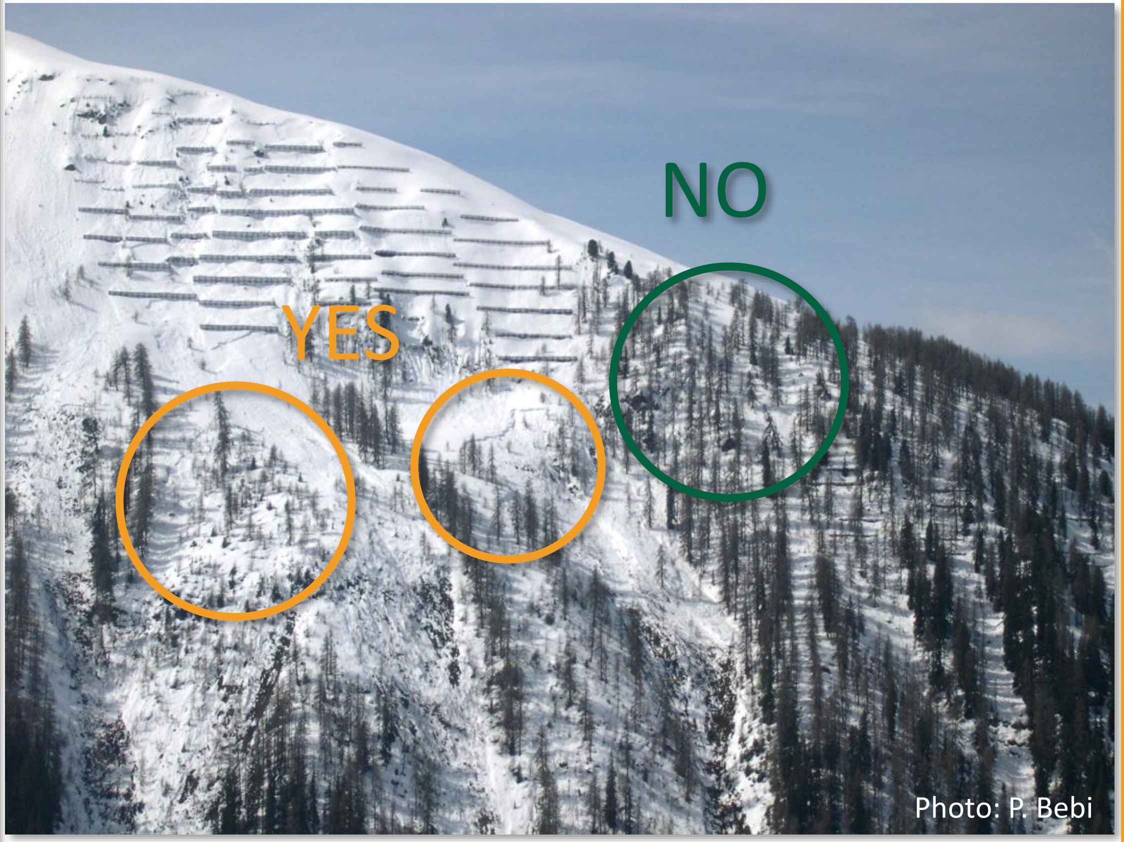
?

…on avalanche runout and intensity

- …
- Takeuchi et. al 2011
- Teich et al. 2012, 2014
- Feistl et al. 2014, 2015
- Takeuchi et al. 2018
- Brožová et al. 2020
- D‘Amboise et al. 2021
- Védrine et al. 2022
- …

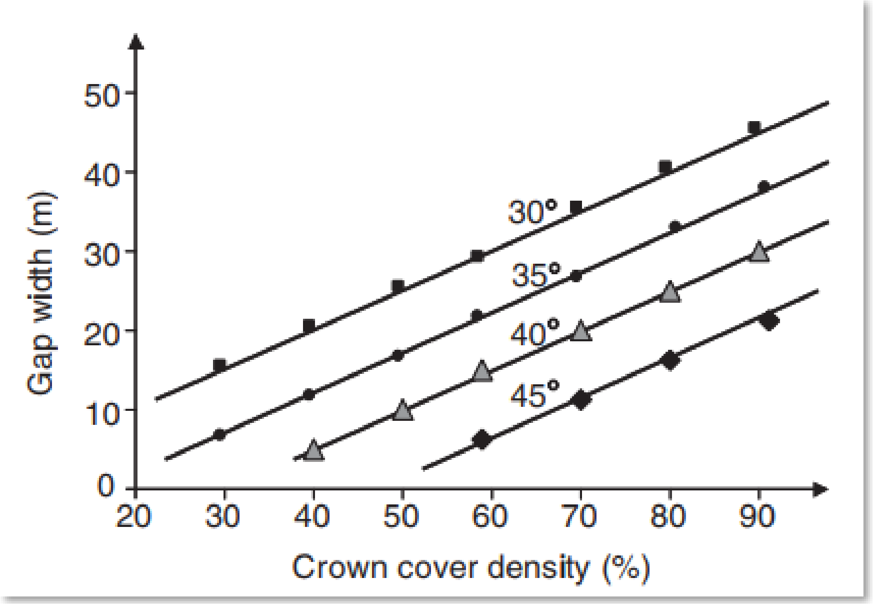
# Quantifying protective effects on avalanche formation and release

Observation-based approaches

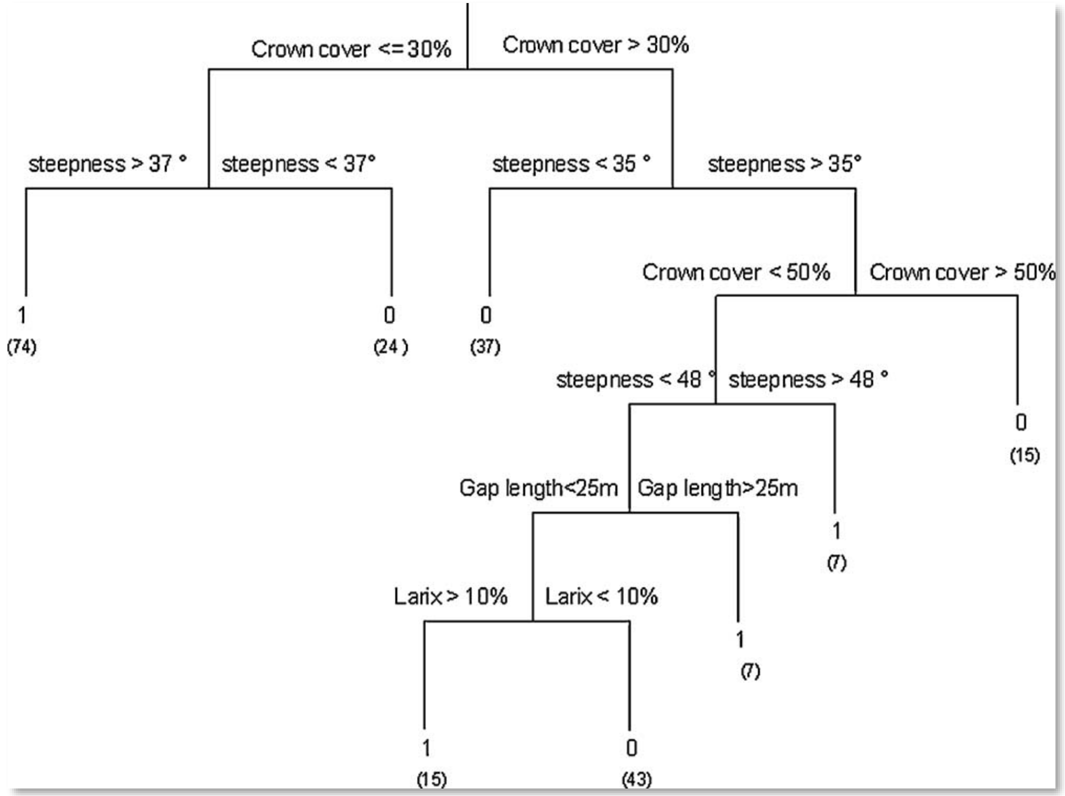



Process-based approaches

# Quantifying protective effects on avalanche formation and release




Relationship between critical gap widths and crown cover densities for avalanches releases for different slope steepness. Based on a multiple linear regression model of 112 avalanches in subalpine coniferous forests (Pfister, 1997).




Influence of different explanatory variables on avalanche releases in forested terrain based on the data set of 110 avalanches releases in spruce- and larch-dominated forests and 113 control stands.

Source: Schneebeli & Bebi 2004 Data: Schneebeli & Meyer-Grass 1993, collected 1985-1990 Source: Bebi et al. 2009

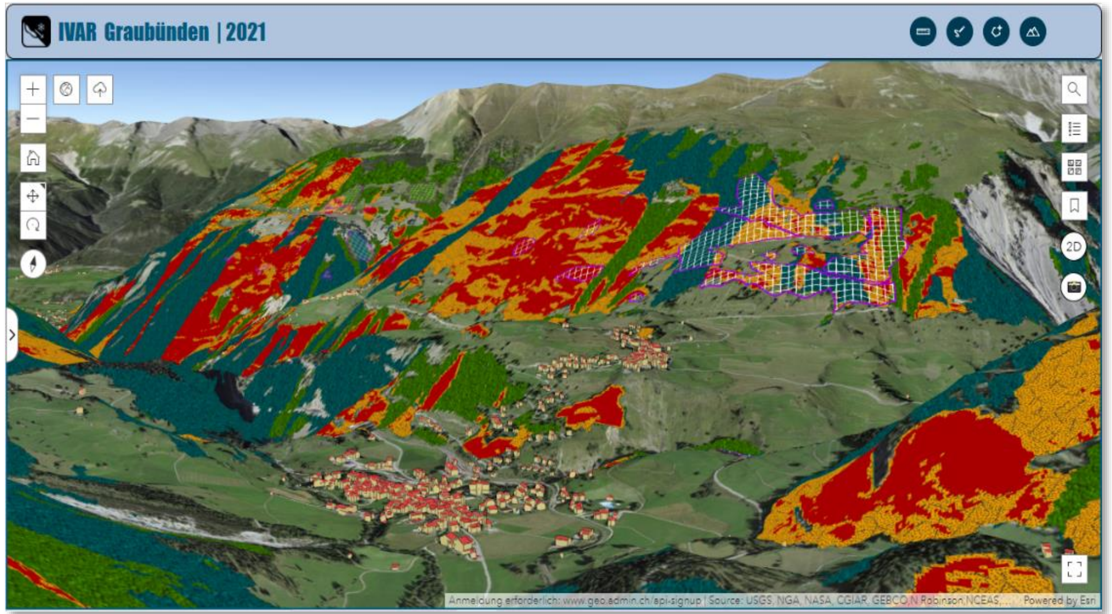
# Quantifying protective effects on avalanche formation and release

Logistic regression model for avalanche release probability (Bebi et al. 2001):

- Crown cover density (%)
- Gap width (m)
- Slope angle (°)

+

- Surface roughness
- Shrub forest layer




Interactive map platform developed at WSL (maps.wsl.ch) for prioritizing interventions in protective forests. Green/blue forest areas affect avalanches, but do not endanger buildings. Light orange (slope < 35°) and red (≥35° steepness) forest areas have a (direct) object protective function and a protective effect against snow avalanches.

Source: Bebi et al. 2021

# Assessment of protective effects in avalanche release areas

## European protective forest management guidelines:

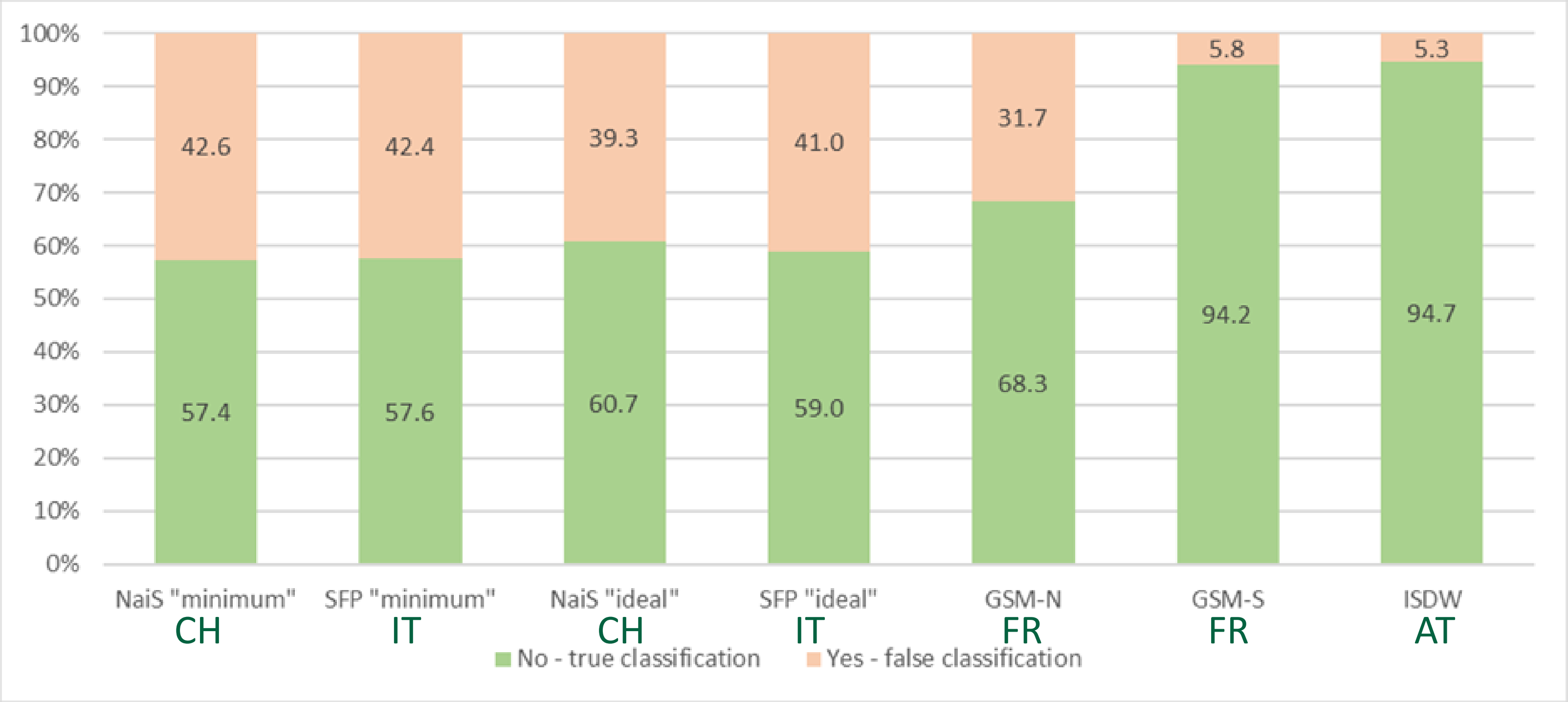
- Switzerland
  - NaiS (Frehner et al. 2005)
- Italy
  - SFP (Berretti et al. 2006)
- France
  - GSM-N (Gauquelin et al. 2006)
  - GSM-S (Ladier et al. 2012)
- Austria
  - ISDW (Perzl 2008)

## Silvicultural targets:

- Crown cover density
- Gap width
- Slope angle
- Gap length
- Evergreen crown cover
- Stem density
- Forest type
- Altitude
- Aspect
- …

# Assessment of protective effects in avalanche release areas is still associated with uncertainty

Comparison of the European protective forest management guidelines with 295 actual forest avalanche events



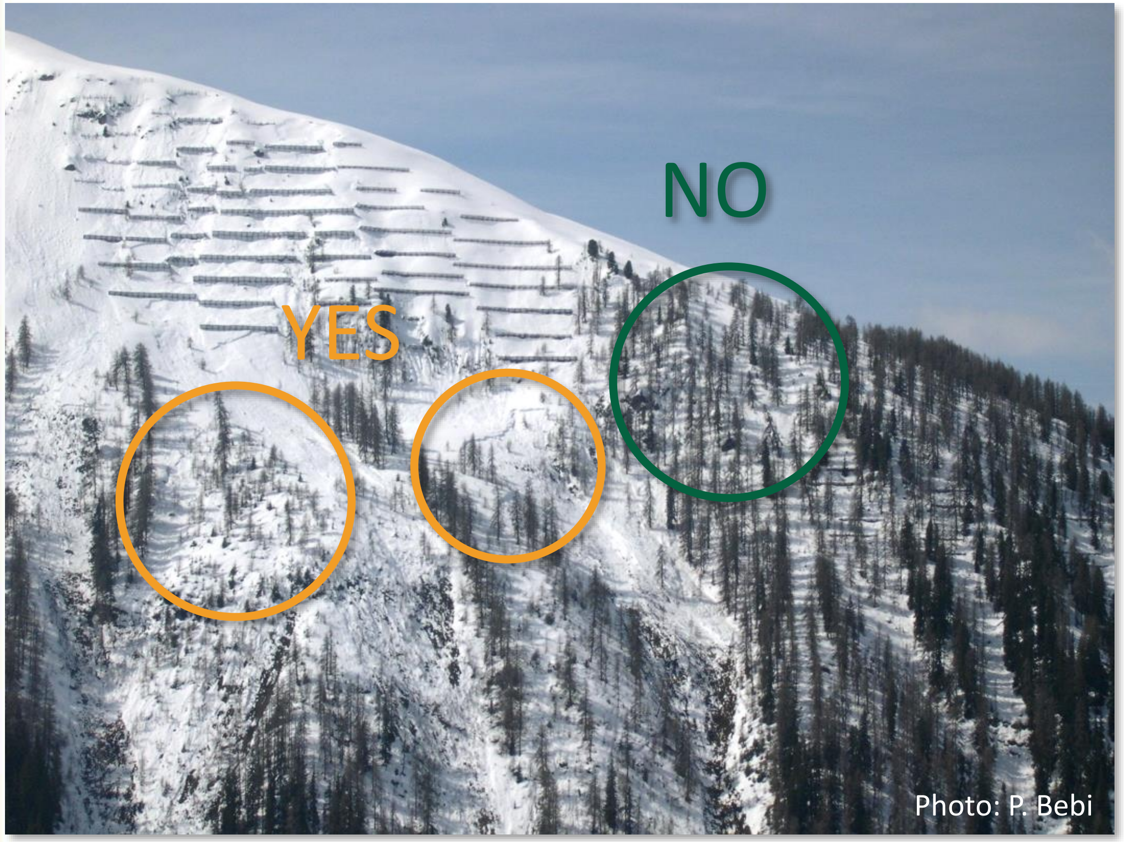

Snow avalanche release – validity of the combined targets of forest characteristics

Source: Perzl & Kleemayr 2020, Perzl et al. 2021


Kals am Großglockner, East Tyrol; October 2021
Do past observations still represent current and future conditions?
...where do we grow from here?
Photos: BFW, M. Adams, M. Plörer

# Quantifying **future** protective effects on avalanche release

Observation-based approaches

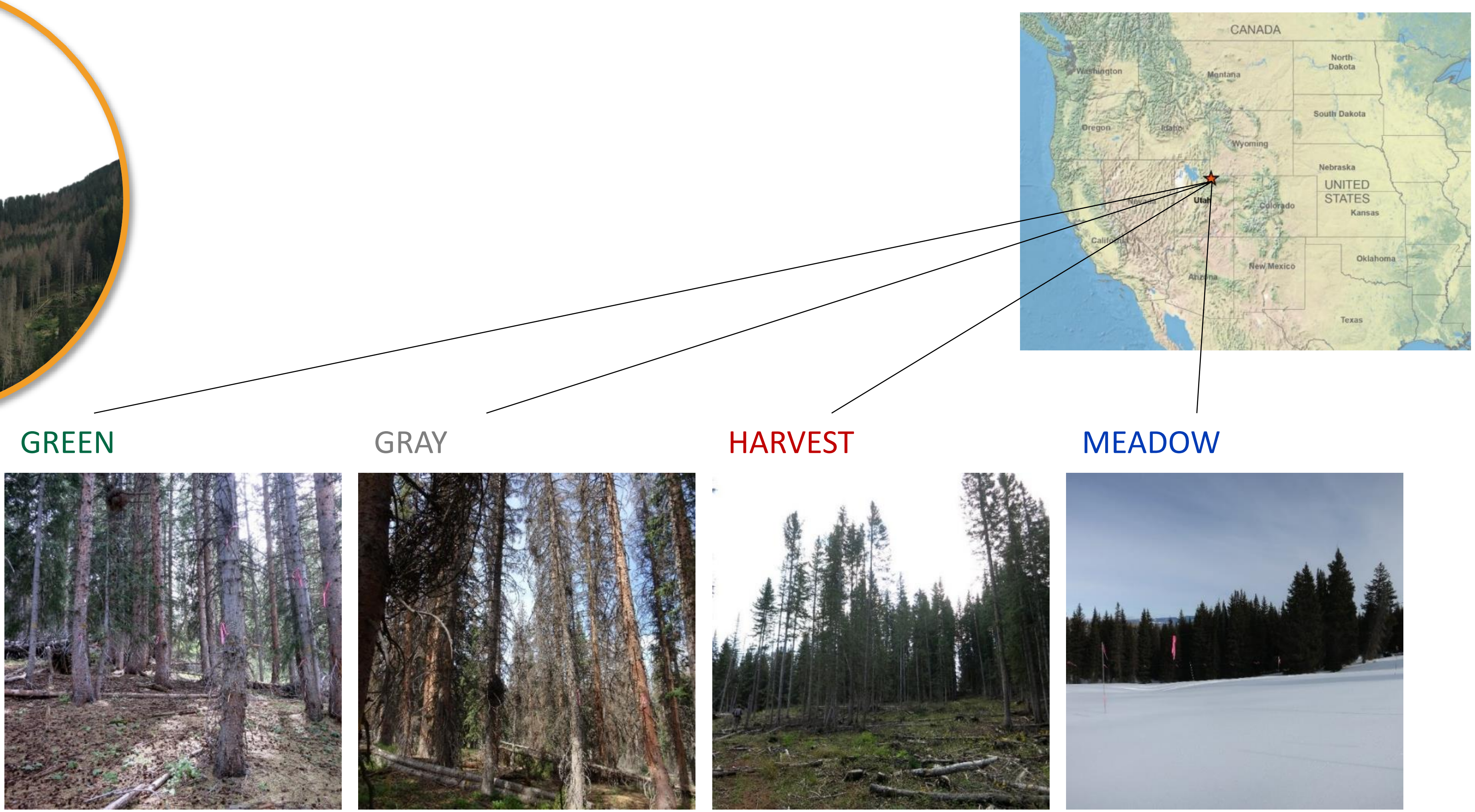



Process-based approaches

# Quantifying and monitoring protective effects after windthrow

# Effects of bark beetle attacks on snowpack and avalanche formation?

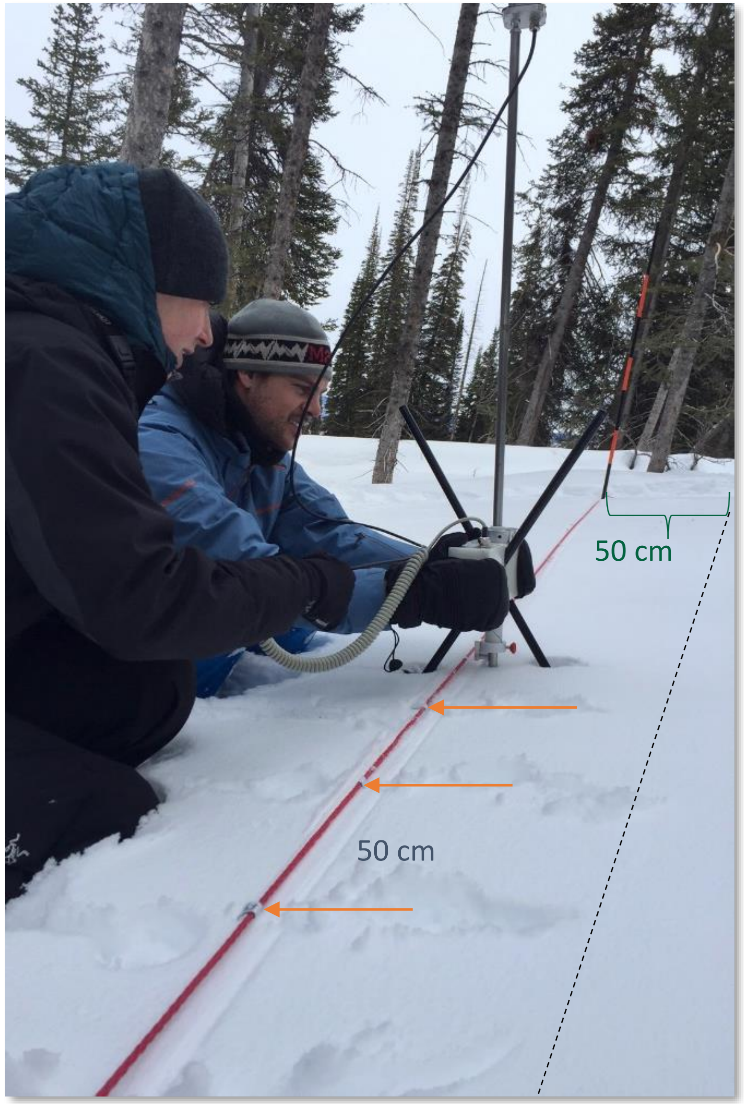




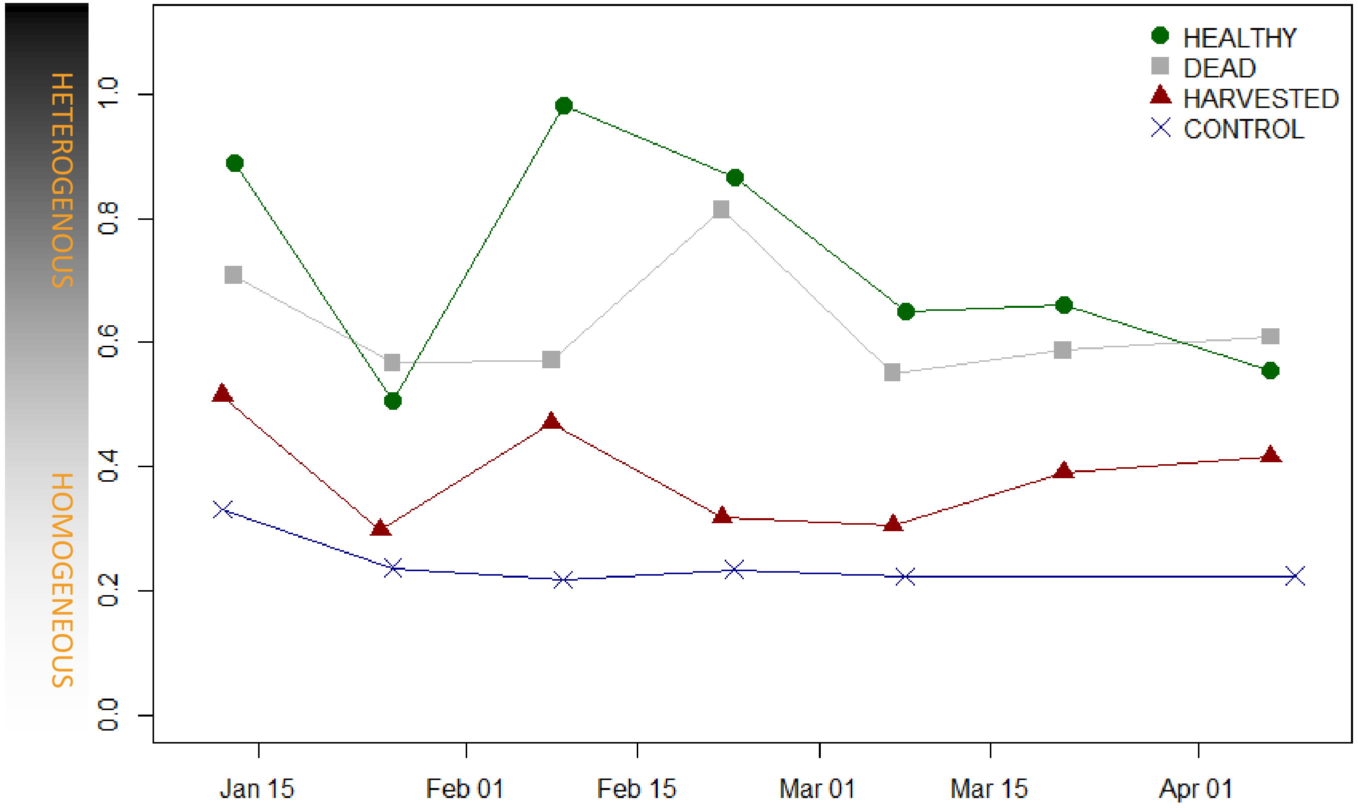

HETEROGENOUS — SNOW STRATIGRAPHY — HOMOGENOUS

Teich et al. 2019

# Effects of bark beetle attacks on snowpack and avalanche formation?




Evolution of spatial variability in snow stratigraphy over time




Teich et al. 2019

# Where do we grow from here?

?

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Federal Research Centre for Forests

Picture | Filmstyle from „See Aural Woods" (Luma.Launisch & Takamovsky)

# Thanks for listening!


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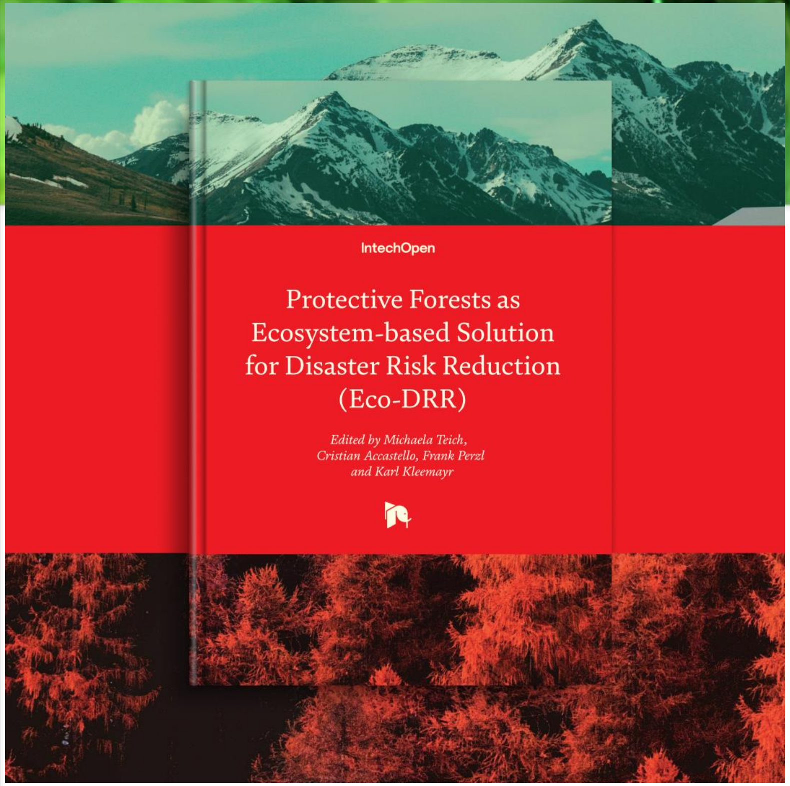


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https://www.facebook.com/BundesforschungszentrumWald

https://twitter.com/bfwald

https://www.youtube.com/user/Waldforschung

NGI

# A Tour of Avalanche Dynamics Along Overgrown Paths

Fonnbu 50 Years Jubilee — Oppstryn, 2023-09-07

Dieter Issler, NGI

# Don’t understand a thing? – Use statistics!

- Heim (1932), Scheidegger (1973), …:
  Friction-dominated flow processes $\Rightarrow$ run-out angle $\alpha$
  1. Look at observations, plot $\alpha$-angles on an axis
  2. From data, select a critical lower value according to your safety needs
  3. Find potentially hazardous areas with GIS techniques

- Russia in 1990s/2000s: $\alpha = 16°$ (too wasteful?)
  Japan presently: $\alpha = 18°$ (examples with $< 18°$)

- Approach unsuitable for Norway!

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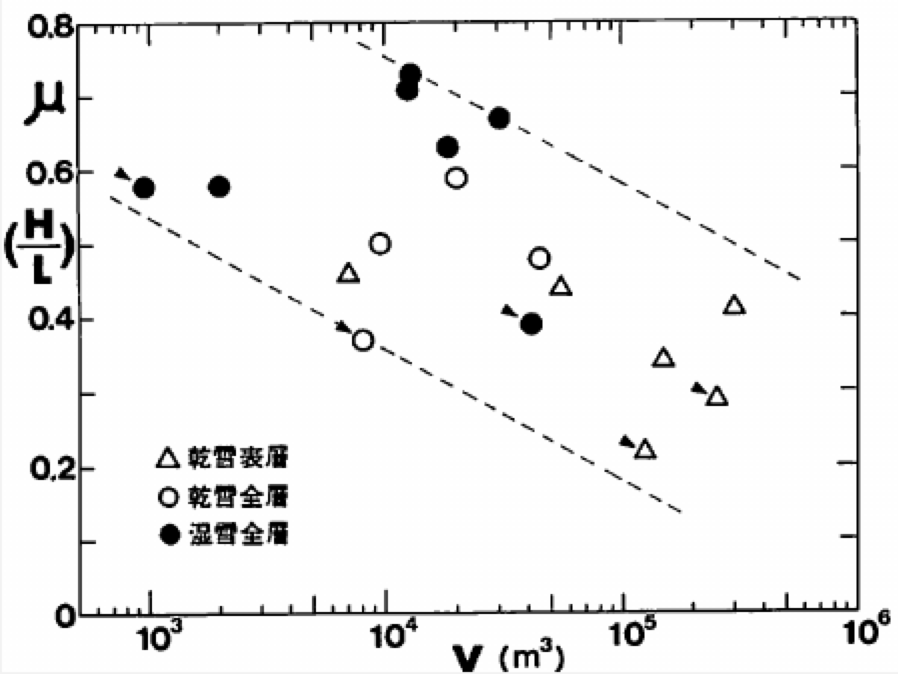
# Don’t understand a thing? – Use statistics! (2)

## Correlation of α with volume?

- Correlation established for big landslides
- Avalanches: limited data set
- Correlation likely but not very strong
- Not so easy to use in practice (how to estimate avalanche volume from terrain data?)
- Perhaps something to take up again with more data?

K. Izumi, Niigata Univ. Report (1985)

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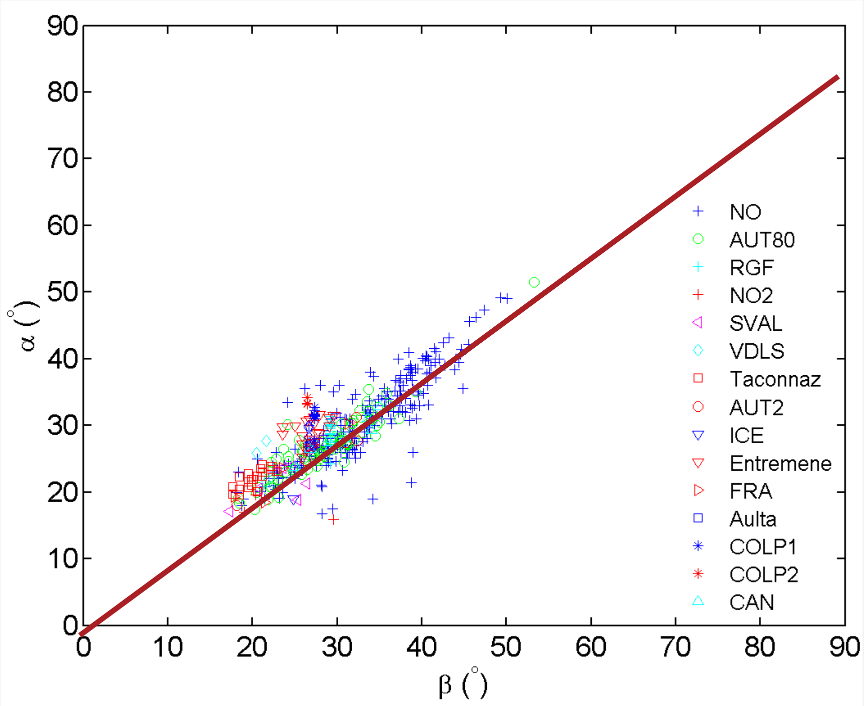
# Don’t understand a thing? – Use statistics!  (3)

## Correlation of α with path steepness β !

Lied, Bakkehøi, Domaas (1970s–1980s):

- Clear correlation but many possible noise sources
  $\alpha = 0.96\,\beta - 1.4°$ (Norway)
- Relatively easy to use in practice except for multiple β-points




Plot by P. Gauer

# Don’t understand a thing? – Use statistics!  (3)

Correlation of α with path steepness β !

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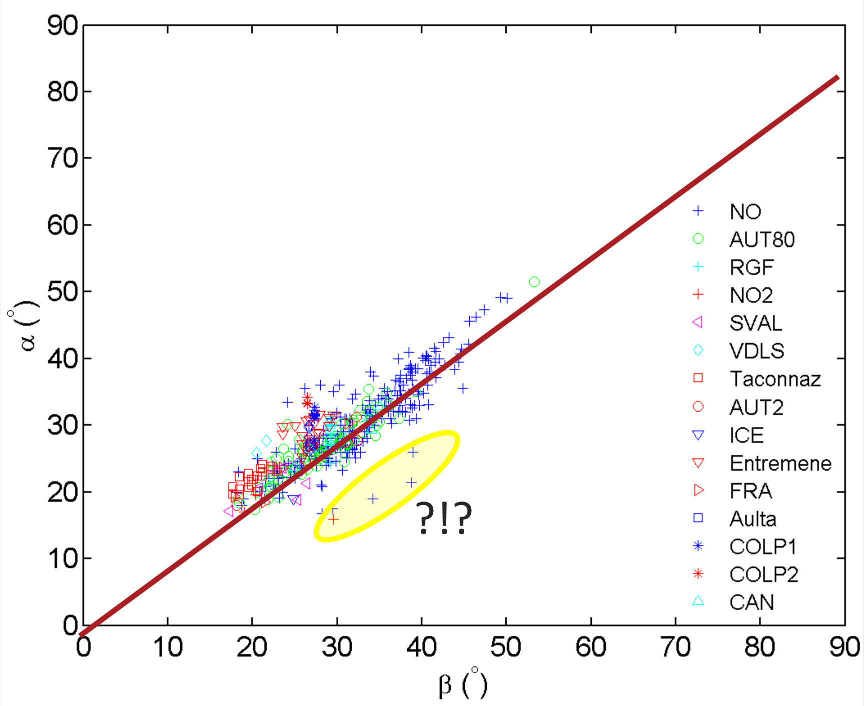


Plot by P. Gauer

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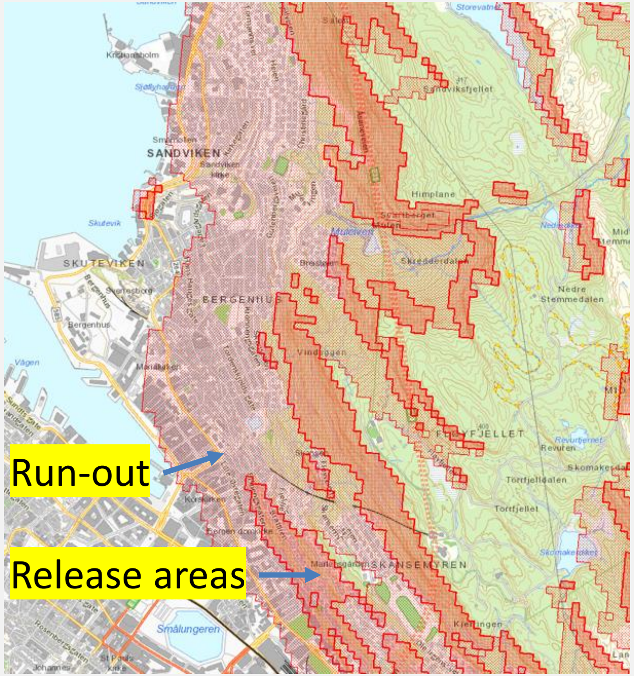
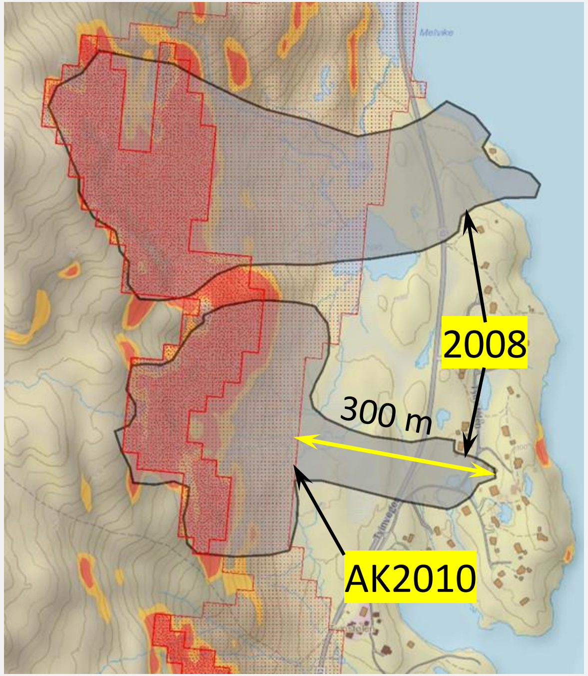
# Don’t understand a thing? – Use statistics!  (4)

AK2010 is…

too conservative in forested coastal areas  /  too optimistic in continental mountain climate




The city of Bergen is shown highly endangered …




Tyinstølen 2008: Run-out 300 m *longer* than in AK2010 (drop height 150 m!)

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# Don't understand a thing? – Use statistics! (5)

- What has gone wrong?
  - Correlation based on data mostly from maritime area
  - Correlation for avalanches without pronounced forest effect

  $\Rightarrow$ These two avalanches / areas belong to different statistical populations!

- Can one improve the α-β model?

  $\Rightarrow$ Collect data from different climate zones, path shapes (and perhaps from forested areas)

  $\Rightarrow$ Use physical insight to define homogeneous «populations»

# Block models – completely outdated?

Simplest mechanical model:

- Neglect spatial extent of avalanche, just consider center of mass
- Solve Newton's equation of motion on path profile $\theta(s)$:

$$a \equiv \frac{\mathrm{d}^2 s}{\mathrm{d}t^2} = \frac{F_{\mathrm{gravity}} - F_{\mathrm{friction}}}{m} = g \sin\theta - f(u, h, m)$$

Many choices for retardation function $f$ – check against experiments!

- Coulomb: $f = \mu g \cos\theta$
- PCM: $f = \mu g \cos\theta + \lambda u^2$
- Voellmy–Salm: $f = \mu g \cos\theta + k u^2 / h$
- . . .

How to choose parameters???

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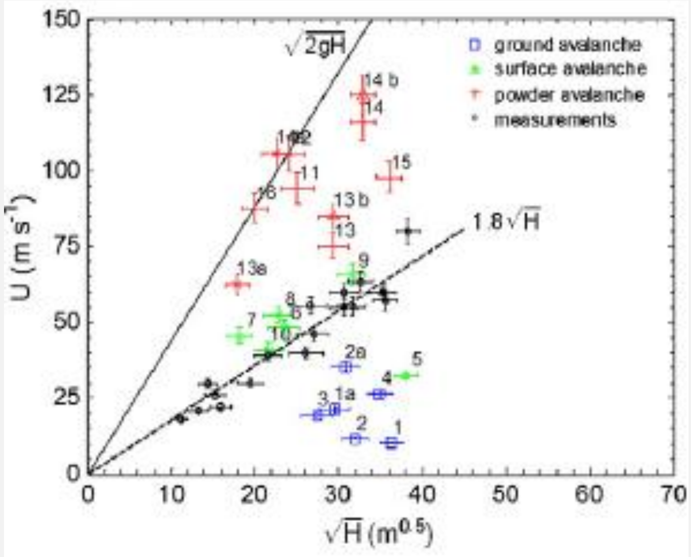
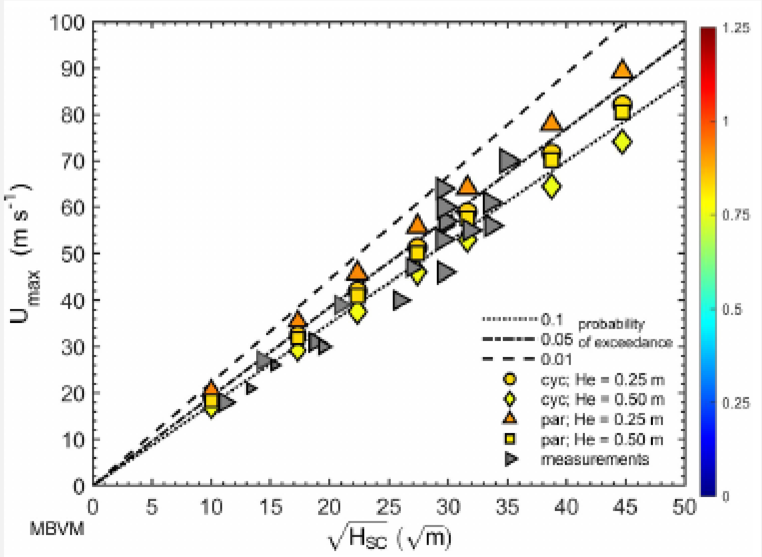
# Block models – completely outdated? (2)

- Mass-point model of powder-snow avalanches
  - Kulikovskii & Sveshnikova (1977), Beghin & Olagne (1991), …
  - Powder-snow cloud modeled as a «balloon» of variable size and mass
  - Entrainment of ambient air and snow
  - Entrainment governed by extra evolution equation for turbulent energy
- PLK – a poor man’s Discrete Element Model in 1984
  - Perla, Lied & Kristensen, *Cold Regions Sci. Technol.* **9** (1984)
  - About 1000 block models combined, particles starting from different places in the release area
  - Stochastic component in friction force to mimic particle collisions

# Block models – completely outdated?   (3)




Gauer (2014, 2018, 2020) studied velocity scaling of observed avalanches by comparing to Monte Carlo simulations with different block models.

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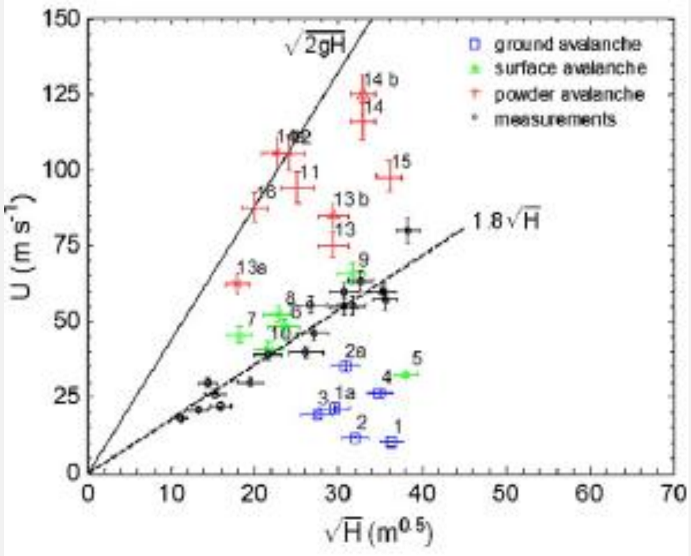
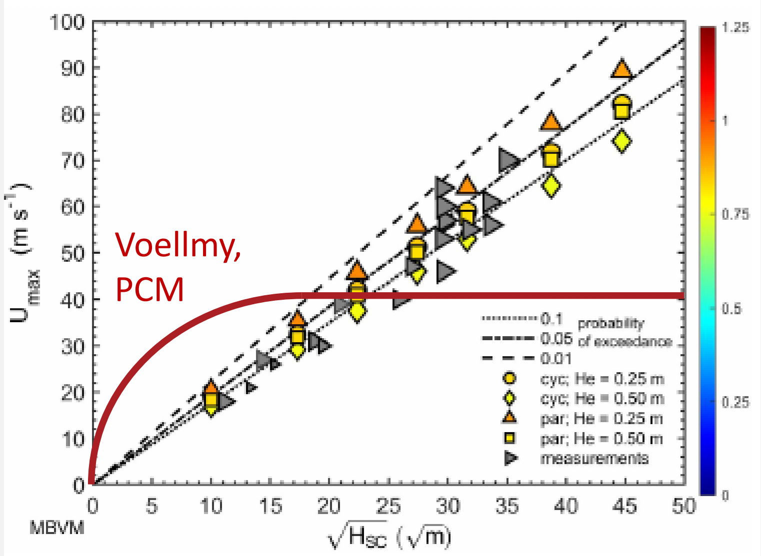
# Block models – completely outdated? (3)




Gauer (2014, 2018, 2020) studied velocity scaling of observed avalanches by comparing to Monte Carlo simulations with different block models.

# Block models – completely outdated? (4)

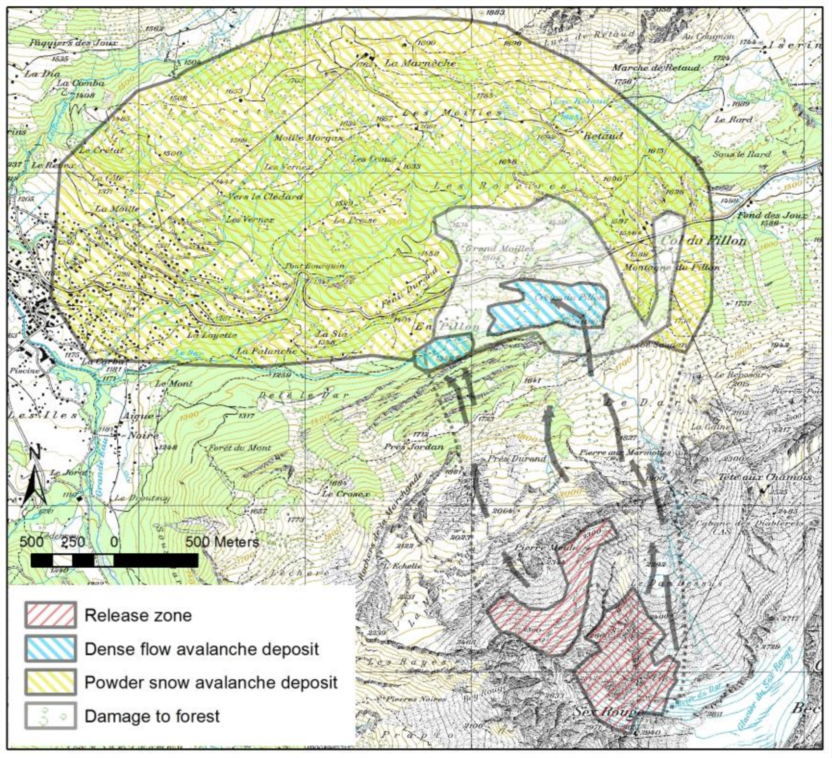
- Understimation of velocities for large avalanche paths: Generic problem of PCM- and Voellmy-type models
- Same situation in 1D and 2D continuum models
- Practitioners compensate shortcoming with size-dependent friction parameters.
- Practically relevant:
  - Avalanche may choose different path in winding gullies.
  - Many protection dams dimensioned too low because of this!

# A look into the world of real avalanches

Gigantic avalanche descent in Switzerland in 1995:

- Release volume > 1 mio m³
- Deposit on valley floor > 10 m
- Run-out powder snow cloud ~ 6 km
- Dense deposit ~ 0.5 m deep on *opposite* slope ~ 100 m above valley
- Must have had speed > 70 m/s but lower density than dense core.

(Issler et al., SLF-Rep, 1996; *Geosci.* **10,** 2020)

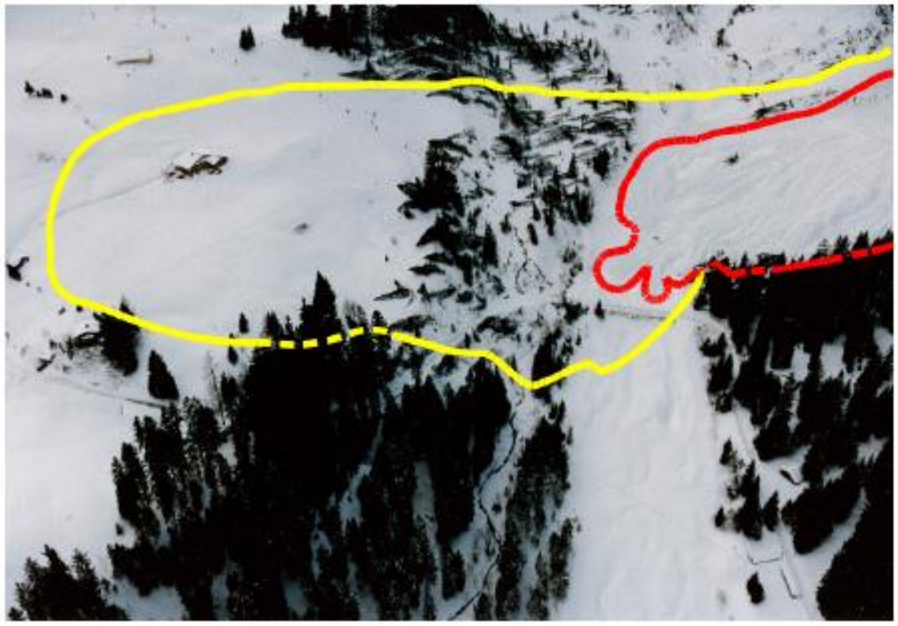


# A look into the world of real avalanches (2)

Many similar observations from other large avalanches!

- Deposit area of dense flow
- Approximate deposit area of fluidized layer (< 0.5 m thick, tapering off)
  Moderate pressure, but forest damage

Powder-snow avalanche deposits extend ~ 500 m to the left (uphill).



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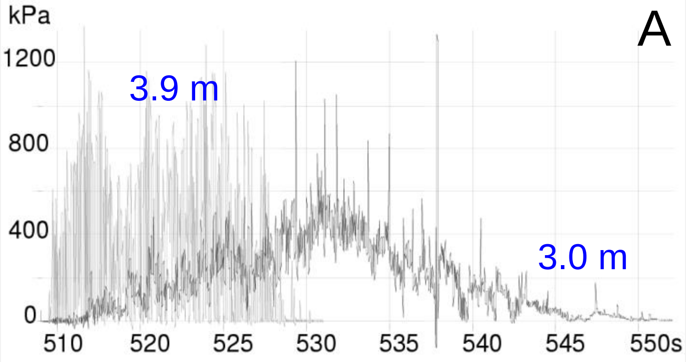
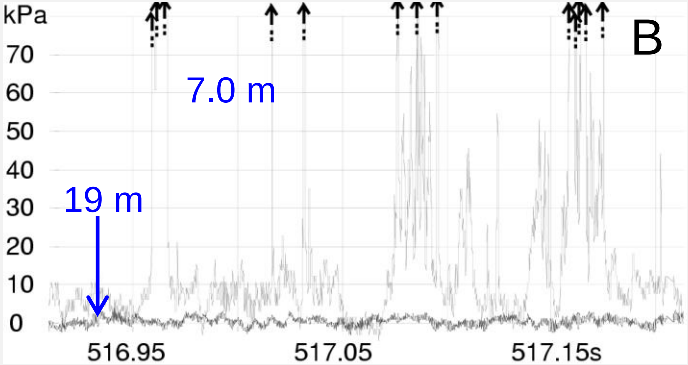
# A look into the world of real avalanches (3)

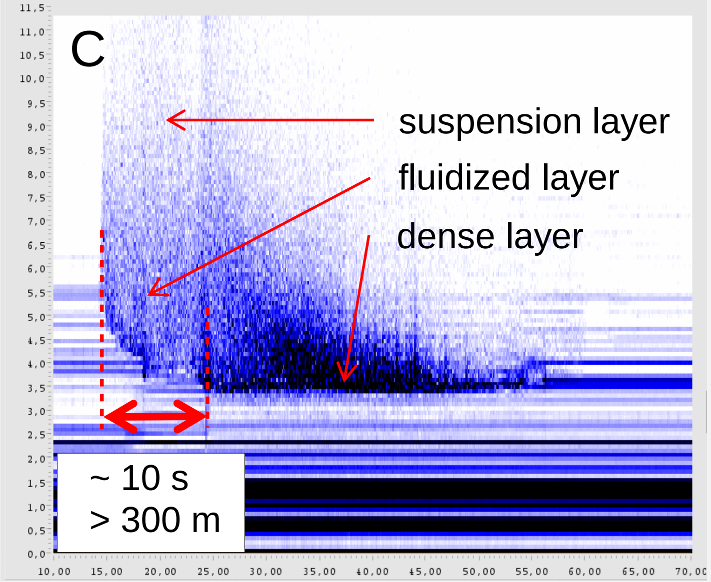



Load cells




1999 measurements at Vallée de la Sionne

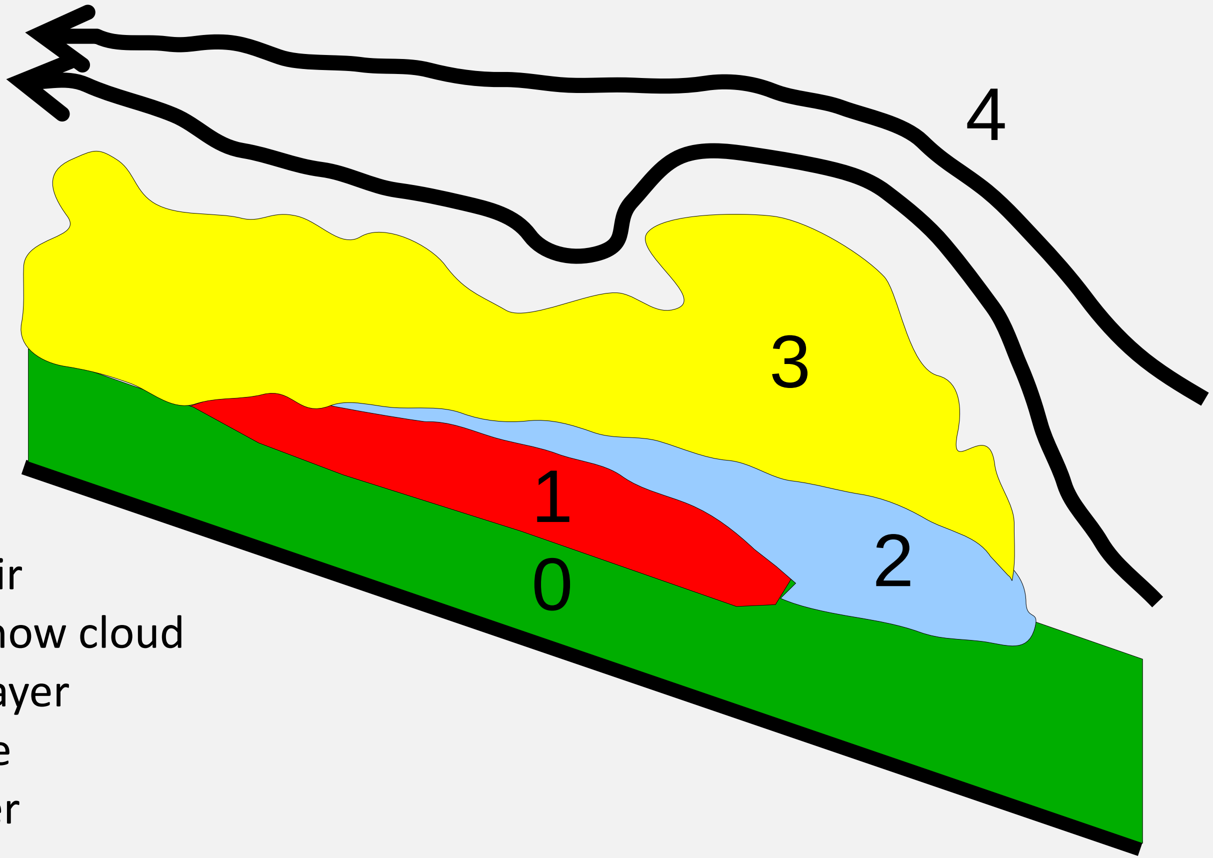
FMCW radar



# A look into the world of real avalanches (4)

Intermediate-density layer (2) is missing in present-day models.

Cannot be remedied by tuning friction parameters!




4 ambient air
3 powder-snow cloud
2 fluidized layer
1 dense core
0 snow cover

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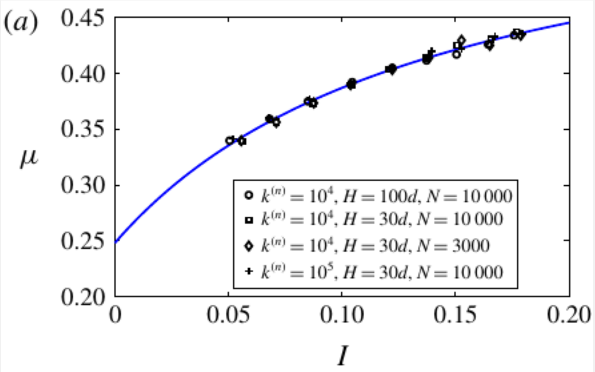
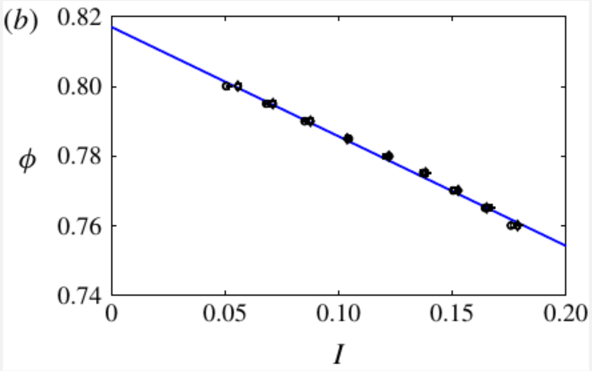
# The modern approach: $\mu(I)$ rheology



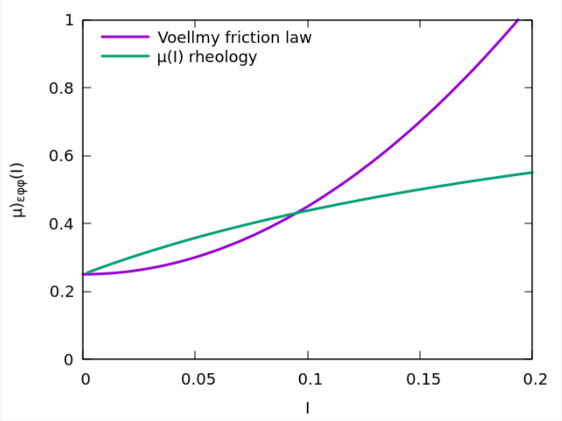




Schaeffer et al., *J. Fluid Mech.*, 2019

Dense granular materials:

- Effective friction coefficient $\mu$ grows *sublinearly* with shear rate *I*.
- Density decreases linearly with *I* (but only by ~10% over realistic range)

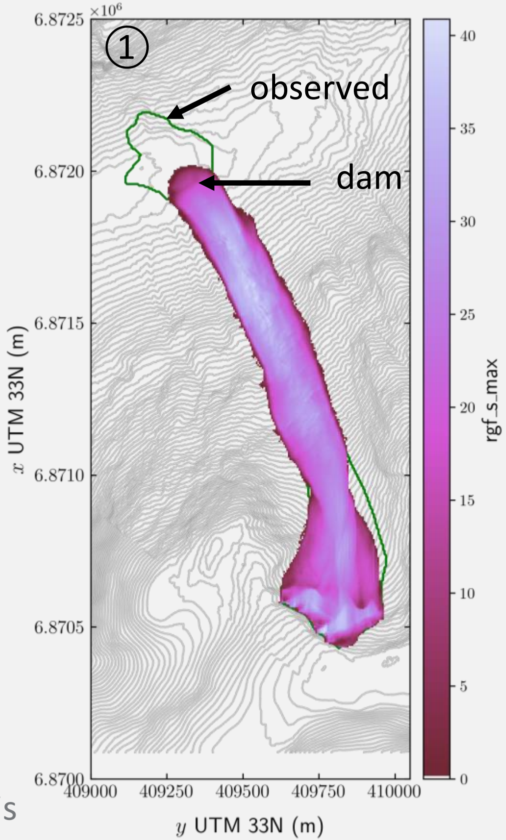
Speed dependence of $\mu_{\text{eff}}$ differs radically from Voellmy model!

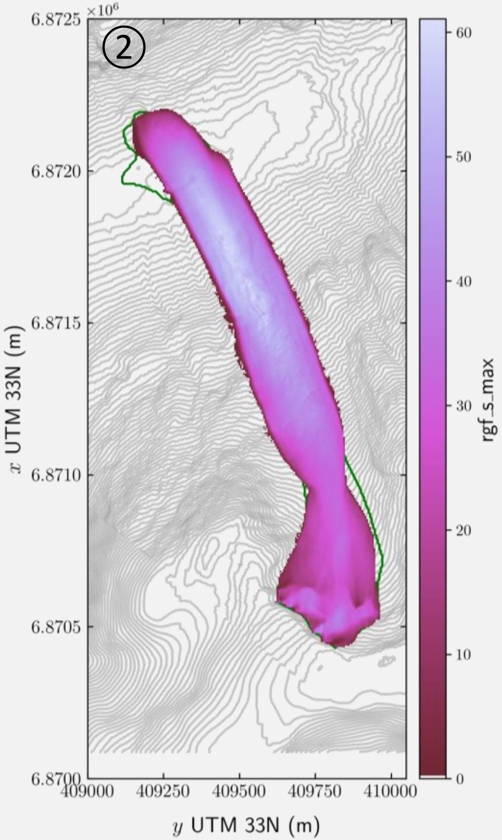


# The modern approach: $\mu(I)$ rheology (2)

## 1987-01-28 avalanche at Ryggfonn:

- 2 simulations with MoT-muI $\mu_{min}$ = 21.4°, $\mu_{max}$ = 34.7°, $d_{part}$ = 1 cm
- Simulation 1 models the dense part, which stopped at the dam, with $I_0$ = 0.1.
- Simulation 2 captures over-run of the fluidized head with $I_0$ = 1.
- Velocities close to measured values

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Simulation by C. Tregaskis

# Reminiscences of the past – the NIS model

1980s: Kinetic theory of granular materials

Bonsak Schieldrop, Fridtjov Irgens and Harald Norem (SIN → NIS) formulated general rheology reproducing granular behavior:

- Density assumed constant
- Two contributions to stresses: frictional and collisional
- Bed-normal stress: $\sigma_n = \sigma_e + \nu_n \rho_p d_p^2 \dot{\gamma}^2$
- Shear stress: $\tau = \mu\sigma_e + \nu_s \rho_p d_p^2 \dot{\gamma}^2 = \mu\sigma_n + (\nu_s - \mu\nu_s)\rho_p d_p^2 \dot{\gamma}^2$

NIS model much used at NGI in 1990s, 2000s (1D code), but…

… $\mu_{\text{eff}} = \mu + Au^2$ as in PCM, Voellmy–Salm models! ☹

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# Reminiscences of the past – the NIS model (2)

Where is the root of the problem?

- Shear stress in granular materials increases with $\dot{\gamma}^2$ **if** the material cannot expand under increasing granular pressure.
- **But:** avalanches may expand freely in upward direction!

  Granular pressure at high shear drives particles apart.

  $\Rightarrow$ Collisions become less frequent.

  $\Rightarrow$ Effective friction coefficient can increase sub-linearly with $\dot{\gamma}$ !

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# Reminiscences of the past – the NIS model

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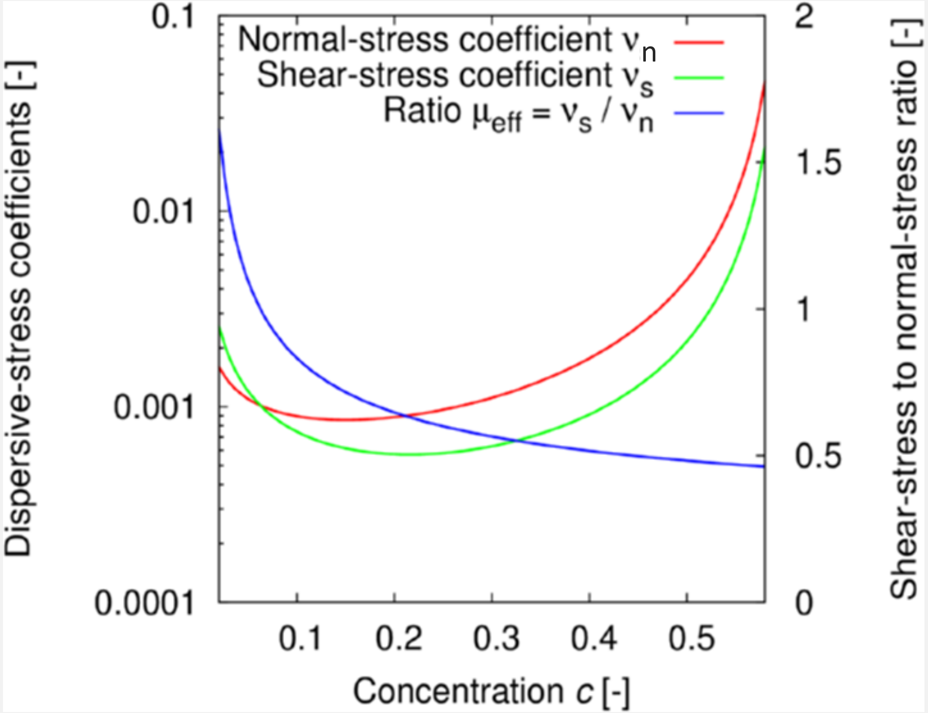
# Reminiscences of the past – the NIS model (3)

- Viscosity coefficients $\nu_n$ and $\nu_s$ depend **differently** and **strongly** on particle concentration $c$.
- Analytical calculations and DEM simulations around 1990 showed how $\nu_n(c)$ and $\nu_s(c)$ look.

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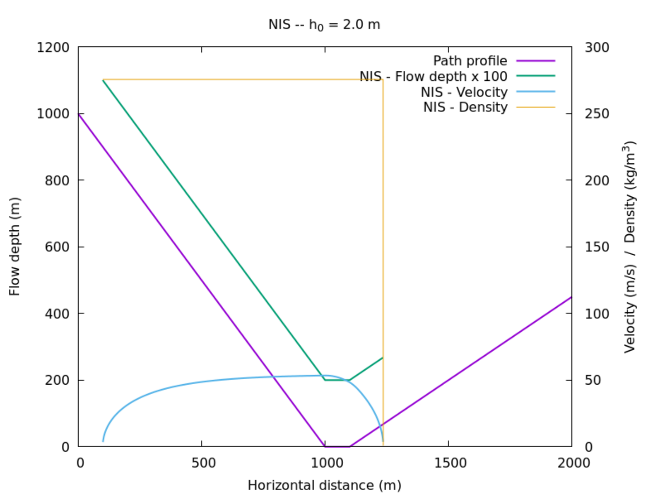
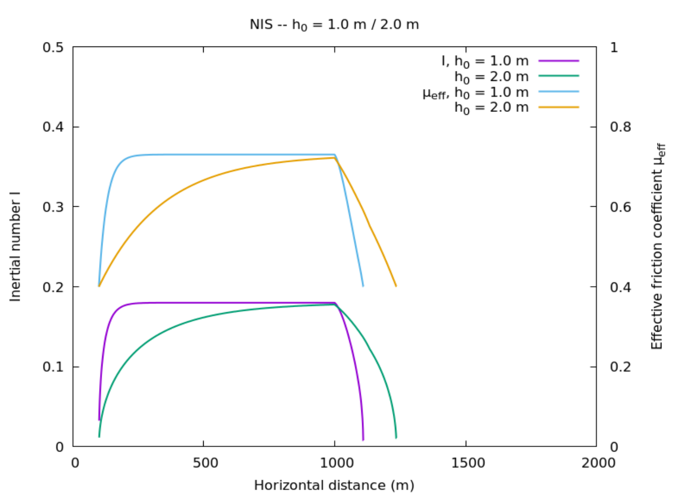
# Reminiscences of the past – the NIS model (4)

Implemented in a block model, can choose constant $\nu_n$, $\nu_s$ (NIS) or variable $\nu_n(c)$, $\nu_s(c)$ (eNIS).

NIS has constant flow depth, shows same behavior as PCM and Voellmy–Salm models.

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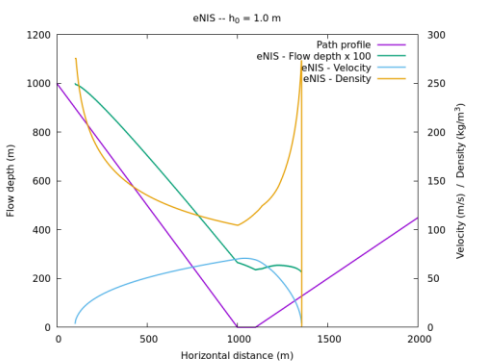
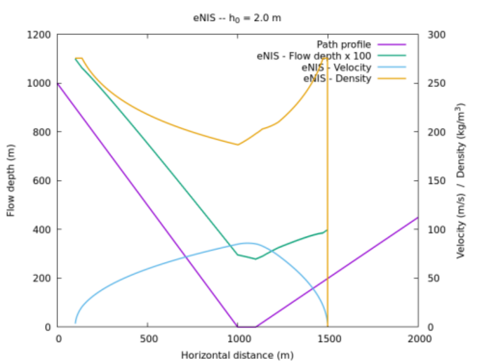
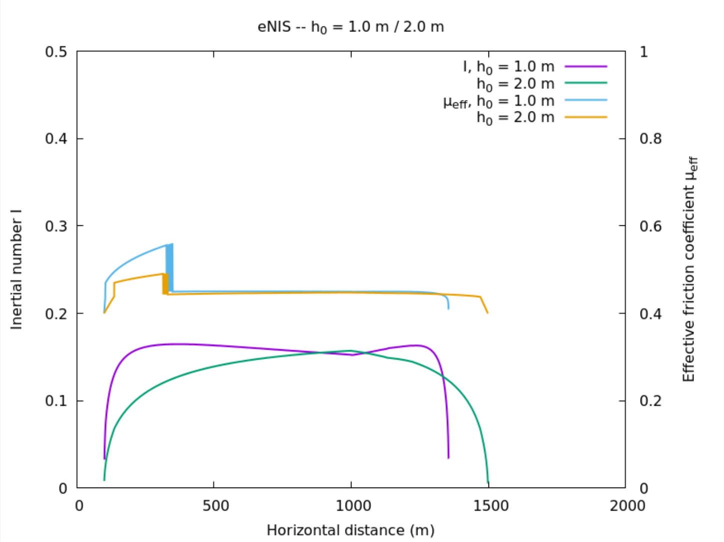
# Reminiscences of the past – the NIS model (5)




## eNIS:

- Variable flow depth
- Reduced density
- Higher speed
- Longer run-out




- $\mu_{eff}$ drops when fluidized state is reached.
- Density reduction *decreases* with avalanche size.

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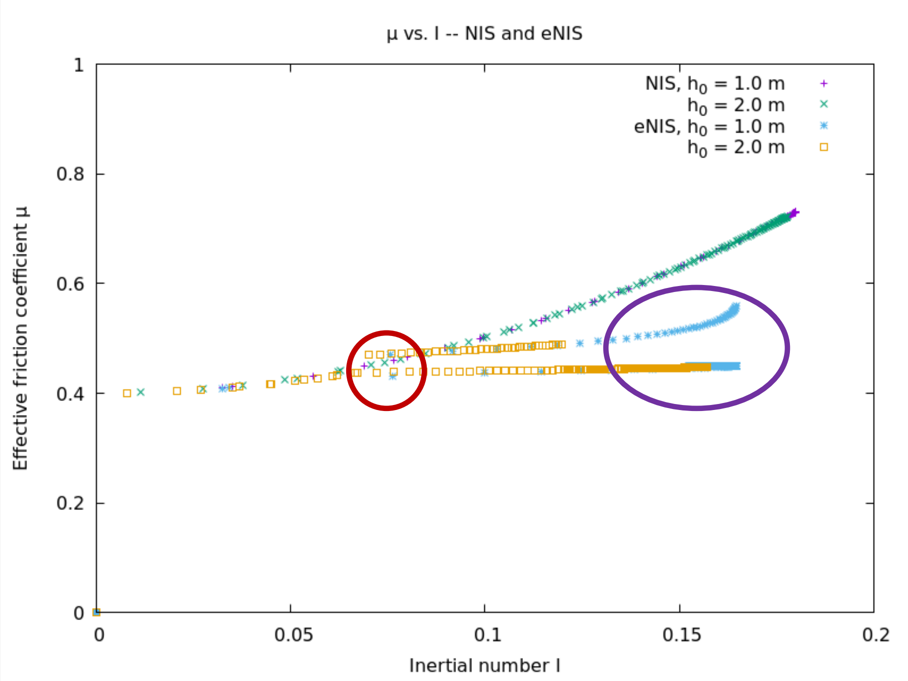
# Reminiscences of the past – the NIS model (6)

Some questions remain:

- Is there hysteresis in this model?
- Is the sudden jump of $\mu_{eff}$ physical???

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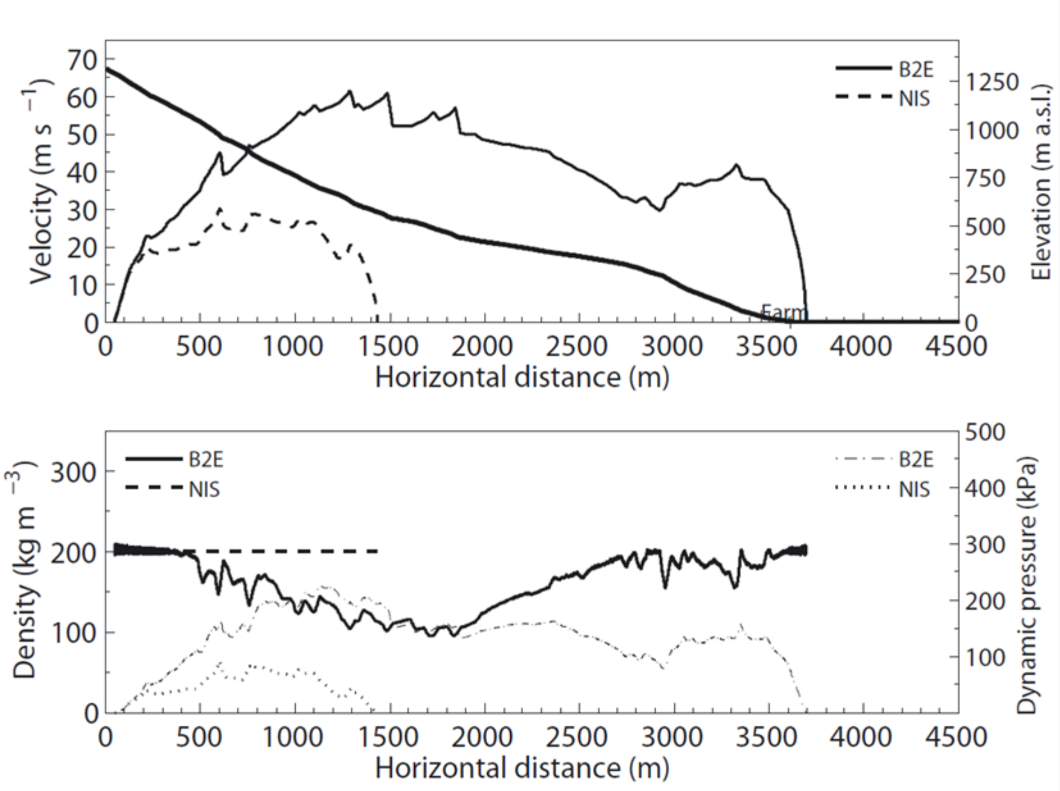
# Reminiscences of the past – the NIS model (7)

Theory has practical applications!

Avalanches at Bleie:

- Usually stop on gentle slope.
- Reached the fjord in 1994.
- NIS stops, eNIS goes all the way—with same parameter set.




Issler & Gauer, *Ann. Glaciol.* **58** (2008)

# Reminiscences of the past – the NIS model (8)

- Simulations: $\rho_{\mathrm{fl}} \sim 100$—$250\ \mathrm{kg/m^3}$
  Low values only in very steep slopes
- Vallée de la Sionne, Ryggfonn: $\rho_{\mathrm{fl}} \sim 30$—$100\ \mathrm{kg/m^3}$
  Low values even on counterslope

$\Rightarrow$ Extra dilatancy not due to particle collisions.
But what else can cause this?

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# Geotechnics to the rescue: pore pressure!

An additional fluidization mechanism must be at work!

Two triggers for a new idea:

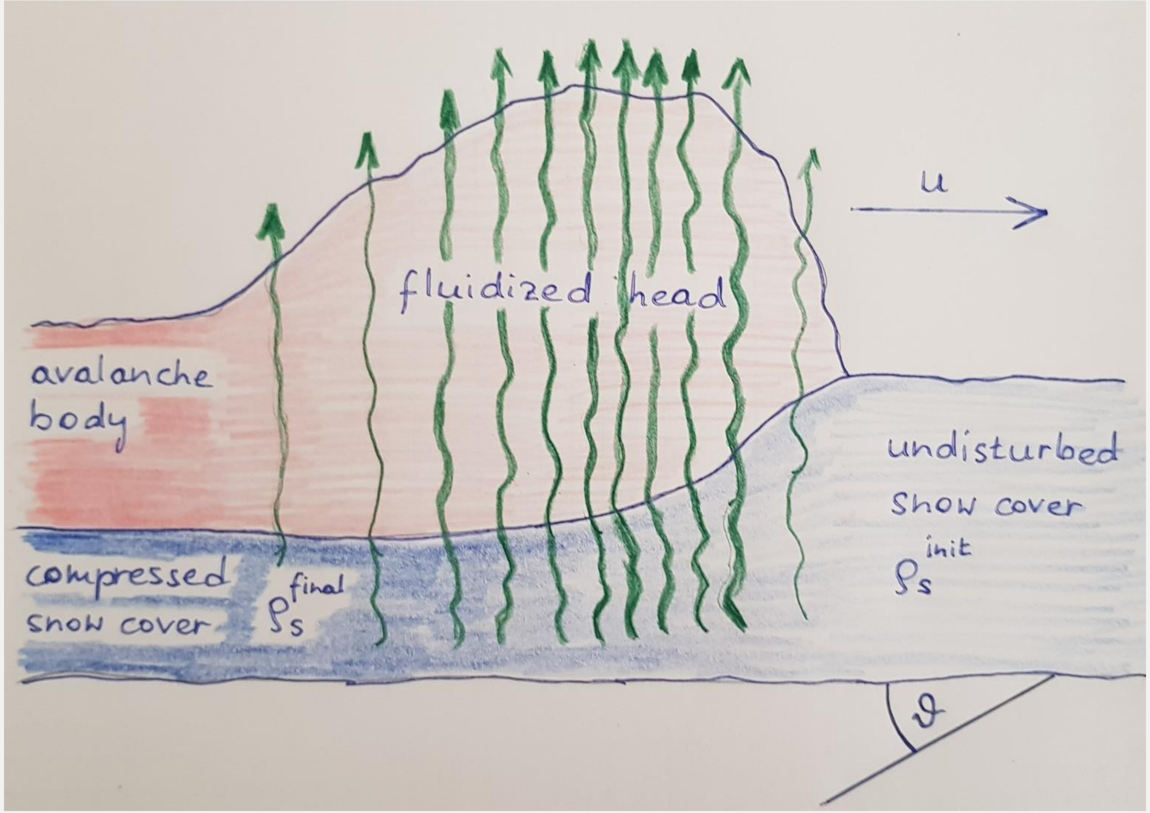
- "It's air, it's just air!"
  (Othmar Buser answering the question "What is snow?" in a TV feature on snow avalanches, late 1990s)
- "Dieter, I think it must have to do with the substrate!"
  (Dave Mohrig at geoflow13 workshop, Santa Barbara, 2013)

# Geotechnics to the rescue – pore pressure!   (2)

Main idea:

Head of avalanche compresses snow cover by its weight, pore air escapes through aval-anche and fluidizes it.

Avalanche body not fluidized because all air has escaped.

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To the next 50 years, dear Fonnbu (and Frode)!

# Important background facts

- Societal mandate:
  NGI’s work must contribute to solving societal problems, e.g., improve management of natural hazards.
  $\Rightarrow$ Strong focus on practical applicability!

- Limited resources:
  State funding for avalanche research amounts to maintenance of Fonnbu, Ryggfonn and approx. 1 full-time equivalent position.
  Successful EU projects on avalanche dynamics in 1990s to early 2000s, acquisition of extra funding has been difficult since.

# The many faces of uncertainty — Risk

- Risk = Expected loss due to an uncertain adverse event
- Useful concept for managing natural hazards under economic constraints
- Qualitative/implicit risk considerations underlie the TEK17 regulations for safety against gravity mass flows.
- Risk *R* depends on probability *P* of event with intensity *I*, vulnerability *V* and exposure *E* of people/objects *O*:

$$R = \sum_{I,O} \boxed{\underbrace{P(I) \cdot V_O(I)}_{\text{our job!}}} \cdot E(O)$$

# The many faces of uncertainty — Sources

Three major sources of uncertainty when modeling natural hazards:

- Weather is a stochastic element in this context
  $\Rightarrow$ Large uncertainty in initial conditions!
- Epistemic uncertainty: Are our model equations adequate?
- Uncertainty in the solution of the model equations

$\Rightarrow$ No point in using expensive high-precision numerics if the model misses the relevant physics or the initial conditions are poorly known!

# The modern approach: $\mu(I)$ rheology (2)

## Experimental code MoT-muI:

- 2D code, Voellmy friction law replaced by $\mu(I)$ rheology, density kept constant (Callum Tregaskis)
- Model has 3 main parameters $\mu_{min}$, $\mu_{max}$, $I_0$ instead of Voellmy friction parameters $\mu$, $k$. 3 additional parameters $\beta$, $\beta^*$, $d_{part}$ influence mainly the stopping behavior.
- Short computation times like MoT-Voellmy. Appears more stable due to $h_{stop}$-mechanism built into the rheology.
- Must find recipe for predicting parameters depending on climatic conditions.

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Chair of Alpine Mass Movements

# Recent advances in depth-resolved simulations of snow avalanches

Prof. Dr. Johan Gaume

# Acknowledgments


Xingyue Li

Betty Sovilla

Nico Gray


Michael Kyburz

Camille Ligneau

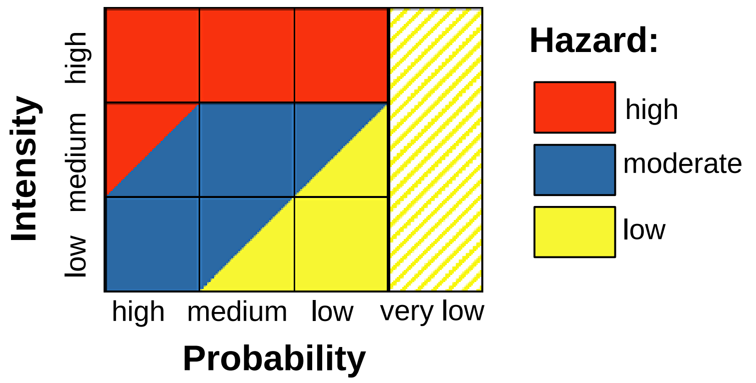
Lars Blatny

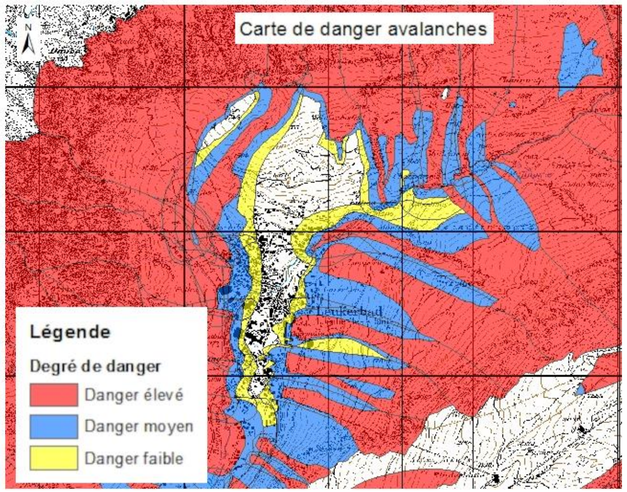
Hervé Vicari

# Introduction

## Context

Hazard assessment



# Introduction

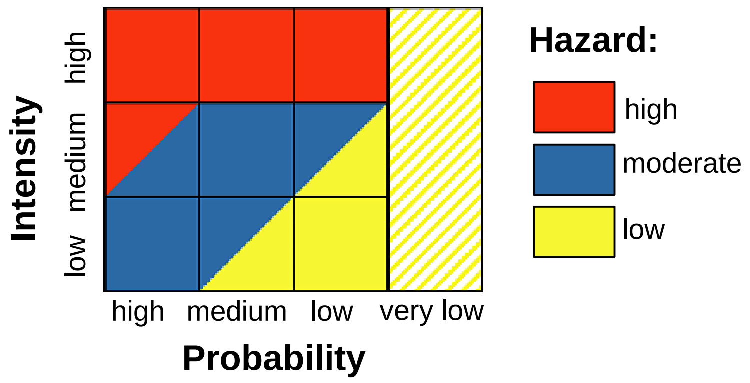
## Context

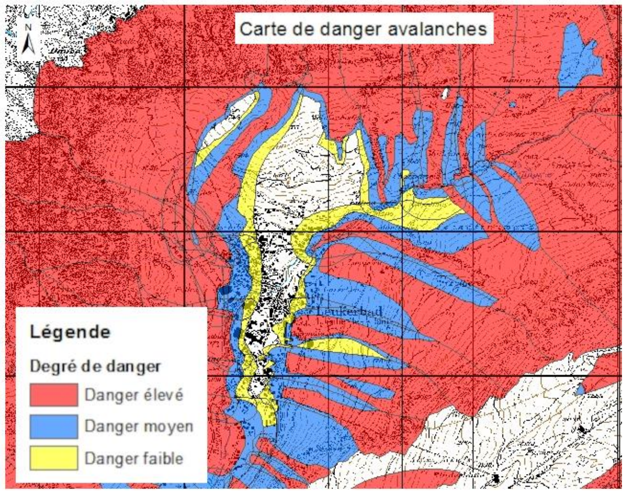
MODELING

Alpine mass movements

EXPERIMENTS

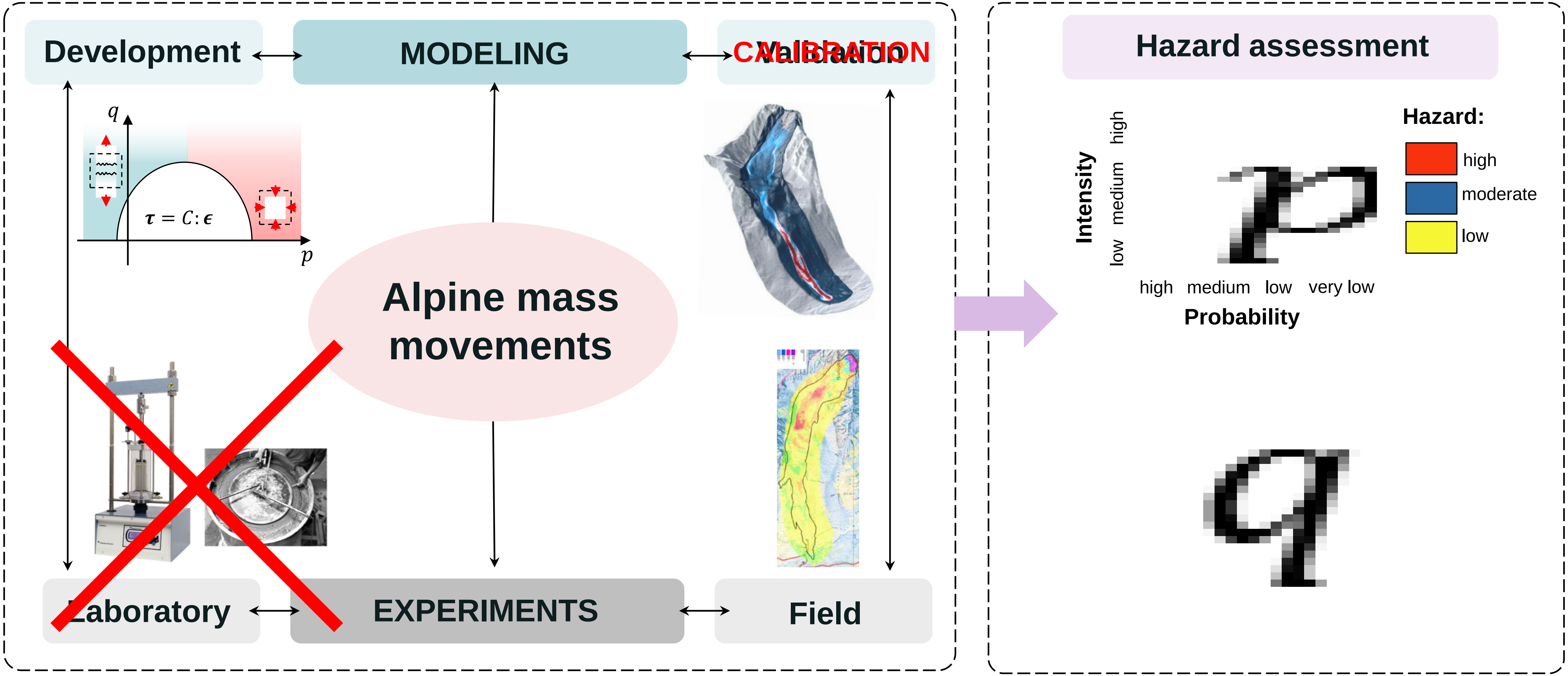
Hazard assessment



# Introduction

## Context



# Modeling snow avalanches

## A short historical perspective

**Block models**
Coulomb friction
Paul Mougin

**Voellmy**
heuristic friction law

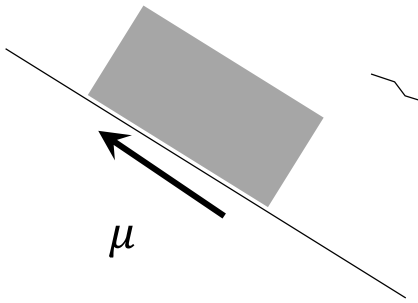
**Salm** analytical evaluation

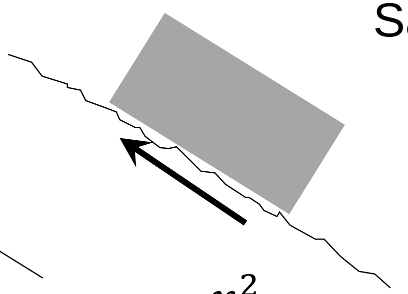
**Aval-1D**
SLF

**2D RAMMS - SLF**
User Extended

**3D Next Gen.**
MPM

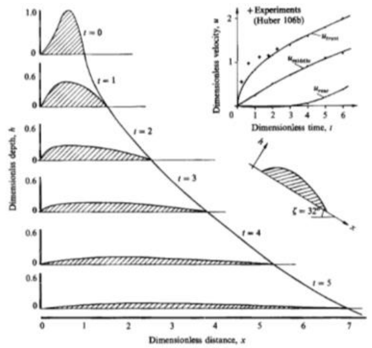
**1922** — **1955** — **1989** / **1990** — **2002** — **2010** — **2022** — **2026?**

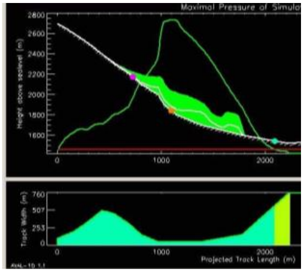


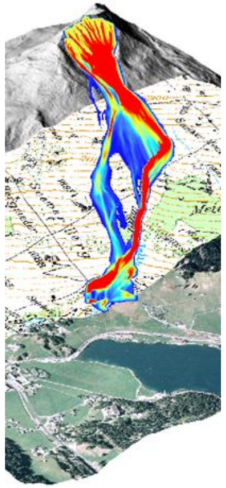



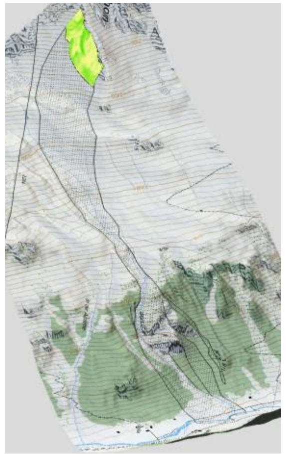
$$\mu + \frac{v^2}{h\xi \cos \psi}$$

Savage-Hutter model









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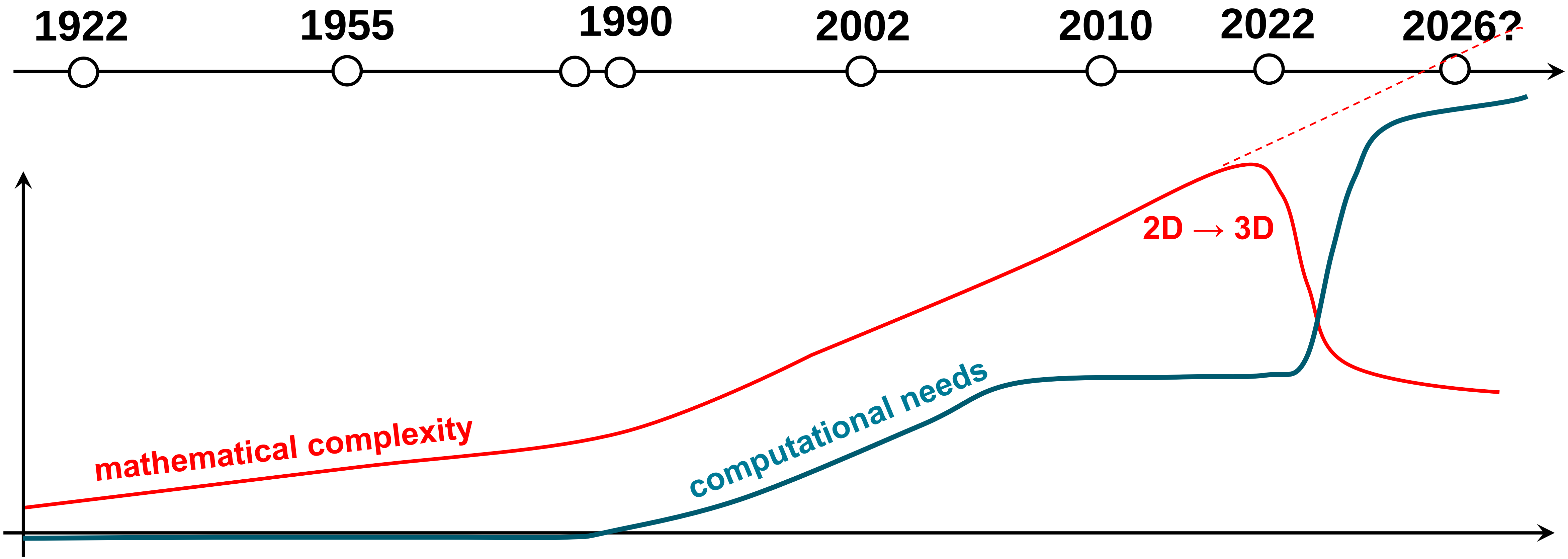
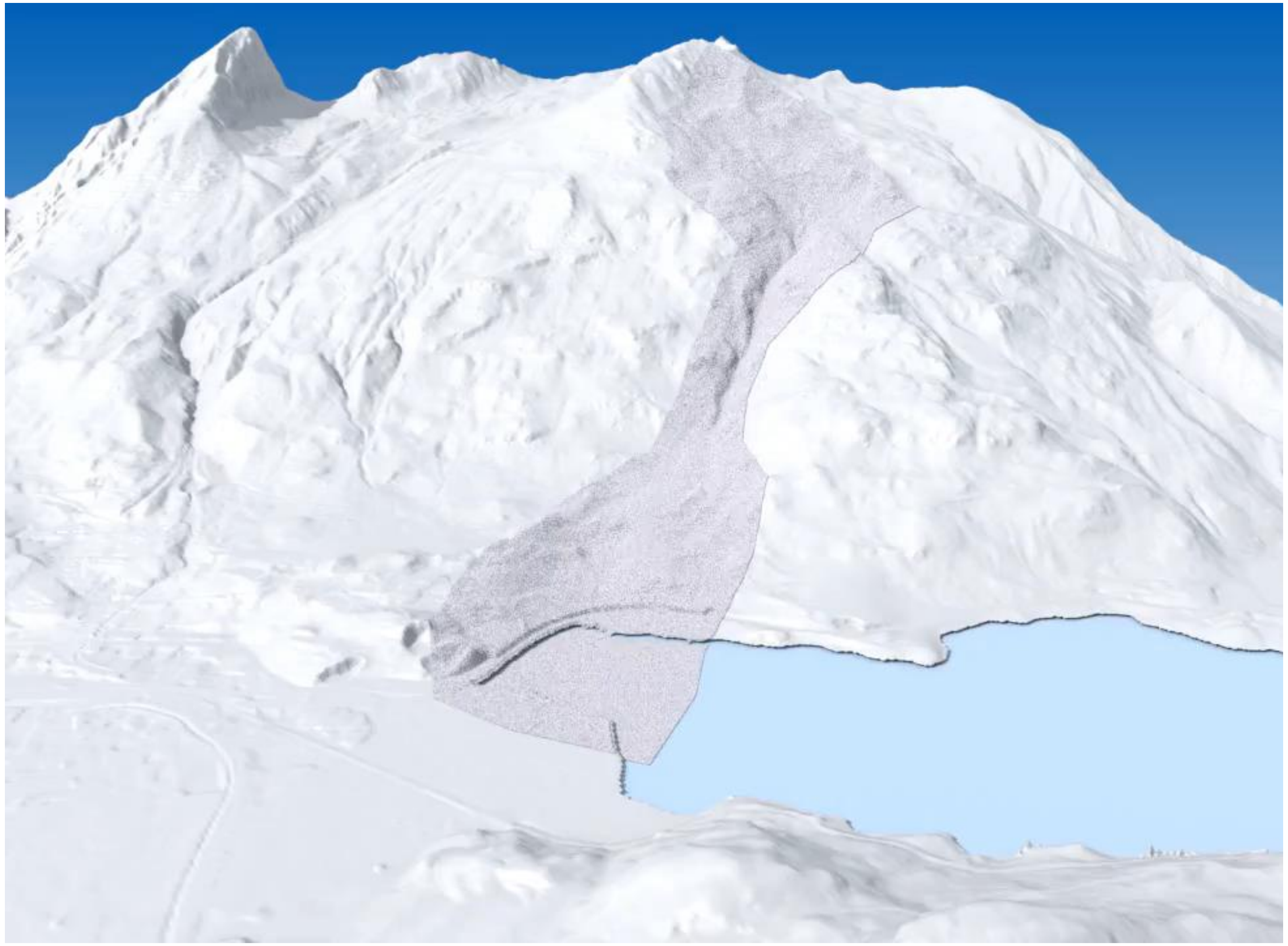
MPM-DEM



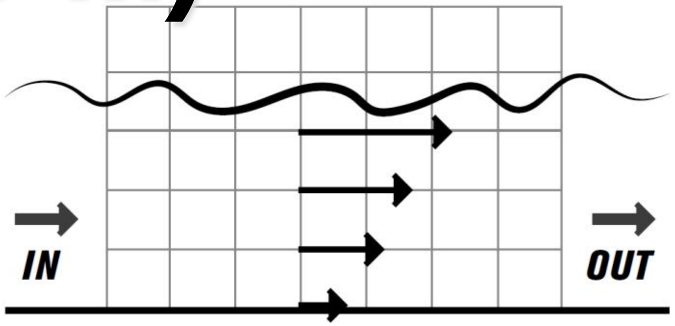
# Modeling snow avalanches

## 3D particle-based methods



# Material Point Method (MPM)

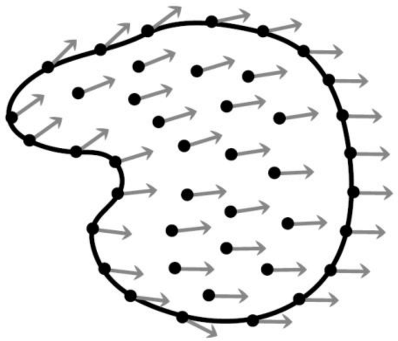
## 1. « FLUID » SIMULATION




CALCULATION POINTS ARE FIXED IN SPACE

**We do not look at motion of individual particles**

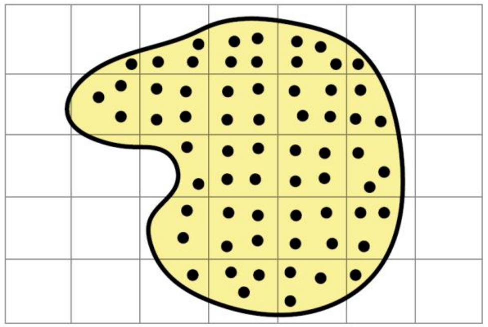
## 2. « SOLID » SIMULATION



CALCULATION POINTS ARE « ATTACHED » TO THE SOLID

**We look at motion of all individual particles**

## 3. MPM HYBRID « SOLID-FLUID »



CALCULATION IS MADE ON THE GRID BUT PARTICLES STORE THE INFORMATION

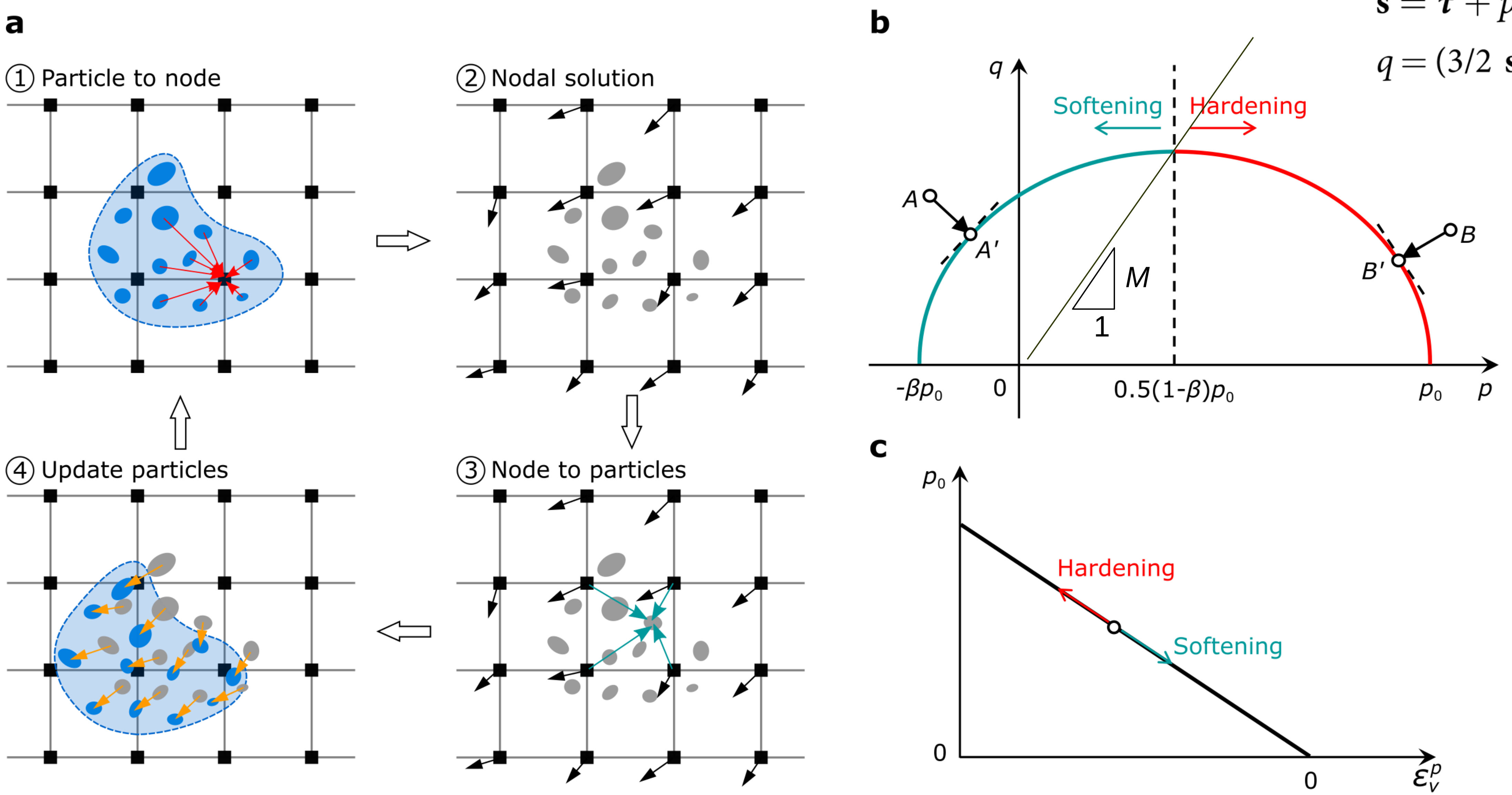
**Particles allow to follow the material in space and time**

# MPM & Critical State Mechanics

$$p = -\frac{1}{d}\mathrm{tr}(\boldsymbol{\tau})$$

$$\mathbf{s} = \boldsymbol{\tau} + p\mathbf{I}$$

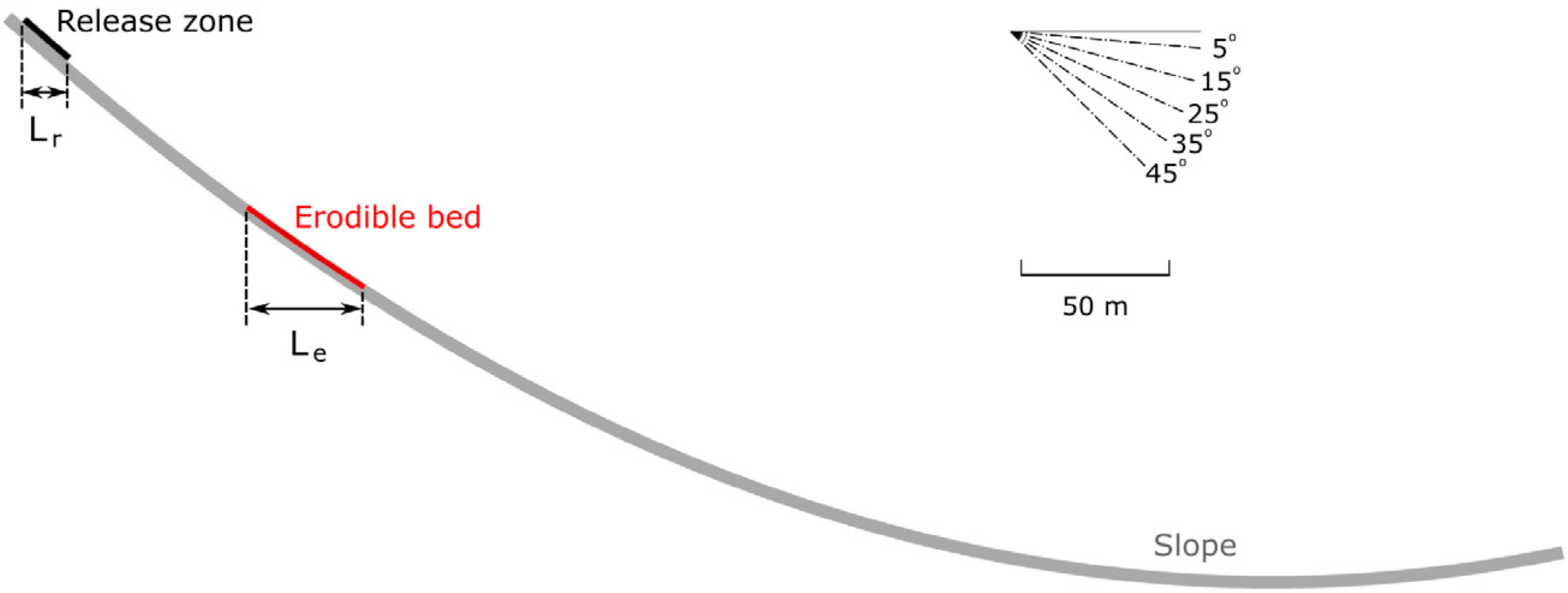
$$q = (3/2\ \mathbf{s} : \mathbf{s})^{1/2}$$



# Investigating erosion and entrainment in snow avalanches with MPM

# Avalanche dynamics with MPM

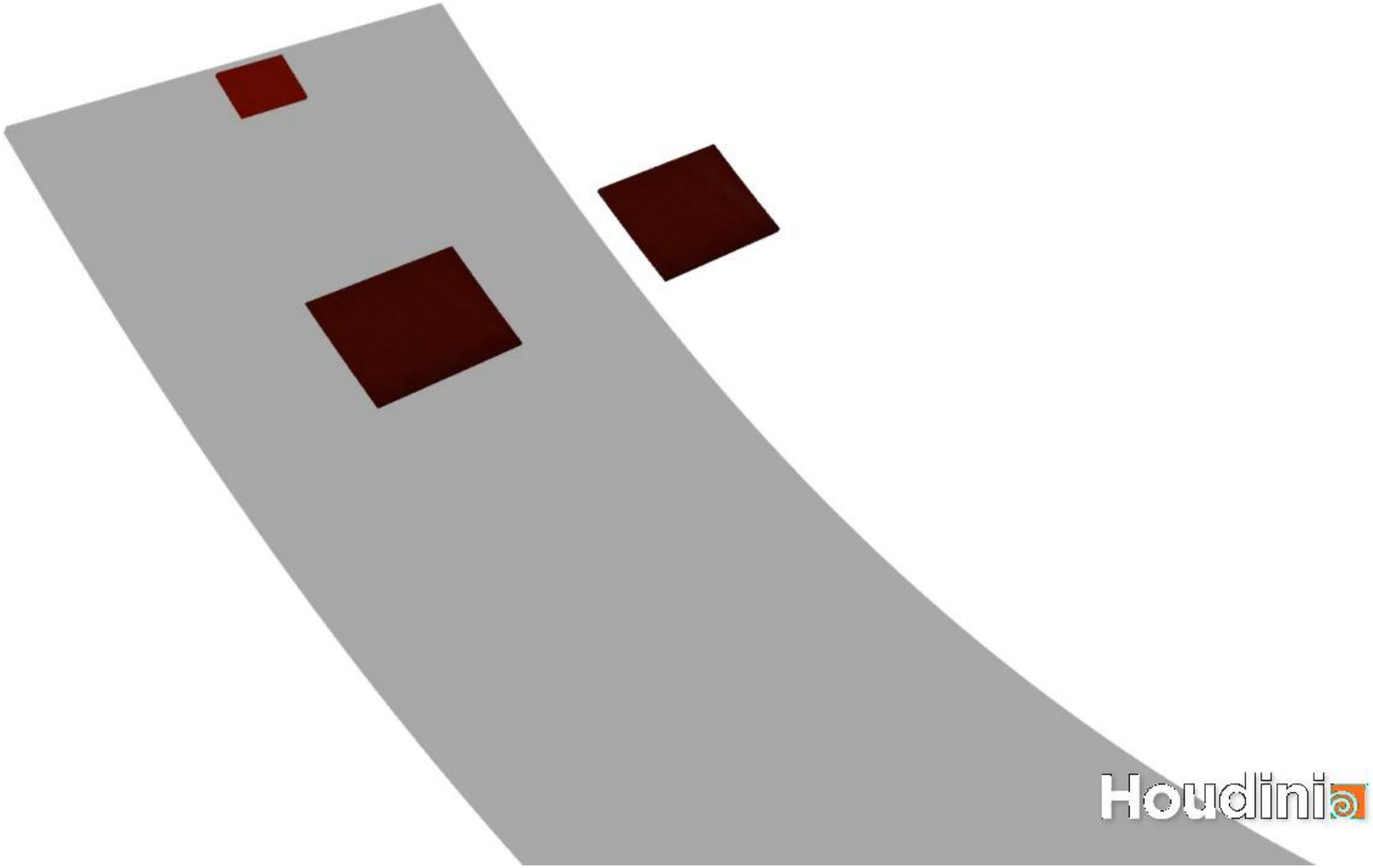
## Erosion – entrainment




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Avalanche dynamics with MPM

## Erosion – entrainment

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# Avalanche dynamics with MPM

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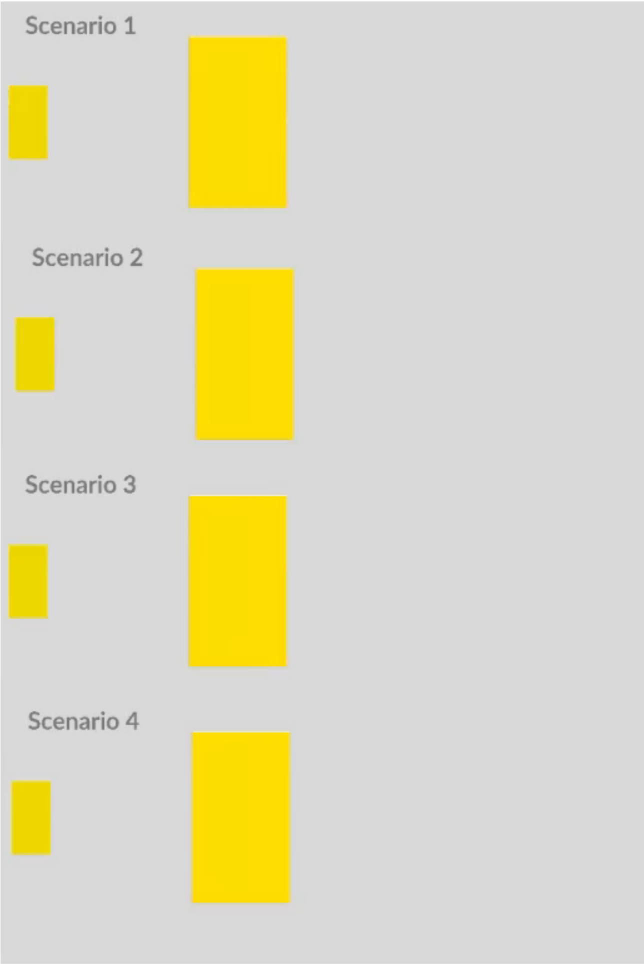


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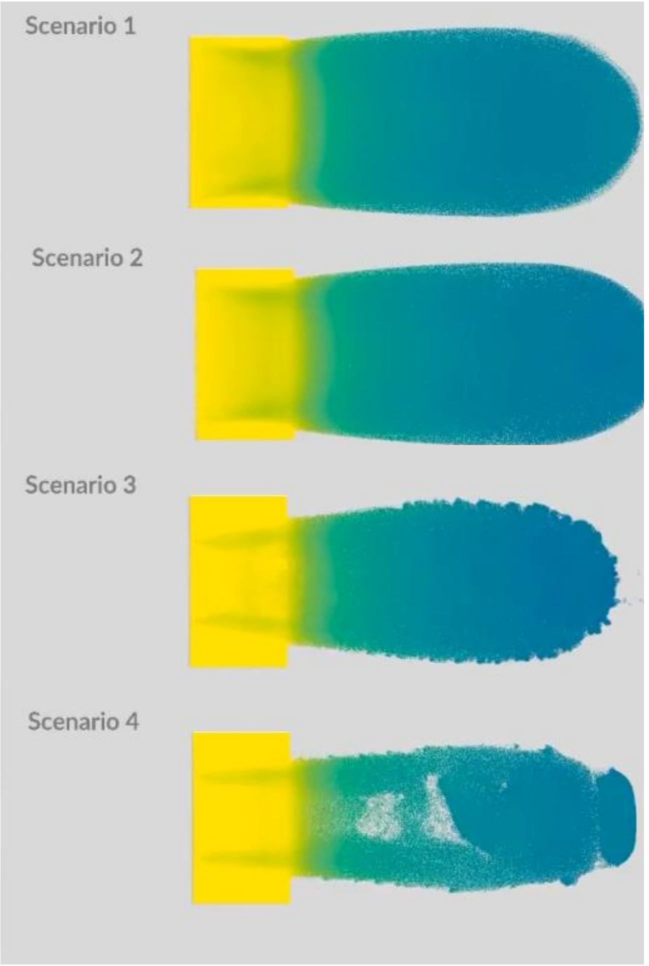


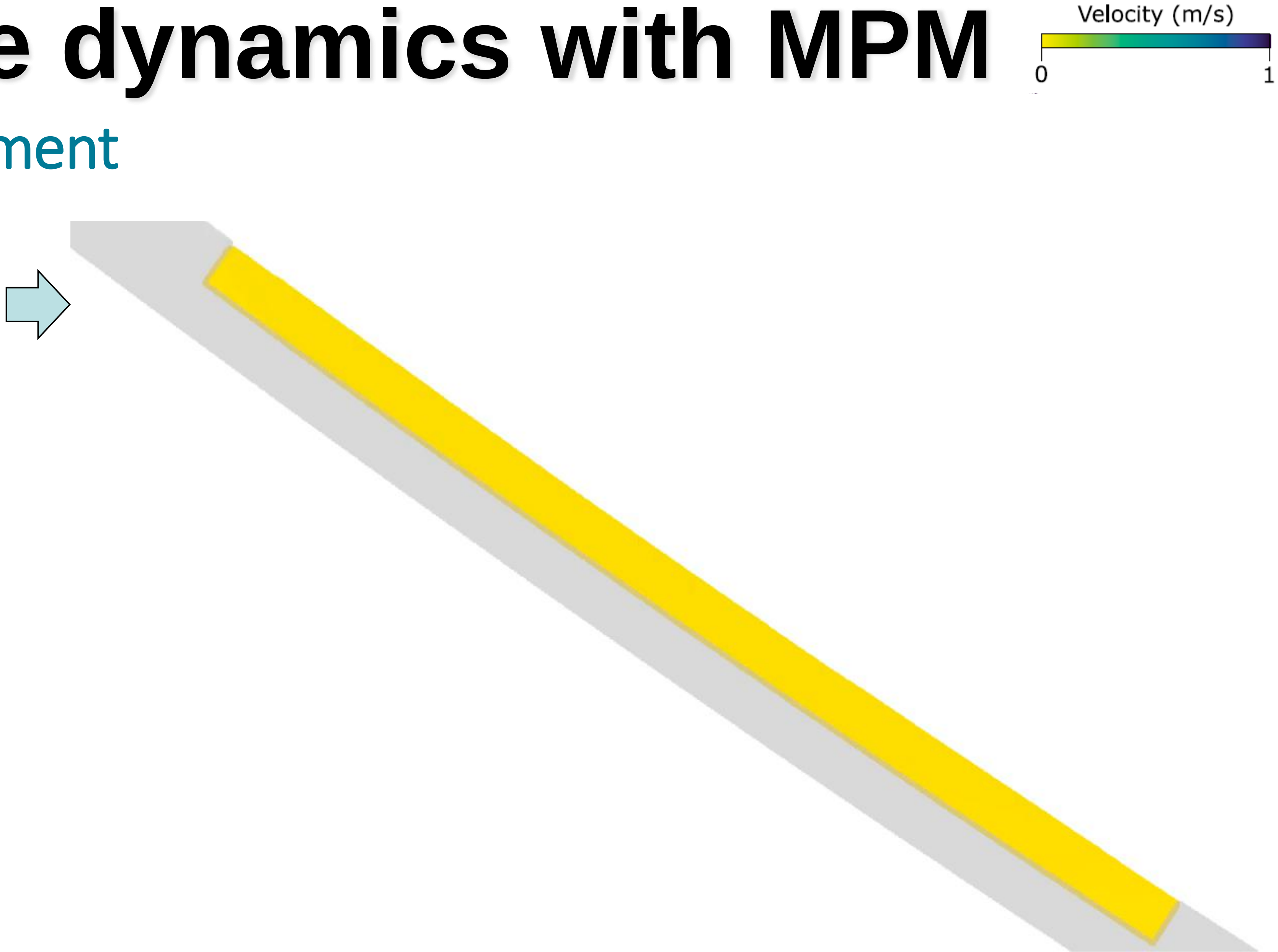


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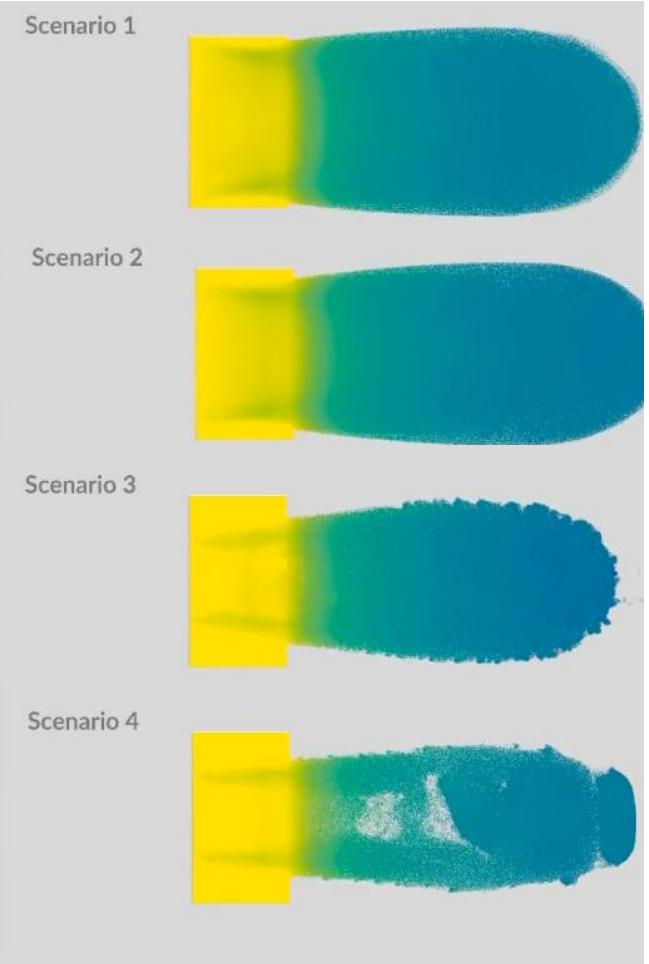
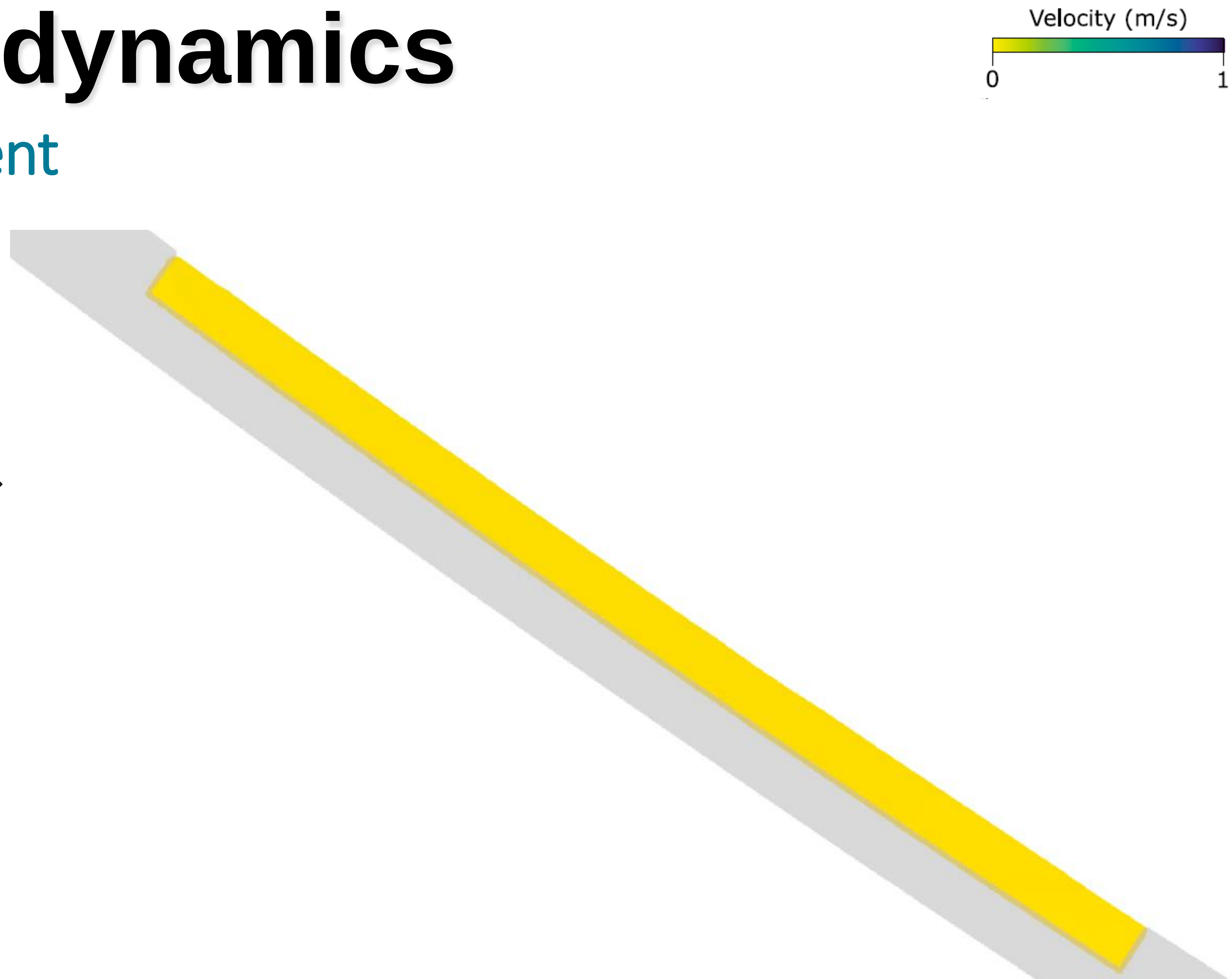
# Avalanche dynamics

## Erosion – entrainment

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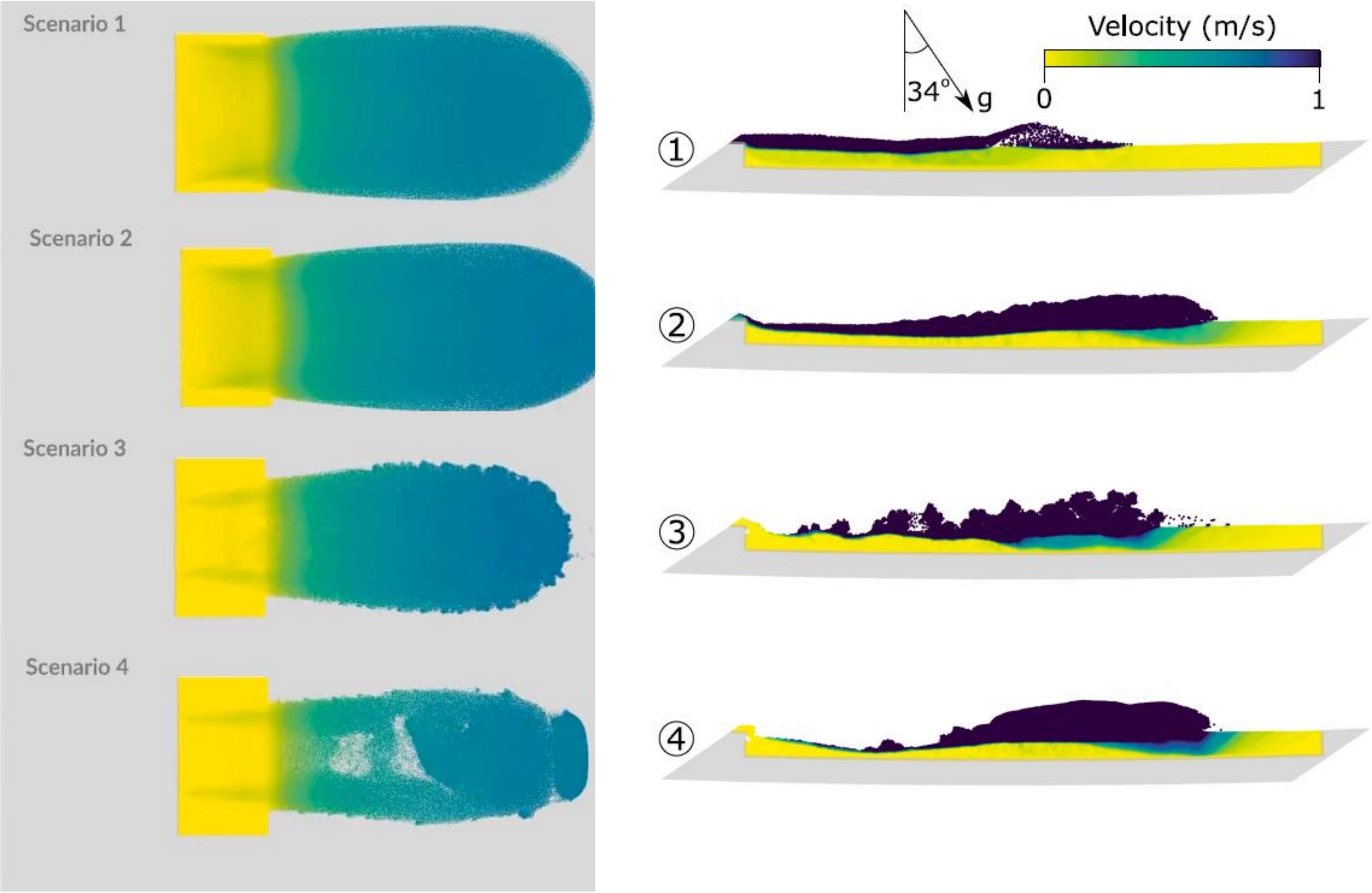
# Avalanche dynamics with MPM

## Erosion – entrainment

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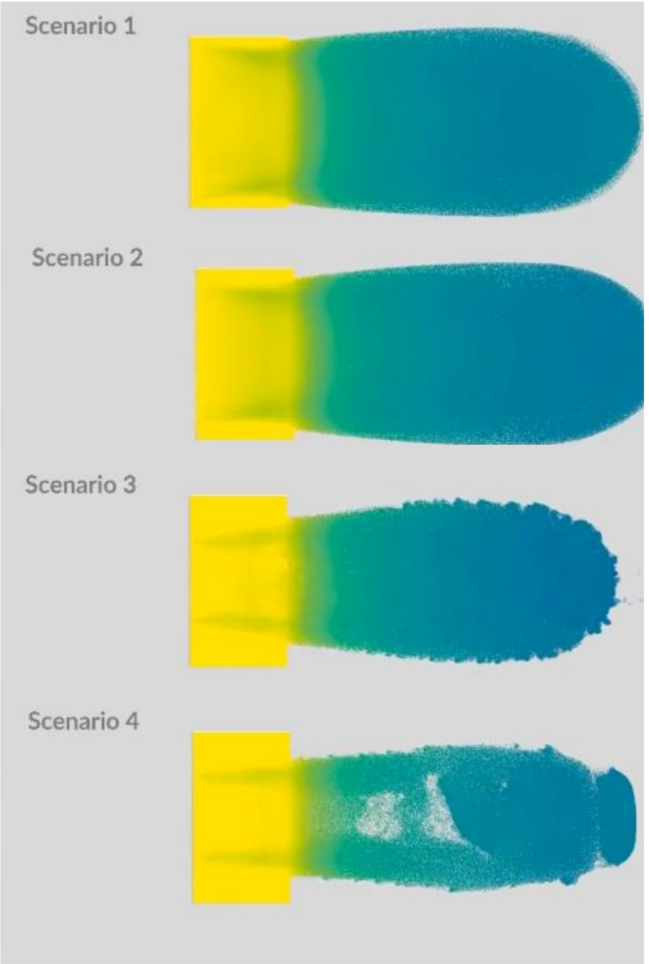
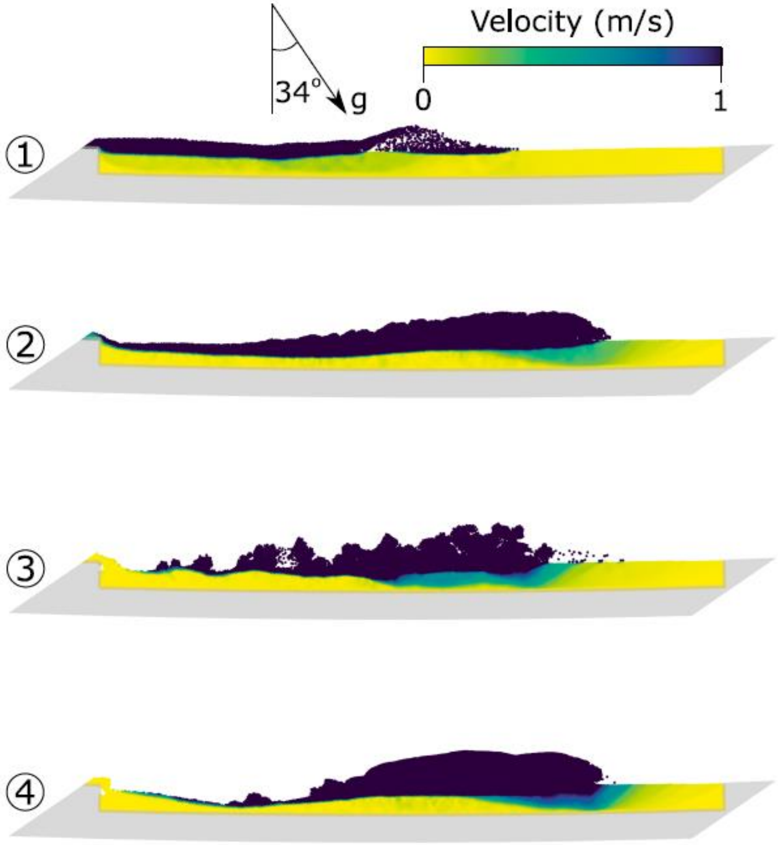
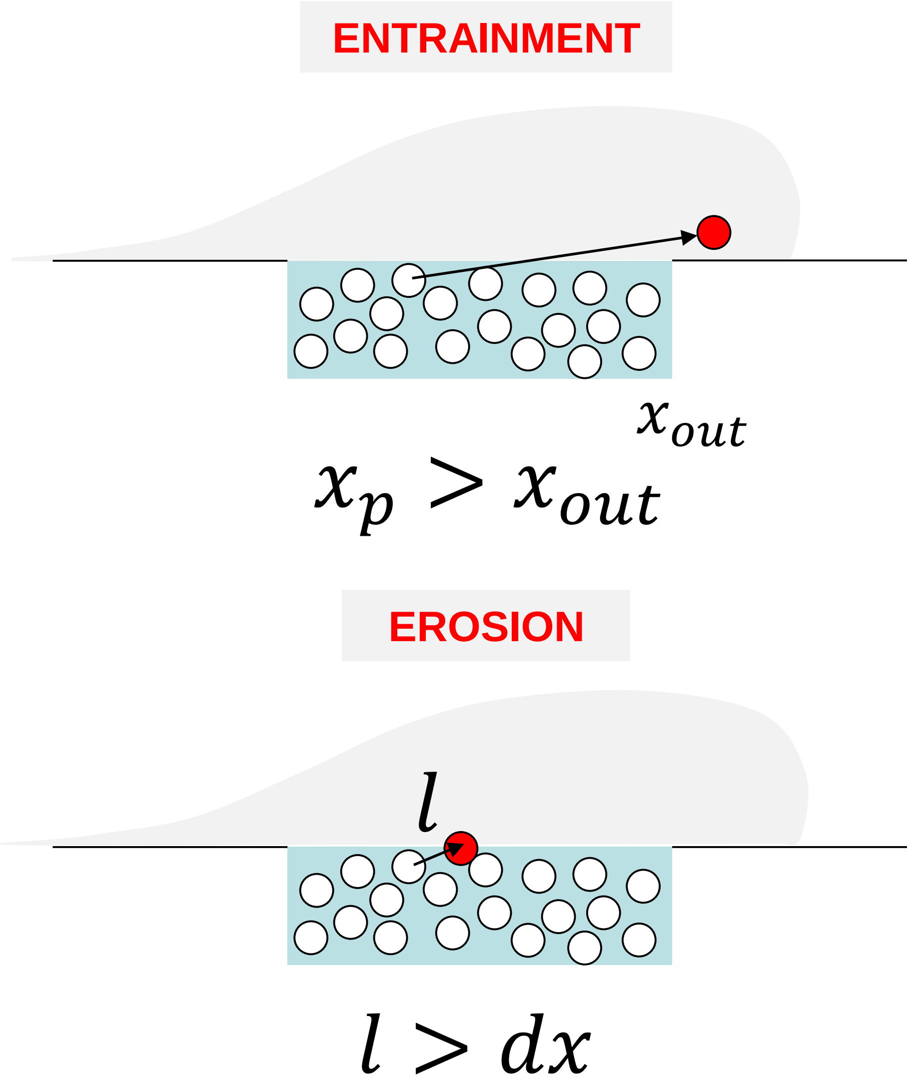
## Erosion – entrainment



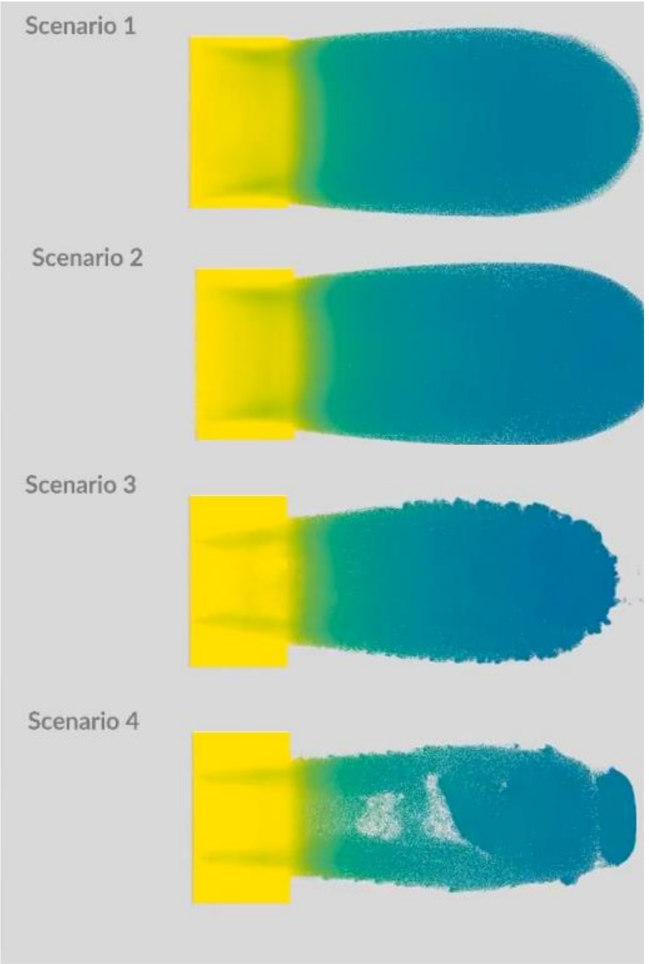



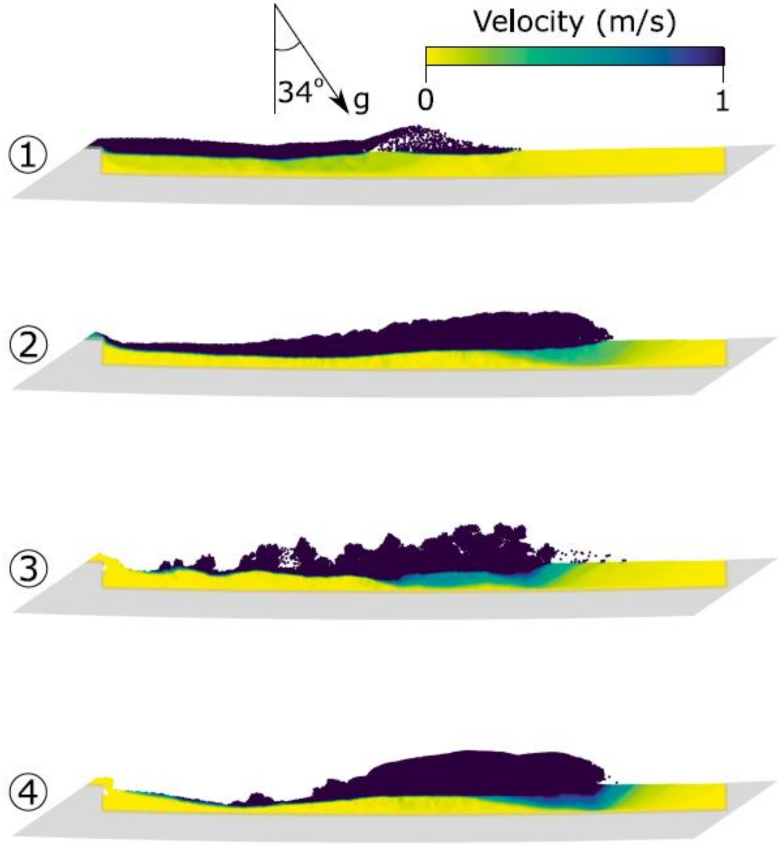


Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

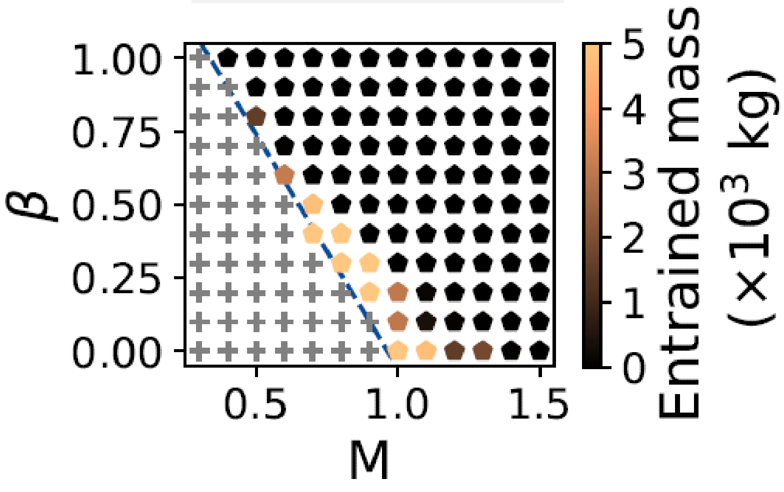
# Avalanche dynamics with MPM

## Erosion – entrainment

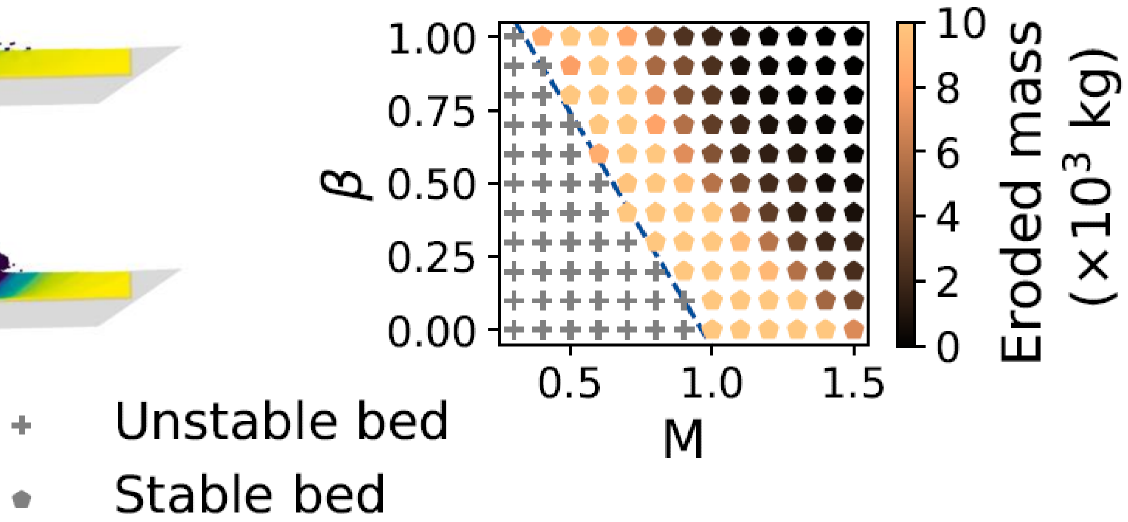



ENTRAINMENT



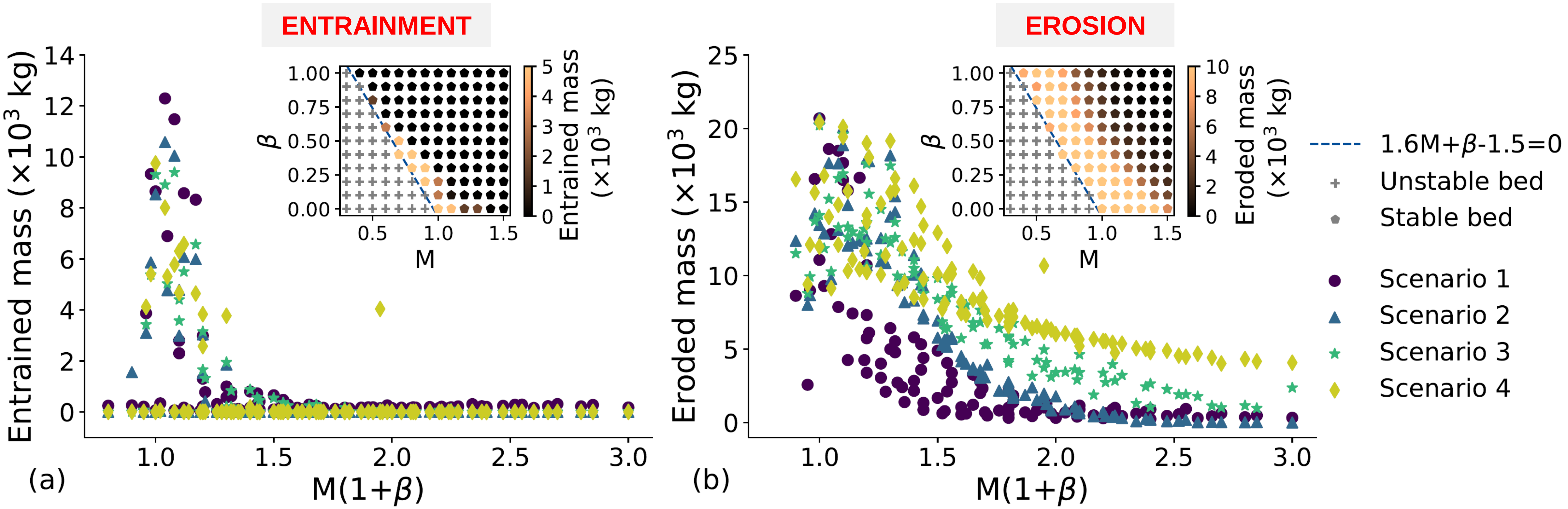

EROSION




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Avalanche dynamics with MPM

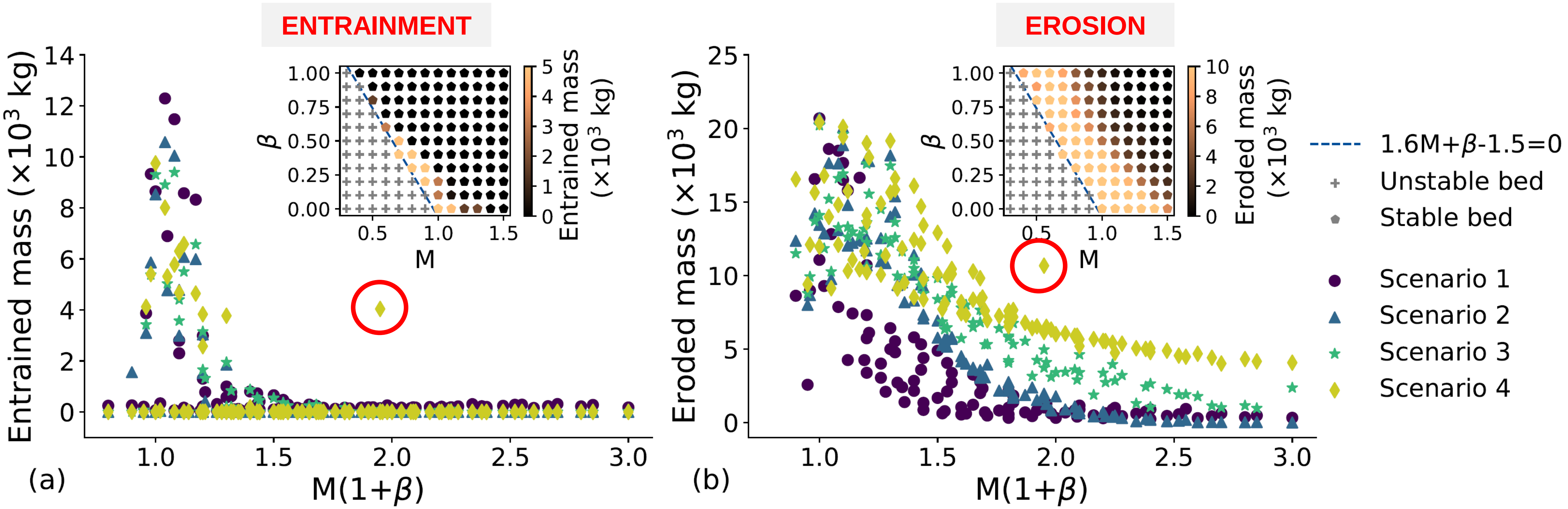
## Erosion – entrainment




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Avalanche dynamics with MPM

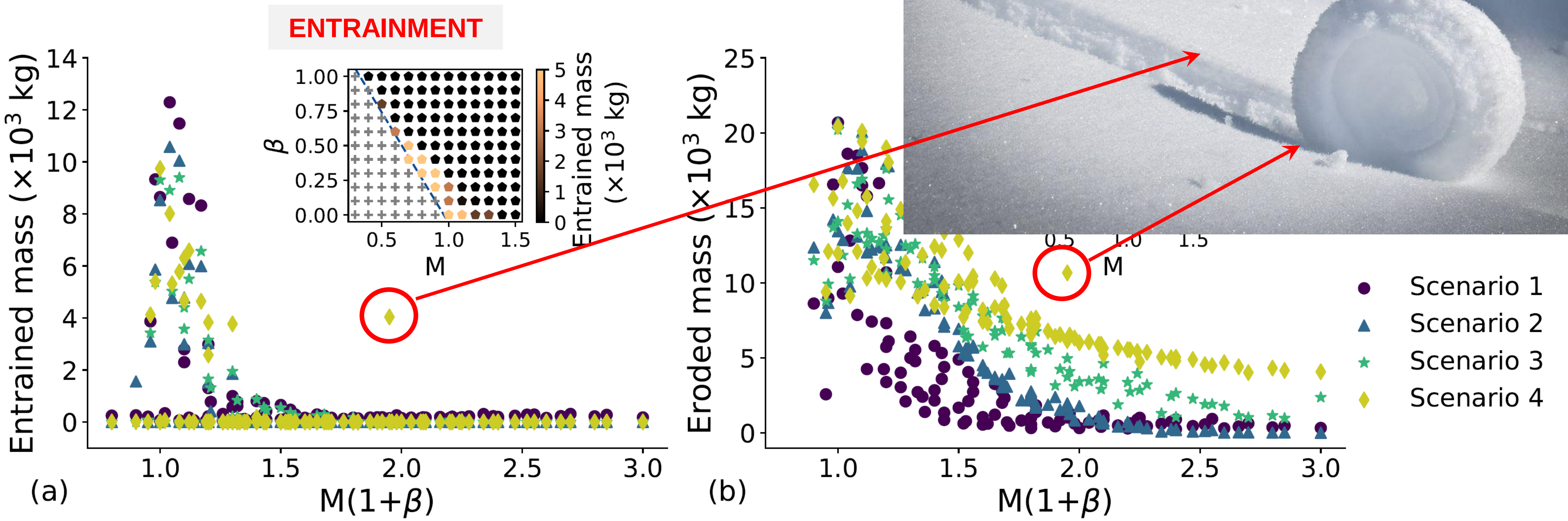
## Erosion – entrainment




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Avalanche dynamics

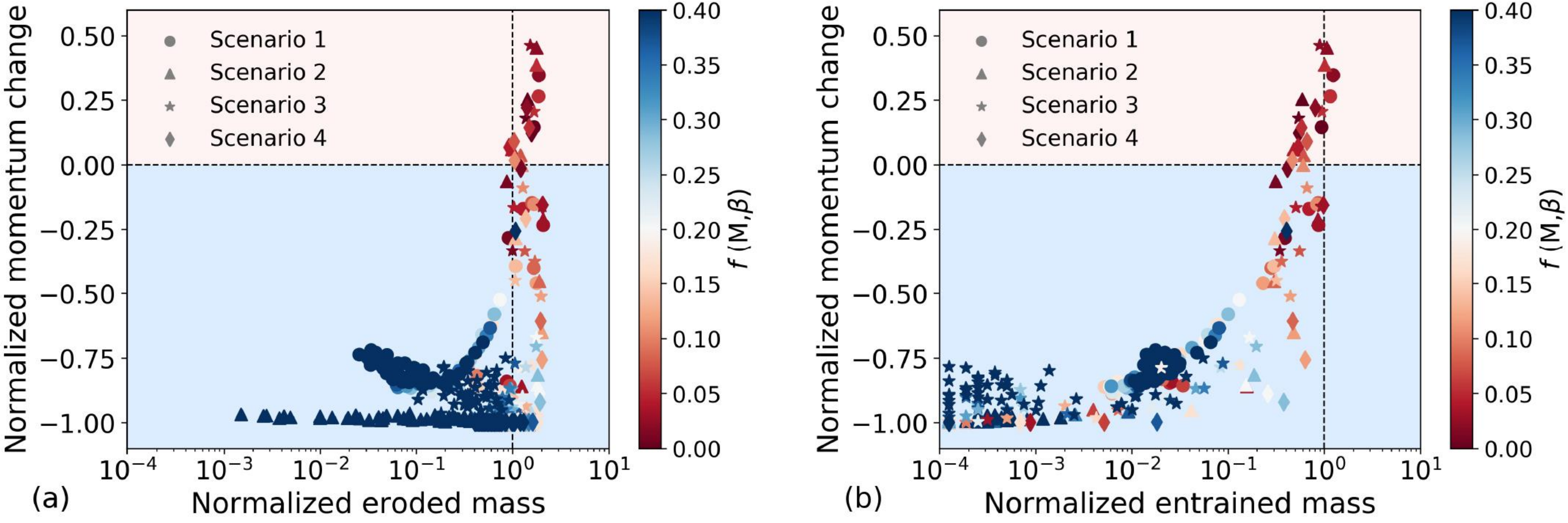
## Erosion – entrainment




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Avalanche dynamics with MPM

## Erosion – entrainment

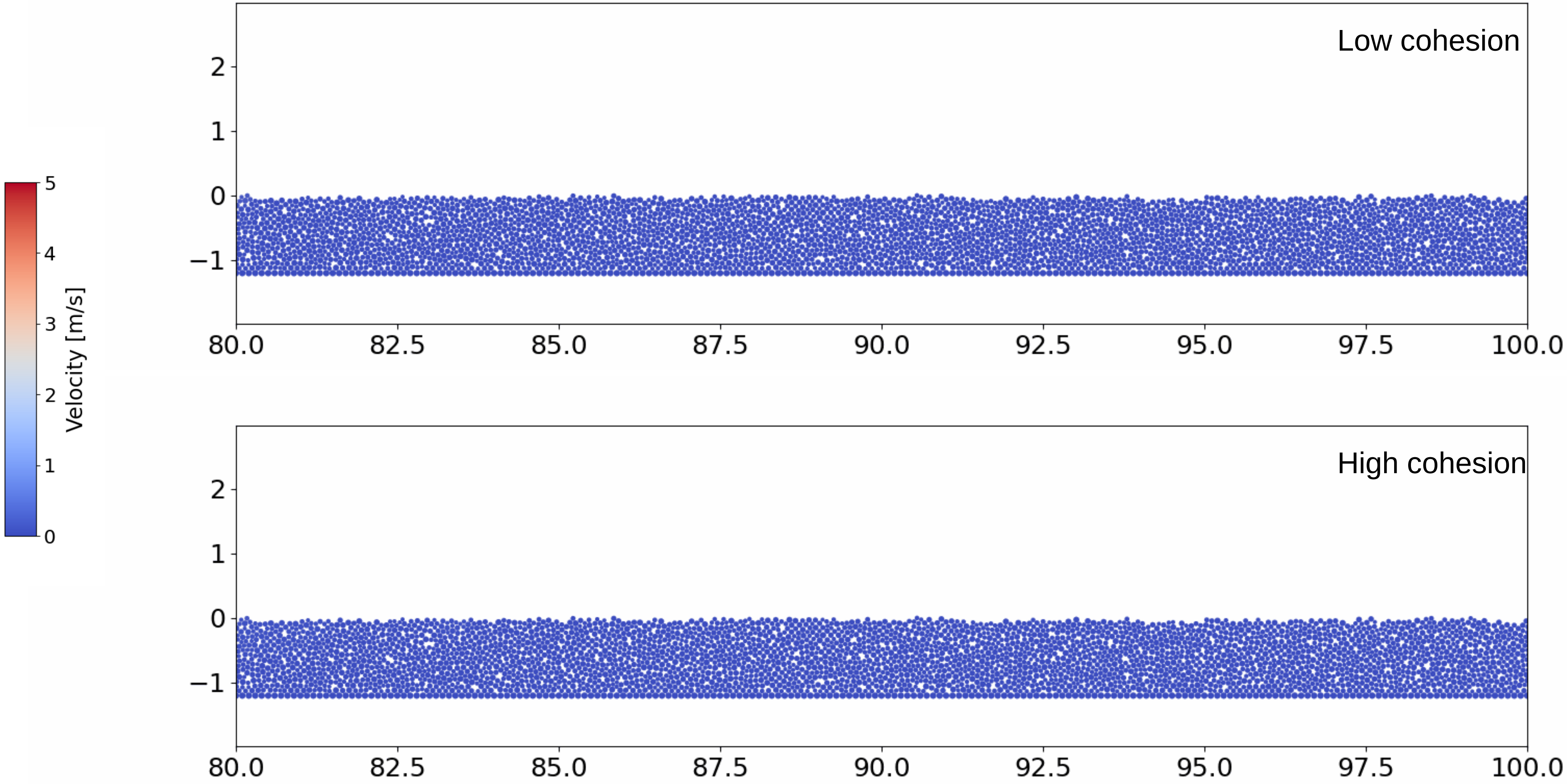



Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***

# Investigating erosion and entrainment in snow avalanches with DEM

# Avalanche dynamics with DEM

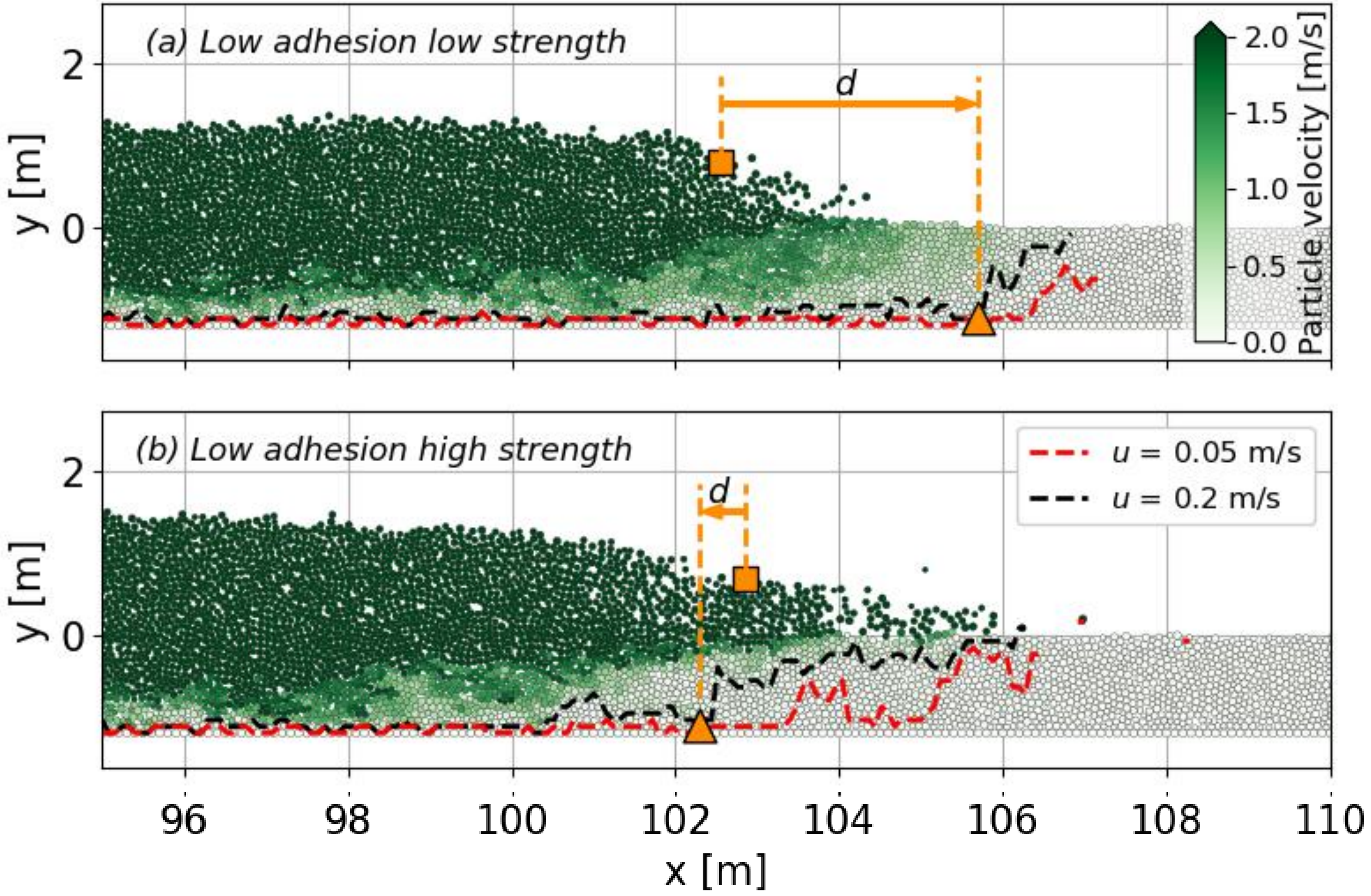
## Erosion – entrainment




Ligneau, Sovilla, Gaume (2023). Modeling erosion, entrainment and deposition in cohesive granular flows: application to dense snow avalanches. Under review

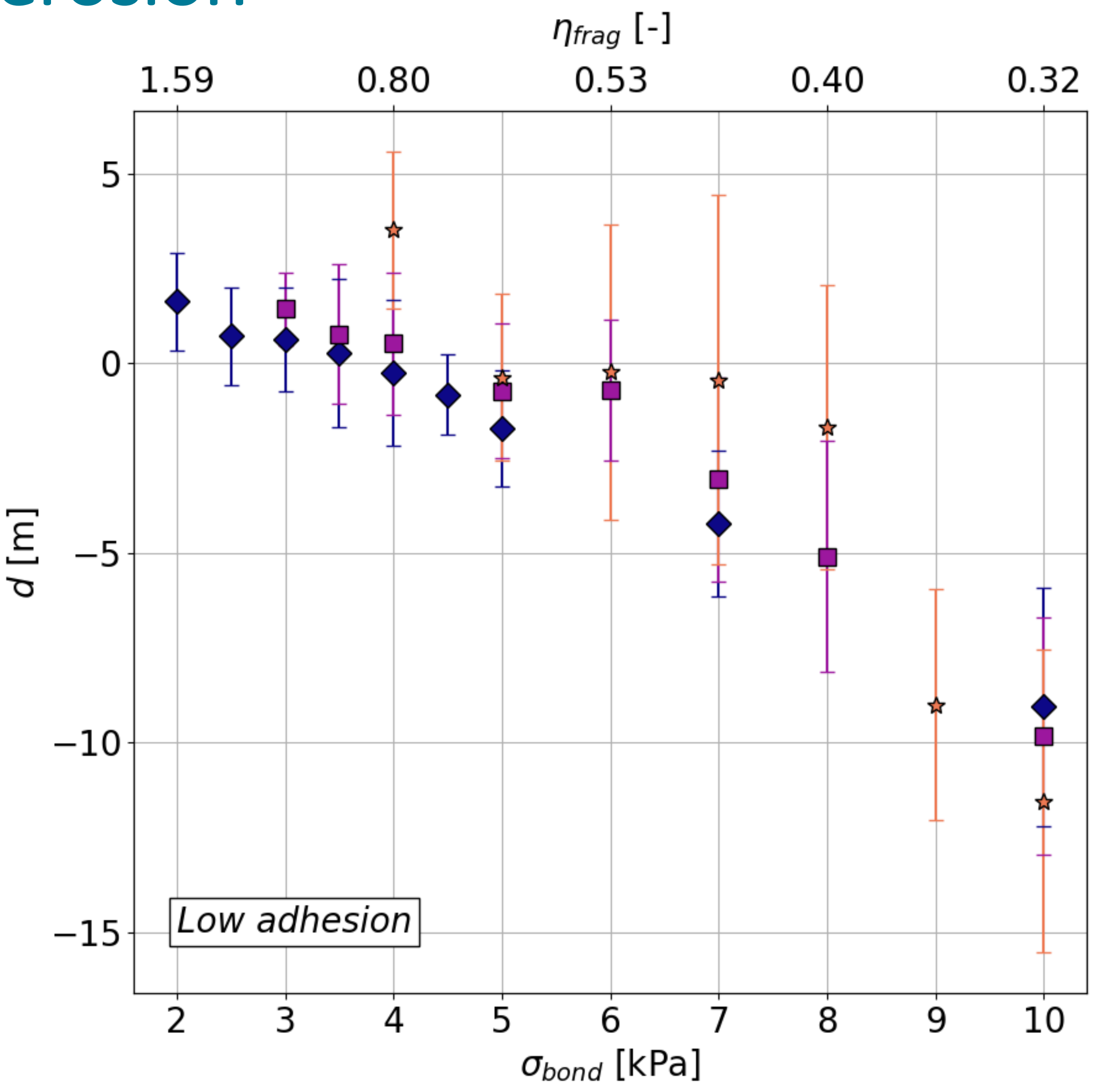
# Avalanche dynamics with DEM

## Ploughing vs basal erosion



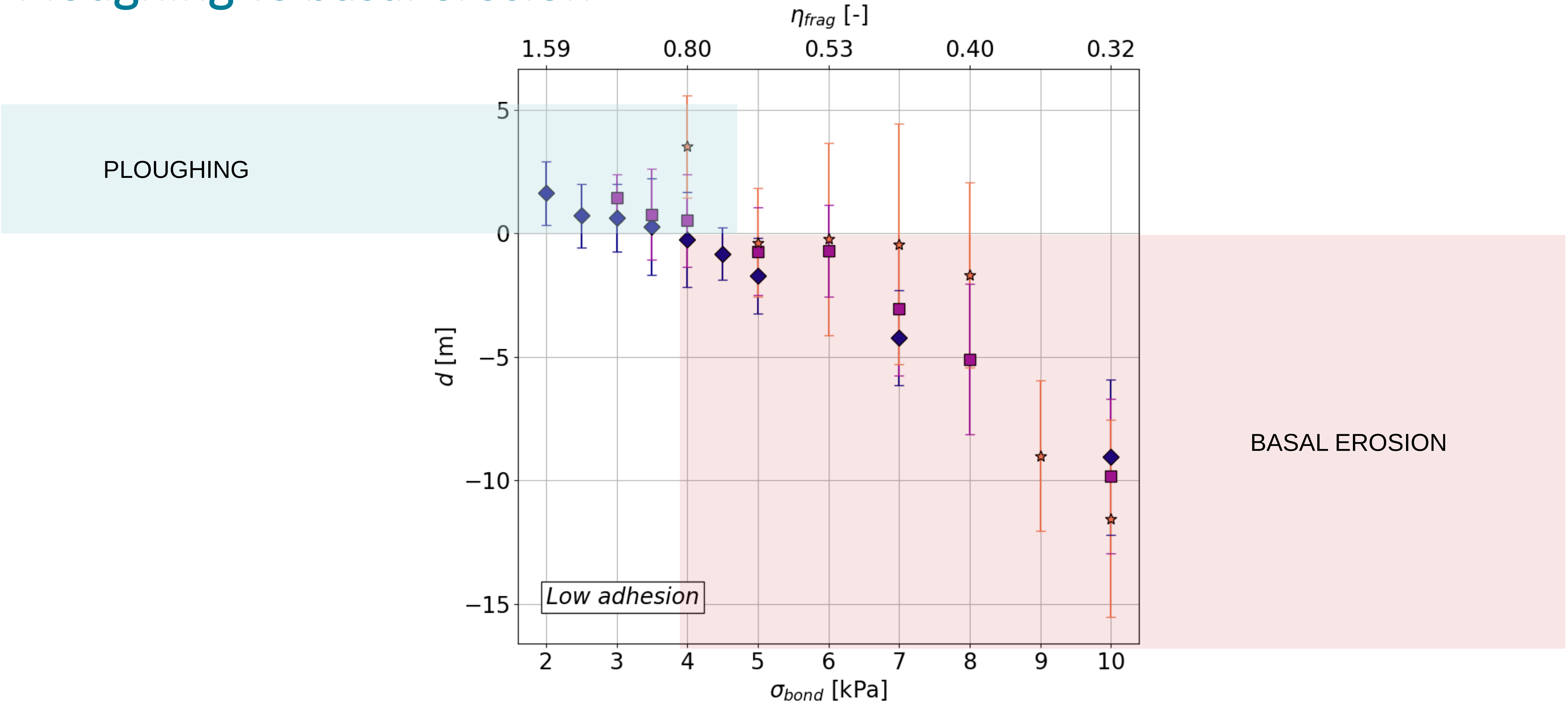
# Avalanche dynamics with DEM

## Ploughing vs basal erosion



# Avalanche dynamics with DEM

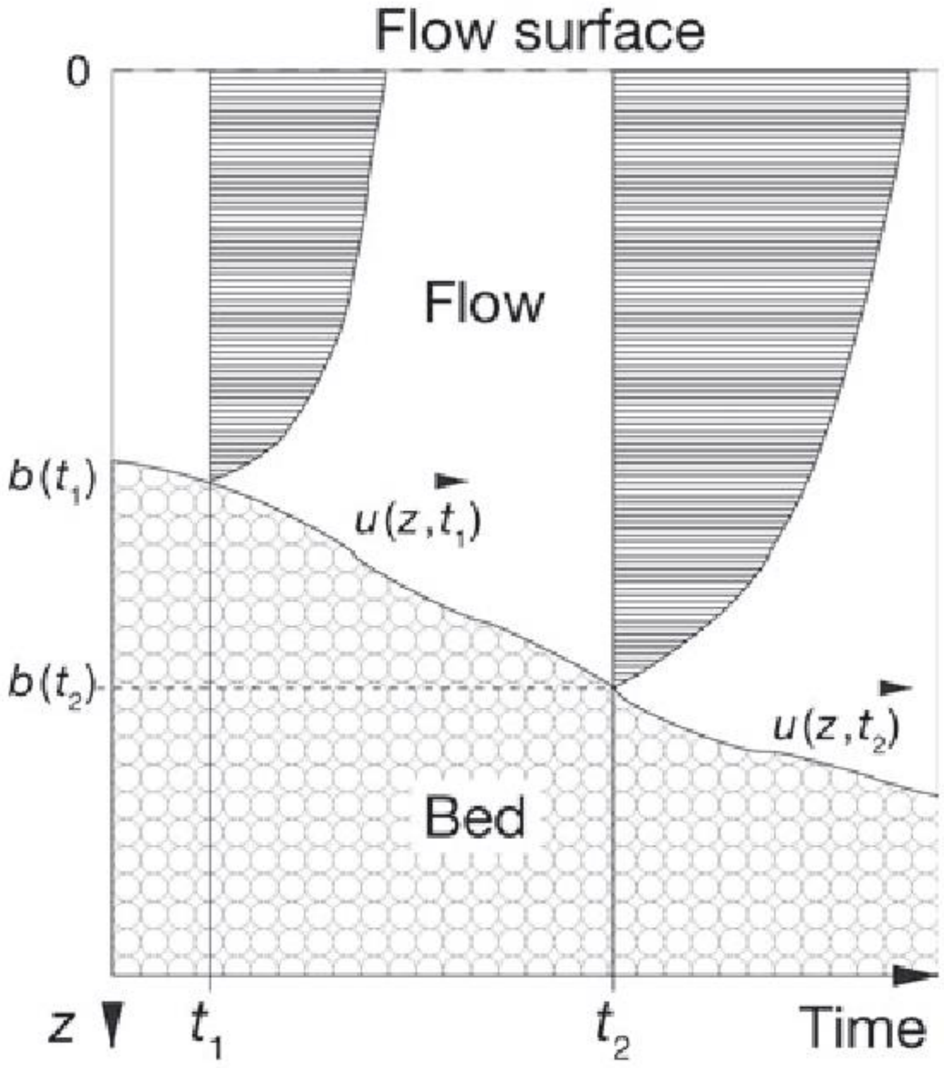
## Ploughing vs basal erosion



# Avalanche dynamics with DEM

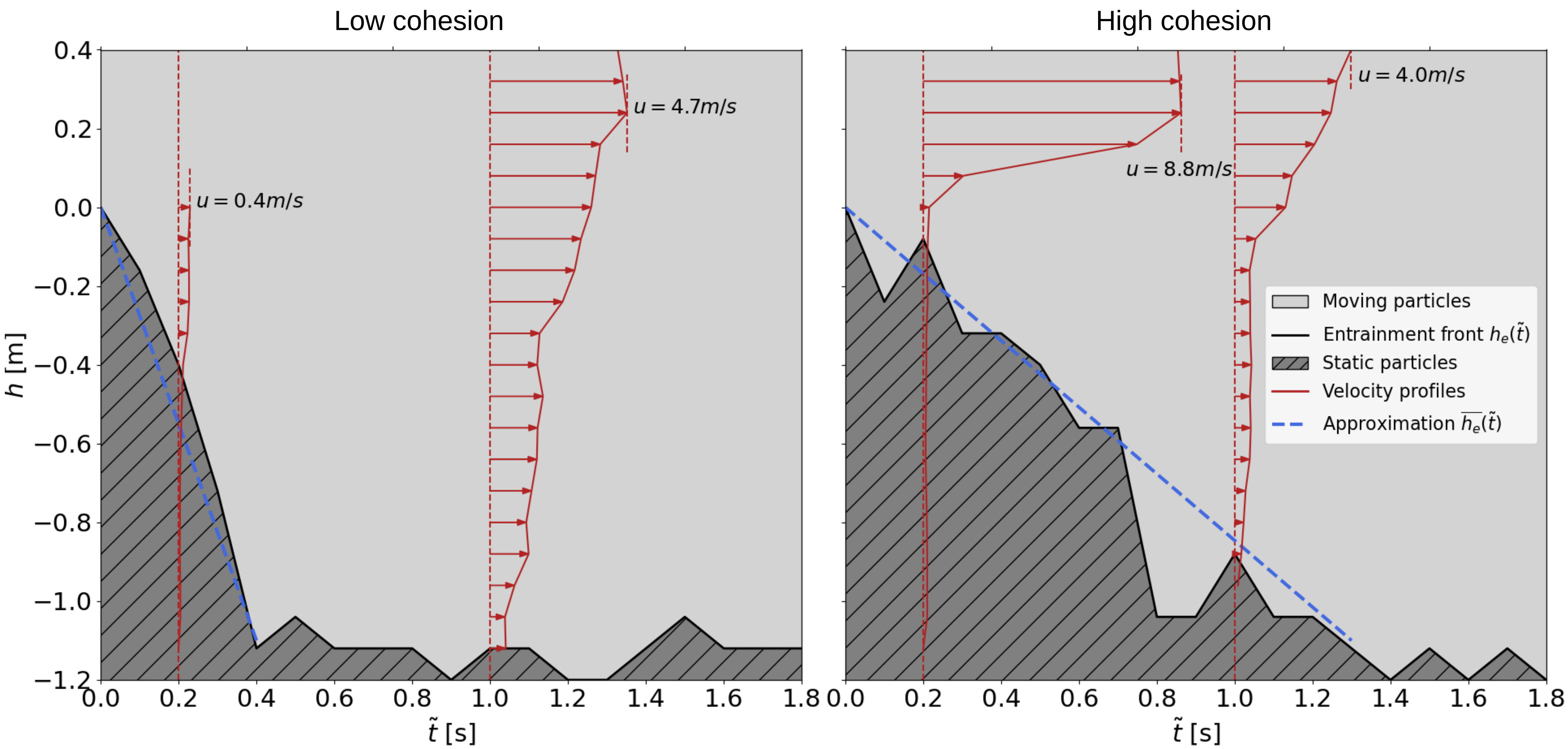
## Entrainment speed

Issler and Pastor (2011)



# Avalanche dynamics with DEM

## Erosion – entrainment

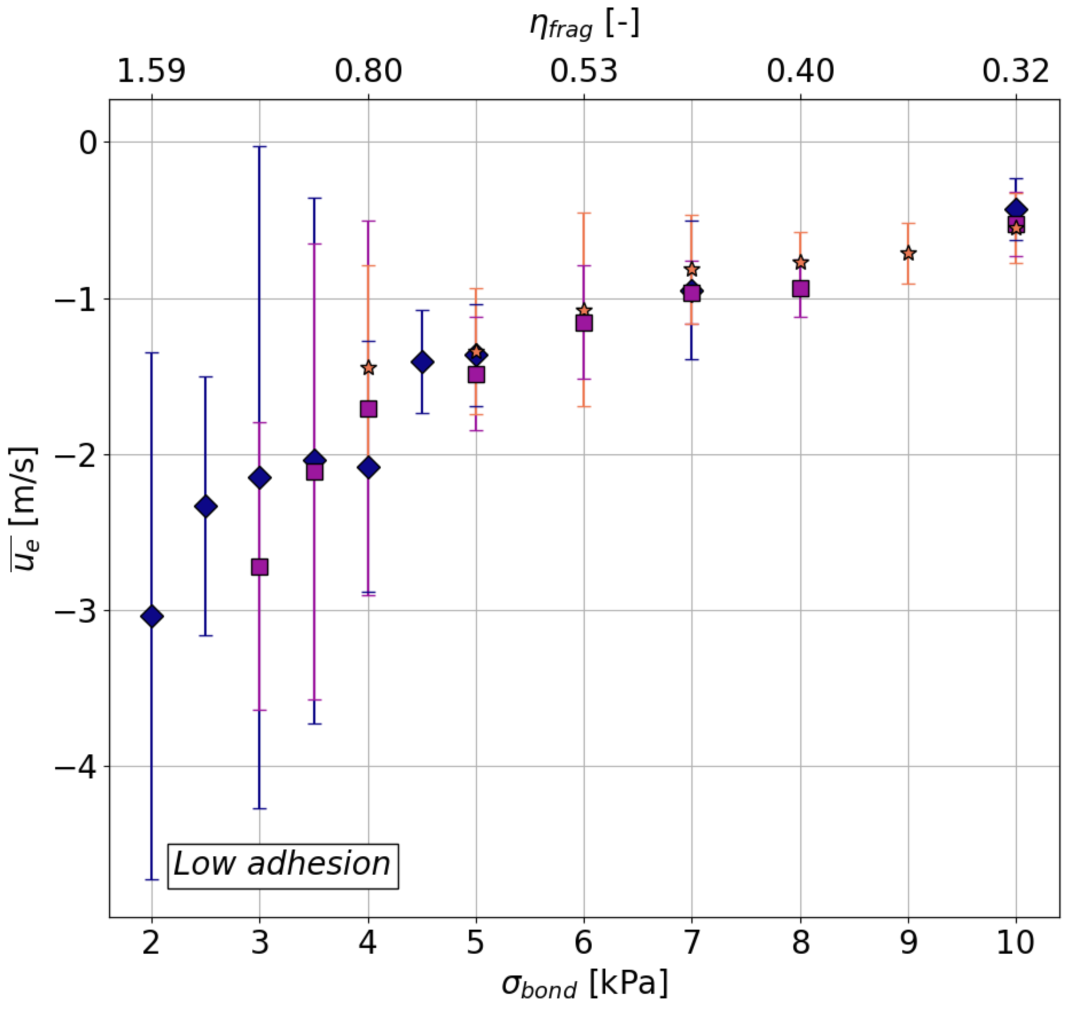


# Avalanche dynamics with DEM

## Erosion – entrainment

$$\overline{u_e} = \frac{1}{L}\int_0^L \dot{h}_e dx$$

Low cohesion



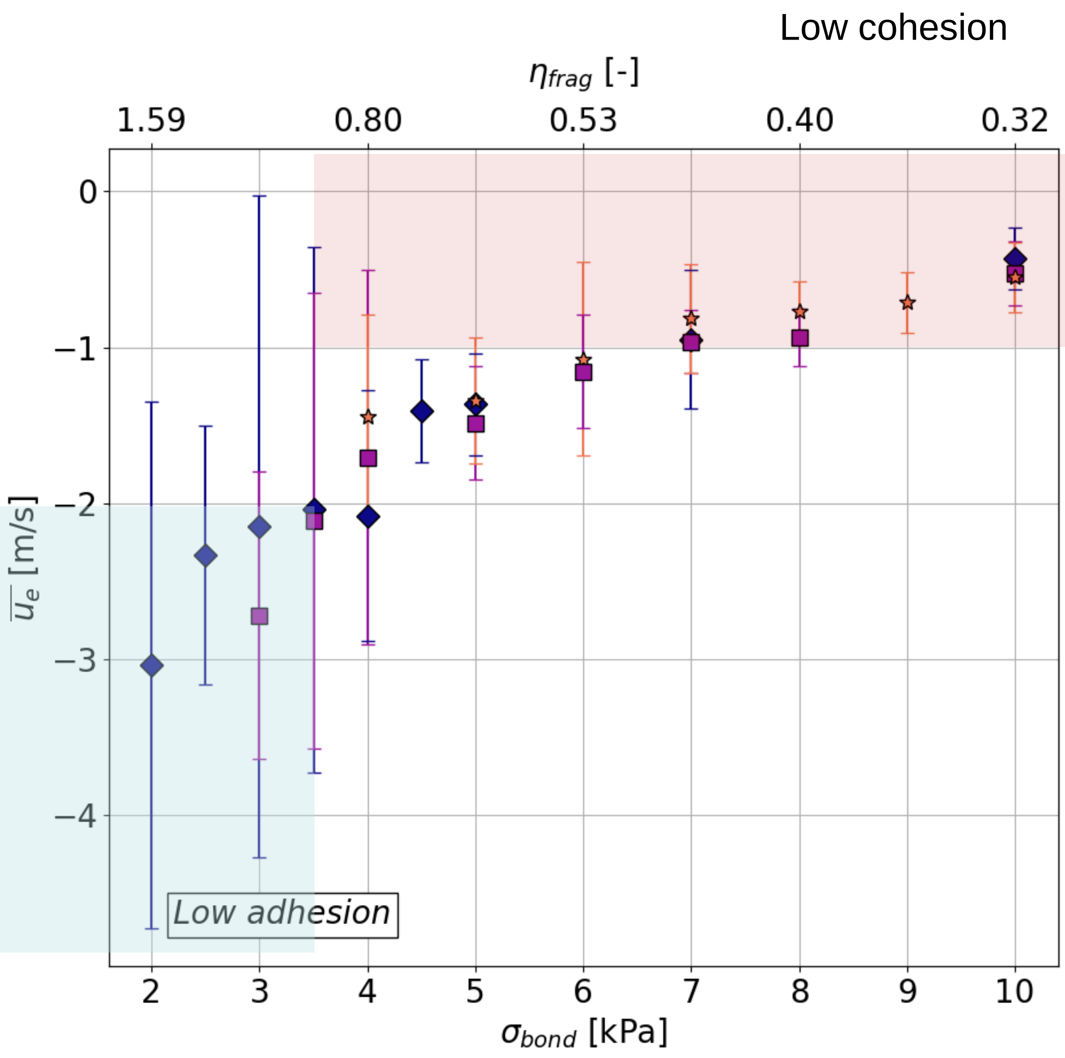
# Avalanche dynamics with DEM

## Erosion – entrainment

$$\overline{u_e} = \frac{1}{L}\int_0^L \dot{h}_e \, dx$$

$|\overline{u_e}| > 2$ m/s

Sovilla et al. (2006)




$|\overline{u_e}| < 1$ m/s

Issler and Pastor (2011)

**With such 3D models, we report a natural emergence of**

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- Wave phenomena

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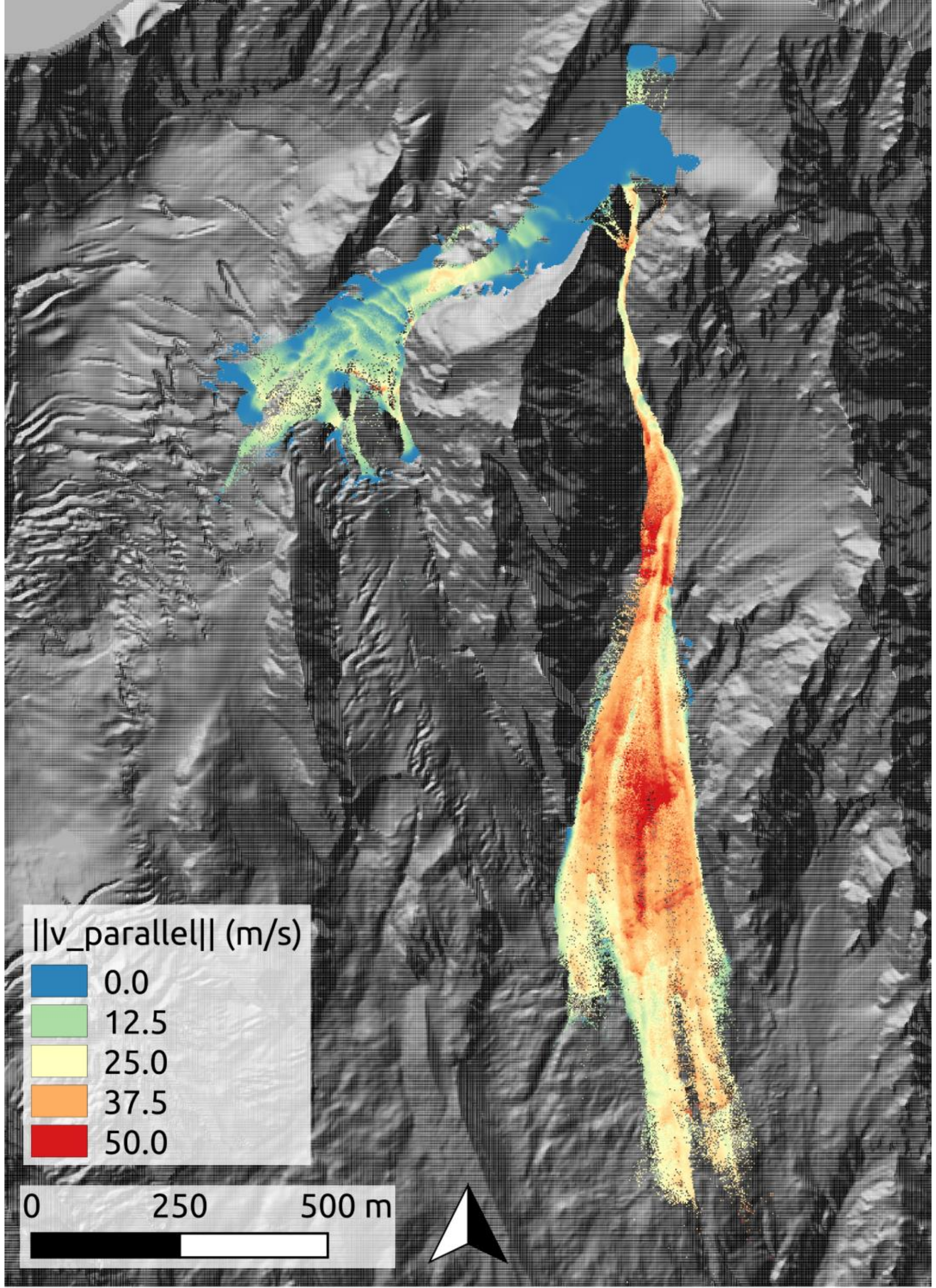
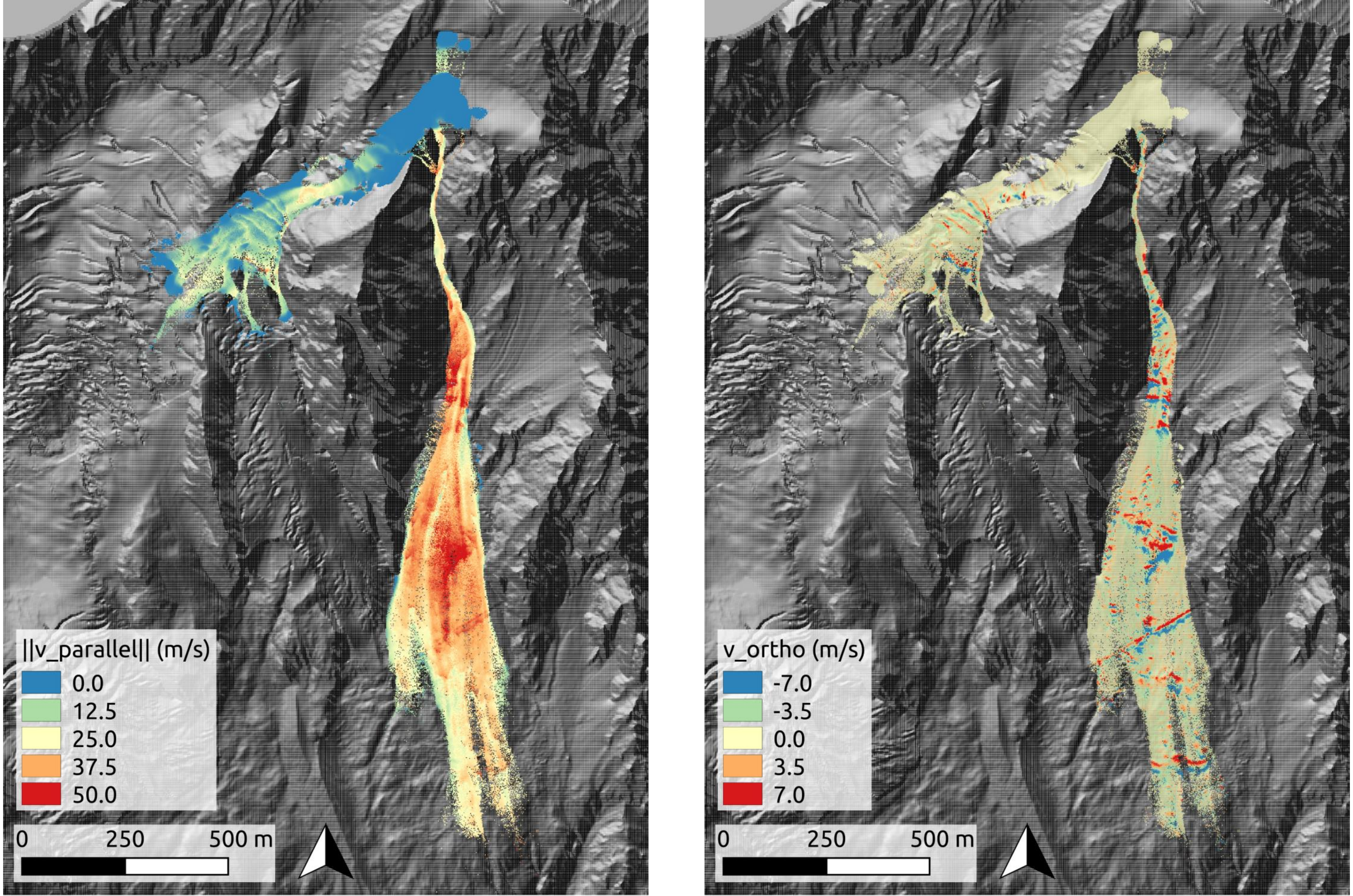
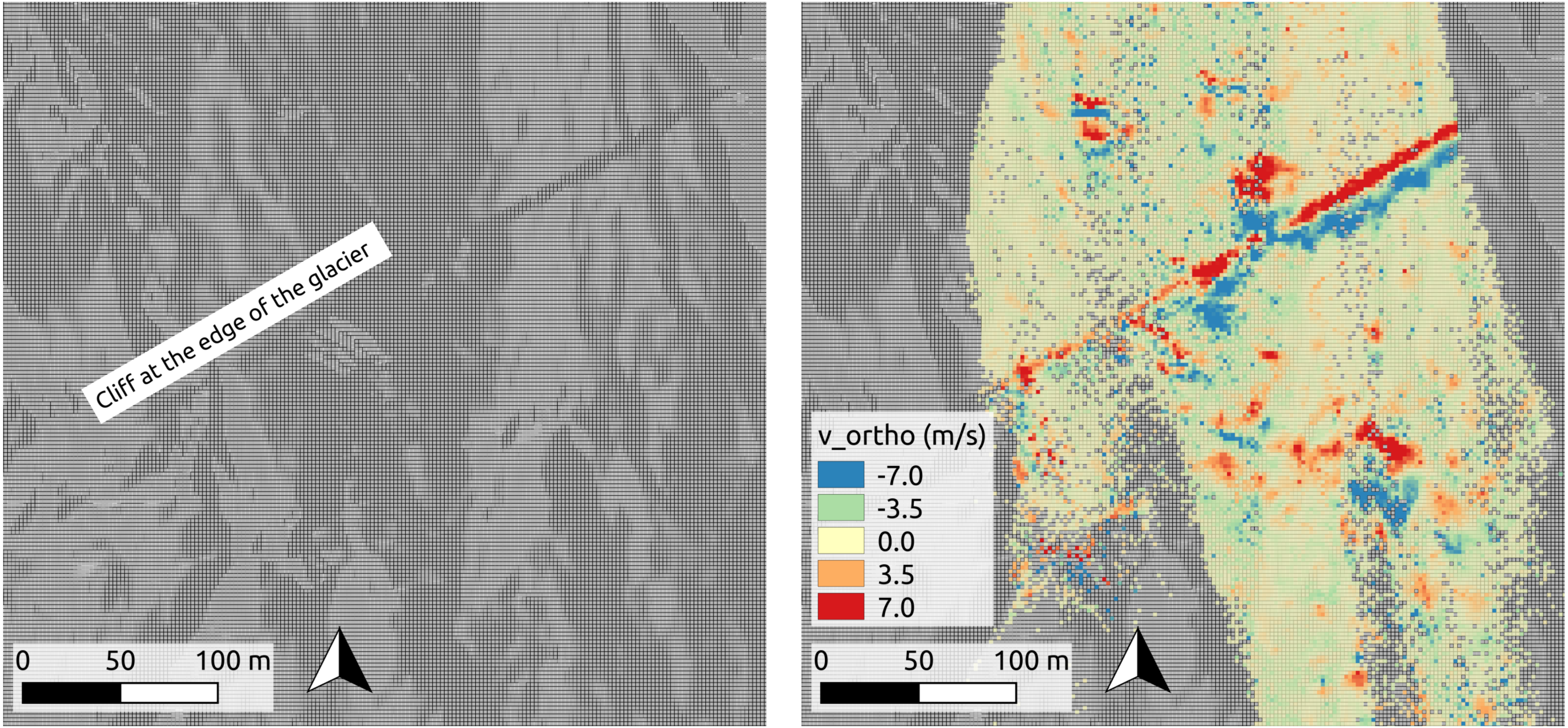
**With such 3D models, we report a natural emergence of**

- Wave phenomena
- Buckling mechanism
- Dispersive pressures


||v_parallel|| (m/s)
0.0
12.5
25.0
37.5
50.0
0
250
500 m


||v_parallel|| (m/s)
0.0
12.5
25.0
37.5
50.0
0
250
500 m
v_ortho (m/s)
-7.0
-3.5
0.0
3.5
7.0
0
250
500 m



Cliff at the edge of the glacier
0
50
100 m
v_ortho (m/s)
-7.0
-3.5
0.0
3.5
7.0
0
50
100 m

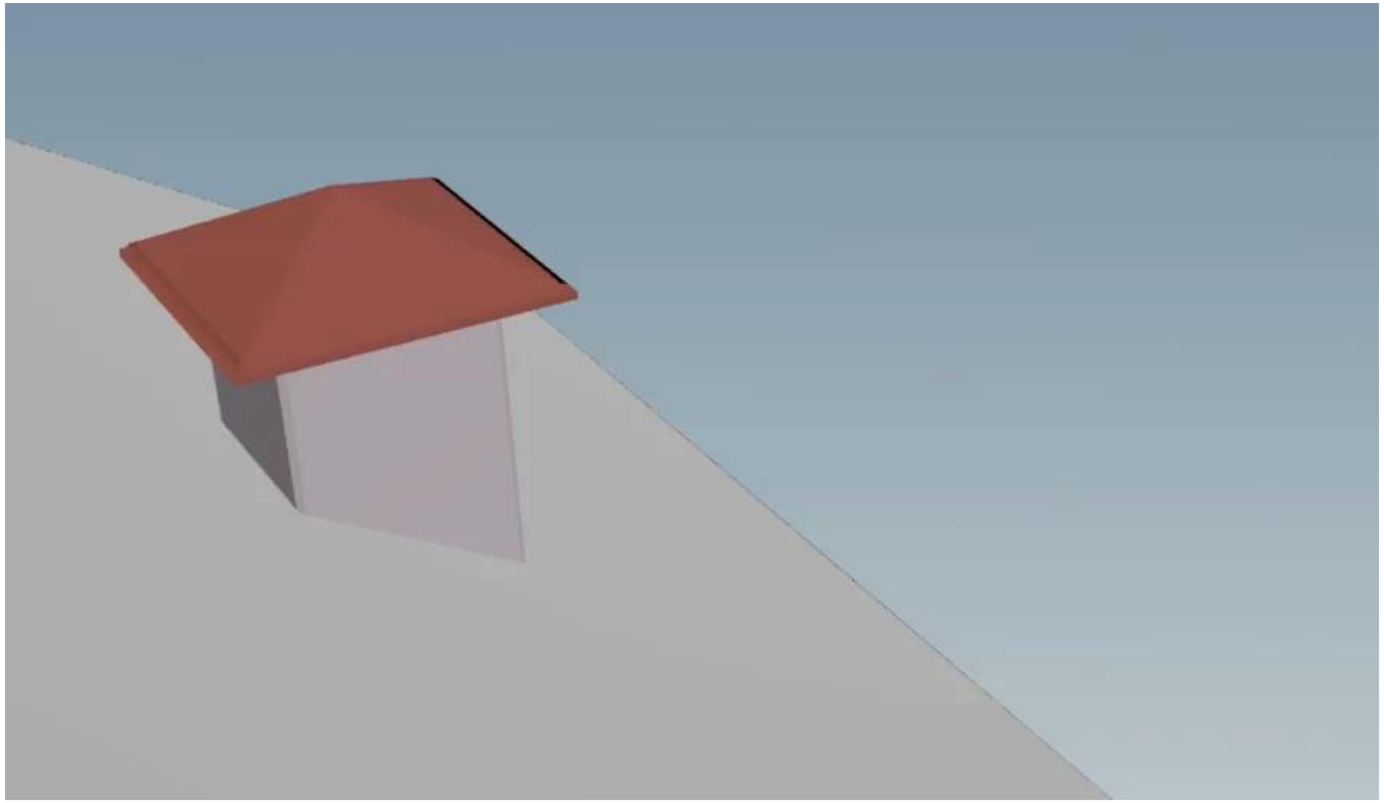
**With such 3D models, we report a natural emergence of**

- Wave phenomena
- Buckling mechanism
- Dispersive pressures

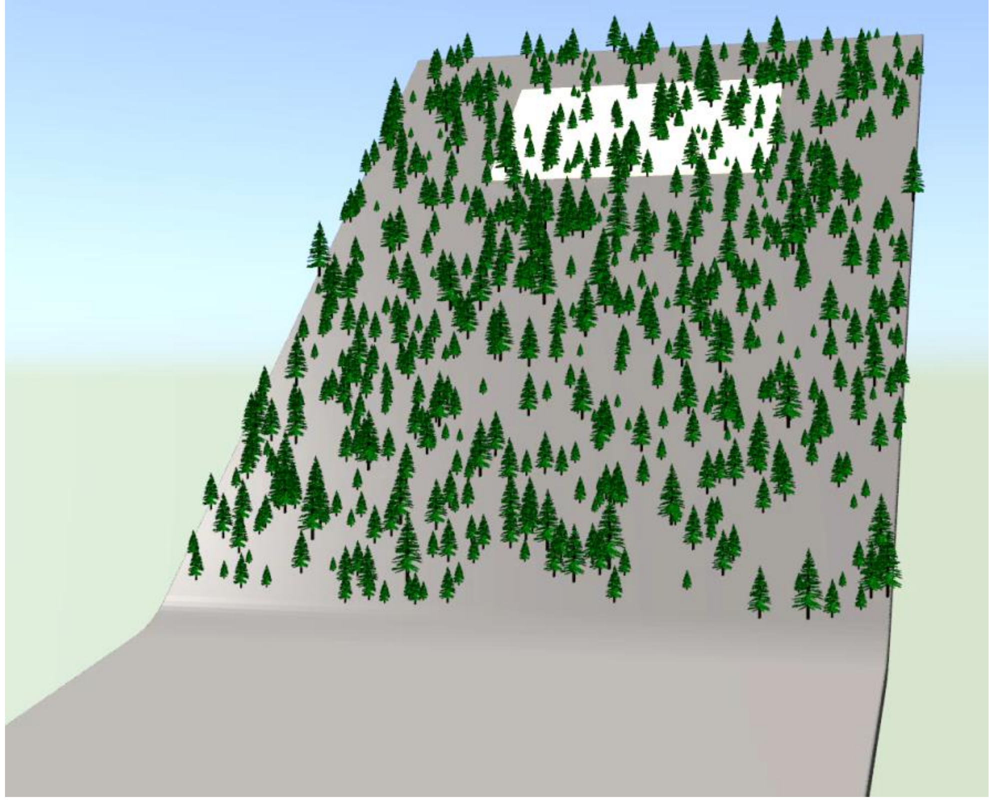
**With such 3D models, we report a natural emergence of**

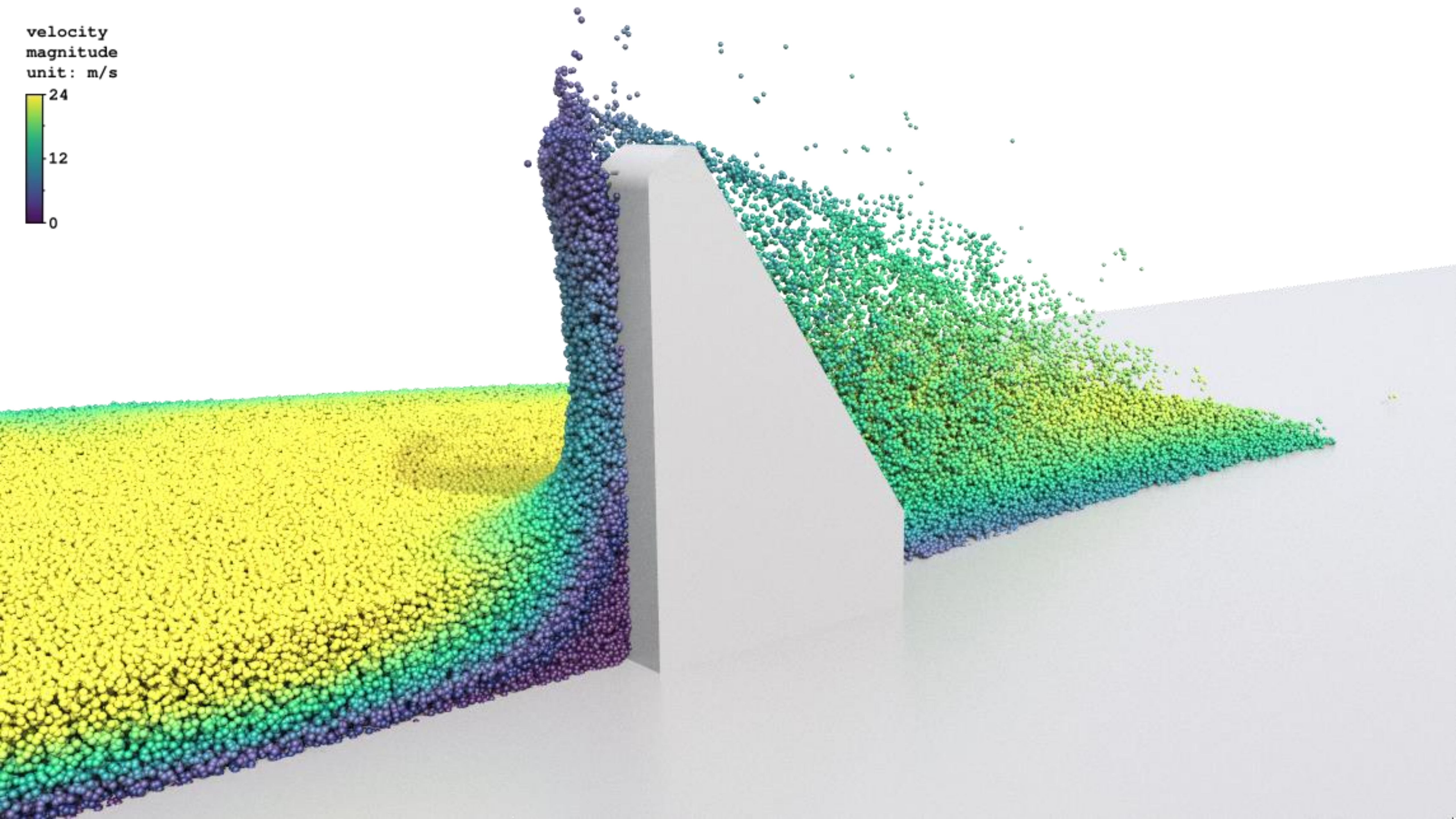
- Wave phenomena
- Buckling mechanism
- Dispersive pressures
- Interaction with obstacles & run-up

BULDINGS



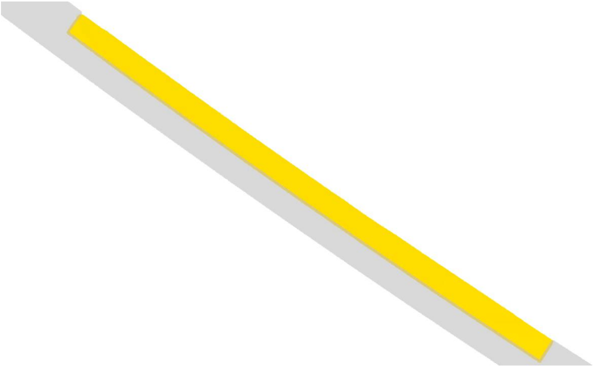
FORESTS




velocity
magnitude
unit: m/s
24
12
0

# Rate dependence?

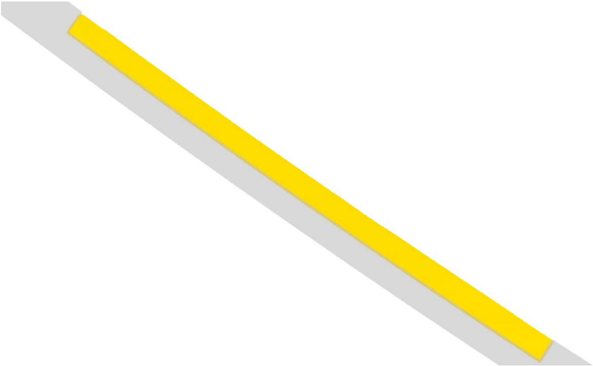
# Rate dependency



MPM simulation entrainment – no rate dependence

$\tan\varphi > \mu \;\rightarrow\; \ddot{x} = 0$ possible (steady – state flow)

# Rate dependency



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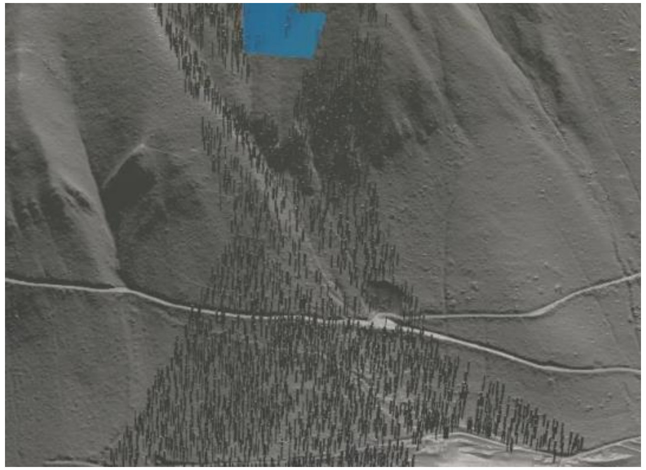
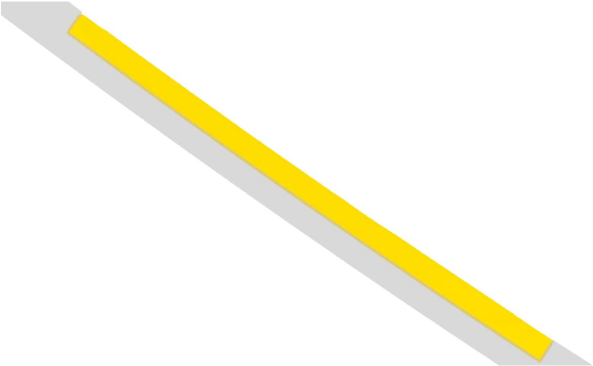


MPM simulation no entrainment – no rate dependence + forest

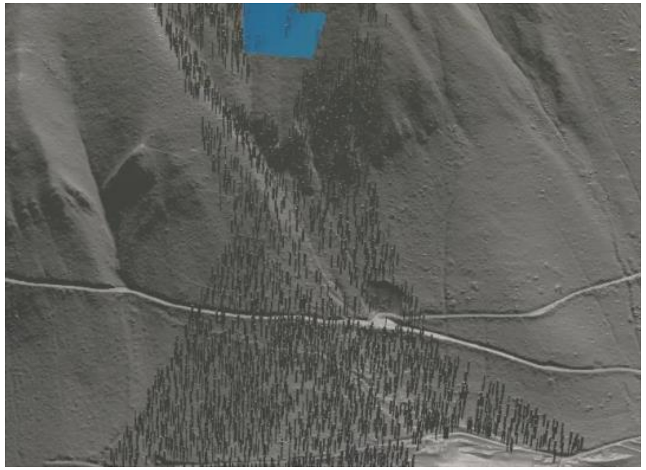
$\tan\varphi > \mu \;\rightarrow\; \ddot{x} = 0$ possible (steady – state flow)

# Rate dependency



MPM simulation entrainment – no rate dependence

$\tan\varphi > \mu \ \rightarrow \ \ddot{x} = 0$ possible (steady – state flow)



MPM simulation no entrainment – no rate dependence + forest

$\tan\varphi > \mu \ \rightarrow \ \ddot{x} = 0$ possible (steady – state flow)

MPM simulation no entrainment – no rate dependence

$\tan\varphi > \mu \ \rightarrow \ \ddot{x} > 0$ (accelerating flow)

# Critical State Soil Mechanics (CSSM)

## + the $\mu(I)$-rheology

**New**: rate-dependent $\mu = \mu(I)$

where $I$ is the inertial number

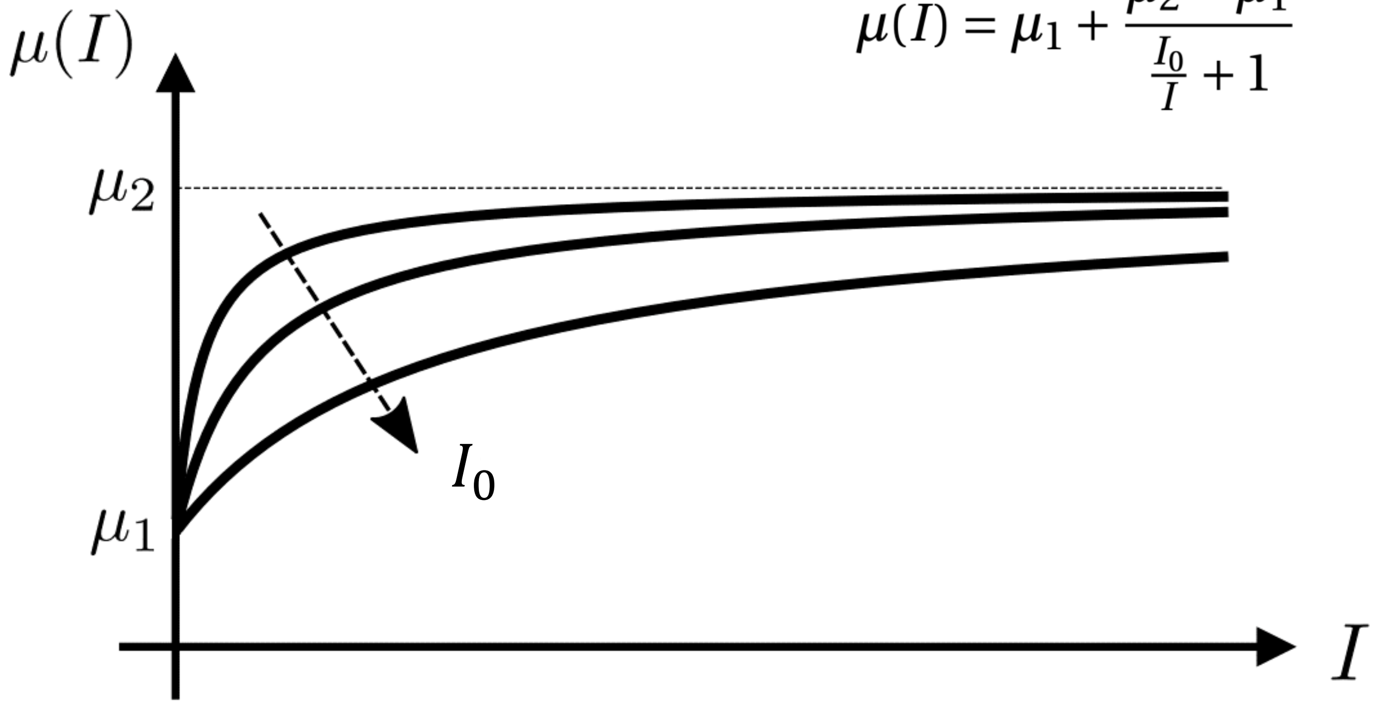
$$I = \frac{\dot{\gamma}_S \, d_g}{\sqrt{p/\rho_g}}$$

This means, at critical state, we have

$$q = \mu(I)\, p$$

This is the $\mu(I)$-rheology!
GDR MiDi (2004)

$$\mu(I) = \mu_1 + \frac{\mu_2 - \mu_1}{\frac{I_0}{I} + 1}$$




Blatny, Gray, Gaume. A critical state $\mu$(I)-rheology model for cohesive granular flows. Under revision i

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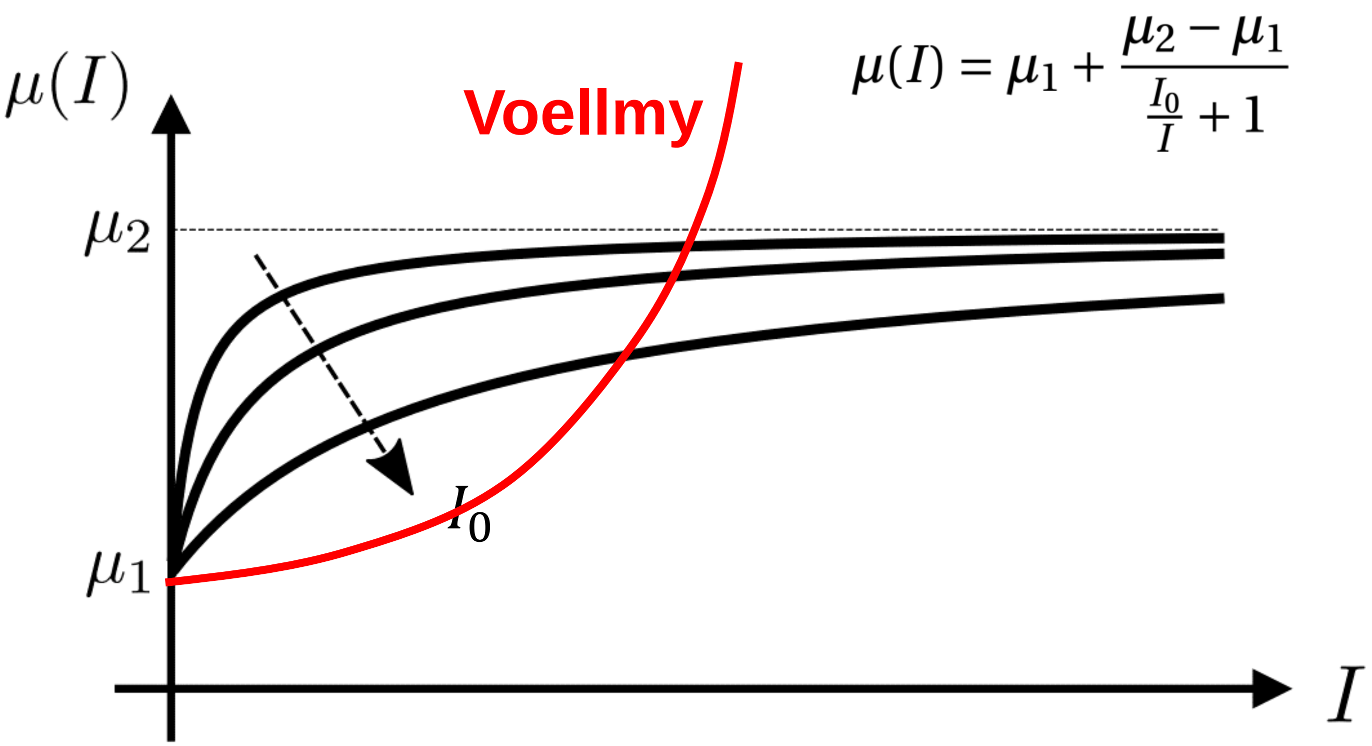
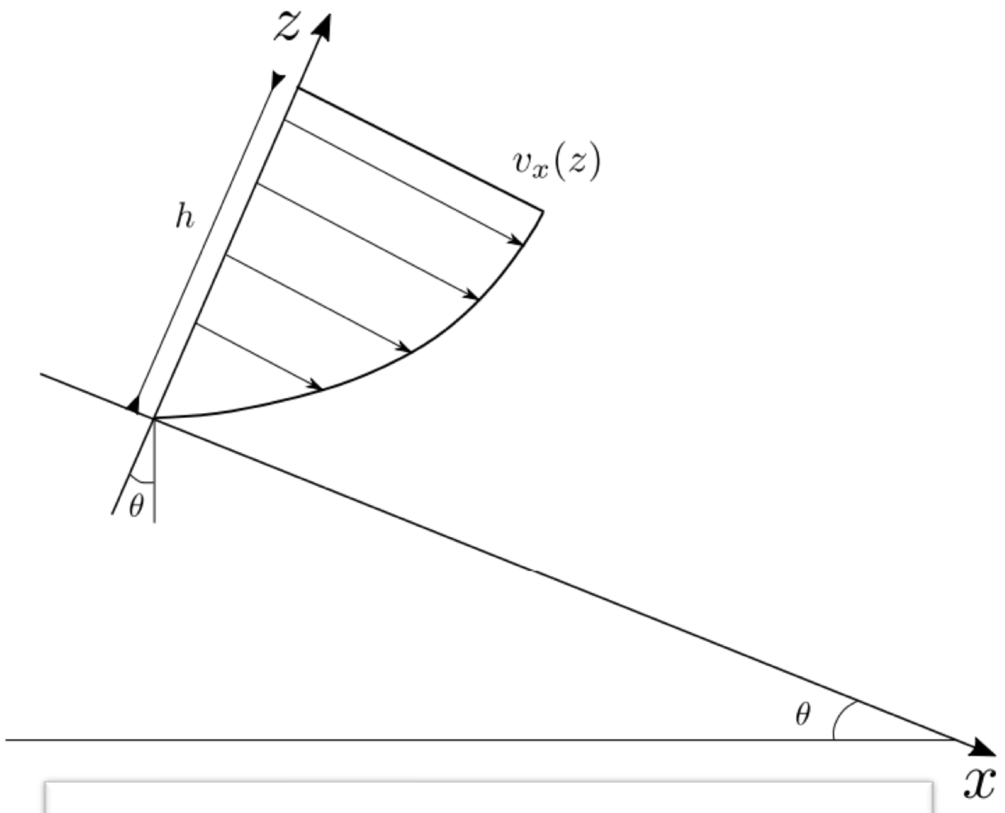



Blatny, Gray, Gaume. A critical state $\mu$(I)-rheology model for cohesive granular flows. Under revision i

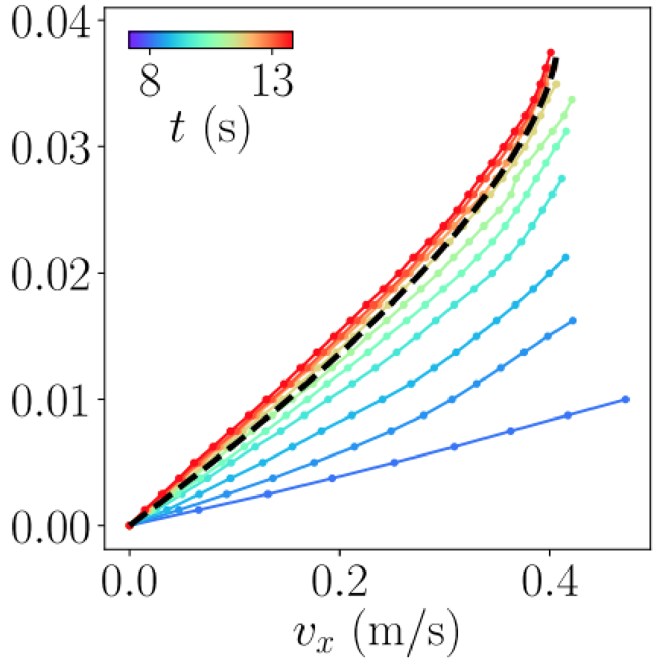
# Validation



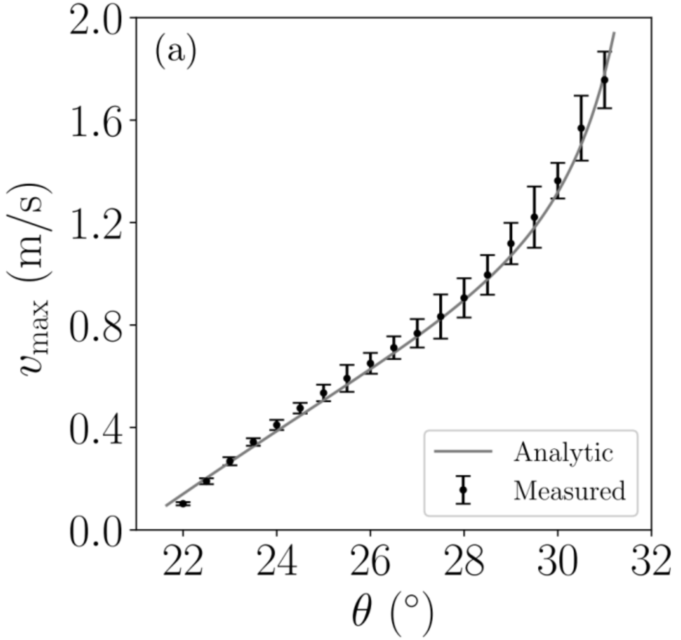

$$v_x(z) = v_{\max}\left[1 - (1 - z/h)^{3/2}\right]$$

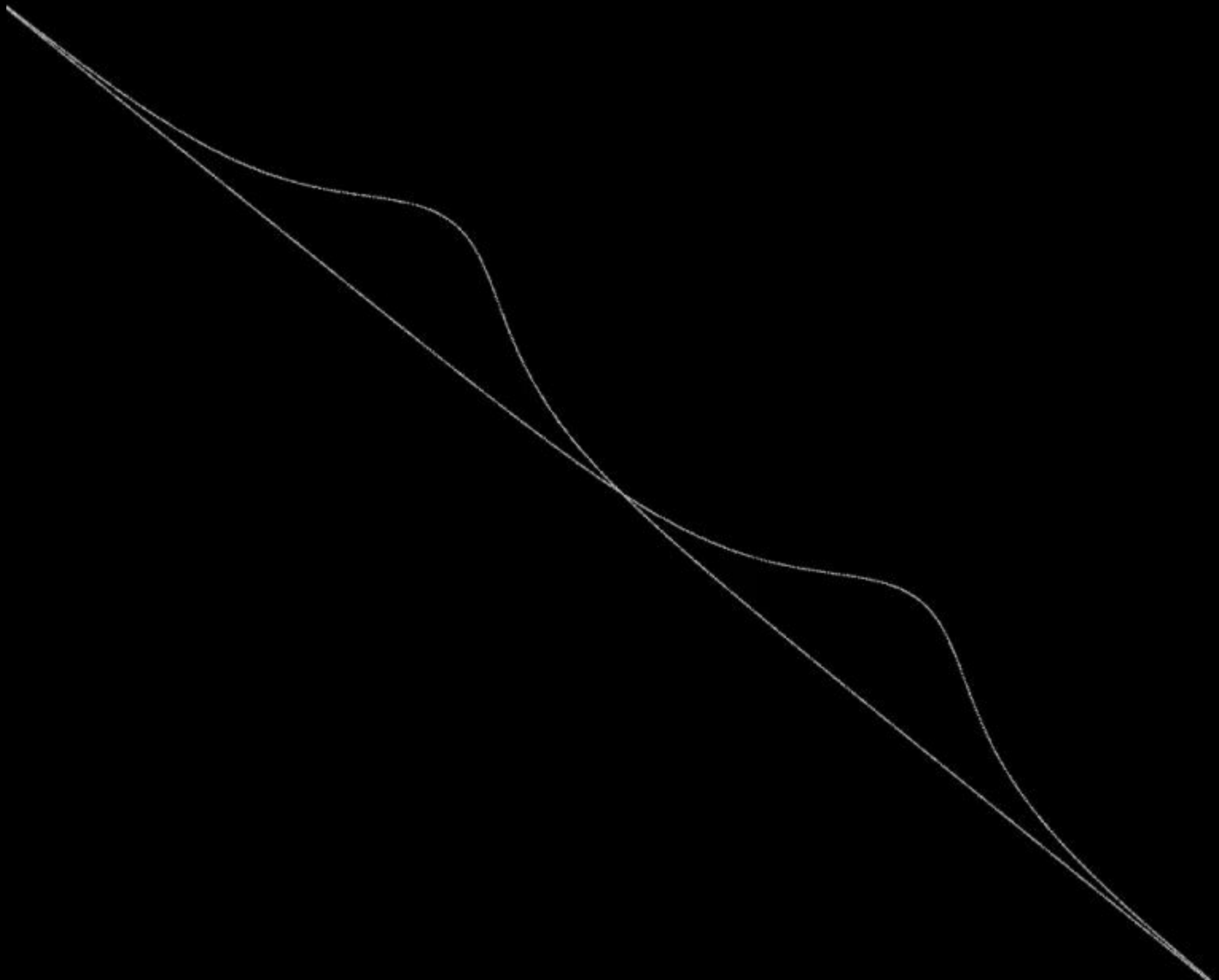
$$v_{\max} = v_x(h) = \frac{2}{3}\omega\frac{\tan\theta - \mu_1}{\mu_2 - \tan\theta}\sqrt{\rho g h^3 \cos\theta}$$

$\theta = 24°$




$\theta = 22° - 32°$





Viroulet et al. (2017) *JFM*

# Conclusions

- 3D models are useful to better understand complex mechanisms at play during avalanche dynamics (e.g. erosion, impact, etc.)

- New understanding can be incorporated in more efficient depth – averaged models or in guidelines.

- 3D model soon ready for practical use (GIS integration in progress).

Chair of Alpine Mass Movements

# Thank you

Questions?


## Acknowledgments

Xingyue Li | Betty Sovilla | Nico Gray | Michael Kyburz | Camille Ligneau | Lars Blatny | Hervé Vicari

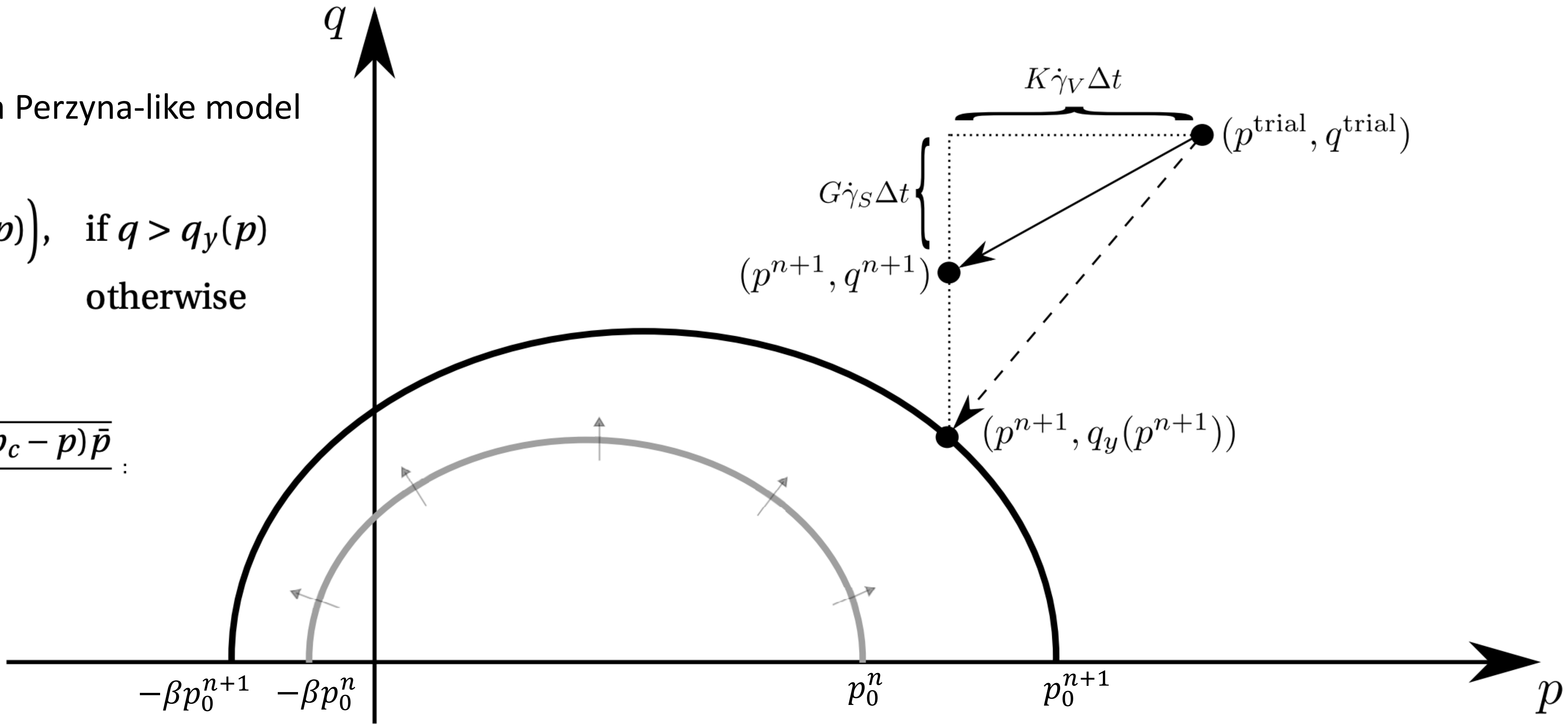
# CSSM + $\mu(I)$ rheology

We can write this as a Perzyna-like model as

$$\dot{\gamma}_S = \begin{cases} \frac{1}{\eta}\left(q - q_y(p)\right), & \text{if } q > q_y(p) \\ 0, & \text{otherwise} \end{cases}$$

with

$$\eta = \frac{(\mu(I) - \mu_1)\sqrt{(p_c - p)\bar{p}}}{\dot{\gamma}_S}.$$



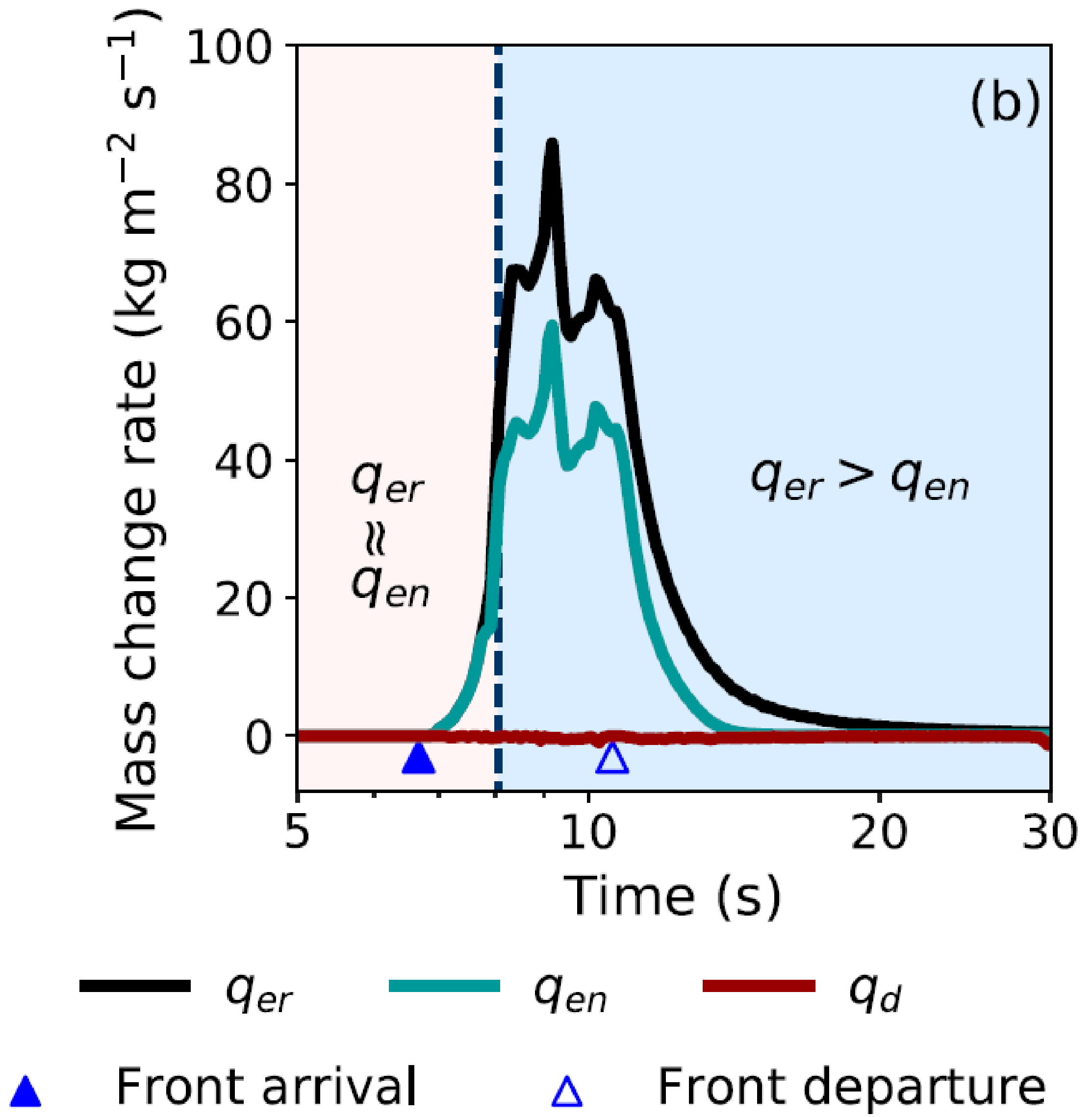
# Avalanche dynamics with MPM

## Erosion – entrainment

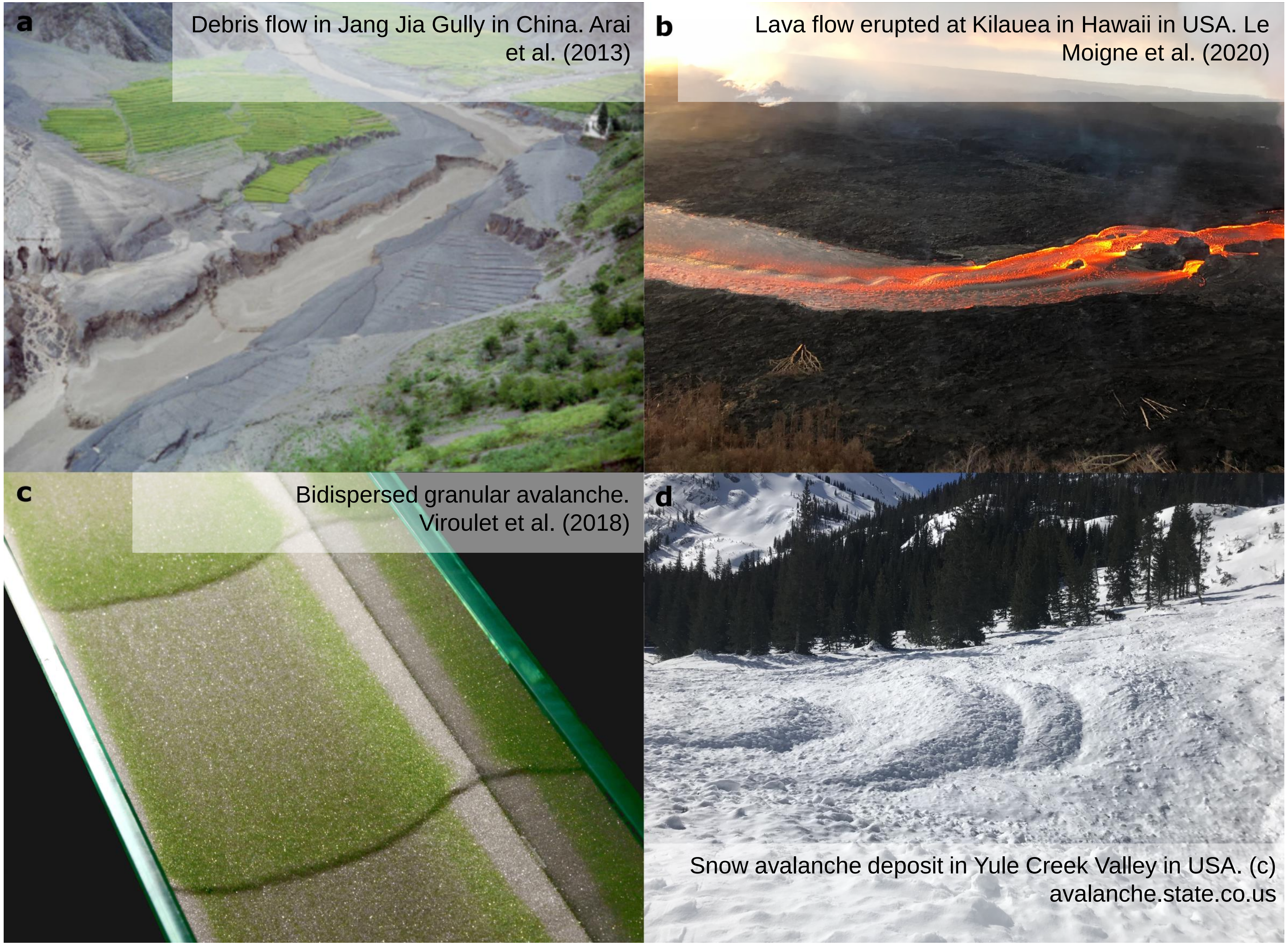
$$q_{er} = \frac{m_{er}}{A_{bed} \times \Delta t}$$

$$q_{en} = \frac{m_{en}}{A_{bed} \times \Delta t}$$

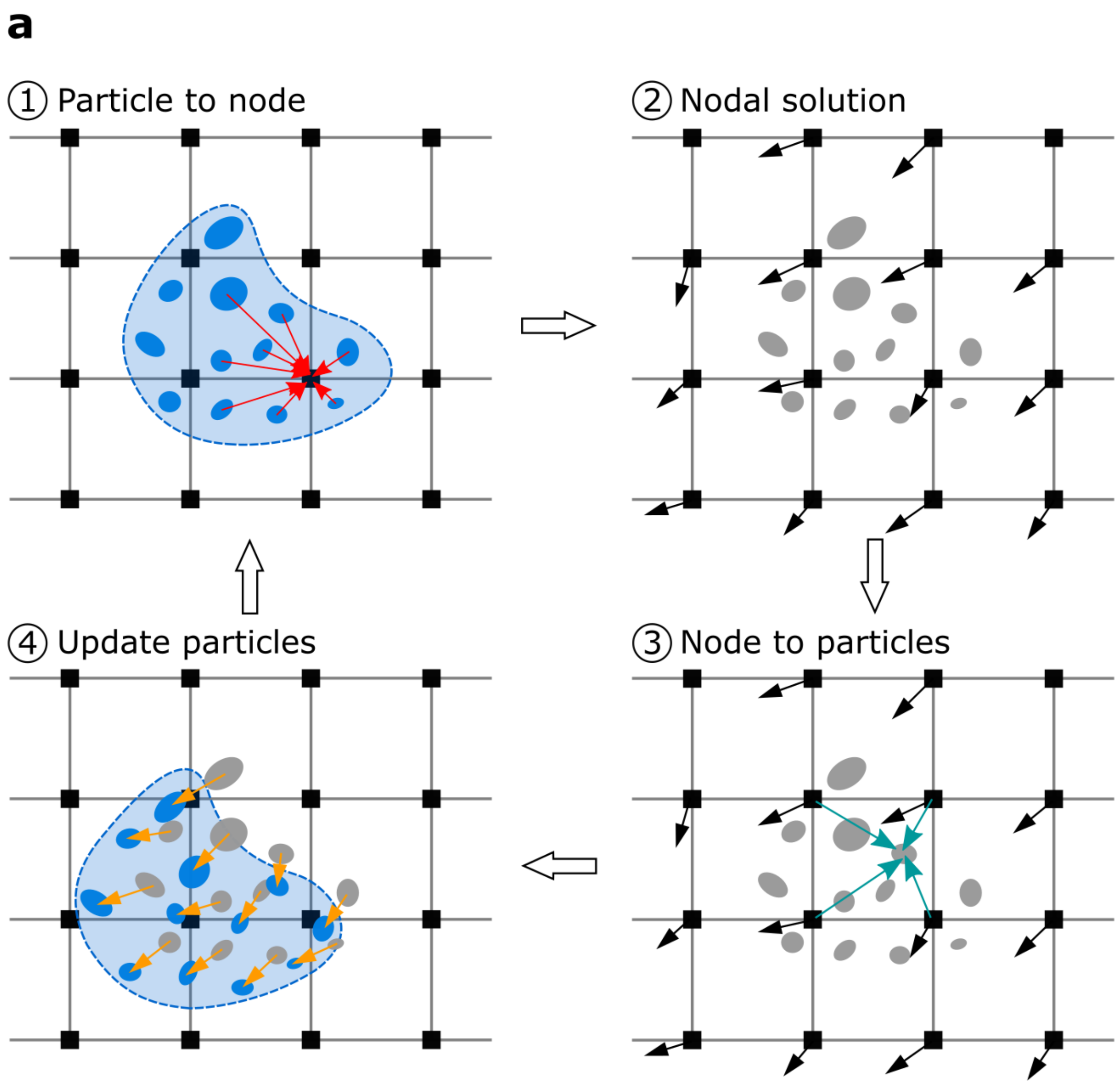
$$q_d = -\frac{m_d}{A_{bed} \times \Delta t}$$




Li, Sovilla, Ligneau, Gaume (2021). Different erosion and entrainment mechanisms in snow avalanches ***Mechanics Research Communications***


a
Debris flow in Jang Jia Gully in China. Arai et al. (2013)
b
Lava flow erupted at Kilauea in Hawaii in USA. Le Moigne et al. (2020)
c
Bidispersed granular avalanche. Viroulet et al. (2018)
d
Snow avalanche deposit in Yule Creek Valley in USA. (c) avalanche.state.co.us

# MPM & Critical State Mechanics

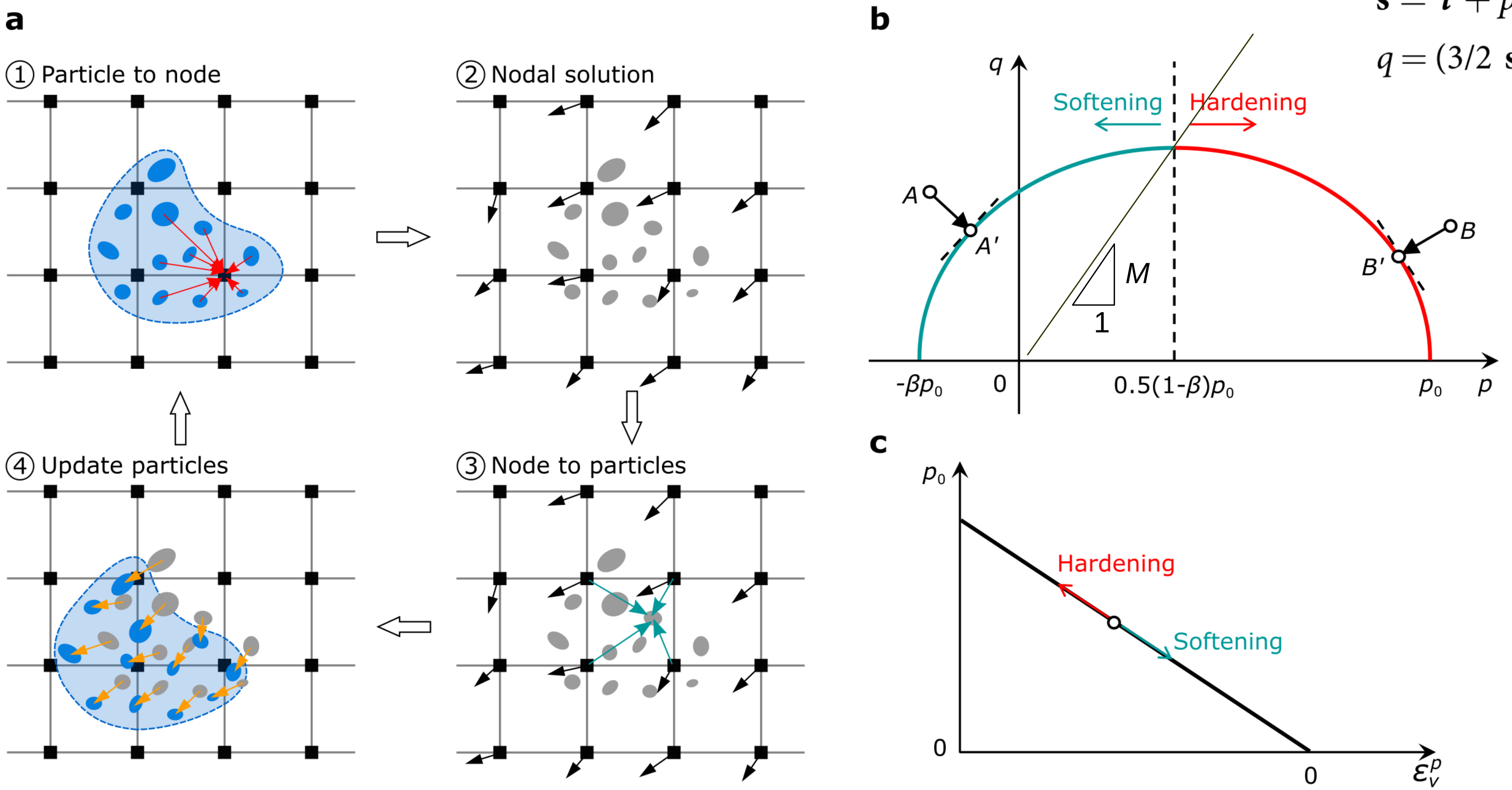


# MPM & Critical State Mechanics

$$p = -\frac{1}{d}\mathrm{tr}(\boldsymbol{\tau})$$

$$\mathbf{s} = \boldsymbol{\tau} + p\mathbf{I}$$

$$q = (3/2\ \mathbf{s} : \mathbf{s})^{1/2}$$




NVE

# Hazard zoning in Norway

**Odd Are Jensen**

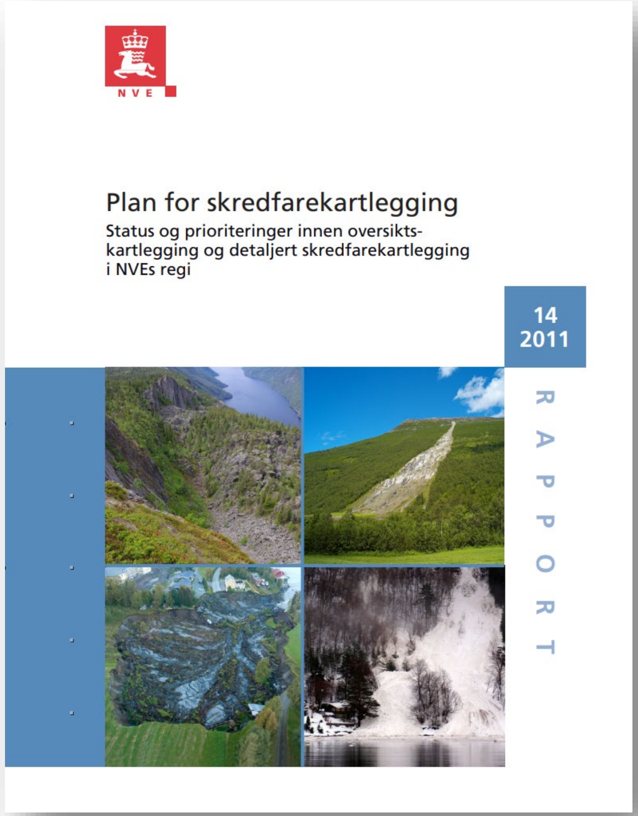
NVE

6. sept. 2023

# Content

- Status on hazard mapping in Norway
- Needs for further development

NVE

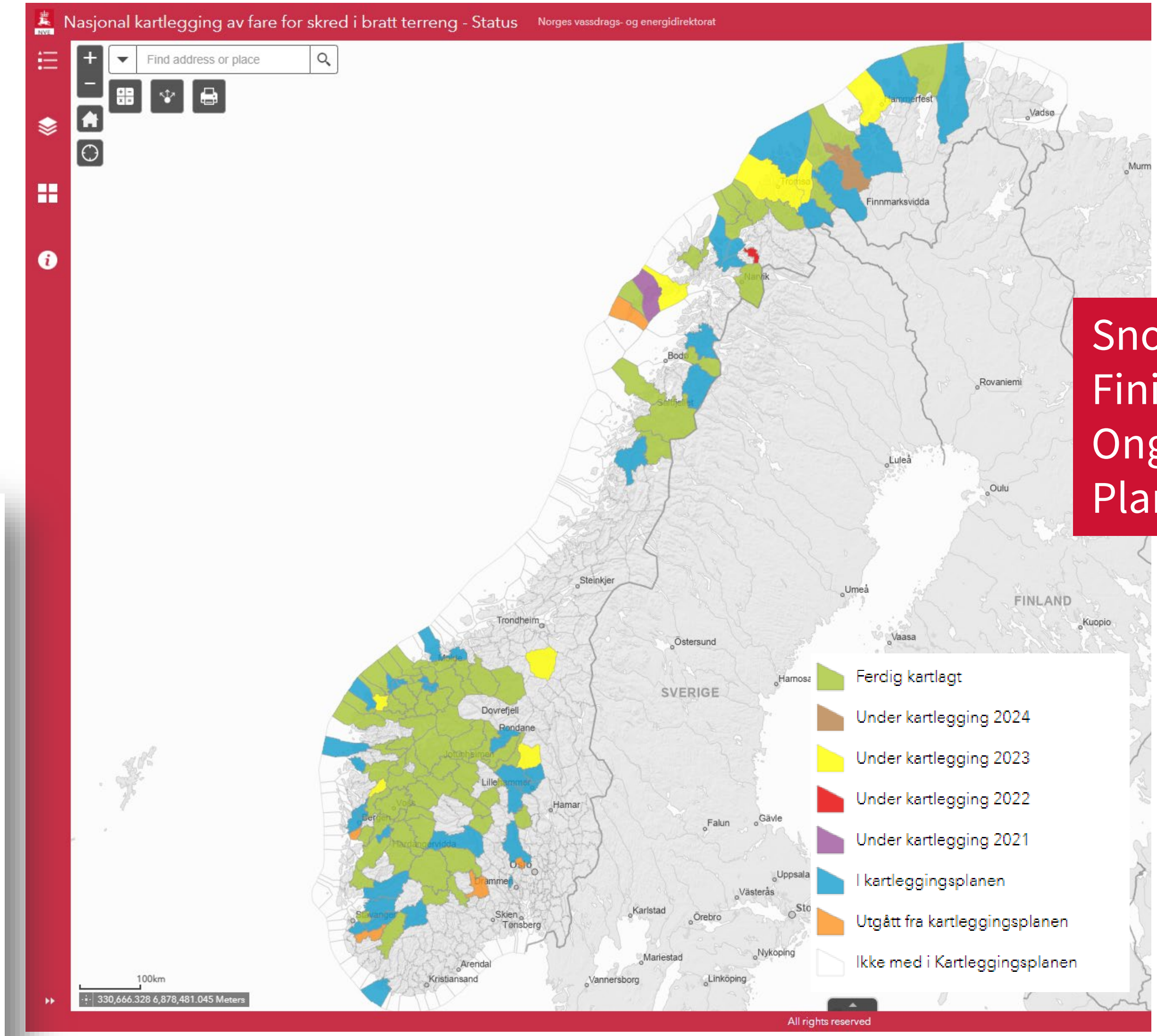

NVE

Plan for skredfarekartlegging

Status og prioriteringer innen oversikts-kartlegging og detaljert skredfarekartlegging i NVEs regi

14
2011

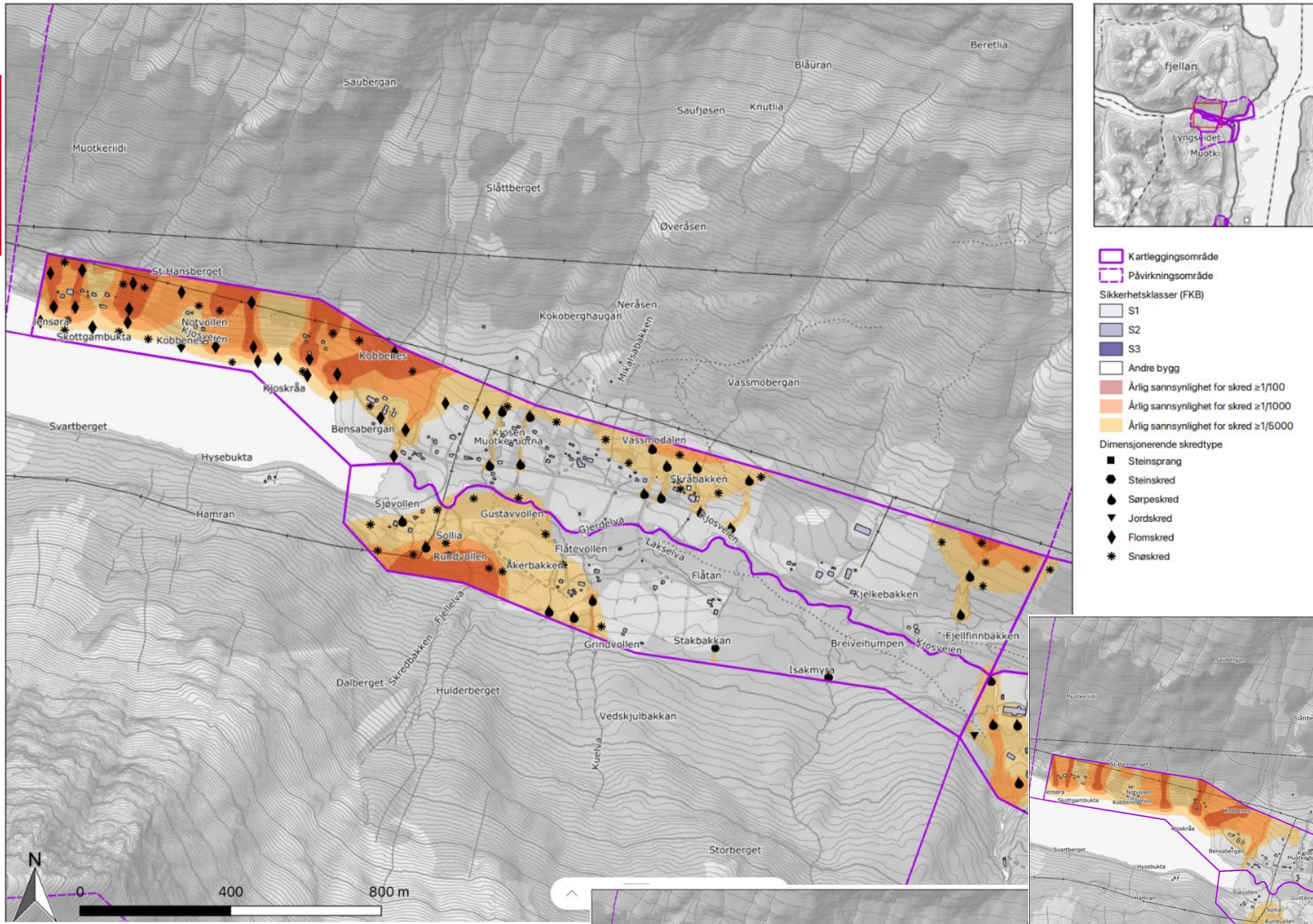
RAPPORT

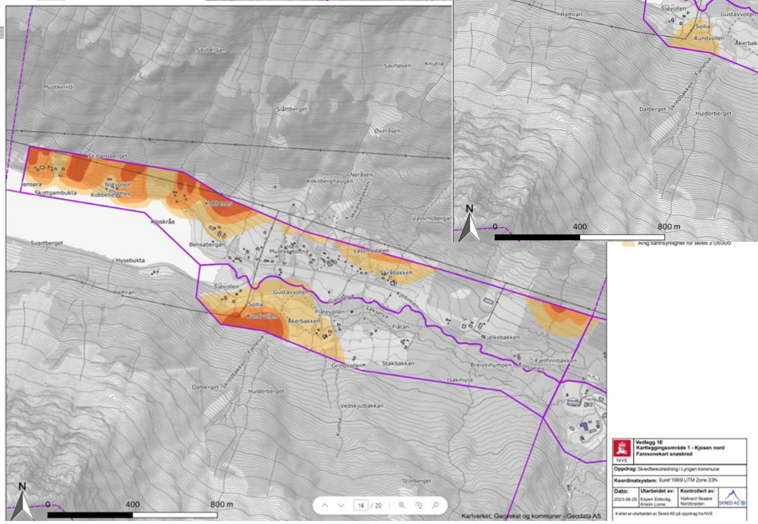


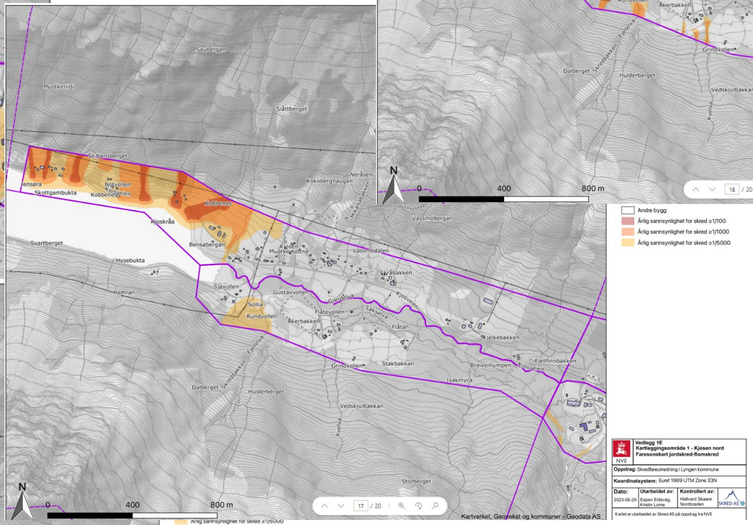


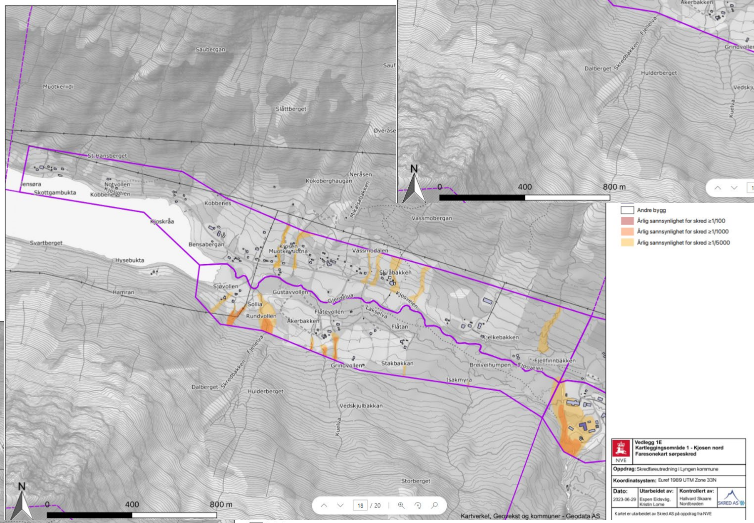
Snow avalanches:
Finished: 56 municipalities
Ongoing: 4 municipalities
Planned: 17 municipalities

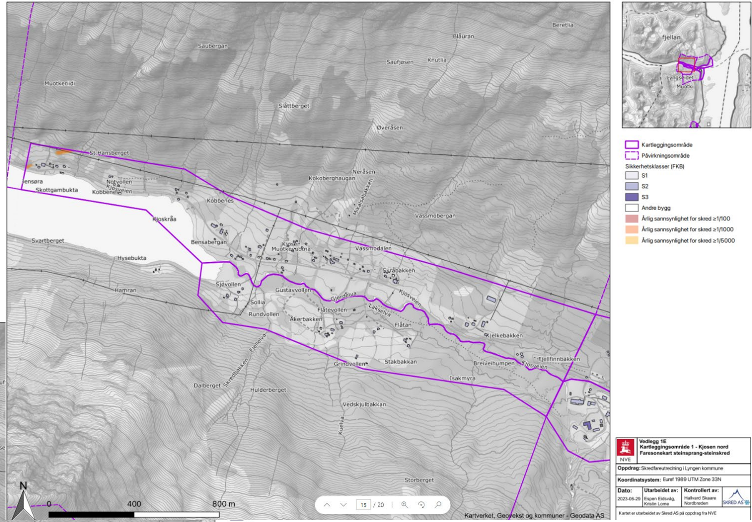

Stein
Snø
Sørpe
Løsmasse
Skredsoner_100
Skredsoner_1000
Skredsoner_5000



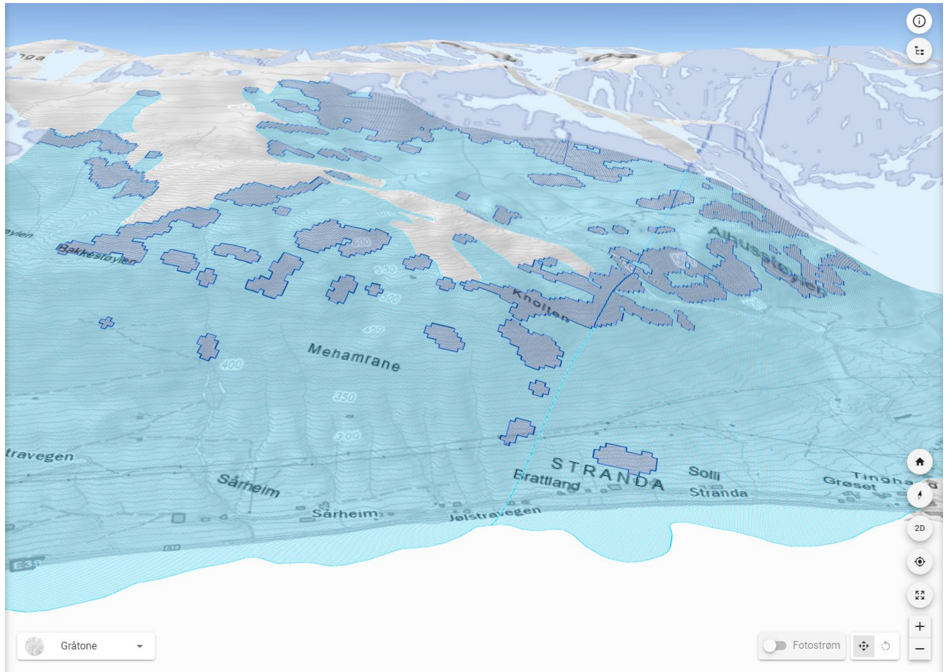



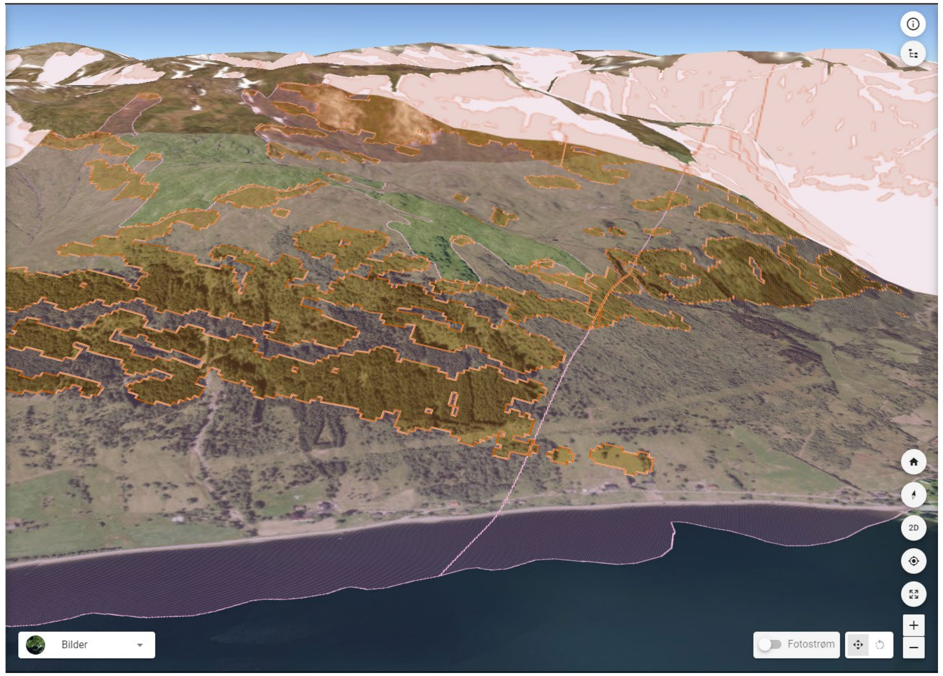






Preliminary results


Mehamrane
STRANDA
Brattland
Solli
Stranda
Sarheim
Jølstravegen
2D
Gråtone
Fotostrøm


2D
Bilder
Fotostrøm


NVE
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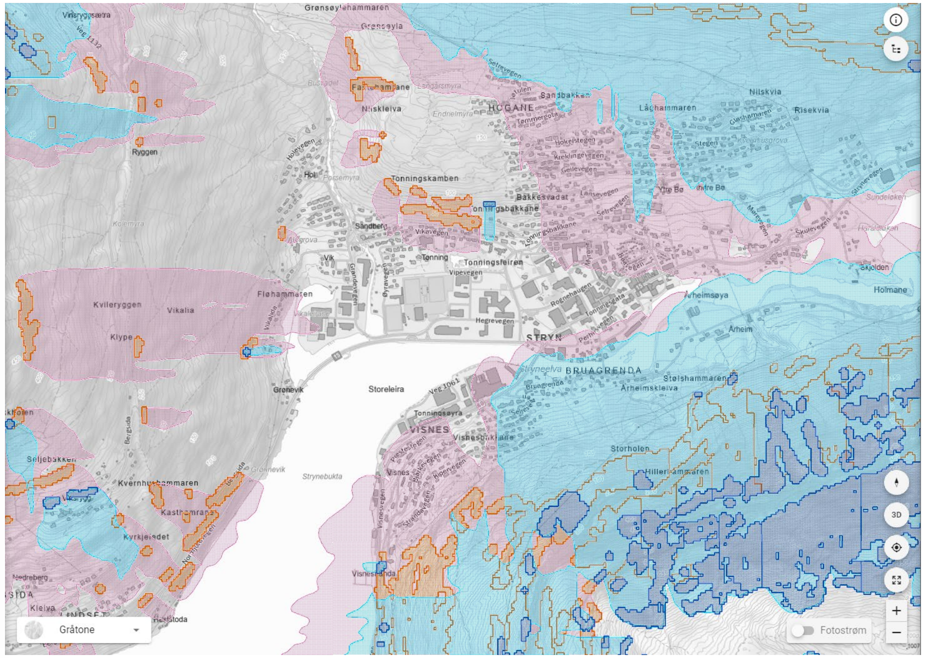
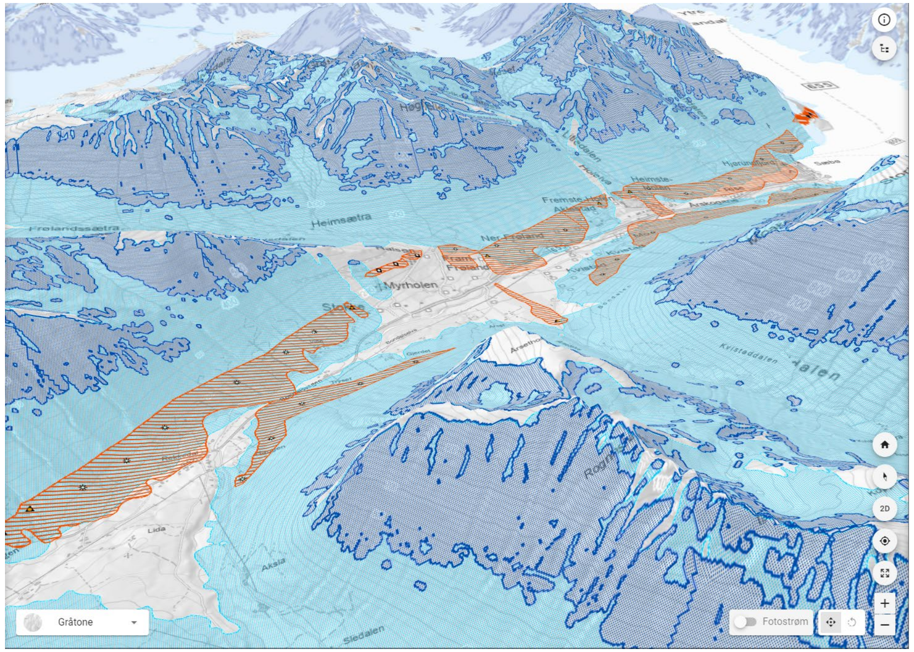
14
2011
RAPPORT


HOGANE
Låghammaren
Nilskvia
Risekvia
Ryggen
Tonningskamben
Flohammaren
Kvileryggen
Vikalia
Klype
Holmane
STRYN
BRUAGRENDA
Storeleira
VISNES
Storeholen
Kvernhushammaren
3D
Gråtone
Fotostrøm


Heimsætra
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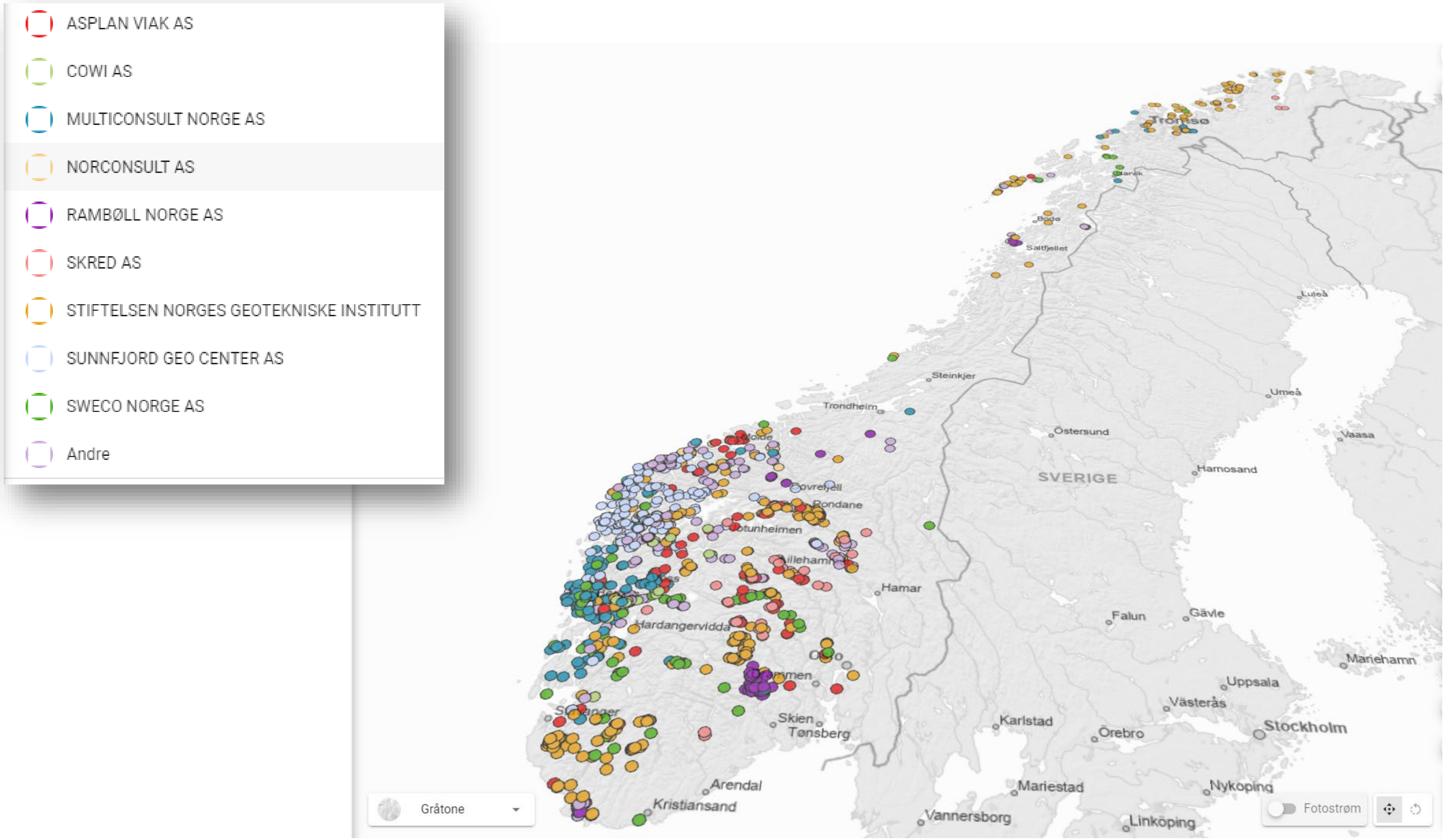
ASPLAN VIAK AS
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SUNNFJORD GEO CENTER AS
SWECO NORGE AS
Andre
Steinkjer
Trondheim
Umeå
Östersund
Vaasa
SVERIGE
Härnösand
Pondane
Hamar
Hardangervidda
Falun
Gävle
Mariehamn
Uppsala
Västerås
Stockholm
Karlstad
Örebro
Skien
Tønsberg
Arendal
Kristiansand
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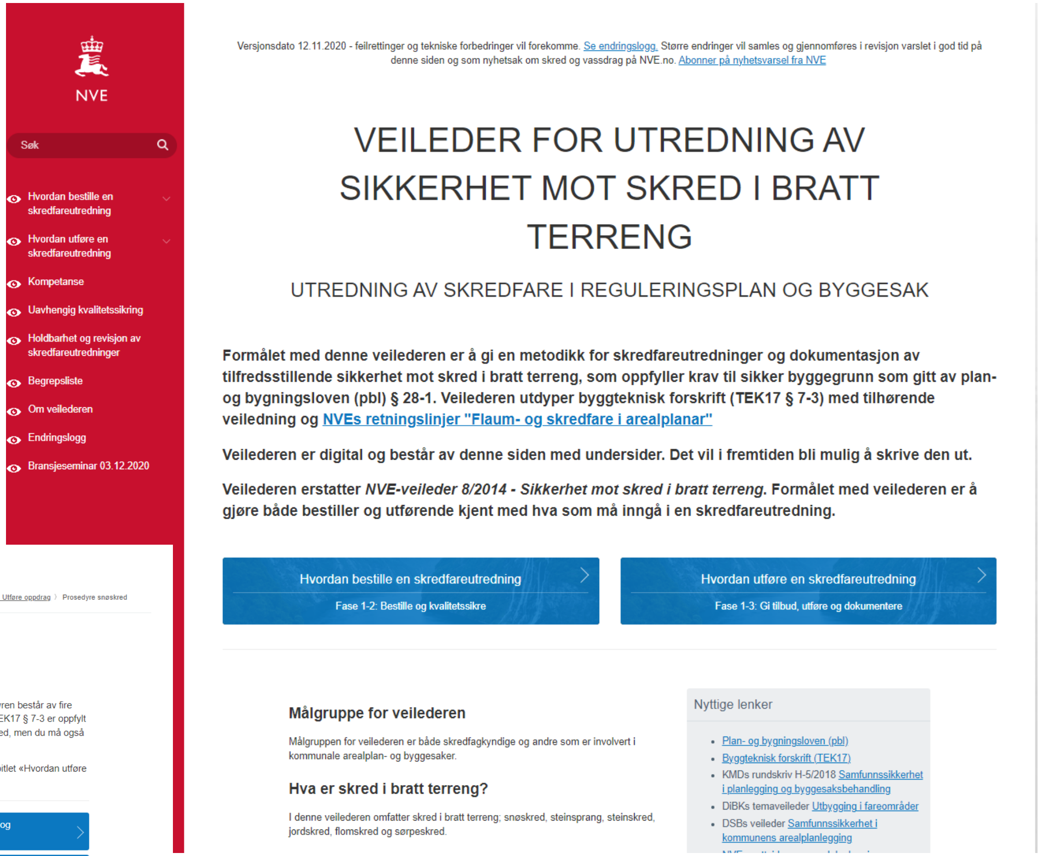
Linköping
Gråtone
Fotostrøm

# Guidelines for hazard zoning/hazard assessment

- Industry standard
- Based on best-practice



NVE

Søk

- Hvordan bestille en skredfareutredning
- Hvordan utføre en skredfareutredning
- Kompetanse
- Uavhengig kvalitetssikring
- Holdbarhet og revisjon av skredfareutredninger
- Begrepsliste
- Om veilederen
- Endringslogg
- Bransjeseminar 03.12.2020

Versjonsdato 12.11.2020 - feilrettinger og tekniske forbedringer vil forekomme. Se endringslogg. Større endringer vil samles og gjennomføres i revisjon varslet i god tid på denne siden og som nyhetsak om skred og vassdrag på NVE.no. Abonner på nyhetsvarsel fra NVE

## VEILEDER FOR UTREDNING AV SIKKERHET MOT SKRED I BRATT TERRENG

UTREDNING AV SKREDFARE I REGULERINGSPLAN OG BYGGESAK

**Formålet med denne veilederen er å gi en metodikk for skredfareutredninger og dokumentasjon av tilfredsstillende sikkerhet mot skred i bratt terreng, som oppfyller krav til sikker byggegrunn som gitt av plan- og bygningsloven (pbl) § 28-1. Veilederen utdyper byggteknisk forskrift (TEK17 § 7-3) med tilhørende veiledning og NVEs retningslinjer "Flaum- og skredfare i arealplanar"**

**Veilederen er digital og består av denne siden med undersider. Det vil i fremtiden bli mulig å skrive den ut.**

**Veilederen erstatter *NVE-veileder 8/2014 - Sikkerhet mot skred i bratt terreng*. Formålet med veilederen er å gjøre både bestiller og utførende kjent med hva som må inngå i en skredfareutredning.**

Hvordan bestille en skredfareutredning
Fase 1-2: Bestille og kvalitetssikre

Hvordan utføre en skredfareutredning
Fase 1-3: Gi tilbud, utføre og dokumentere

### Målgruppe for veilederen

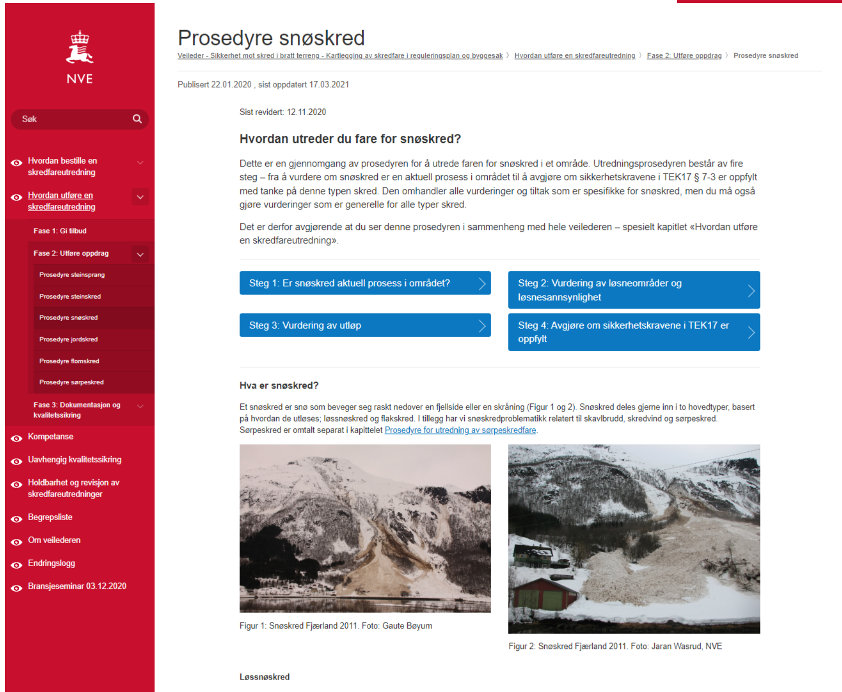
Målgruppen for veilederen er både skredfagkyndige og andre som er involvert i kommunale arealplan- og byggesaker.

### Hva er skred i bratt terreng?

I denne veilederen omfatter skred i bratt terreng; snøskred, steinsprang, steinskred, jordskred, flomskred og sørpeskred.

Nyttige lenker

- Plan- og bygningsloven (pbl)
- Byggteknisk forskrift (TEK17)
- KMDs rundskriv H-5/2018 Samfunnssikkerhet i planlegging og byggesaksbehandling
- DiBKs temaveileder Utbygging i fareområder
- DSBs veileder Samfunnssikkerhet i kommunens arealplanlegging



NVE

Søk

- Hvordan bestille en skredfareutredning
- Hvordan utføre en skredfareutredning
  - Fase 1: Gi tilbud
  - Fase 2: Utføre oppdrag
    - Prosedyre steinsprang
    - Prosedyre steinskred
    - Prosedyre snøskred
    - Prosedyre jordskred
    - Prosedyre flomskred
    - Prosedyre sørpeskred
  - Fase 3: Dokumentasjon og kvalitetssikring
- Kompetanse
- Uavhengig kvalitetssikring
- Holdbarhet og revisjon av skredfareutredninger
- Begrepsliste
- Om veilederen
- Endringslogg
- Bransjeseminar 03.12.2020

## Prosedyre snøskred

Veileder - Sikkerhet mot skred i bratt terreng - Kartlegging av skredfare i reguleringsplan og byggesak › Hvordan utføre en skredfareutredning › Fase 2: Utføre oppdrag › Prosedyre snøskred

Publisert 22.01.2020 , sist oppdatert 17.03.2021

Sist revidert: 12.11.2020

### Hvordan utreder du fare for snøskred?

Dette er en gjennomgang av prosedyren for å utrede faren for snøskred i et område. Utredningsprosedyren består av fire steg – fra å vurdere om snøskred er en aktuell prosess i området til å avgjøre om sikkerhetskravene i TEK17 § 7-3 er oppfylt med tanke på denne typen skred. Den omhandler alle vurderinger og tiltak som er spesifikke for snøskred, men du må også gjøre vurderinger som er generelle for alle typer skred.

Det er derfor avgjørende at du ser denne prosedyren i sammenheng med hele veilederen – spesielt kapitlet «Hvordan utføre en skredfareutredning».

- Steg 1: Er snøskred aktuell prosess i området?
- Steg 2: Vurdering av løsneområder og løsnesannsynlighet
- Steg 3: Vurdering av utløp
- Steg 4: Avgjøre om sikkerhetskravene i TEK17 er oppfylt

#### Hva er snøskred?

Et snøskred er snø som beveger seg raskt nedover en fjellside eller en skråning (Figur 1 og 2). Snøskred deles gjerne inn i to hovedtyper, basert på hvordan de utløses; løssnøskred og flakskred. I tillegg har vi snøskredproblematikk relatert til skavlbrudd, skredvind og sørpeskred. Sørpeskred er omtalt separat i kapittelet Prosedyre for utredning av sørpeskredfare.

Figur 1: Snøskred Fjærland 2011. Foto: Gaute Bøyum

Figur 2: Snøskred Fjærland 2011. Foto: Jaran Wasrud, NVE

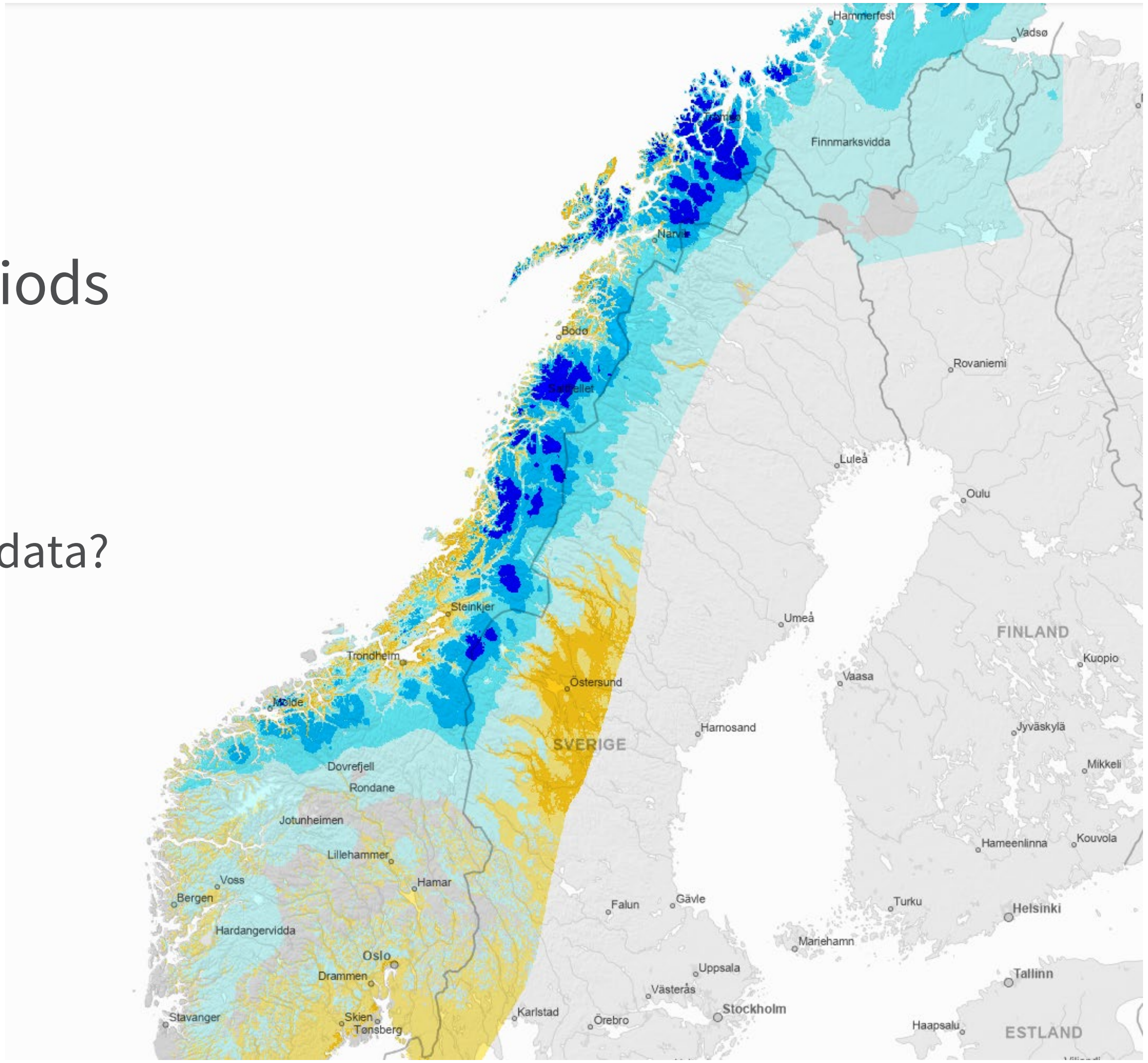
Løssnøskred

# Results

- Houses susceptible to avalanches w/return period of ca. 1/1000:
  - With present forests 144 000
  - Without effect of forests 304 000
- FOSS – analysis of mitigation needs for existing buildings in Norway
  - Floods, landslides and avalanches
  - 85 000 000 000 NOK (7 500 000 000 EURO)

# Future development

- Avalanche release with long return periods
  - Realistic release area and fracture depths
  - Wind drift
  - Differentiated for large regional differences
  - How far can we stretch the available climate data?
  - Forest effects



- Run-out
  - Differentiated for large regional differences in snow cover and snow properties
  - Powder cloud
  - Forest effects
- Hazard zoning
  - Pressure/intensity criteria
- Effects of climate change
  - More precipitation
  - Shorter winters
  - Forests?

- Natural hazards in forest management
- Maps, tools and guidelines for contingency planning and local avalanche forecasting

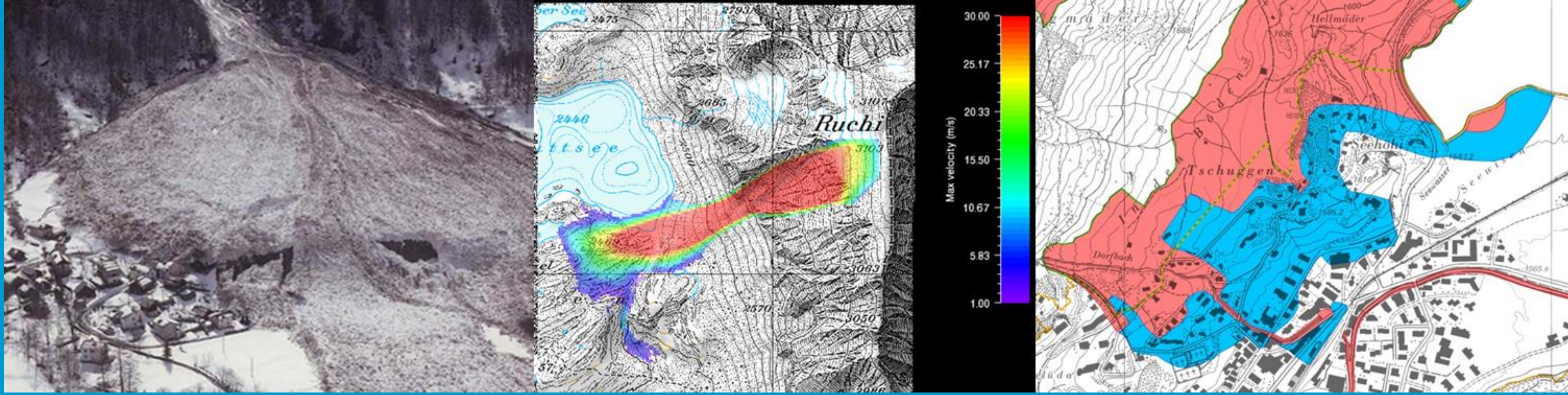
# Education

- Researchers and practitioners with a background in snow avalanches
- Mitigation measures
- Most private consultants have people hired that have had some affiliation with NGIs snow avalanche research

Thank you!

oaj@nve.no

Part of the WSL and
thus of the ETH Domain



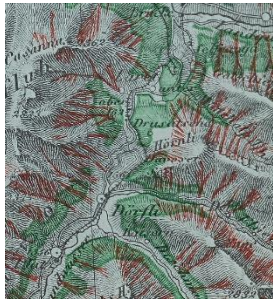

# The challenging task of avalanche hazard mapping – the Swiss perspective

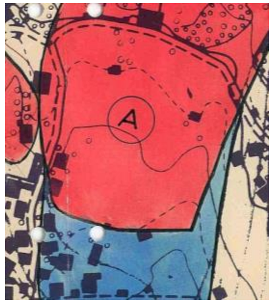
Stefan Margreth, WSL Institute for Snow and Avalanche Research SLF

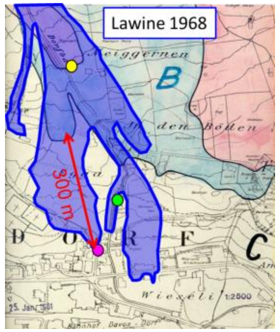
50-YEAR ANNIVERSARY FOR FONNBU AVALANCHE RESEARCH STATION - 7 Sep 2023

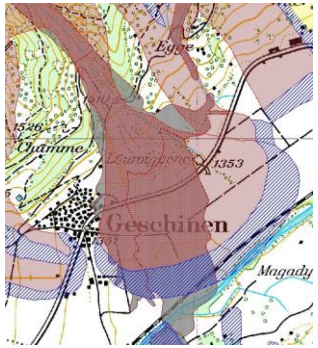
# Road map of history of avalanche hazard mapping in Switzerland

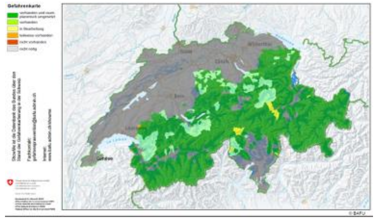
**Consequences**









| 1889 | 1910 | 1942 | 1954 | 1968 | 1984 | 2000 | 2023 |
|---|---|---|---|---|---|---|---|
| 1. Event-analysis by J.F. Coaz | Avalanche map by J.F. Coaz | Foundation SLF | 1. avalanche hazard map | Stricter criteria: 300 y. and 30 kPa | Guideline hazard mapping | Event analysis: verification hazard maps | – 99% of hazard maps established<br>– revision of maps |

1880 1900 1920 1940 1960 1980 2000 2020

**Decisive avalanche cycles**

1888
Avalanche winter

49†
850

1951
Avalanche winter

98†
1500

1968
Avalanche winter

37†
404

1999
Avalanche winter

17†
1700

# Swiss criteria for the definition of the hazard level

**Hazard level** depends on Frequency and Intensity of an avalanche

**Frequency (return period of avalanche with specific runout):**

- **300-y avalanche: extreme event,** fracture depth can be +/- extrapolated from snow data up to 80 years back, oldest recorded avalanche events back to 17th century.
- **100-y avalanche:** origin from flood hazards, former design scenario
- **30-y avalanche: small, frequent avalanche,** 10 times smaller return period - significant difference to the 300 year avalanche - a 30 year avalanche might be directly observed in many situations.

**Intensity (impact pressure):**

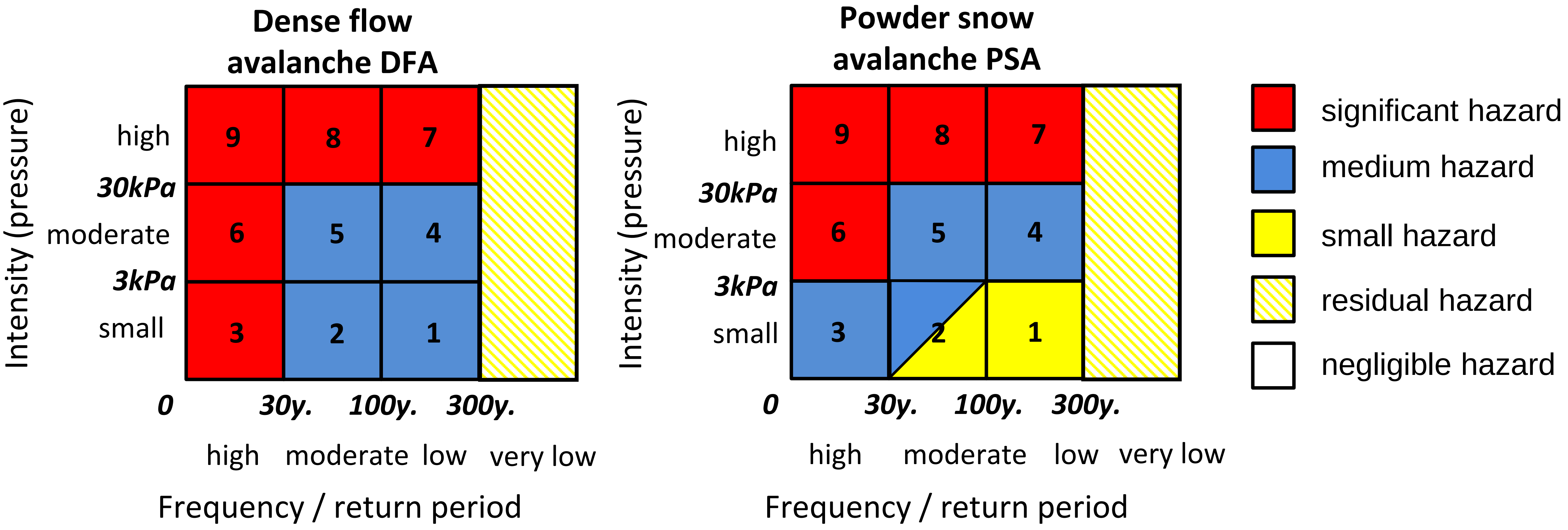
- **Impact threshold** between high – medium intensity = **30 kPa**
- defined by SLF in 1970 by expert choice: “up to an impact pressure of 30 kPa a building can be reinforced with justifiable cost”
- Impact pressure on a **large virtual object**: $p = \rho \cdot v^2$; with $\rho = 300\ kg/m^3$ and $v = 10\ m/s \rightarrow p = 30\ kPa$

Galtür: before 1999 avalanche


After avalanche: pressure ca. 50 $kN/m^2$

# Hazard matrix for the determination of the danger level:

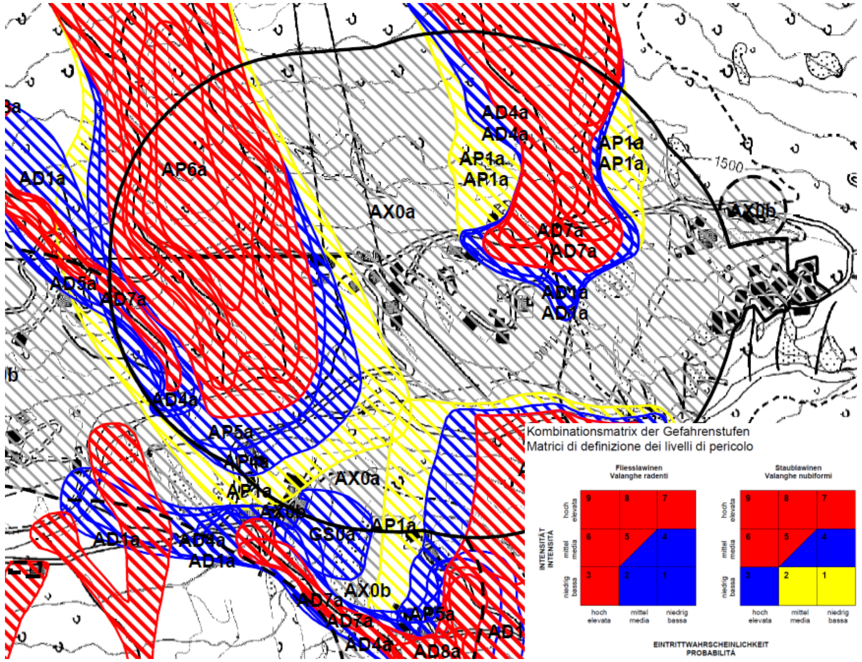
- For all natural hazard the same scenarios (30, 100 and 300 years) and colors (red, blue and yellow) are used
- Flooding: extreme scenario > 300 years → in future for all hazards!!



# Criteria for hazard mapping in other countries: Austria, Italy and Iceland – three different concepts

**Austria:** small pressure limit
- max. return period **150 years**
- > 10 kPa = red zone (no building zone)
- 0 – 10 kPa = yellow zone (building with obligations)

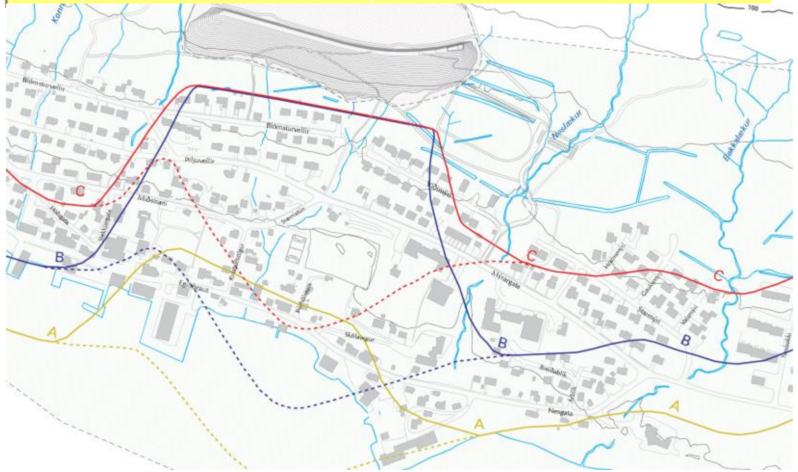
**Italy:** not unified criteria (Autonomous Region = own law)
- max. return period 100 to 300 years
- red zone: > 15 to 30 kPa
- blue / green zone: > 3 to 5 kPa
- yellow / blue zone: < 3 to 5 kPa



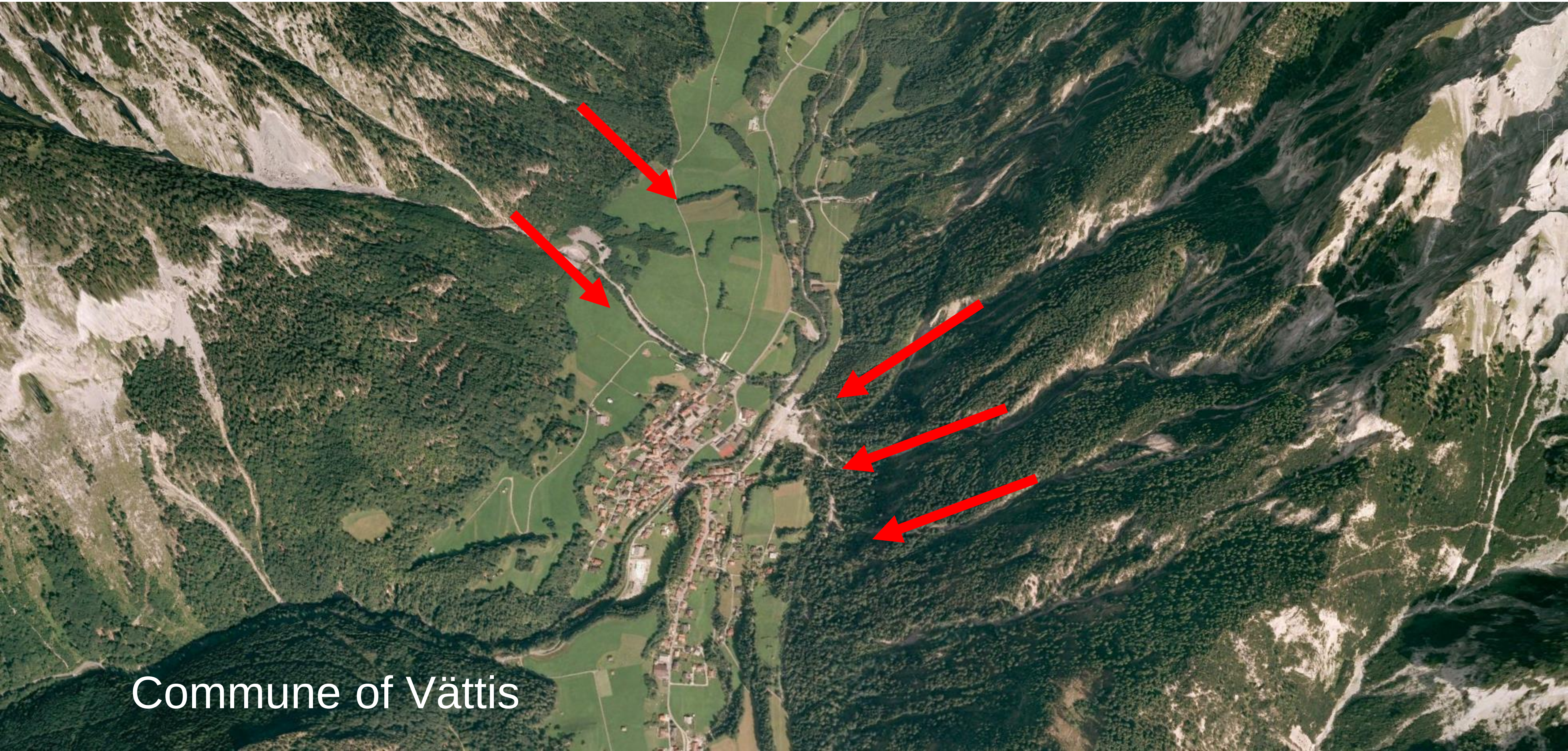

**Iceland:** risk based approach
hazard zoning is based on individual risk – probability of death in a wood-frame house

Criteria for hazard zones:
- Local risk for death < $0.3 \cdot 10^{-4}$/year is considered acceptable
  ⇒ No restrictions
- Three risk zones A, B, C where local risk ≥ $0.3 \cdot 10^{-4}$/year:

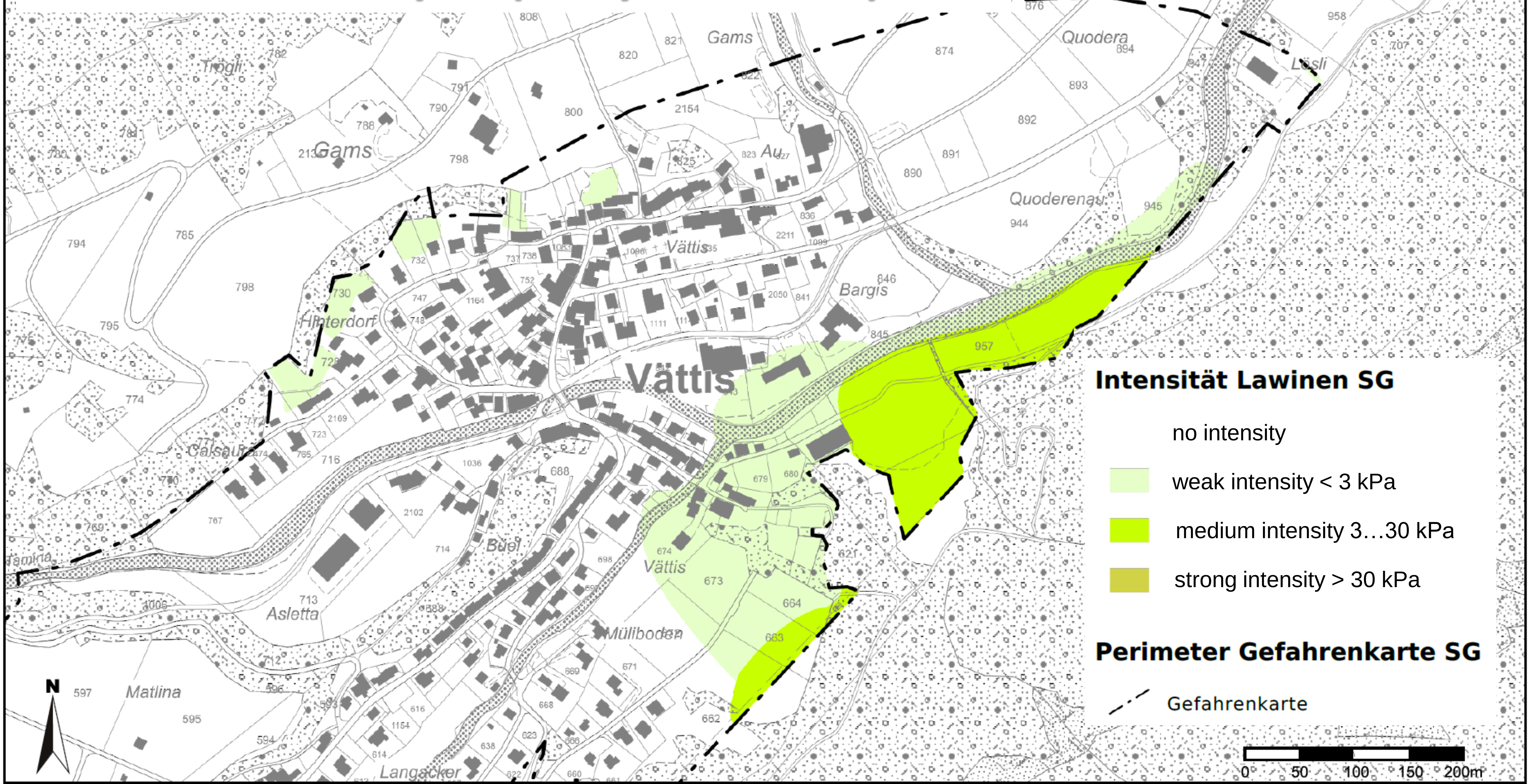
| Zone | Local risk range | Requirements |
|---|---|---|
| C | > $3.0 \cdot 10^{-4}$/year | No new buildings (except summer houses and rarely used buildings). |
| B | $1.0…3.0 \cdot 10^{-4}$/year | No restrictions for industrial buildings. No new housing allowed, existing homes and public buildings to be reinforced. |
| A | $0.3…1.0 \cdot 10^{-4}$/year | Public buildings to be reinforced. |



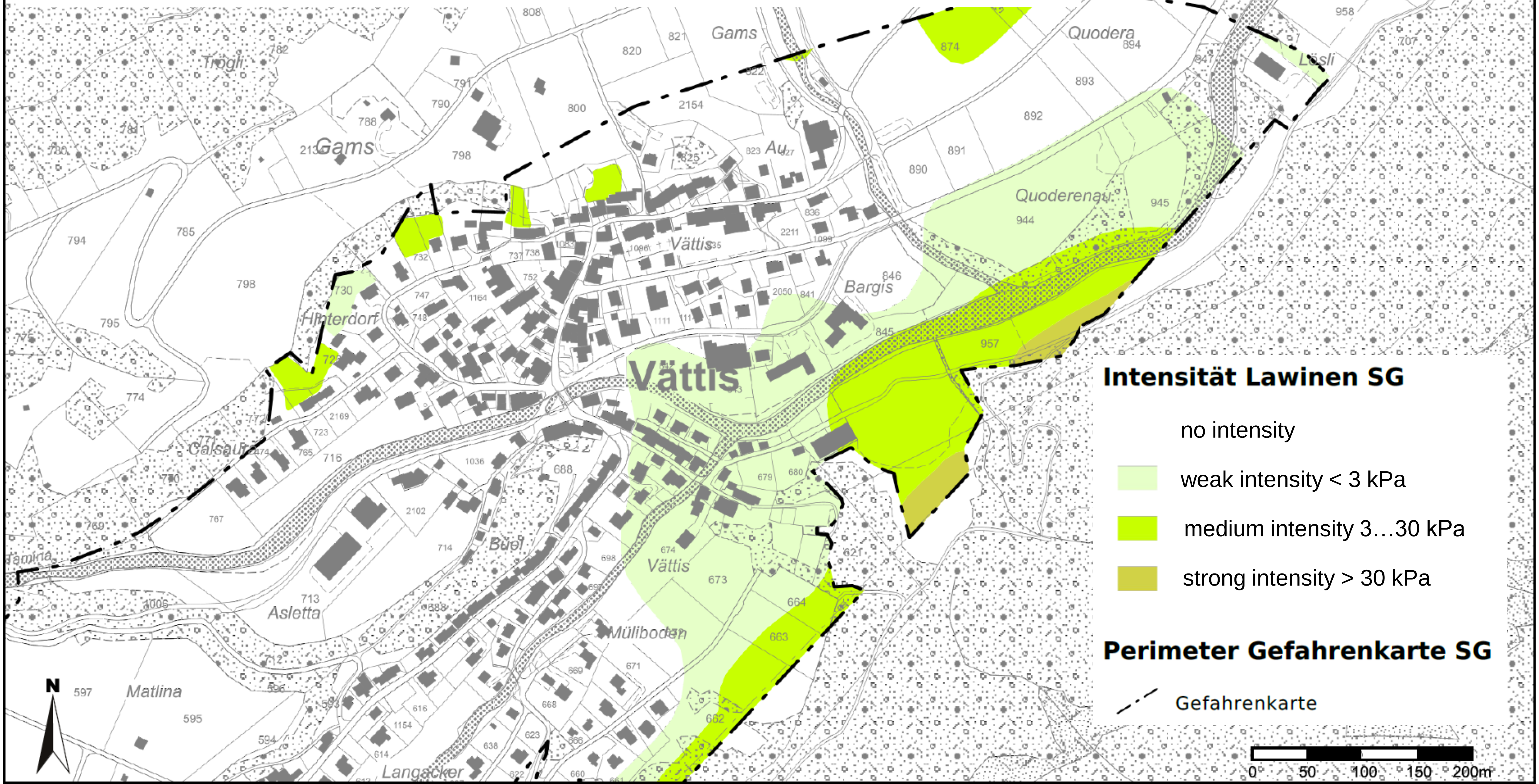
# Example for the elaboration of a hazard map: hazard map is based on intensity maps for return periods of 30, 100 and 300 years



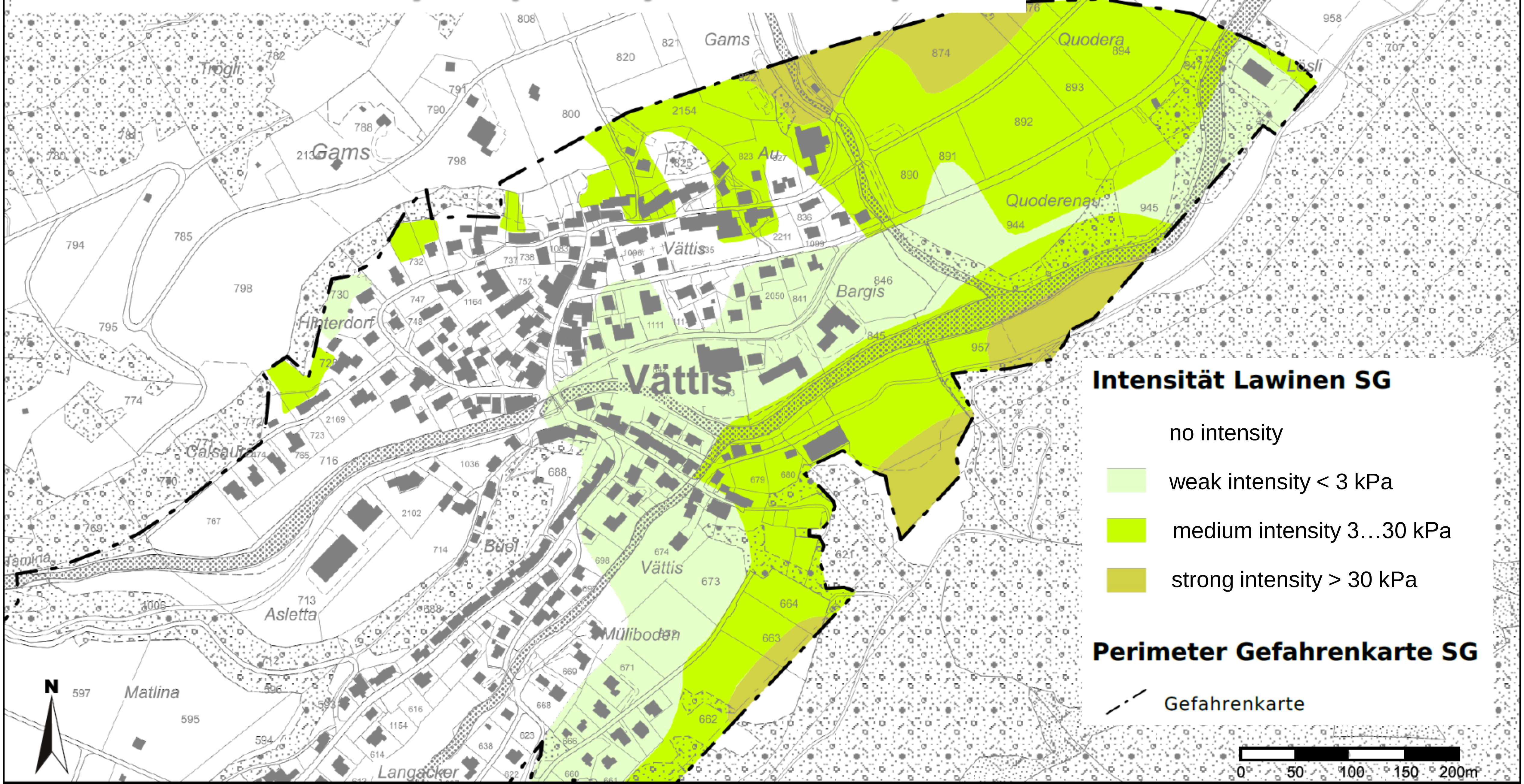
# Avalanche intensity map 30 year return period



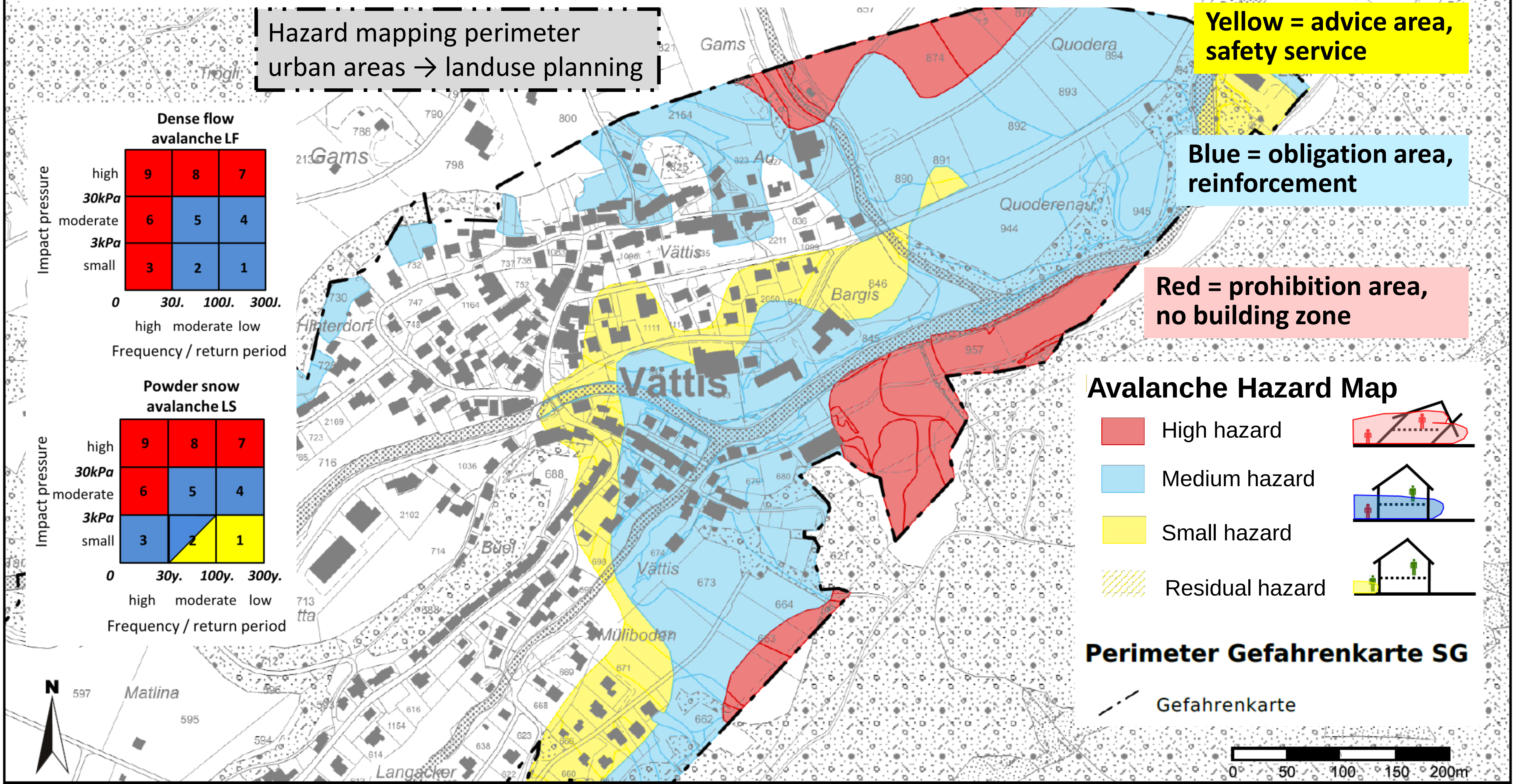
# Avalanche intensity map 100 year return period



# Avalanche intensity map 300 year return period

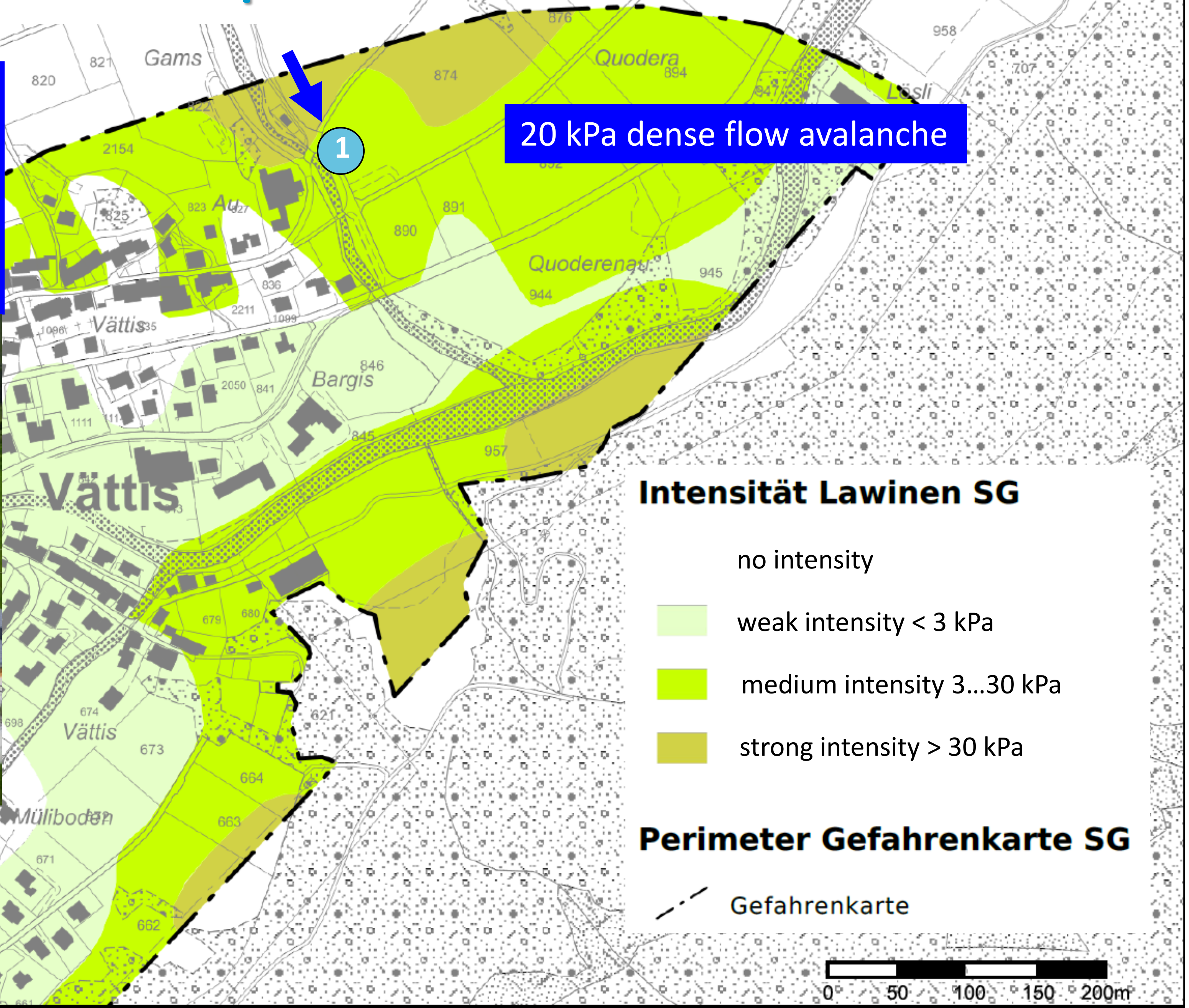


# Hazard map based on 30-, 100- and 300-year scenario

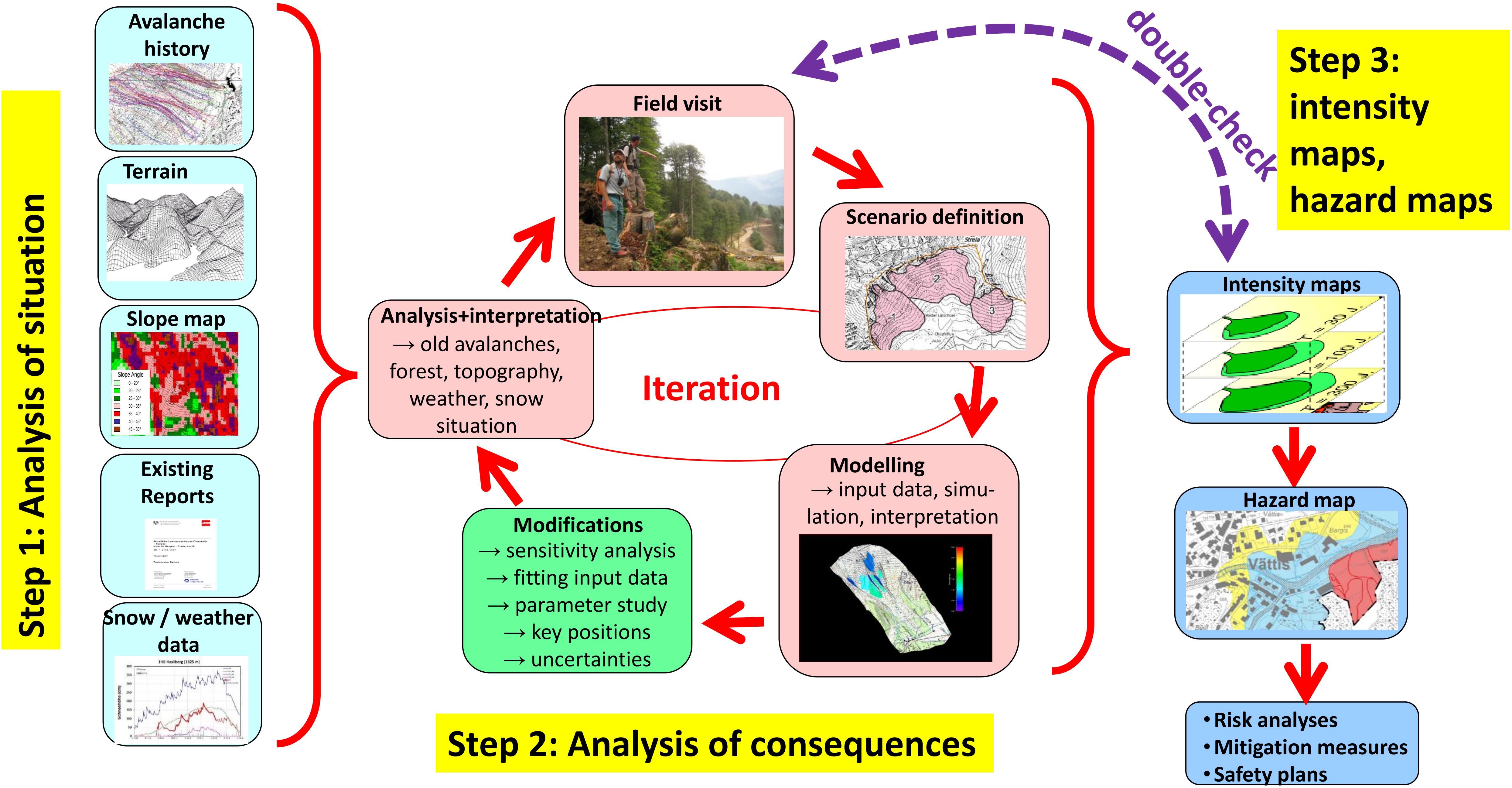


# Avalanche intensity map 300 year return period

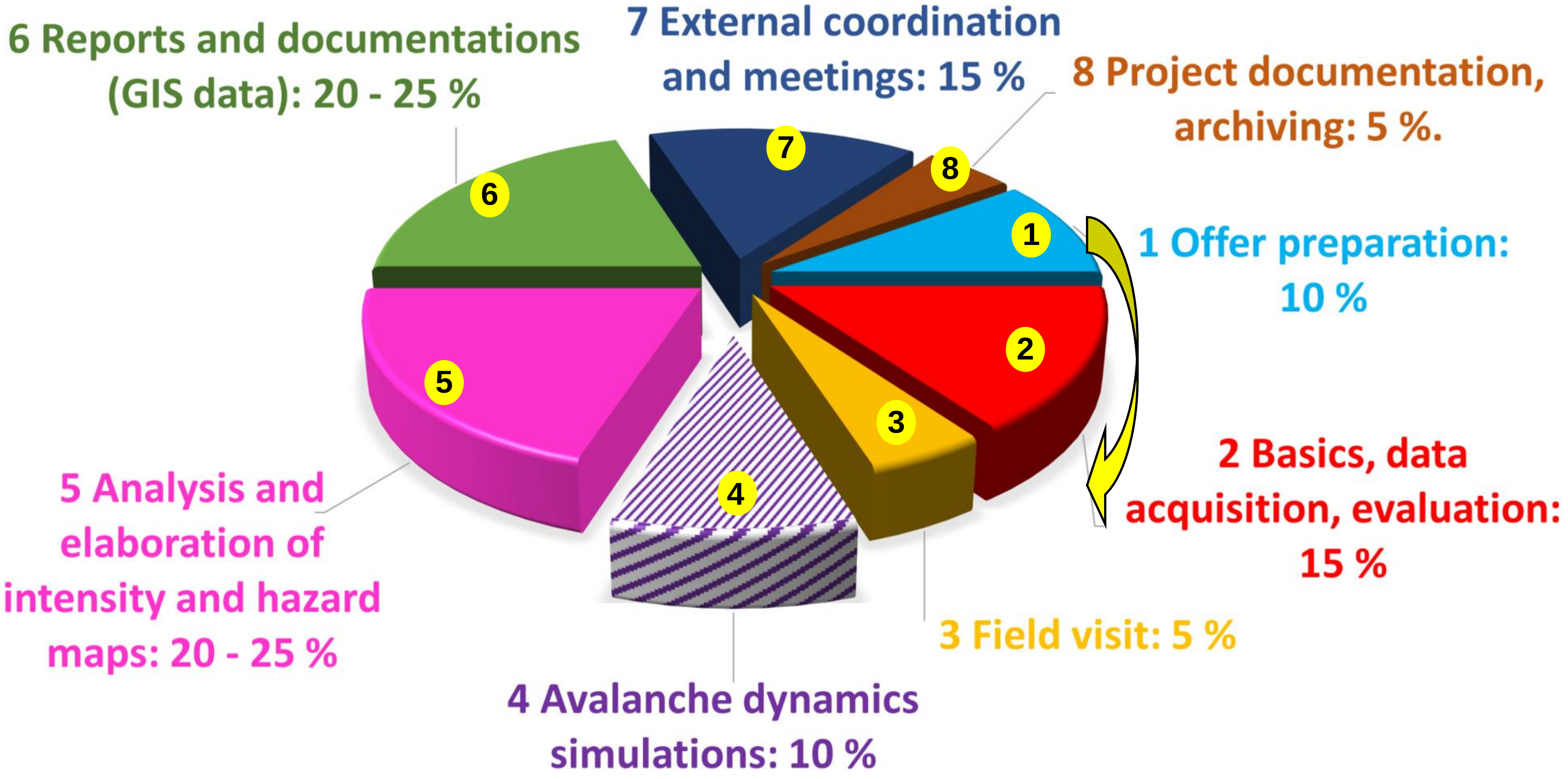
Application of intensity maps: planning of mitigation measures e.g. impact pressure for building reinforcement

# Procedure for the elaboration of hazard maps: 3 main steps



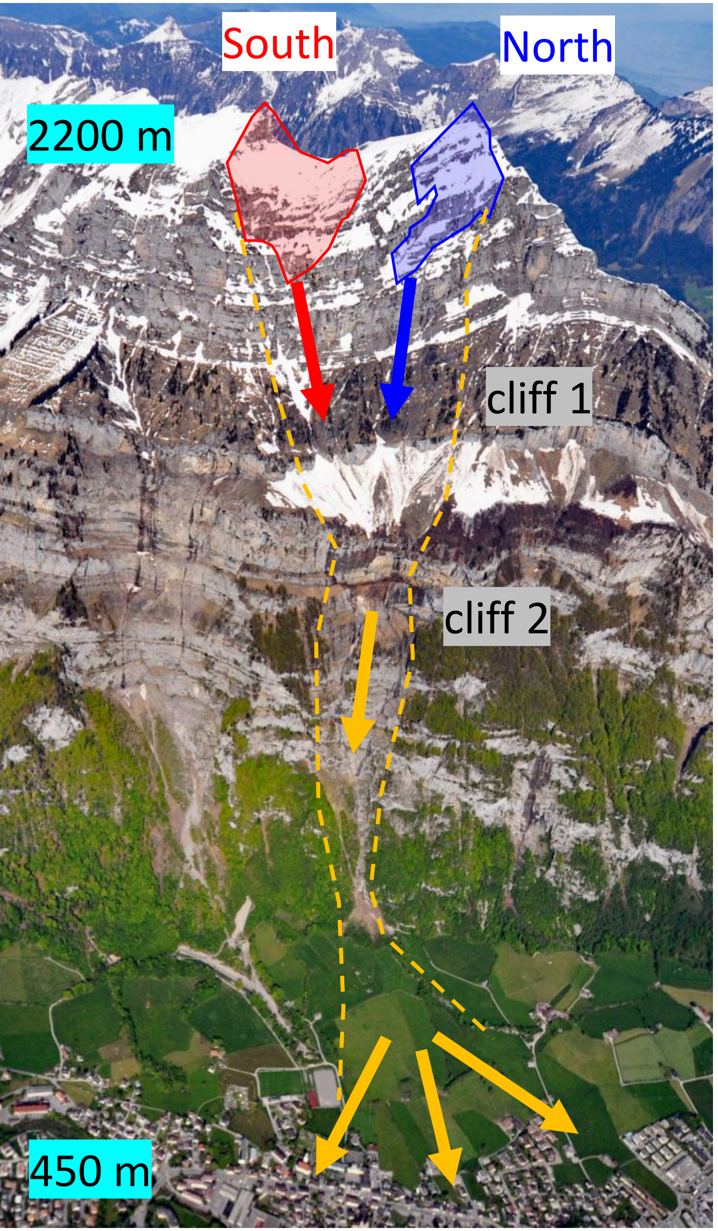
# Elaboration of hazard maps: typical rough time distribution




geoformer

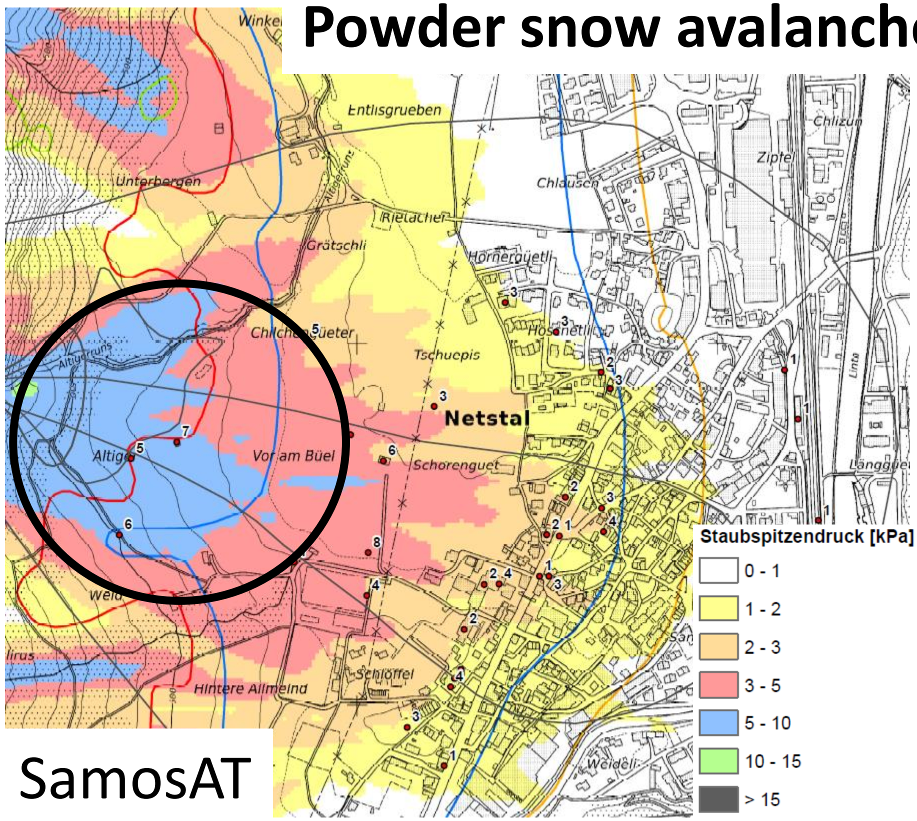
Estimation of engineering company geoformer igp (Brig, CH): may vary from project to project

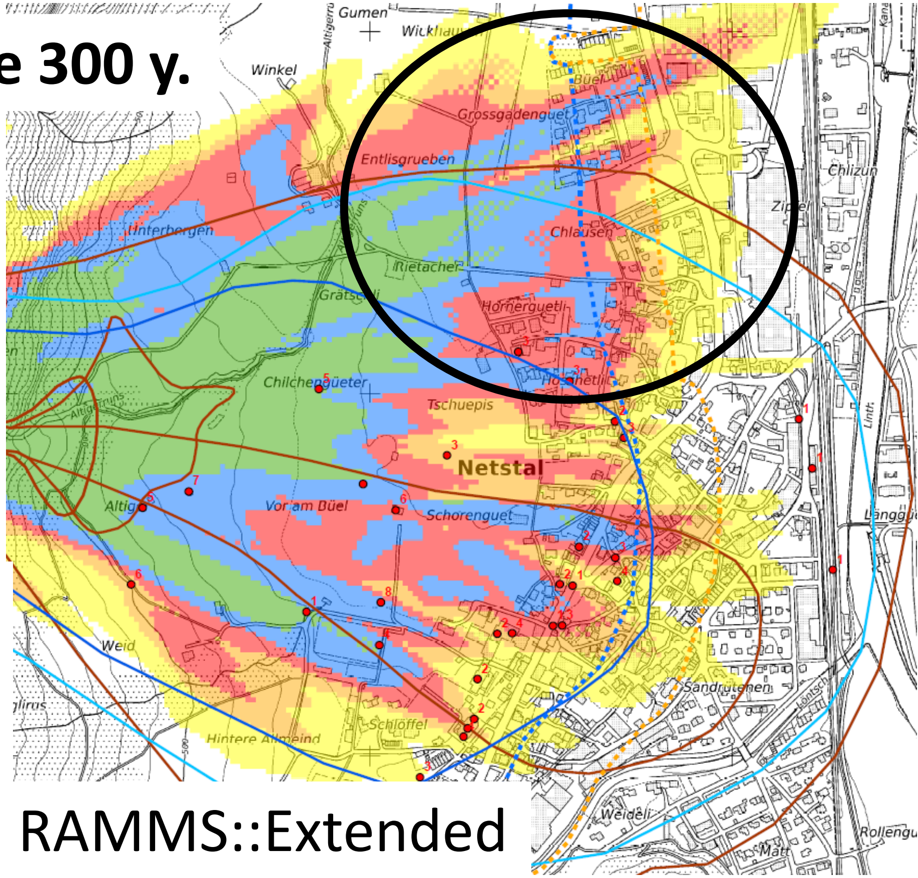
# Application of avalanche models: powder snow avalanche




Altiger avalanche, Netstal/GL

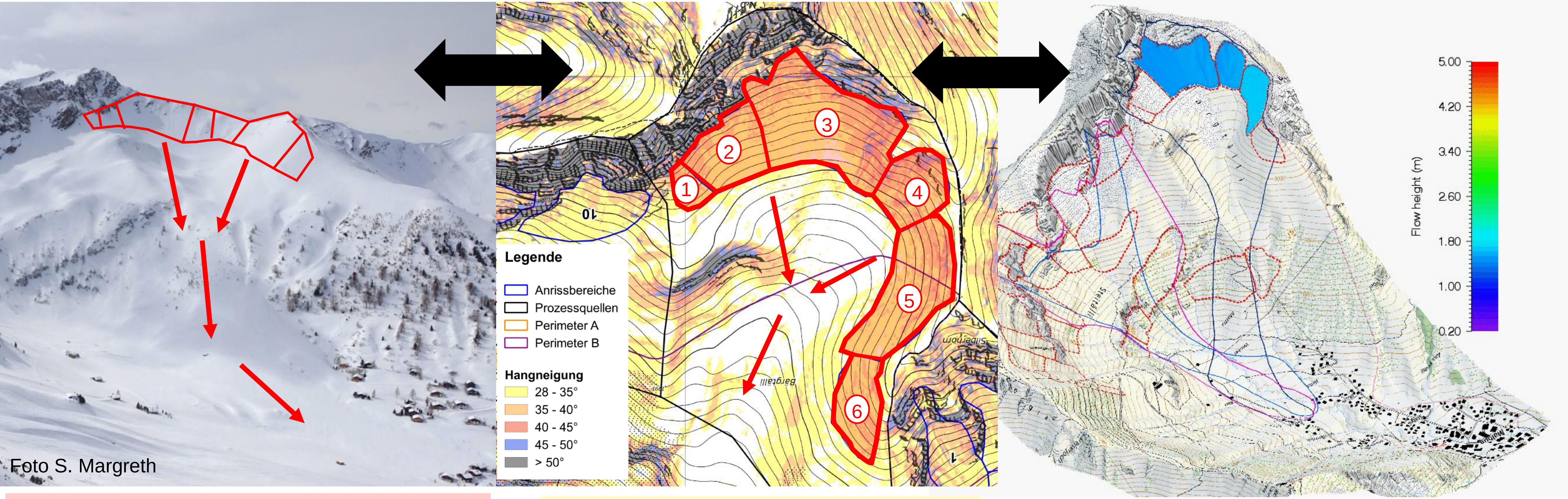
## Powder snow avalanche 300 y.




- **Decisive release area**: SamosAT: Altiger North, RAMMS::E: Altiger South
  RAMMS::E: stronger propagation in NE direction and higher impact pressure.
- **Which model is right!?** Critical interpretation of results by comparison with avalanche history: > 30 documented powder snow avalanches!
- **Requirements for a dynamic model?** Reliable, easy to apply, documented calibration, robust results, user manual, documented limits of model.

# Release area for simulations: how to define? no non-subjective rules




- **Topography**: ridges, terrain terraces, gullies, roughness…
- **Snow situation**: snow distributions, snow drift, snow erosion…
- **Avalanche type**
- **Fracture depth, volumes**
- **Observations, avalanche history**

- Slope map 28-60°
- **Potential release area**
- Division in **partial release areas**
- Definition of **scenarios:**
  - 30 y: 2+3
  - 100 y. 1+2+3+4
  - 300 y.: 1+2+3+4+5

- Simulation of scenario
- **Doublecheck of simulation results** with avalanche history, forest pattern, construction date of buildings, result field visit

# Estimation of return period / probability of scenario: 300 y = 300 y!?

## fracture depth $d_o$

- DHS3 for return period i: GEV / GUM extrapolation
- elevation correction: 5 (3-9) cm
- snow drift: 0-50 cm
- slope reduction: mean/min/max
- snow-entrainment: 0 - > 100 cm

## simulation

**release area:**
- slope angle, area
- geometry, location,
- release probability
- multiple release areas

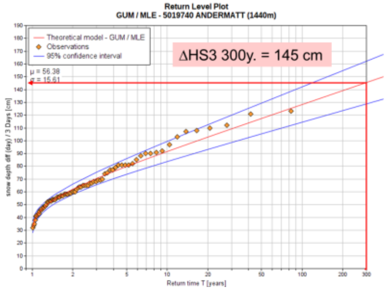
**avalanche volume V:**
- choice - T/S/M/L
- flow width / split
- entrainment
- deposit along track

**friction parameters:**
- volume
- elevation
- terrain roughness

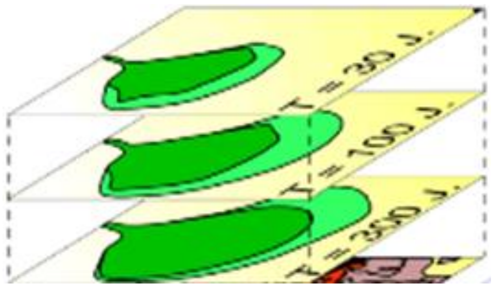
## interpretation simulation:

- avalanche history: plausible?
- topography / silent witnesses: plausible?
- vegetation: plausible?

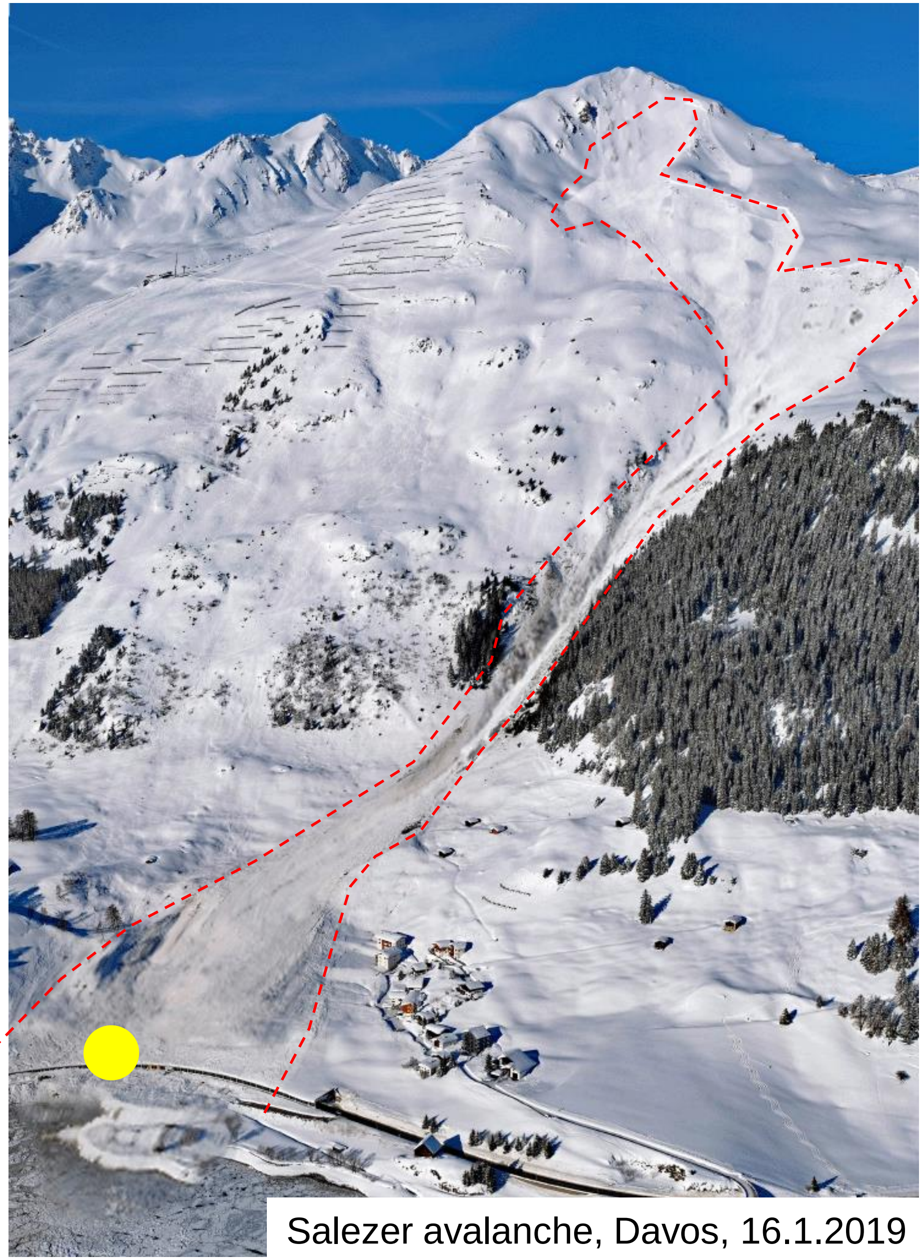
**intensity map for scenario with return period i**



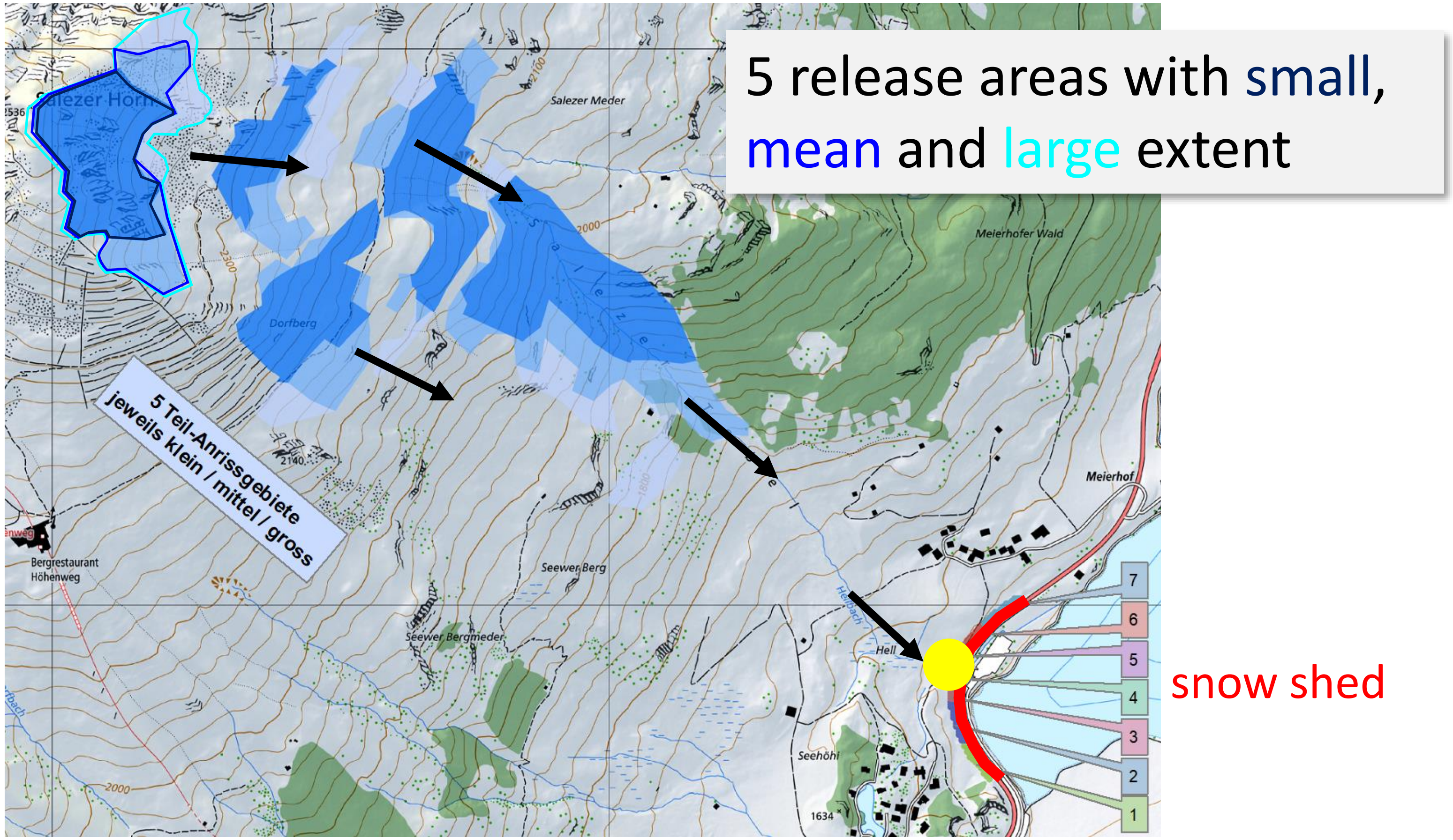

- return period of snow depth increase in 3 days ≠ return period scenario!!
- release probability is only taken into account indirectly!



# Probabilistic avalanche simulations: quantification of uncertainty



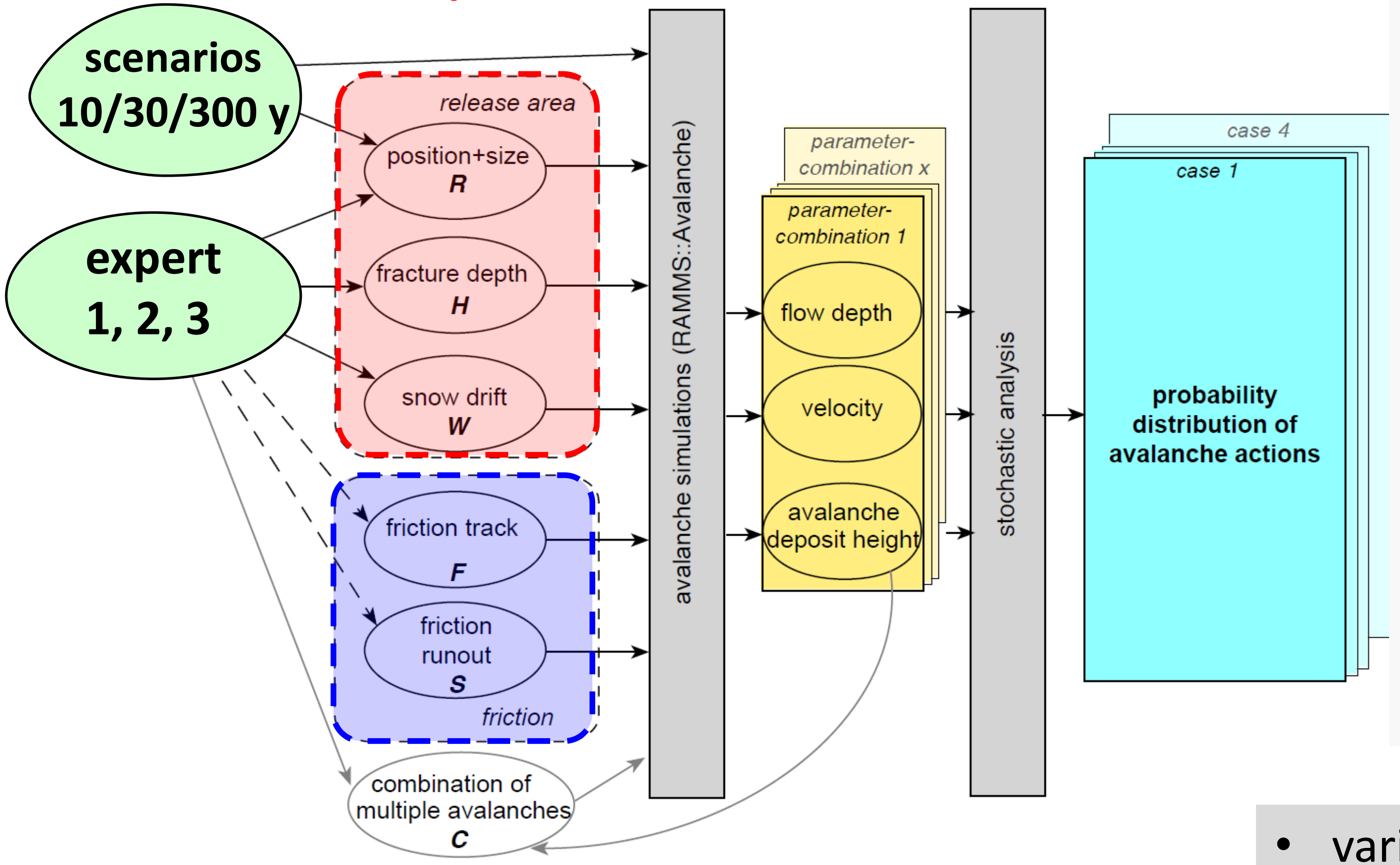
Salezer avalanche, Davos, 16.1.2019

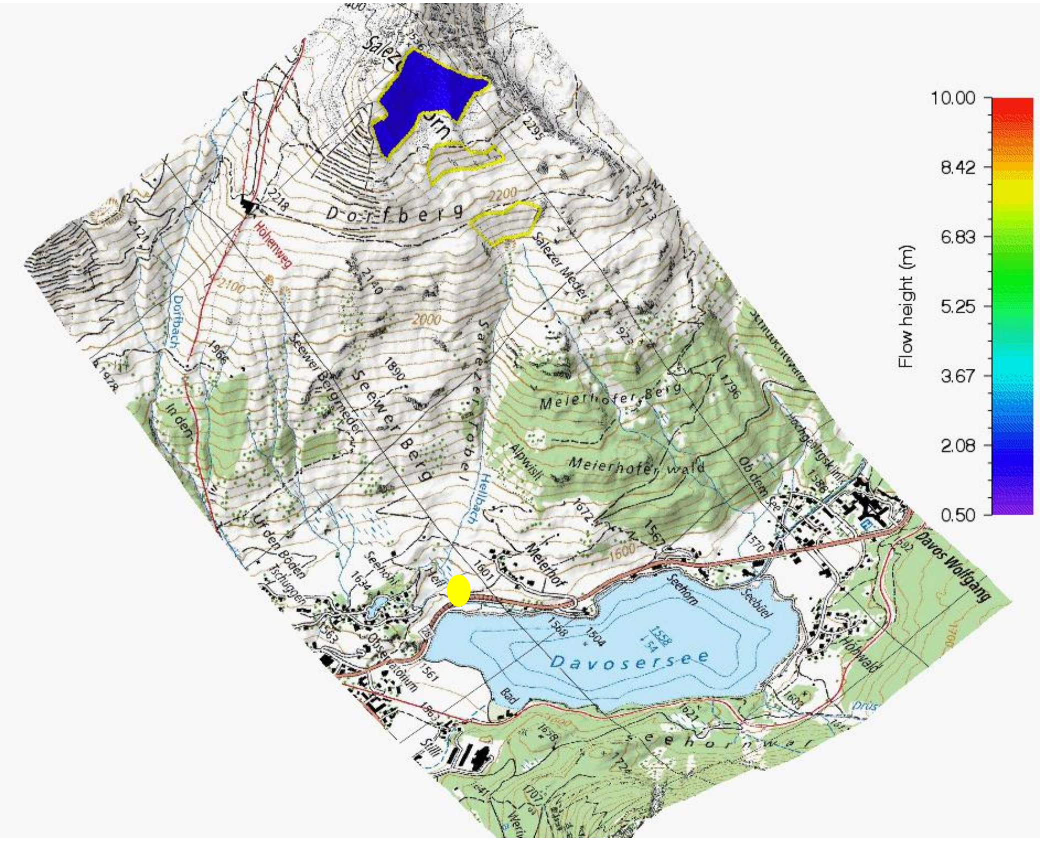



- Salezer avalanche: verification of design loads of snow shed
- Goal: **quantification of uncertainty** in the definition of avalanche actions – example of **flow height** at snow shed
- Systematical **variation of all relevant input parameters** by 3 experts.

# Probabilistic avalanche simulations: quantification of uncertainty

4 choices: optimistic/realistic/ cautious/pessimistic



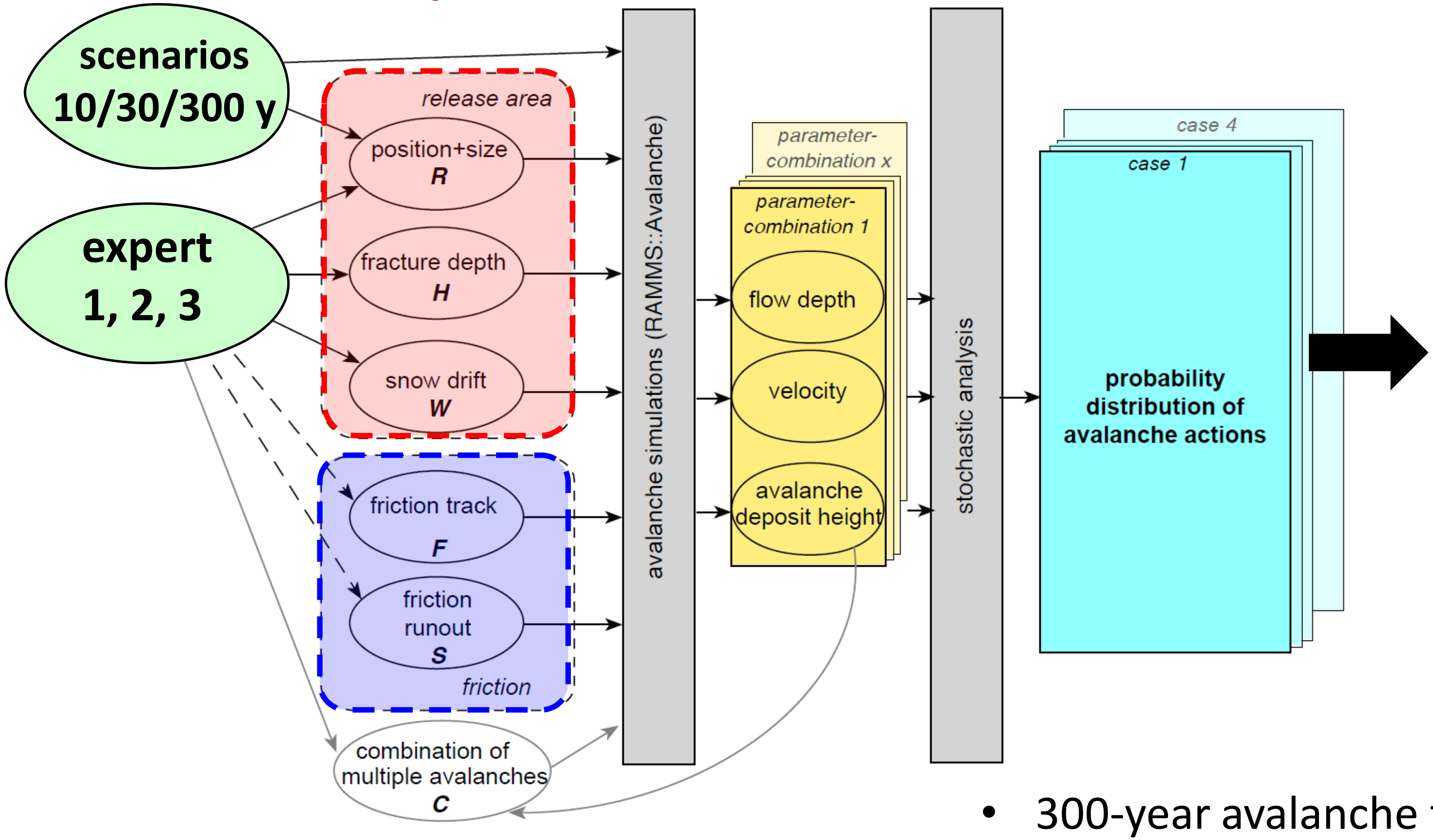



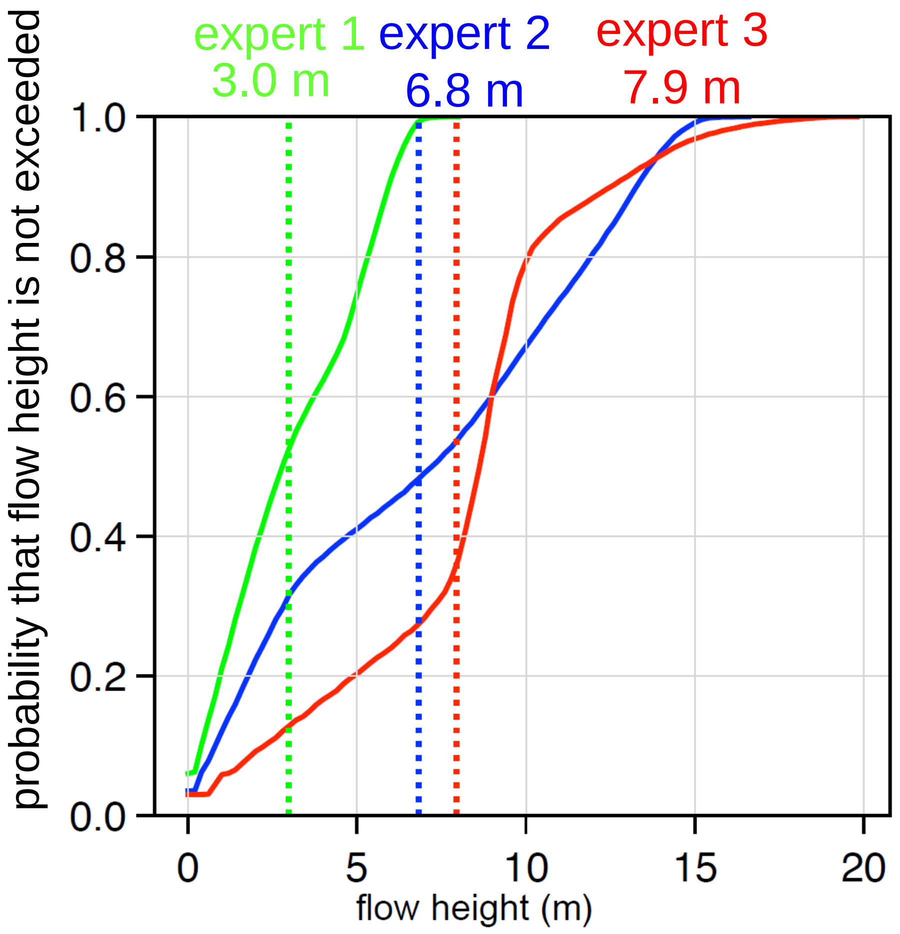

4 choices for friction: much smaller/smaller/ equal/higher as guideline values

- variation of all relevant input parameters
- total 1728 combinations
- RAMMS simulations (batch mode) of all combinations: max. flow height at snow shed

# Probabilistic avalanche simulations: quantification of uncertainty

4 choices: optimistic/realistic/ cautious/pessimistic

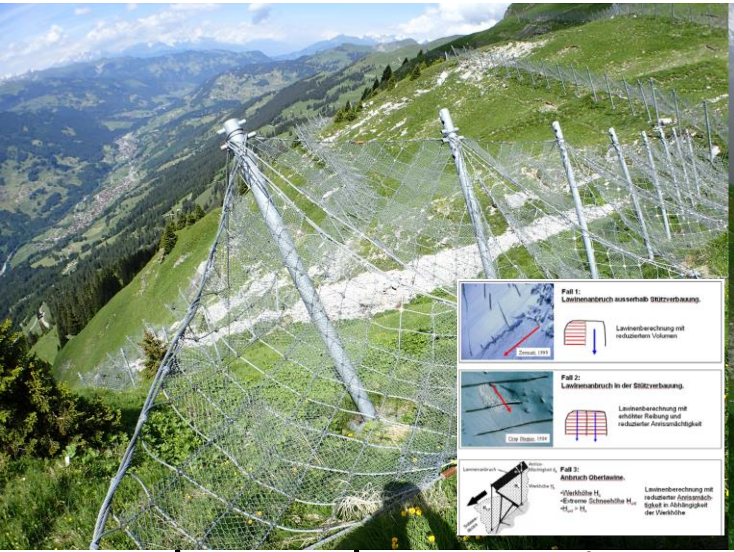


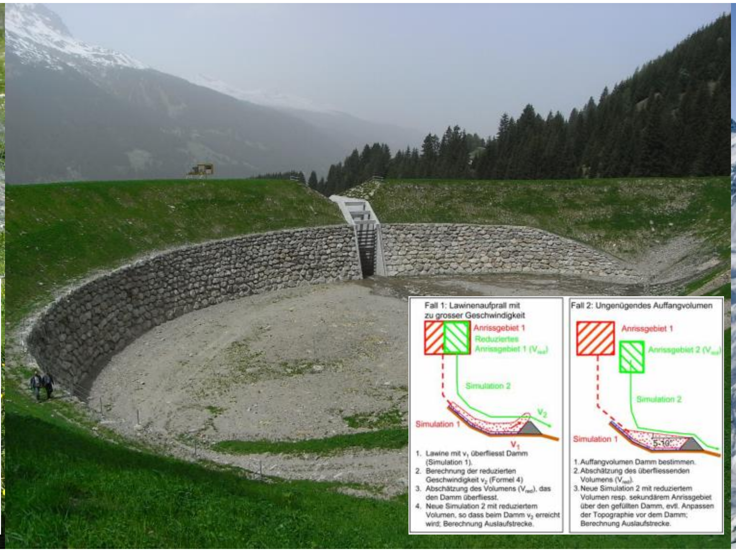

4 choices for friction: much smaller/smaller/ equal/higher as guideline values

- 300-year avalanche flow height on the Salezer snow shed.
- "green" expert more optimistic than "blue" and "red" expert.
- difference up to a factor of 2.7: complex release area!
- quantification of the assessment uncertainty in defining hazard zones?

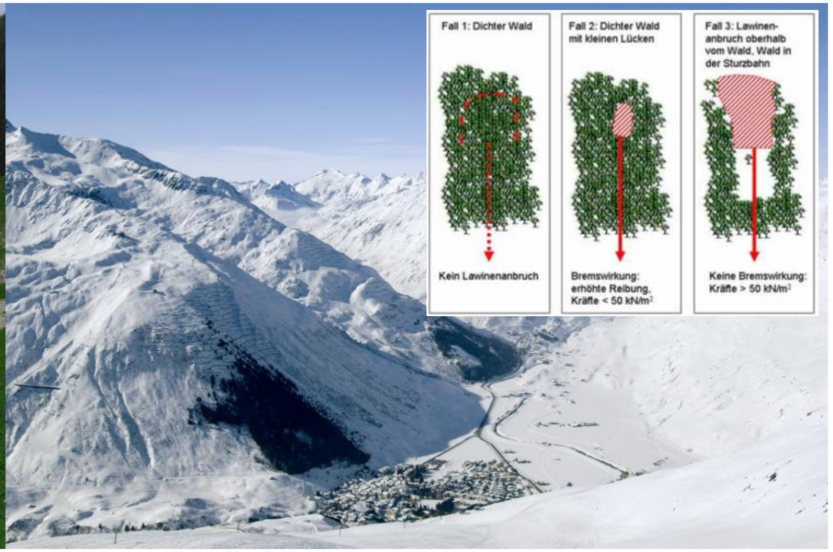
# Consideration of mitigation measures in hazard maps



Homologated supporting structures



Avalanche dams




Protecting forests

yes


Not - homologated supporting structures

Artificial release

Snow drift measures

no

# Consideration of mitigation measures in hazard maps

Homologated supporting structures

Strategie Naturgefahren Schweiz
Umsetzung des Aktionsplans PLANAT 2005 - 2008

Projekt A 3
Wirkung von Schutzmassnahmen

Schlussbericht 2. Phase
Testversion
Dezember 2008

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

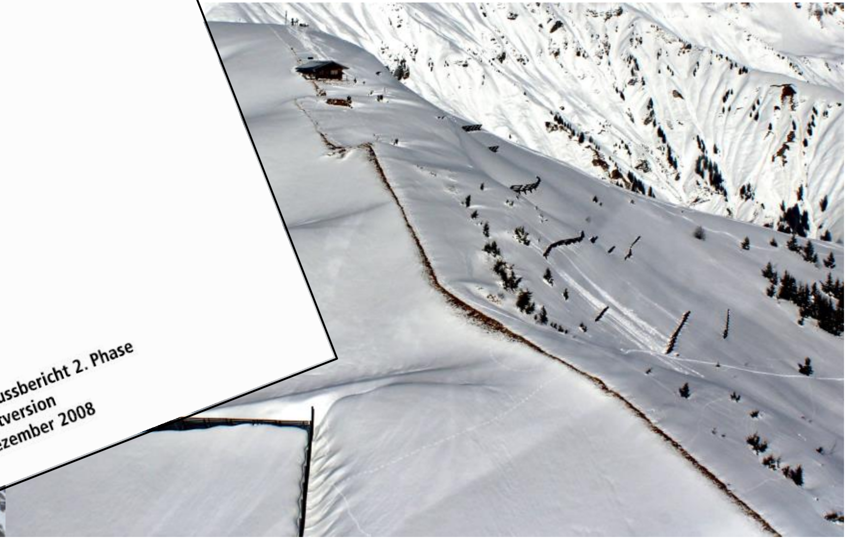
Nationale Plattform Naturgefahren PLANAT
Plate-forme nationale «Dangers naturels»
Piattaforma nazionale «Pericoli naturali»
National Platform for Natural Hazards

Protecting forests

yes

Not - homologated supporting structures

A [illegible] elease

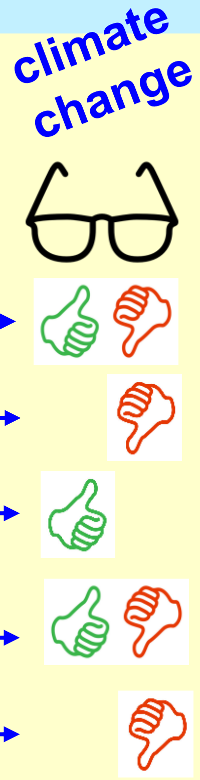


Snow drift measures

no

# Climate change: consequences on hazard mapping?

In hazard assessments, climate change has always to be considered in principle (FOEN, 2022): how??




- **Relevant influence has to be expected**:
  - ➢ Avalanche path **glaciated**: positive or negative effect on hazard possible →
  - ➢ **Wet snow avalanches or slush flow decisive**: higher probability →
  - ➢ Avalanche path **< 1500 m**: avalanche hazard **smaller** →
  - ➢ Avalanche path **1500 – 2500 m**: **constant** avalanche hazard →
  - ➢ Avalanche path **> 2500 m**: **constant to slightly increasing** avalanche risk →

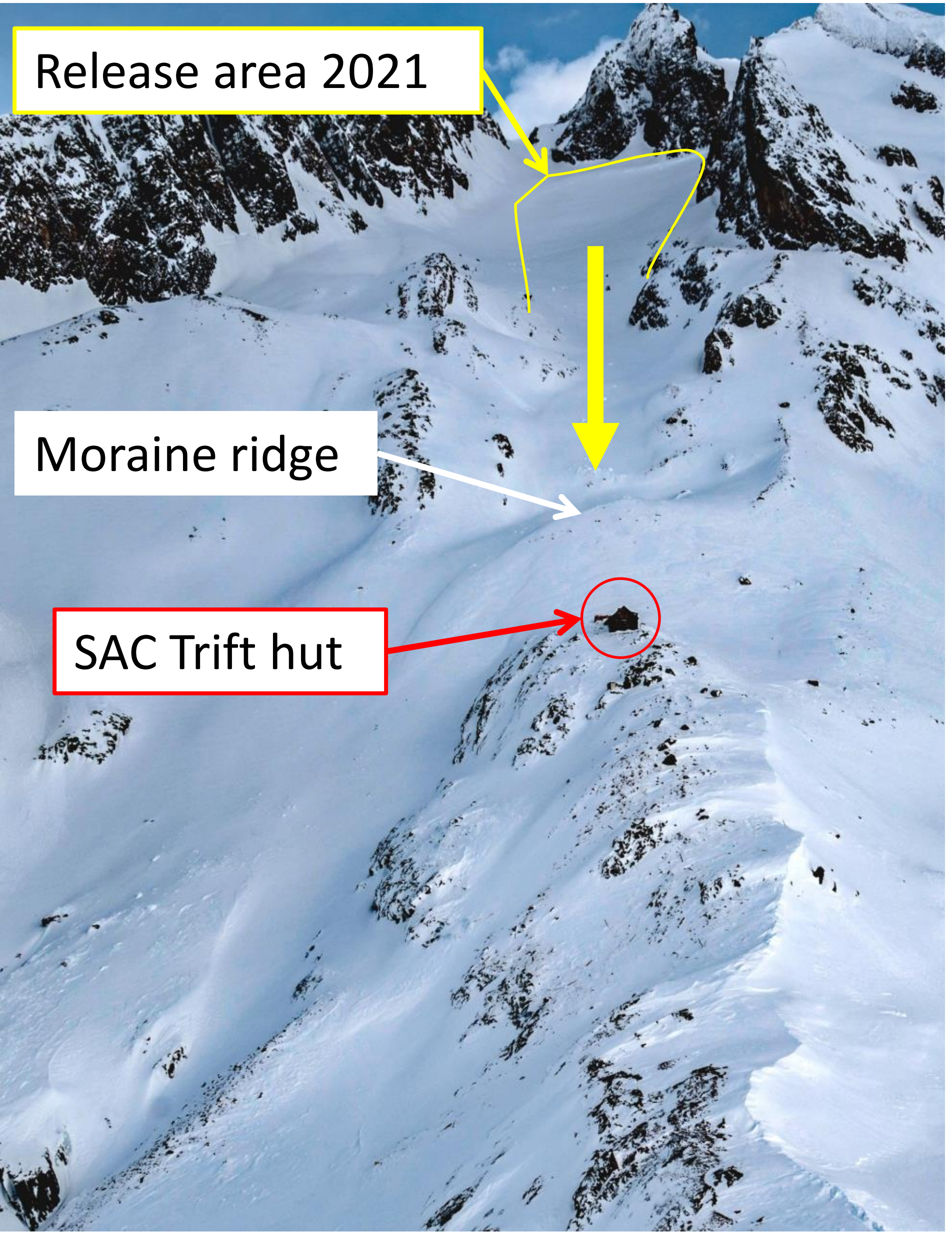
- Influence of climate change on hazard assessment often **disappears in the "noise" of existing uncertainties** (e.g. choice of size of a release area).

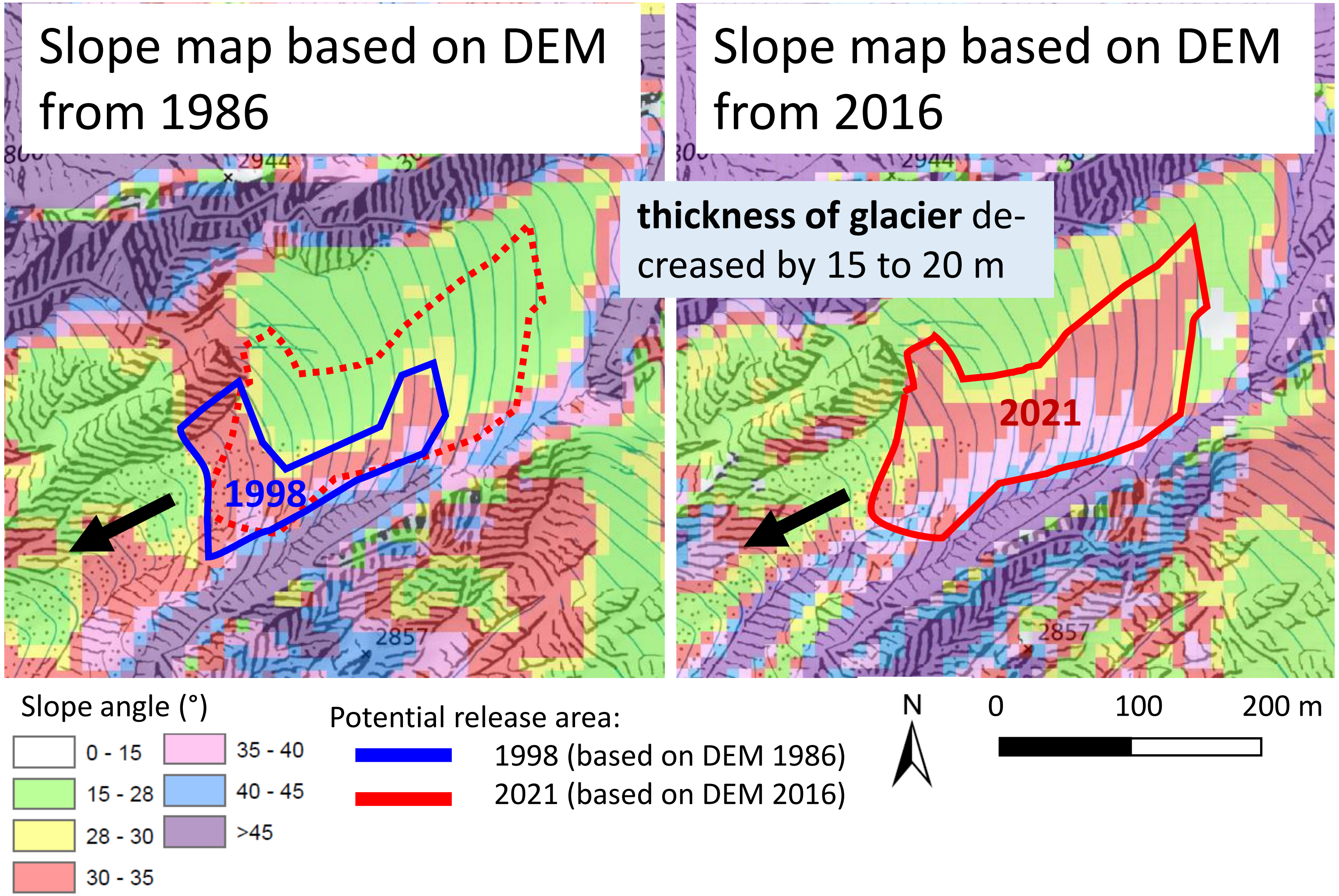
# Climate change: consequences on hazard mapping?

SAC Trift hutte heavily damaged in Jan. 2021: impact pressure > 30 kPa

SAC Trift hutte extension in 1998: SLF study “blue zone”, ramp roof reinforced on 10 kPa (unfavorable mounting of the roof cover!)

# Climate change: consequences on hazard mapping?



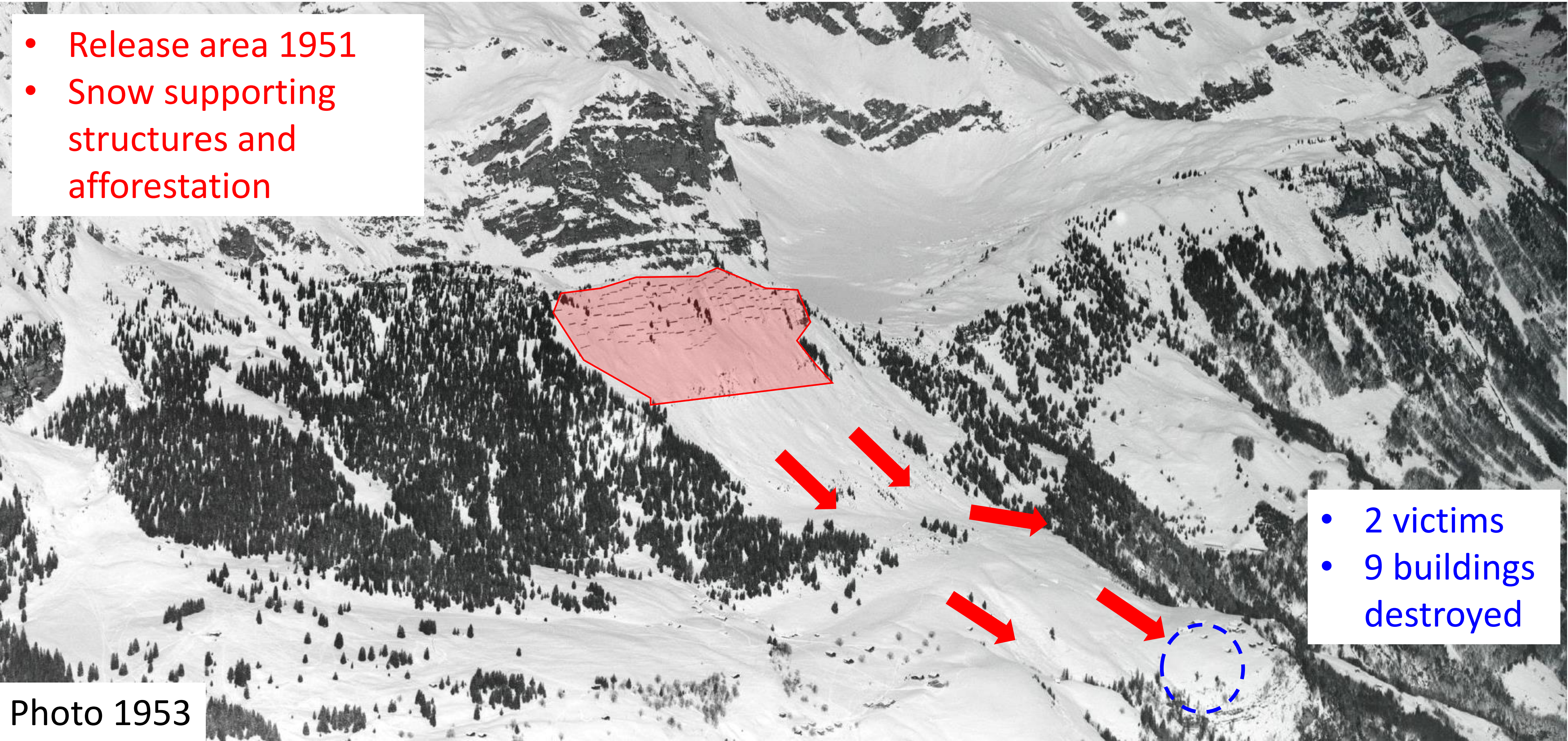




**Evaluation 1998:** blue hazard zone, p < 30 kPa

**Evaluation 2021:** red hazard zone, p >> 30 kPa

# Extreme scenario > 300 years: where and how determine?

**Example Braunwald / GL: Orenplatte – new planned resort with hotel, cableway and golf court**



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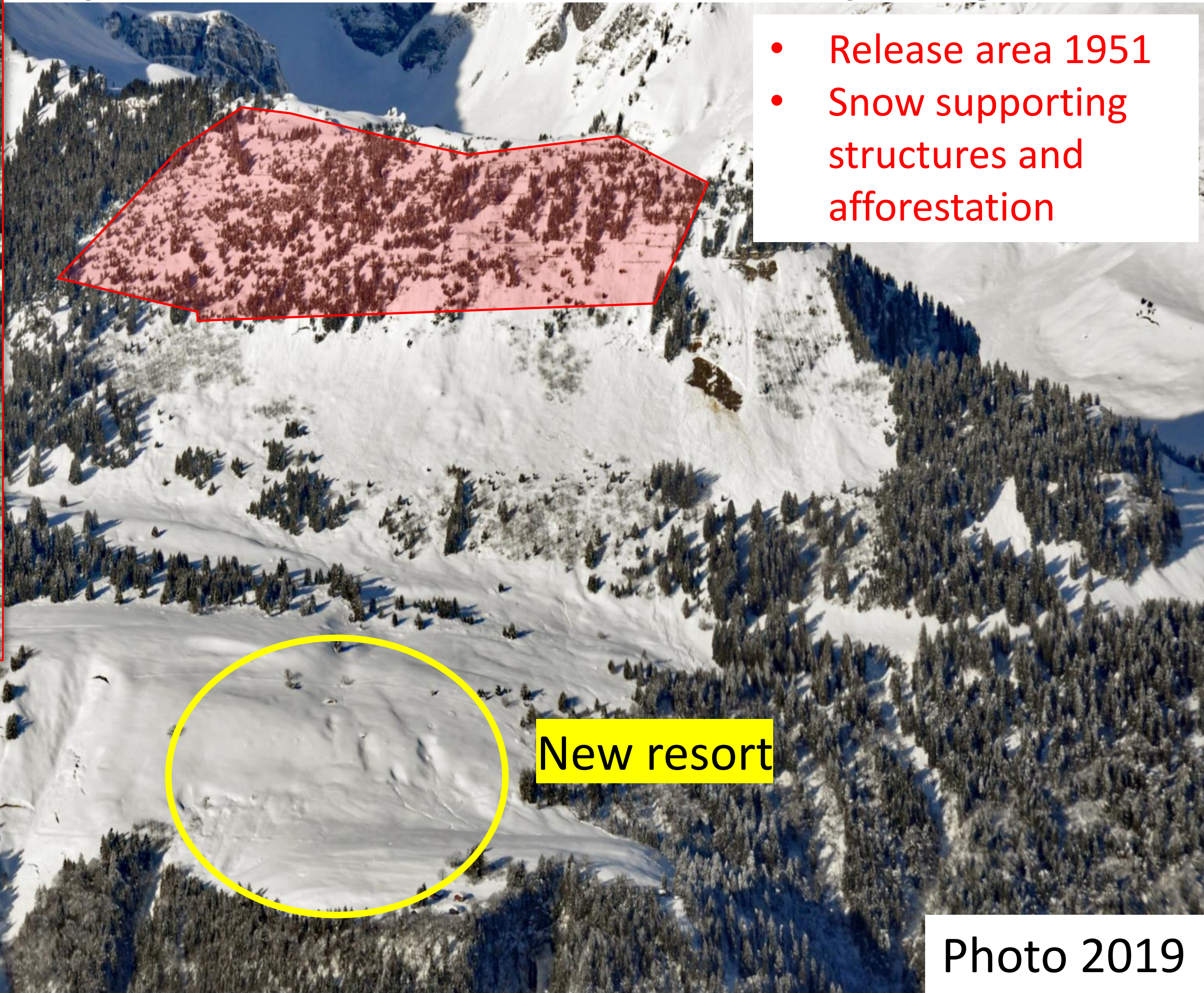
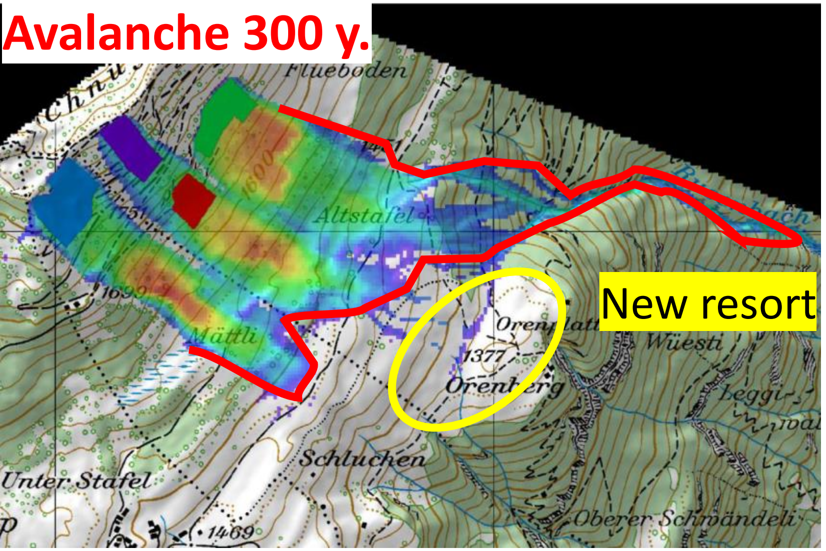
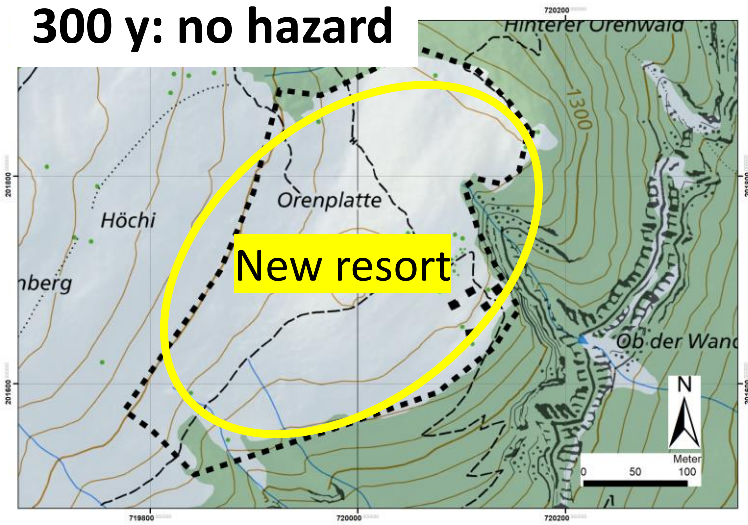
**Example Braunwald / GL: Orenplatte – new planned resort with hotel, cableway and golf court**

# Extreme scenario > 300 years: where and how determine?

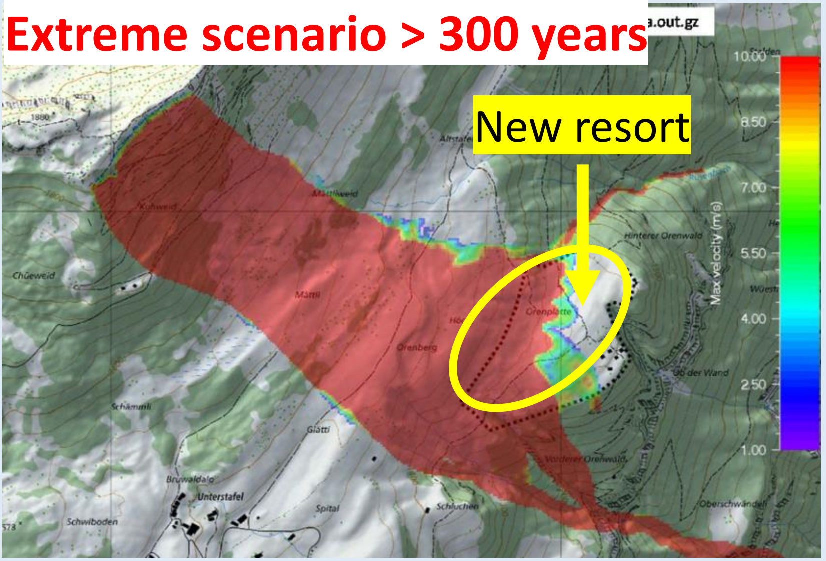
**Example Braunwald / GL: Orenplatte – new planned resort with hotel, cableway and golf court**

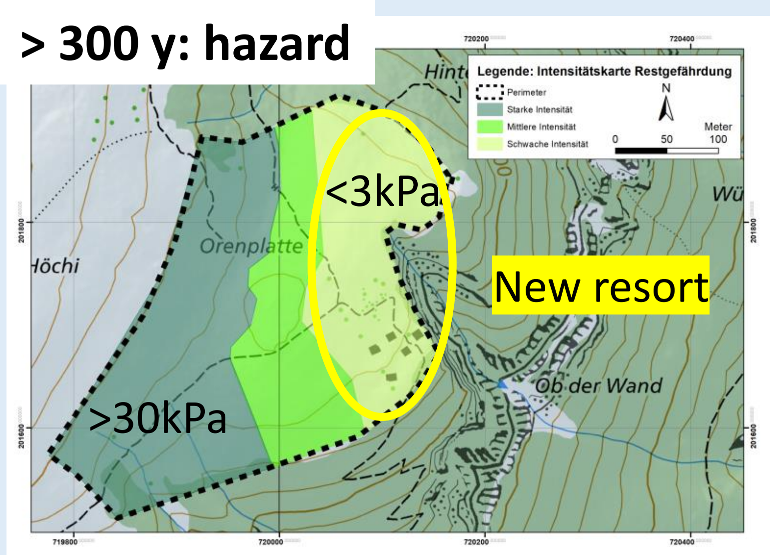



**Hazard map Braunwald**
- white zone no hazard
- based on 300 y scenario

- extreme scenario > 300 y?




**Intensity map extreme scenario** (500-1000 years):
- main risk = overfilled supporting structures and afforestation
- advice: plan resort outside of zone with > 3 kPa.

# Outlook – Swiss perspective:

- Hazard maps and elaboration procedures (30/100/300 y + pressure limits) **have generally been successful**, as demonstrated in the extreme winters of 1999 and 2018 (event analyses).
- Hazard matrices of dense flow and powder snow avalanches will be combined; **structural requirements** also in the yellow zone.
- Future: **risk-based land use planning** that considers not only the hazard level but also the utilization.
- A more systematic capture of the uncertainties of a hazard assessment: **probabilistic simulation models**
- **Non-subjective rules** for defining release areas and release probability.
- Definition how to handle **extreme scenarios** (1000 years?)
- Improved **assessment of the effect of mitigation measures** (simulations?): catching dams, retarding structures
- Rules for systematic consideration of **climate change** in hazard assessments


Karstein
Horst Schaffhauser
Stefan
Davos, Avalanche dynamics workshop, 1990


Stefan
Thorstein
Frode
Tomas J.
Oddur
Isafjördur 1996


Stefan
Peter
Davos 2006

# Thank you!


Tomas J.
Karstein
Joseph Hopf
Neskaupstadur 1996


Paul Föhn
Karstein
Joseph Hopf
Dave
Stefan
Chamonix 1995 (Photo K. Kristensen)

# Kontroll- og referanseside/ Review and reference page

| **Dokumentinformasjon/*Document information*** | | |
|---|---|---|
| **Dokumenttittel/*Document title***<br>Fonnbu 50 year celebration | | **Dokumentnr./*Document no.***<br>20230100-02-R |
| **Dokumenttype/*Type of document***<br>Rapport / Report | **Oppdragsgiver/*Client***<br>NVE | **Dato/*Date***<br>2023-11-10 |
| **Rettigheter til dokumentet iht kontrakt/ *Proprietary rights to the document according to contract***<br>NGI | | **Rev.nr.&dato/*Rev.no.&date***<br>0 / |
| **Distribusjon/*Distribution***<br>ÅPEN: Skal tilgjengeliggjøres i åpent arkiv (BRAGE) / OPEN: To be published in open archives (BRAGE) | | |
| **Emneord/*Keywords***<br>avalanche, Fonnbu, Ryggfonn, celebration | | |

| **Stedfesting/*Geographical information*** | |
|---|---|
| **Land, fylke/*Country***<br>Norway | **Havområde/*Offshore area*** |
| **Kommune/*Municipality***<br>Stryn | **Feltnavn/*Field name*** |
| **Sted/*Location***<br>Hjelle | **Sted/*Location*** |
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| **UTM-koordinater/*UTM-coordinates***<br>**Zone: East: North:** | **Koordinater/*Coordinates***<br>**Projection, datum: East: North:** |

**Dokumentkontroll/*Document control***
**Kvalitetssikring i henhold til/*Quality assurance according to NS-EN ISO9001***

| **Rev/ *Rev.*** | **Revisjonsgrunnlag/*Reason for revision*** | **Egenkontroll av/ *Self review by:*** | **Sidemanns-kontroll av/ *Colleague review by:*** | **Uavhengig kontroll av/ *Independent review by:*** | **Tverrfaglig kontroll av/ *Interdisciplinary review by:*** |
|---|---|---|---|---|---|
| 0 | Original document | 2023-11-08<br>Kjersti G. Gisnås | 2023-11-08<br>Peter Gauer | | |
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| **Dokument godkjent for utsendelse/ *Document approved for release*** | **Dato/*Date***<br>10 November 2023 | **Prosjektleder/*Project Manager***<br>Kjersti G. Gisnås |
|---|---|---|

2015-10-16, 043 n/e, rev.03

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