Model development in avalanche forecasting

Alec van Herwijnen and many others…

EUMeTrain SNOW Event Week, 10 February 2021

WSL Institute for Snow and Avalanche Research SLF

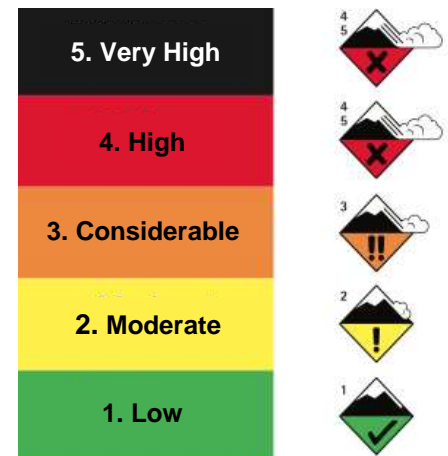# Snow avalanches

Avalanche recipe

- Steep slope

- Snow

- Trigger

Avalanche forecasting: danger level

Avalanche forecasting is the prediction of current and future snow *stability* in space and time relative to a given triggering level.

- What will it take to trigger an avalanche?

- What is the spatial distribution of trigger locations?

- How large will avalanches be?

5. Very High	
4. High	
3. Considerable	
2. Moderate	
1. Low	

When (and where) will avalanches release?

- When it snows (additional load destabilizes the snowpack)

- When it is warm (water destabilizes the snowpack)

When (and where) will avalanches release?

- When it snows (additional load destabilizes the snowpack)
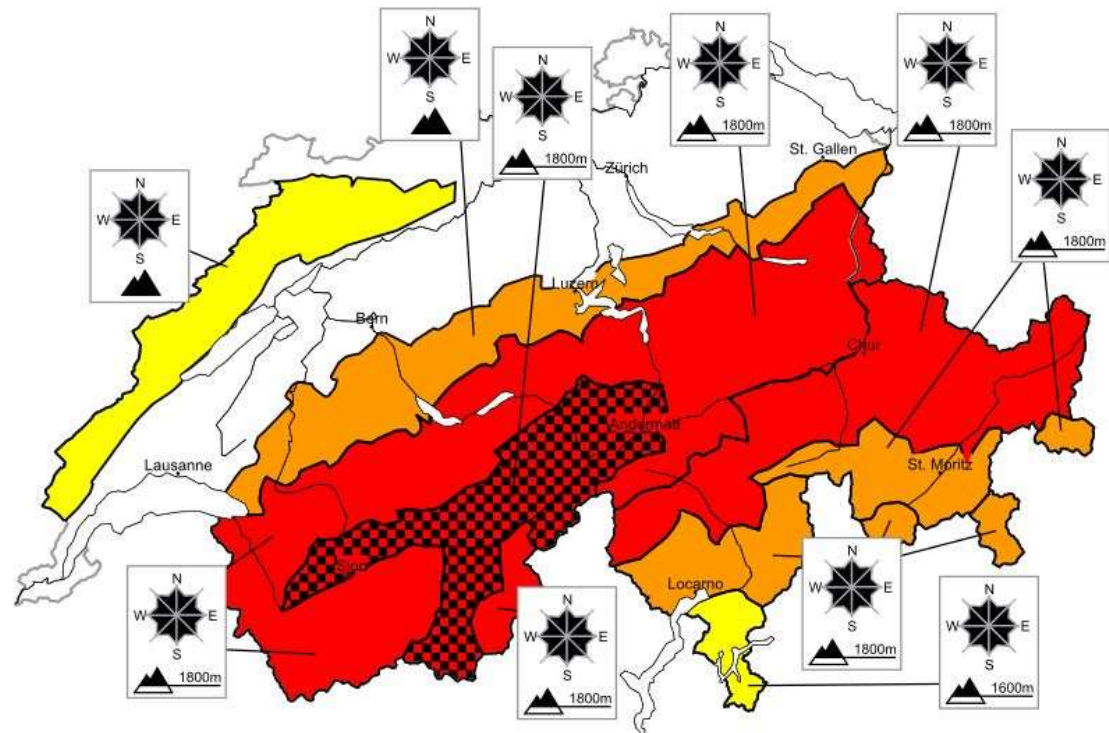
→ More accurate forecast required
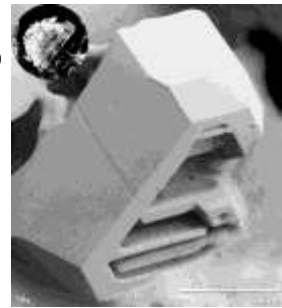
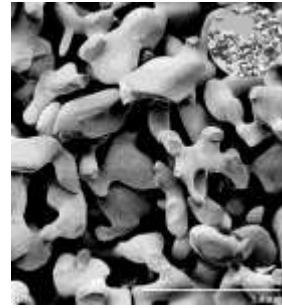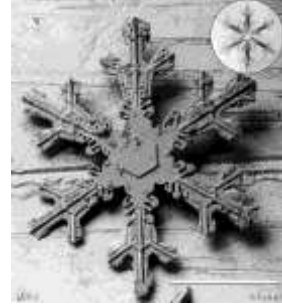- When it is warm (water destabilizes the snowpack)

Avalanche forecasting

To estimate the avalanche danger level requires data on:

- Weather

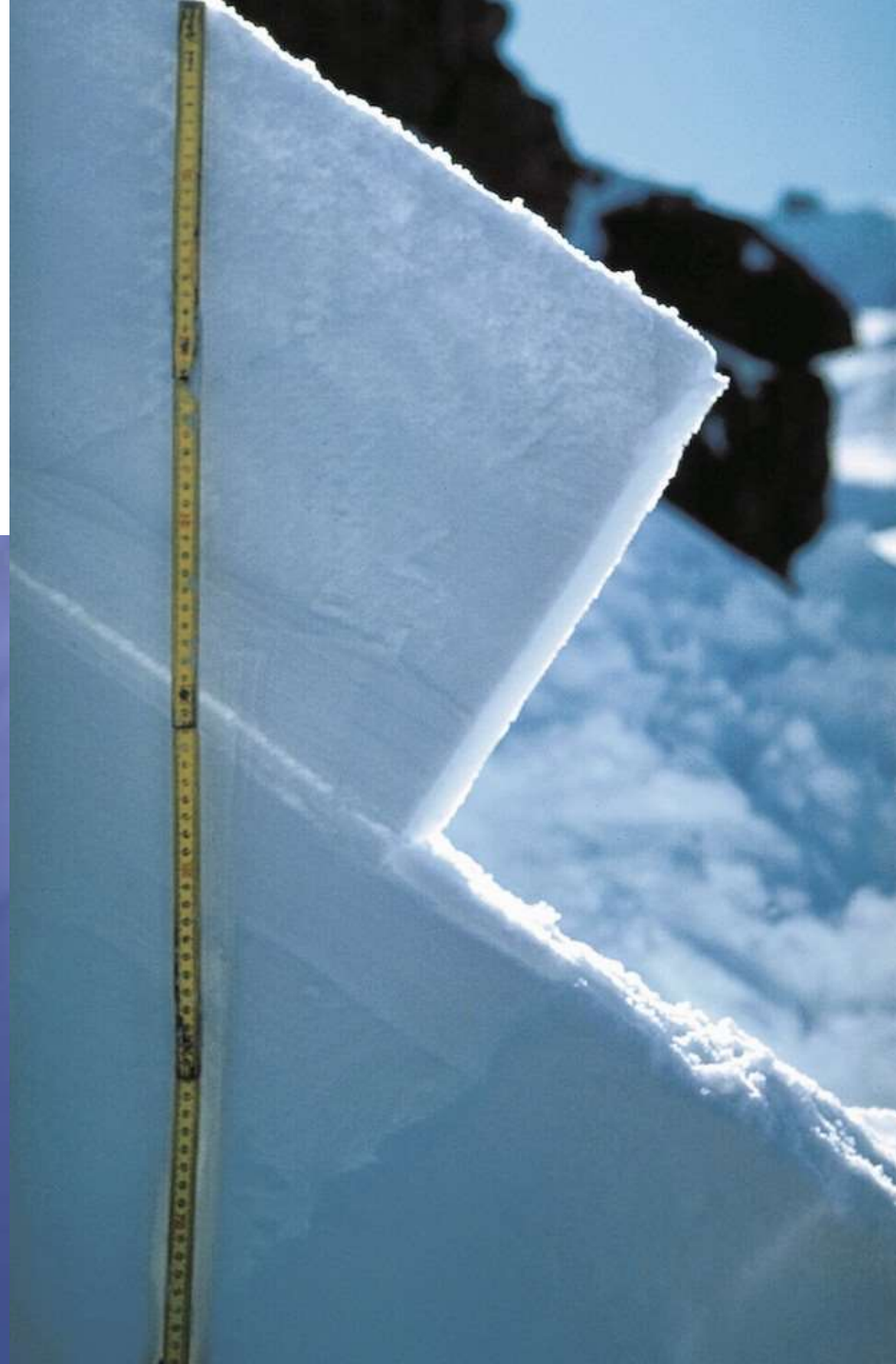- Snow stratigraphy
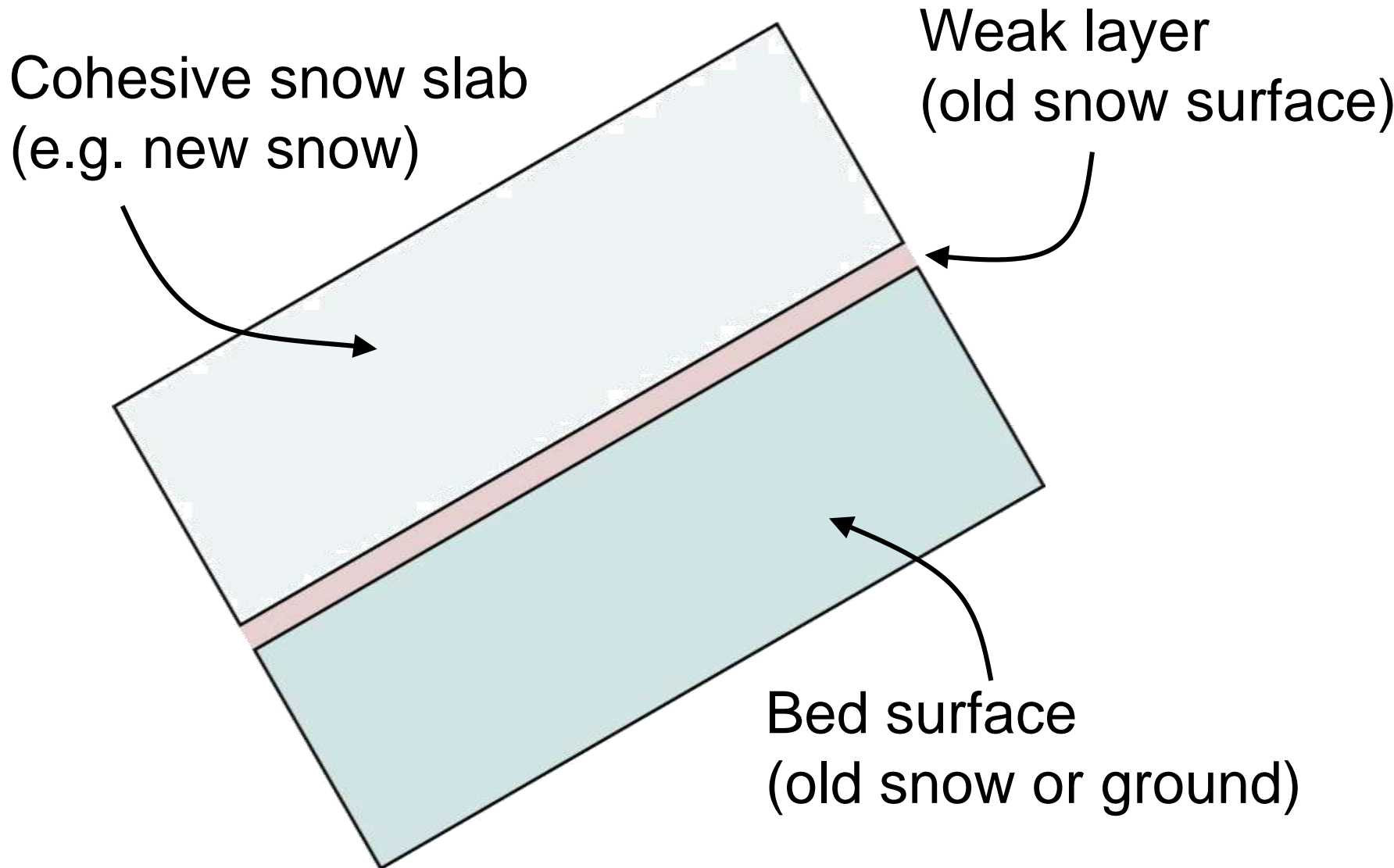
- Snowpack stability

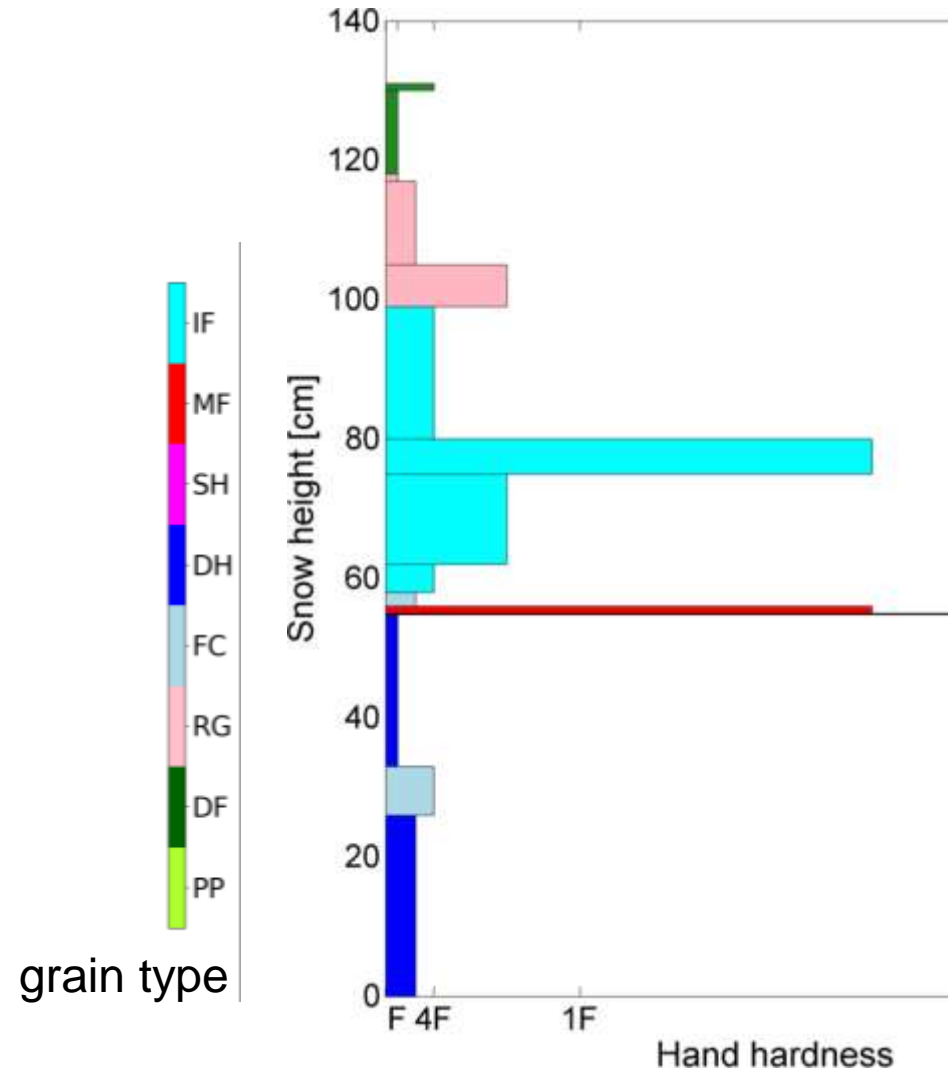# Snow stratigraphy

Snow stratigraphy

- Weak layer

- Slab

Snow stratigraphy and avalanches

Cohesive snow slab
(e.g. new snow)

Weak layer
(old snow surface)

Bed surface
(old snow or ground)

Snow cover stratigraphy

1942

2021

grain type

IF
MF
SH
DH
FC
RG
DF
PP

Snow height [cm]

Hand hardness

Snow stability tests

Avalanche mechanical models

Gaume et al., 2018

30 million particles
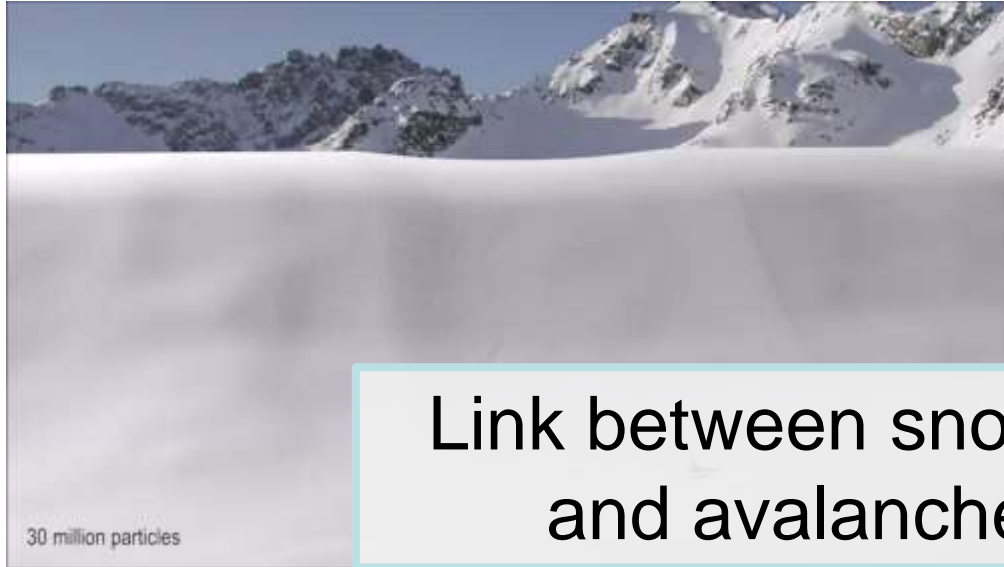
Link between snow properties
and avalanche release

Bobillier et al., 2020

Normal displacement [mm]

−10.0   −7.5   −5.0   −2.5   0.0   2.5   5.0   7.5   10.0
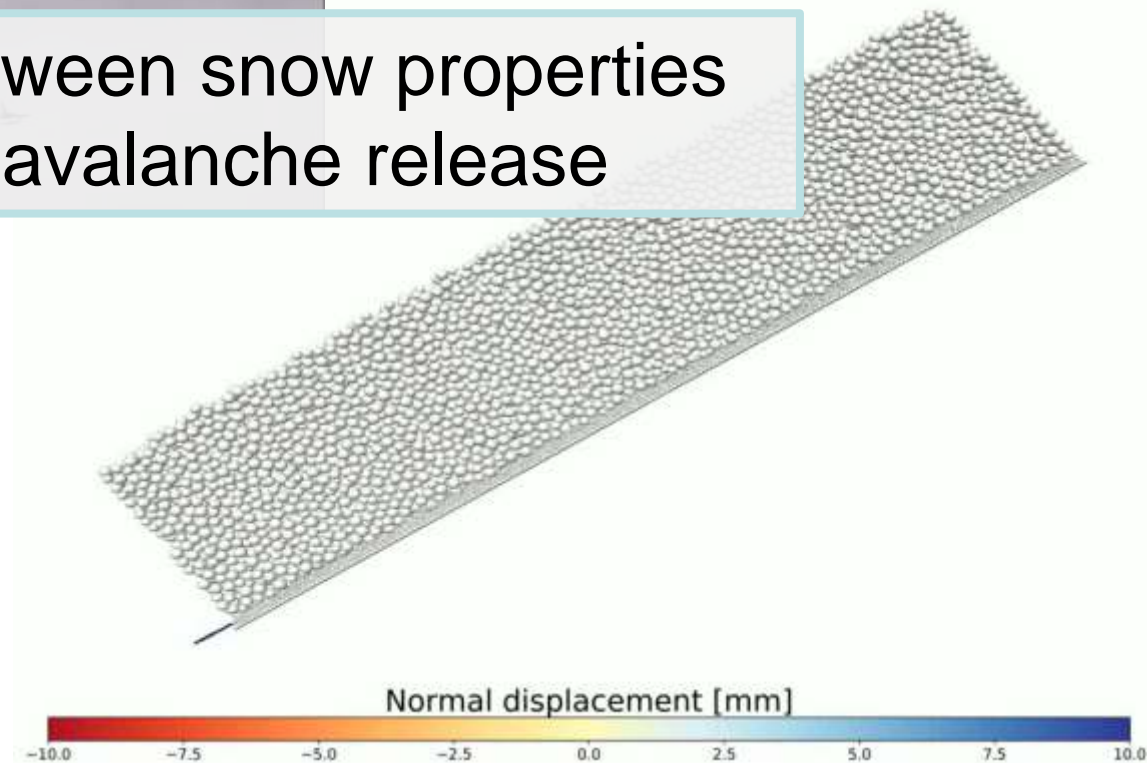
Local observers

- Over 200 observers in the Swiss Alps (📍 📍)

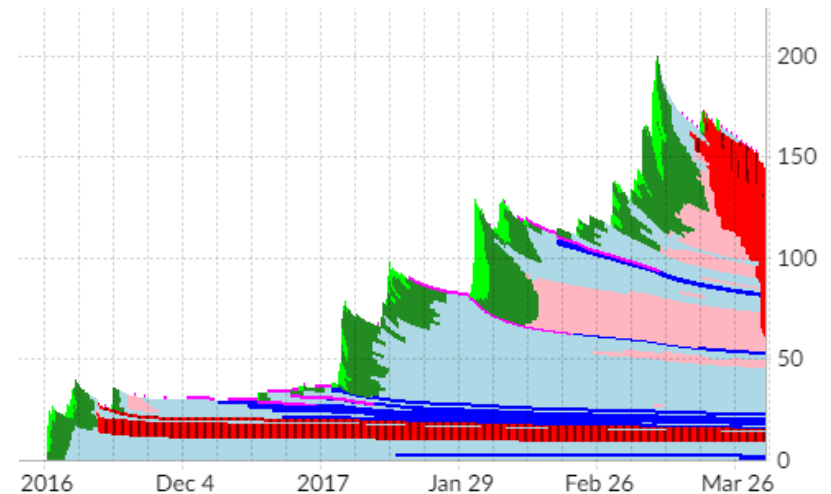- Regular snow profiles, daily snow cover and avalanche observations

Very little data when it is most needed

Automatic weather stations

- Over 130 stations in the Swiss Alps (📍 📍)

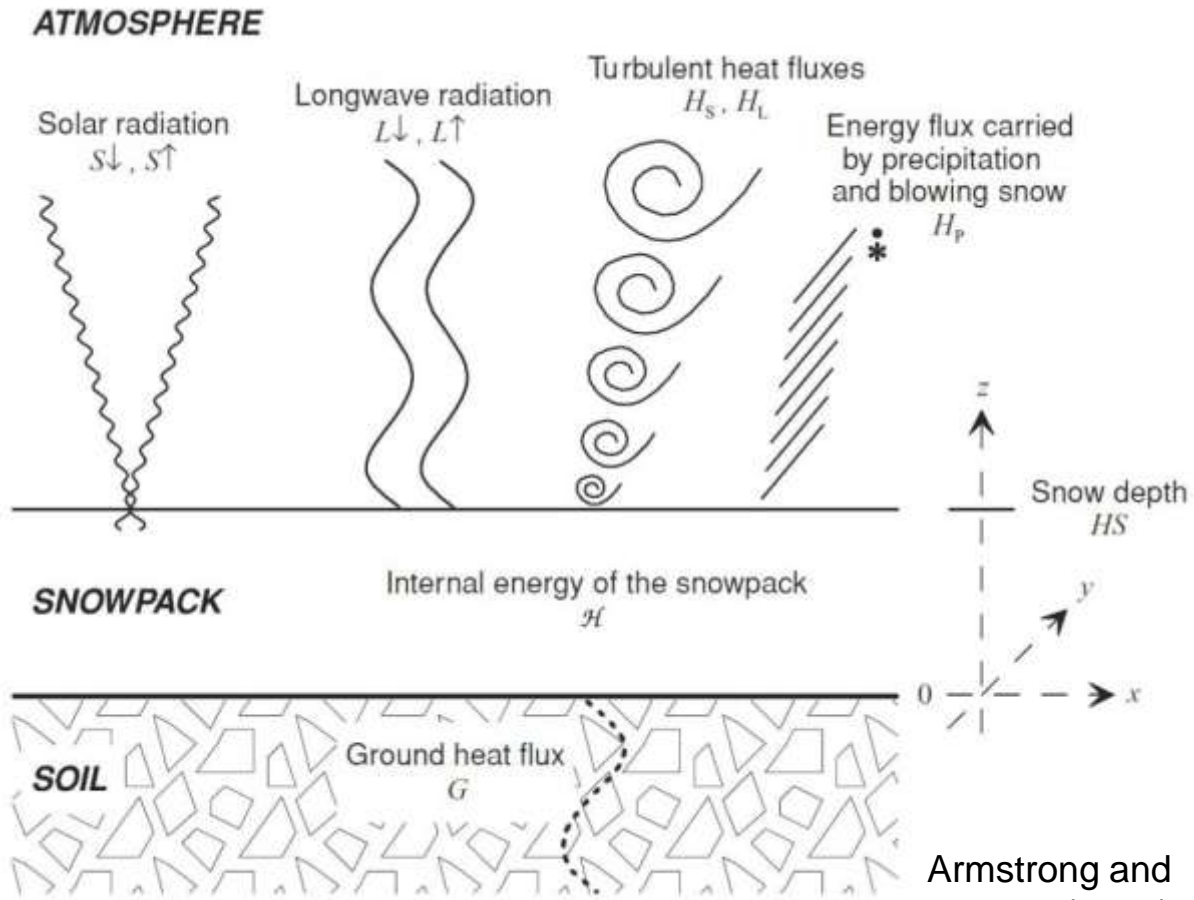- Real-time data

- Snowpack modelling

Snowpack modelling

Mass and energy fluxes

Mass and energy fluxes

Armstrong and
Brun (2008)

SNOWPACK

- Simulate snow stratigraphy: mass and energy exchange at boundaries and internal processes (heat diffusion, metamorphism, water percolation, …)

- Properties of each layer: density, temperature,, microstructural descriptors, water content, …

Output parameters and indices: new snow, wind drift, surface hoar, snow stability, …
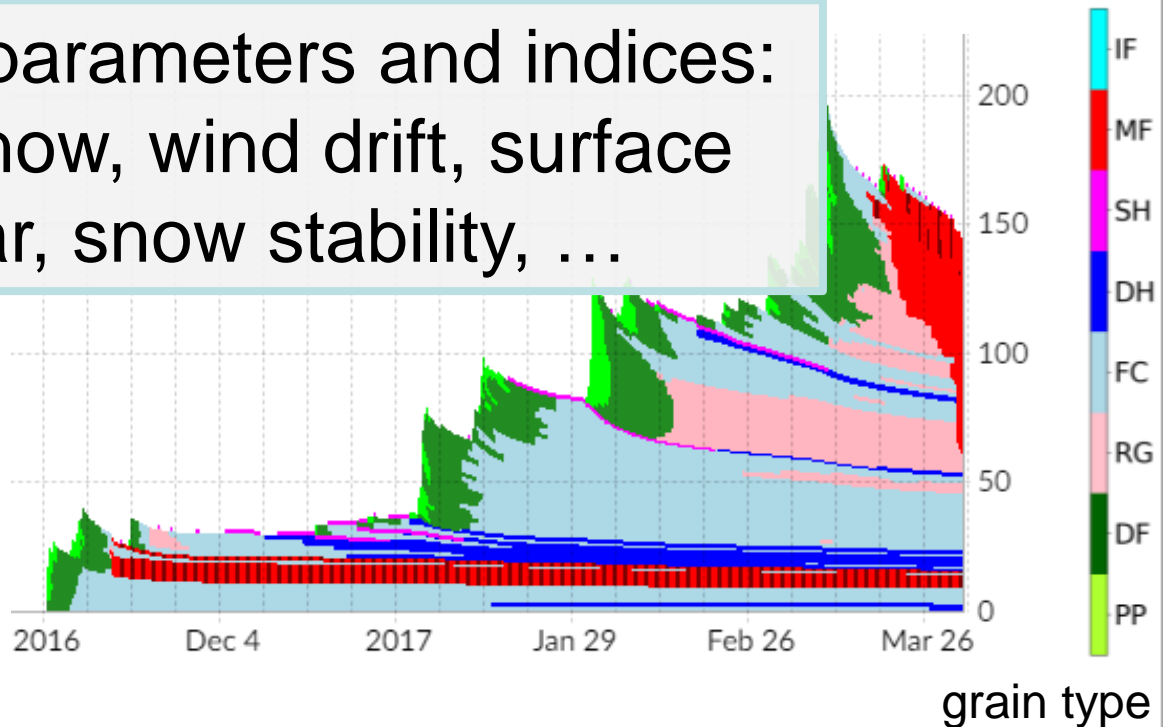
IF
MF
SH
DH
FC
RG
DF
PP

200
150
100
50
0

2016   Dec 4   2017   Jan 29   Feb 26   Mar 26

grain type

When (and where) will avalanches release?

- **When it snows (additional load destabilizes the snowpack)**

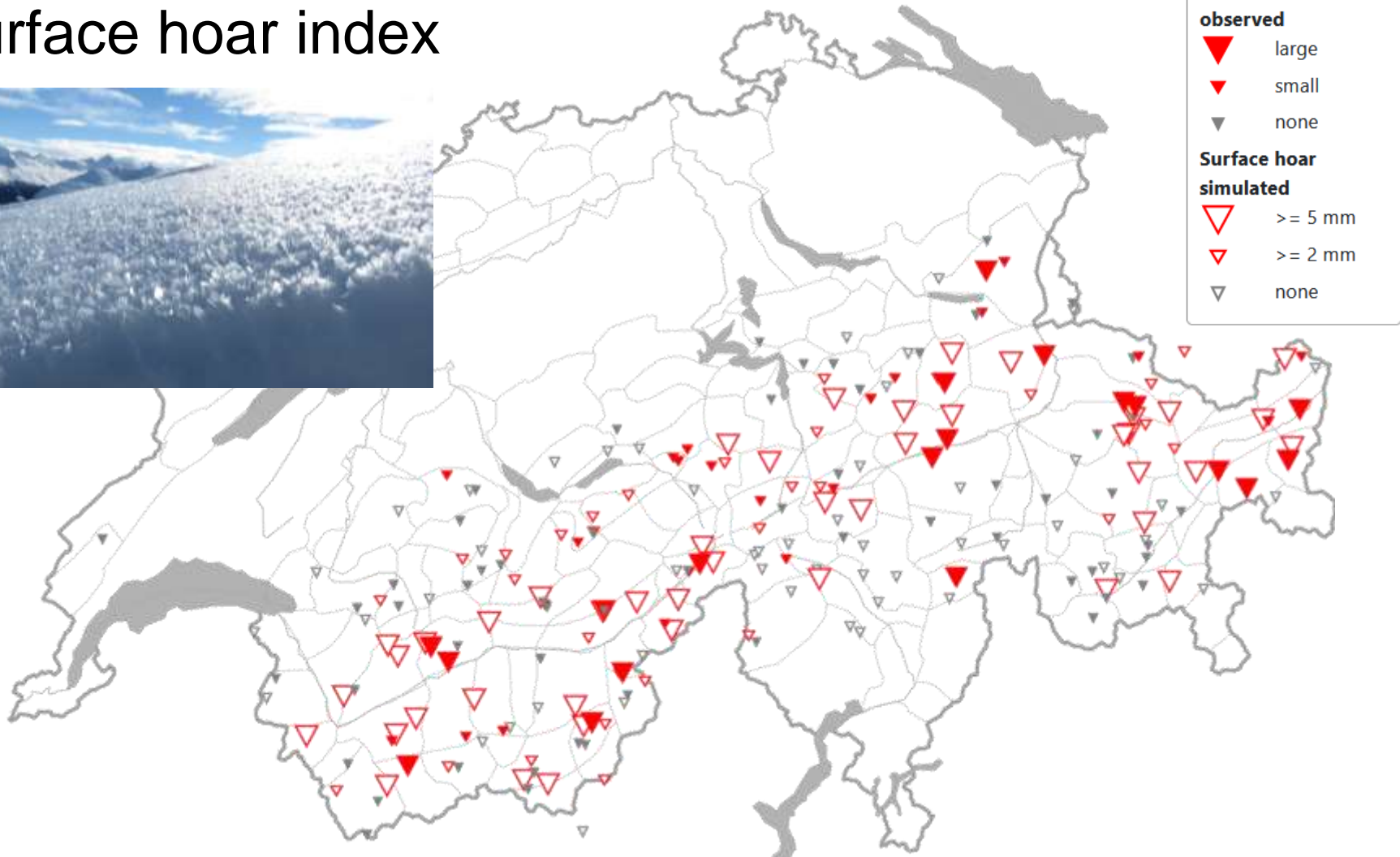- When it is warm (water destabilizes the snowpack)

SNOWPACK: potential weak layer

Surface hoar index

SNOWPACK: potential weak layer

Surface hoar index

SNOWPACK: potential slab

Wind drift index

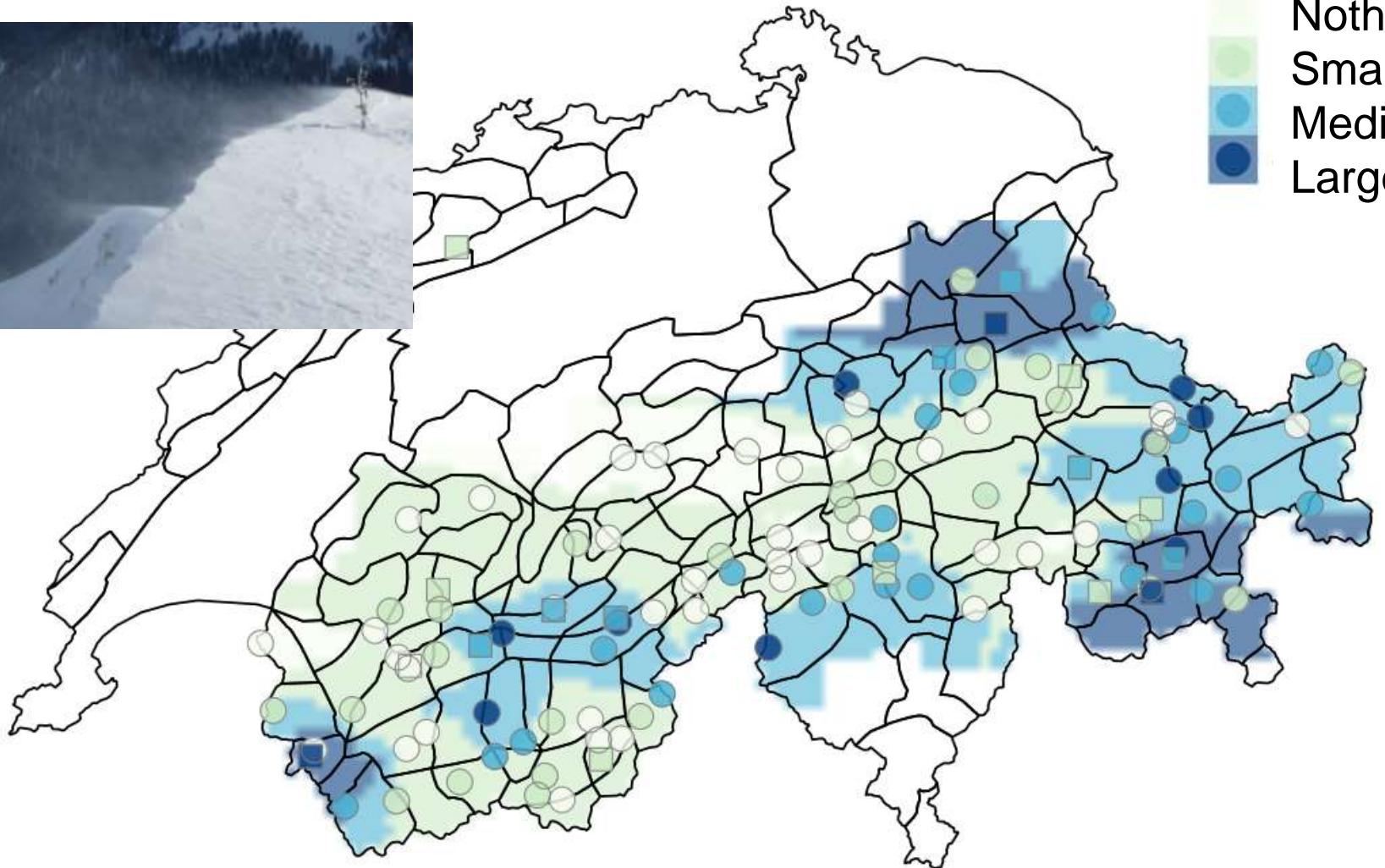# SNOWPACK: potential slab

Wind drift index

Data
Obs.
Station

Class
Nothing
Small
Medium
Large

SNOWPACK: buried weak layer

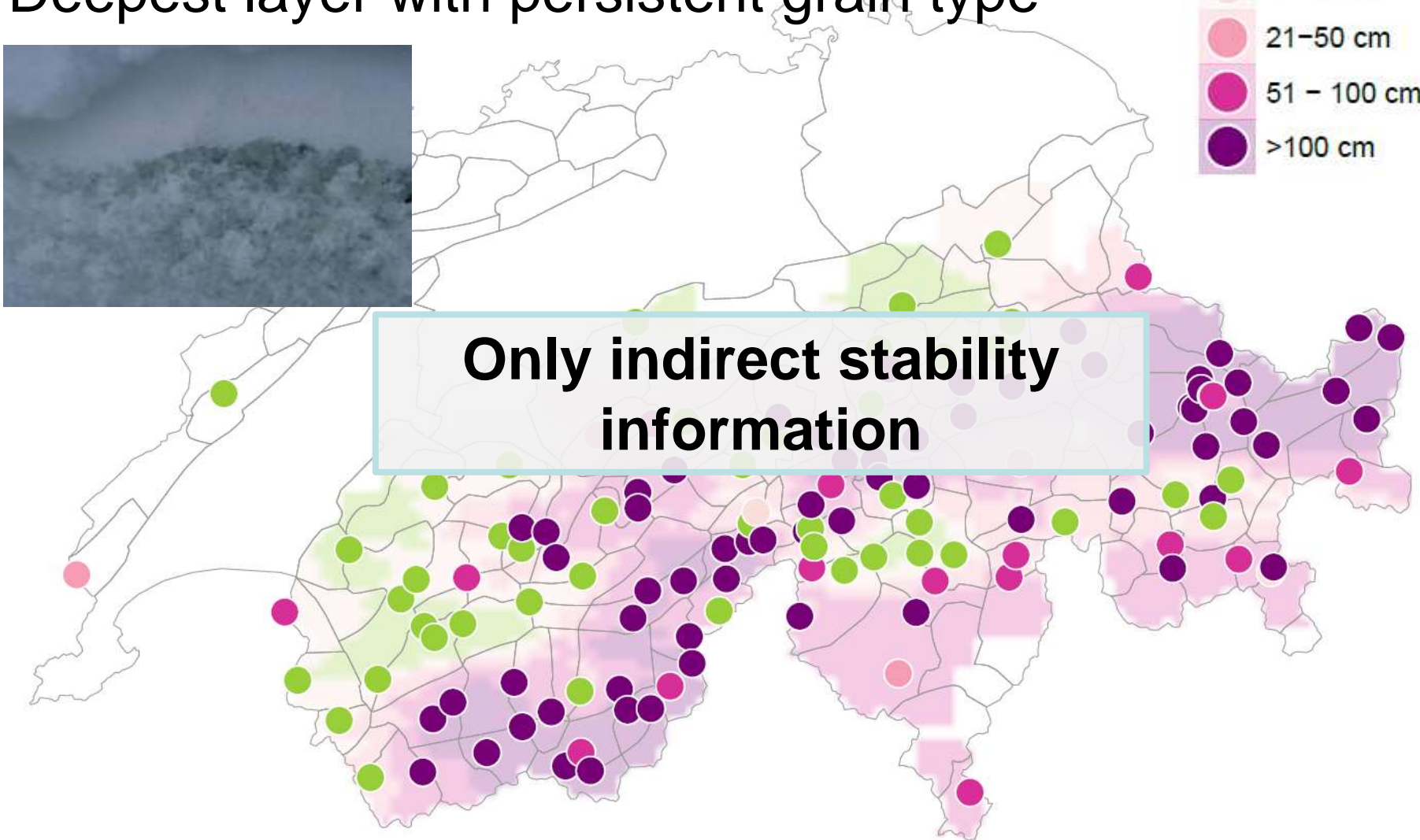Deepest layer with persistent grain type

SNOWPACK: buried weak layer

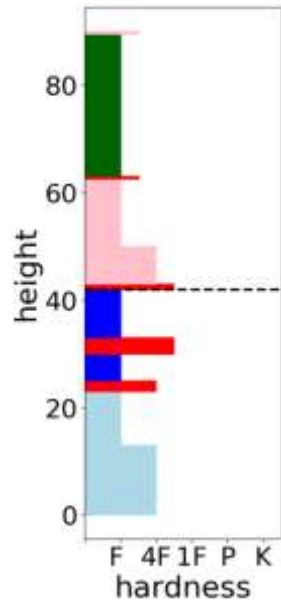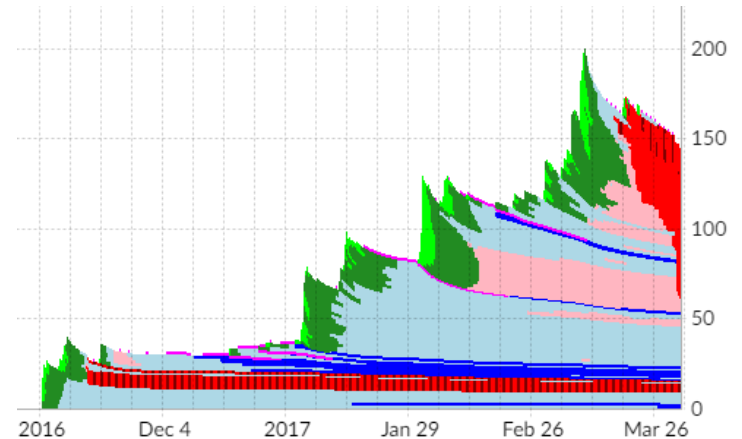Deepest layer with persistent grain type

Depth

- 🟢 No layer
- 🔴 1−20 cm
- 🔴 21−50 cm
- 🔴 51 − 100 cm
- 🟣 >100 cm

Only indirect stability information
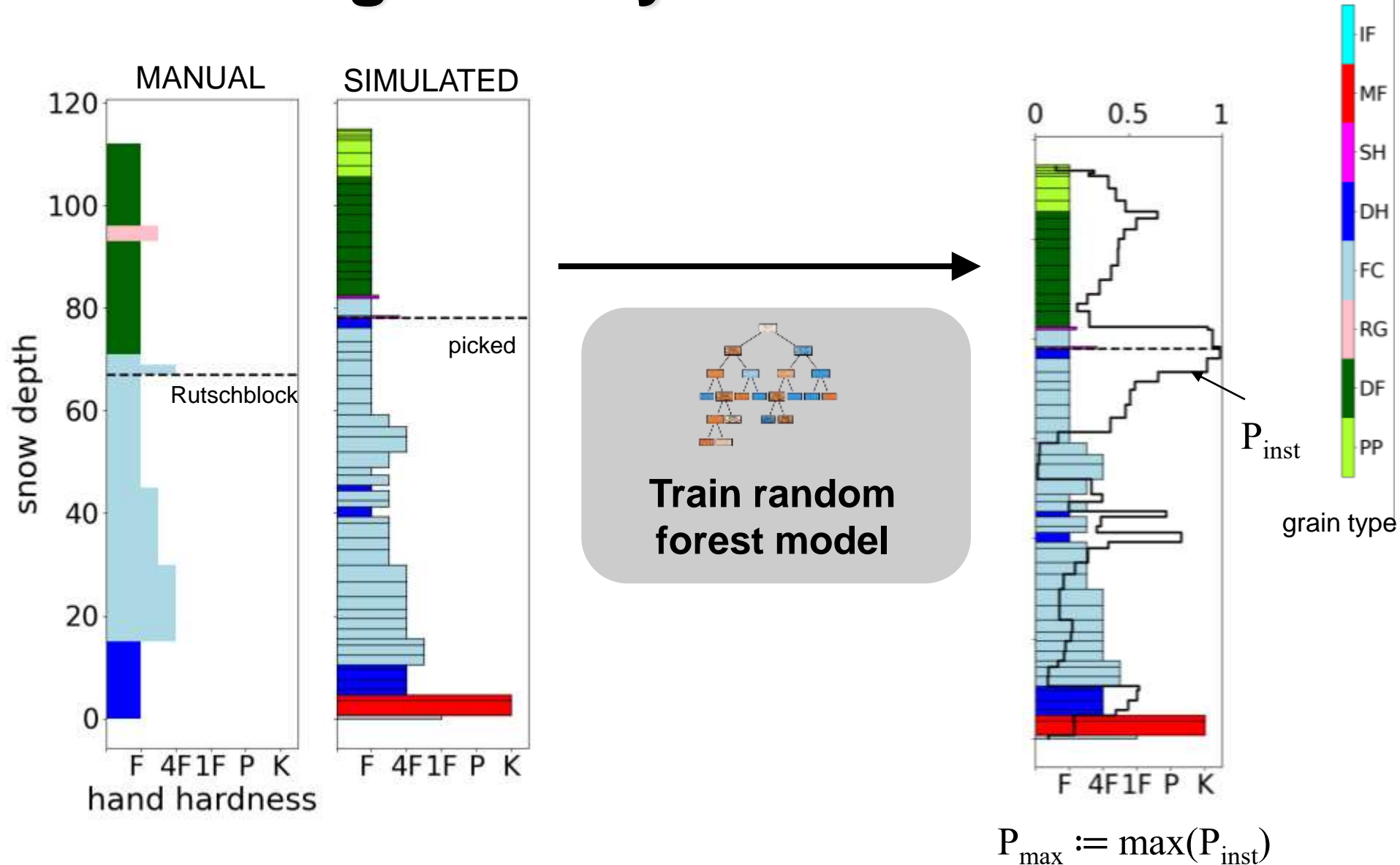
Modeling stability with SNOWPACK

VS.

566 manual snow profiles and stability tests

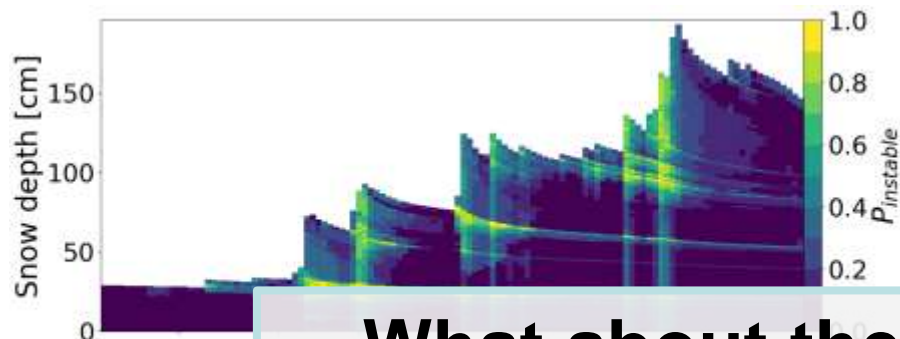**566 SNOWPACK simulations at the location of the observations**

Modeling stability with SNOWPACK

$$P_{max} := \max(P_{inst})$$
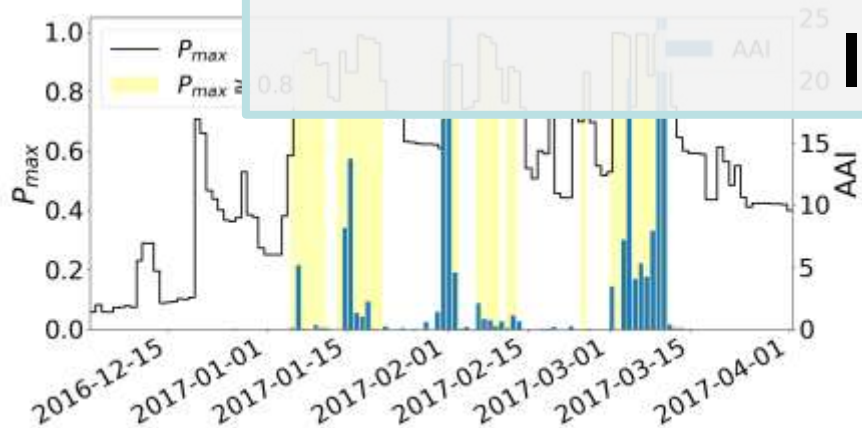
Modeling stability with SNOWPACK

Winter 2016/17

Temporal evolution of $P_{inst.}$

$\downarrow$

Compute $P_{max} := max(P_{inst})$ every day

What about the avalanche danger level?

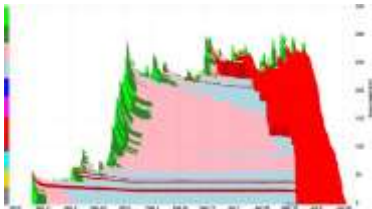Avalanche periods correspond to higher values of P_{max}

SNOWPACK: Danger level prediction

Input data:

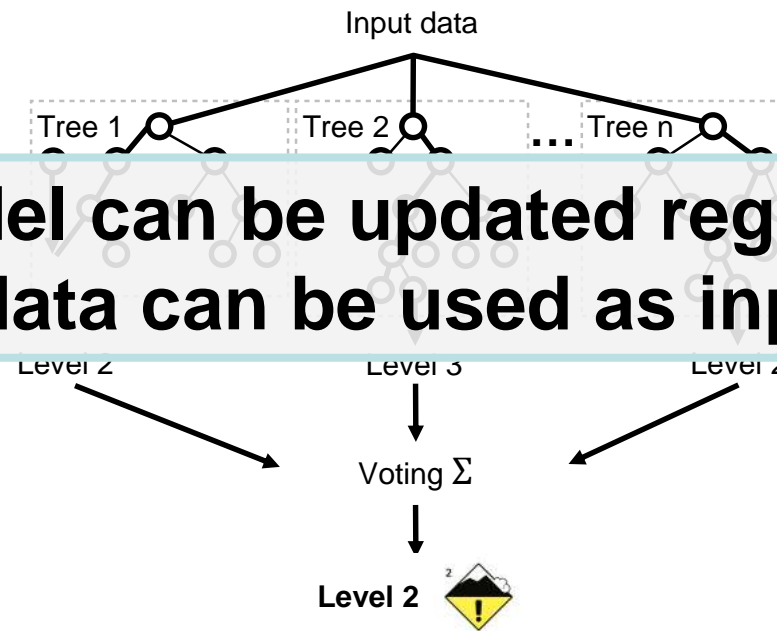Weather data: air and surface temperature, wind speed,,…

SNOWPACK data:new snow, wind drift index, stability indiced…
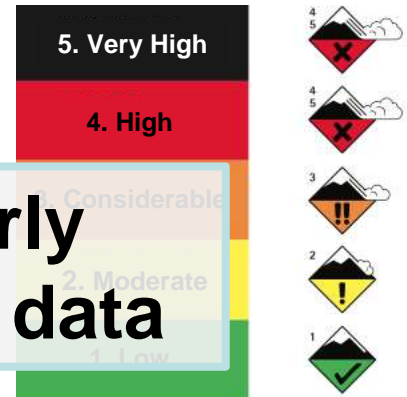
Supervised machine learning:

Random Forest

Input data

Tree 1   Tree 2   …   Tree n

Level 2   Level 3   Level 2

Voting Σ

Level 2

Output:

Danger scale

5. Very High
4. High
3. Considerable
2. Moderate
1. Low

Regional danger level
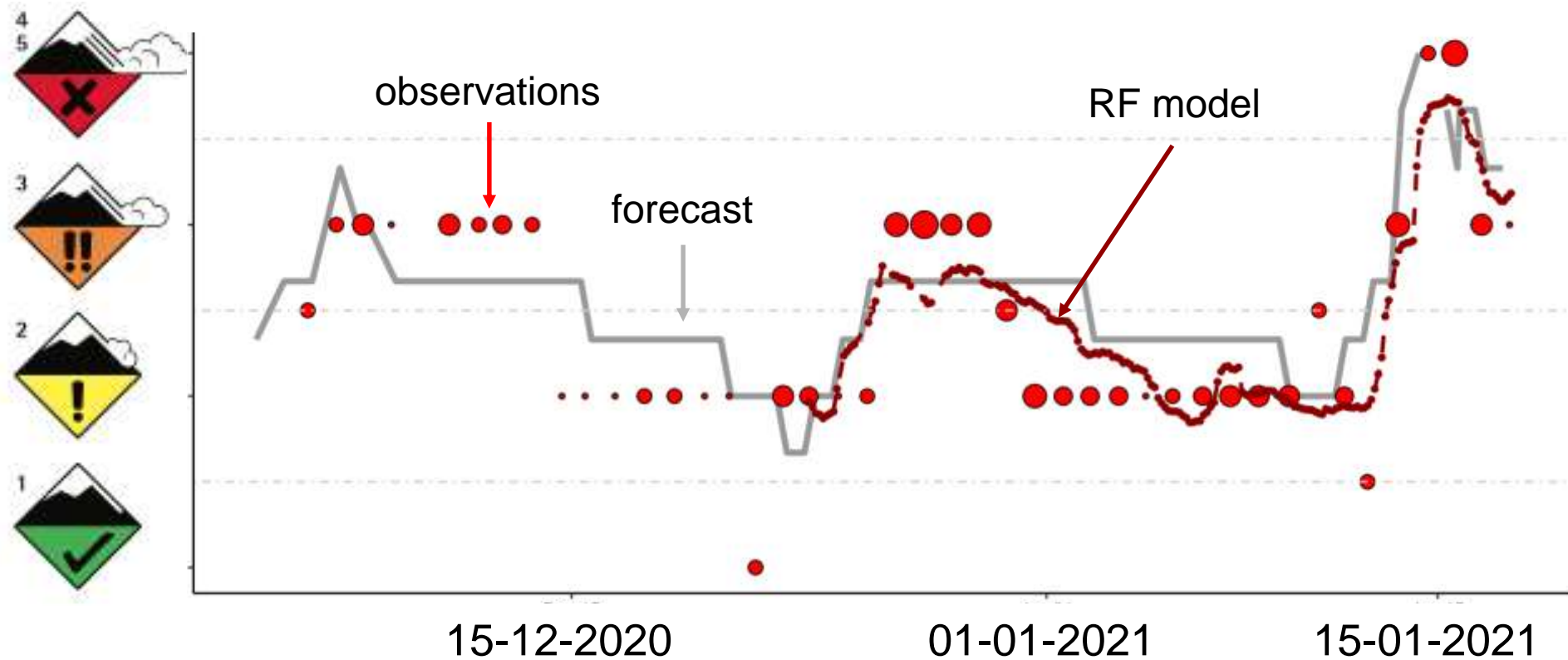
Model can be updated regularly
NWP data can be used as input data
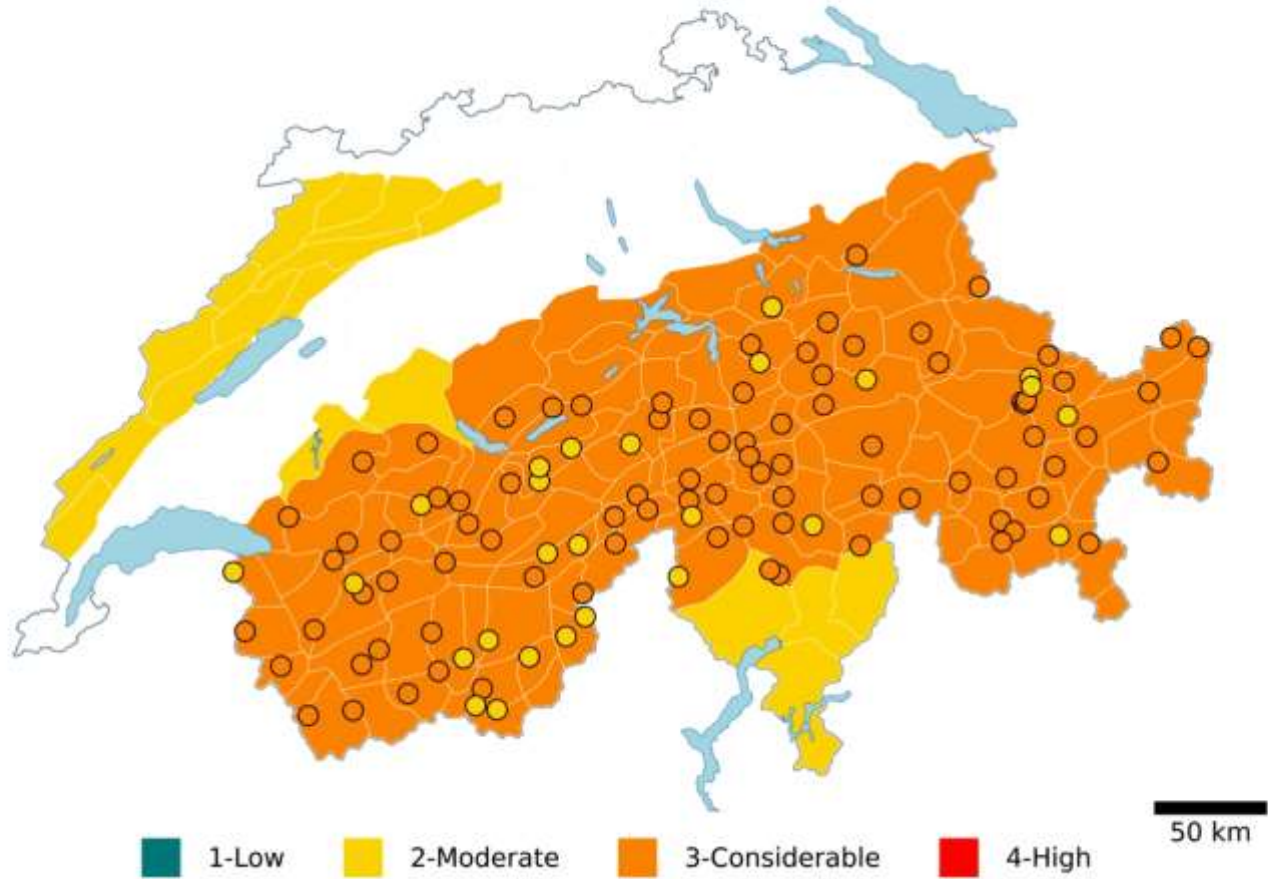
SNOWPACK: Danger level prediction

One weather station in Davos

SNOWPACK: Danger level prediction

All weather stations in Switzerland

Forecast predictions on Thursday, 21 Jan 2021

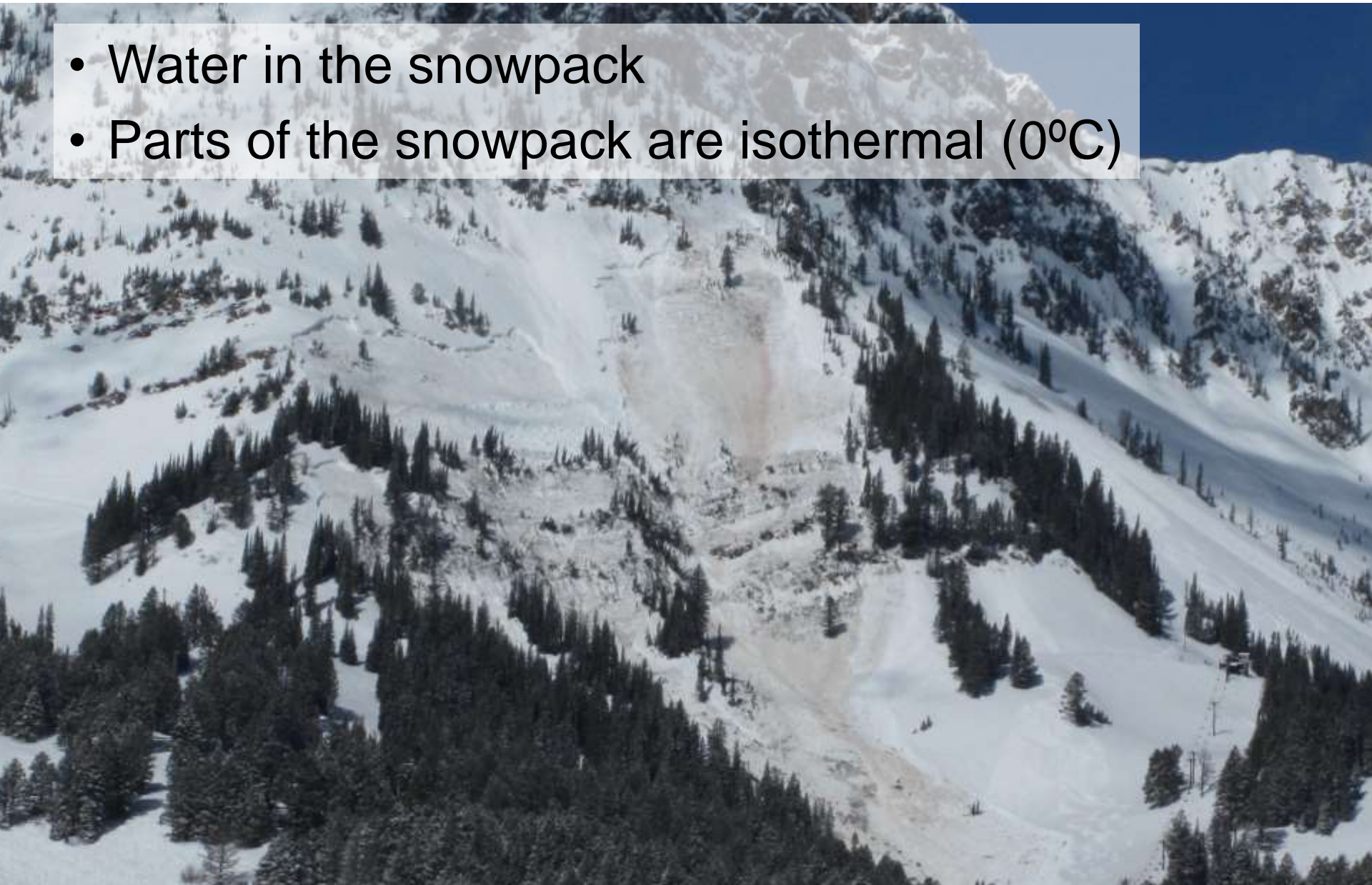1-Low 2-Moderate 3-Considerable 4-High

50 km

When (and where) will avalanches release?

- When it snows (additional load destabilizes the snowpack)

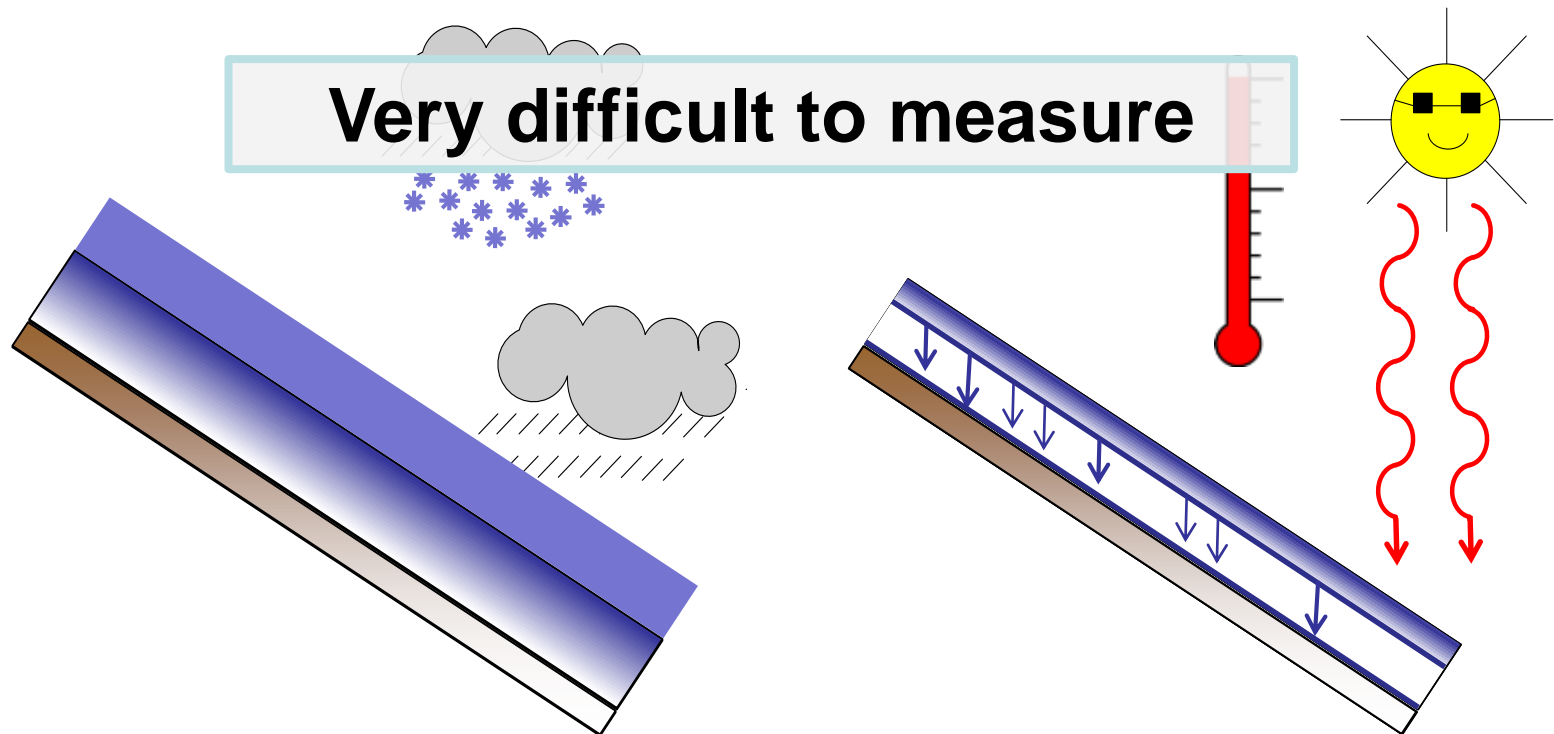- **When it is warm (water destabilizes the snowpack)**

Wet-snow avalanches

- Water in the snowpack
- Parts of the snowpack are isothermal ($0^{\circ}C$)
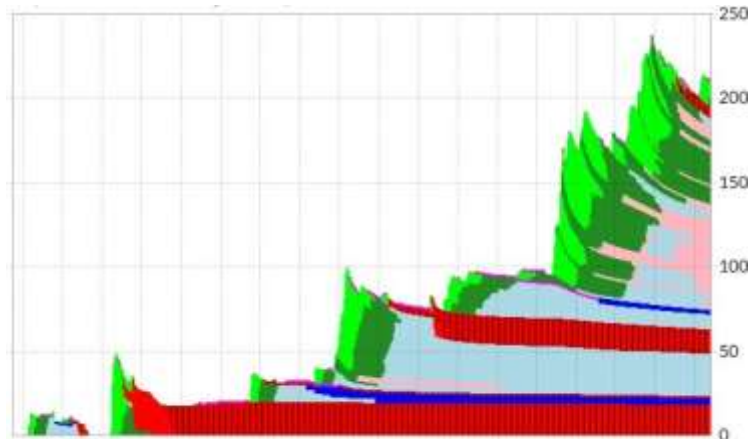
How do wet-snow avalanches fail?

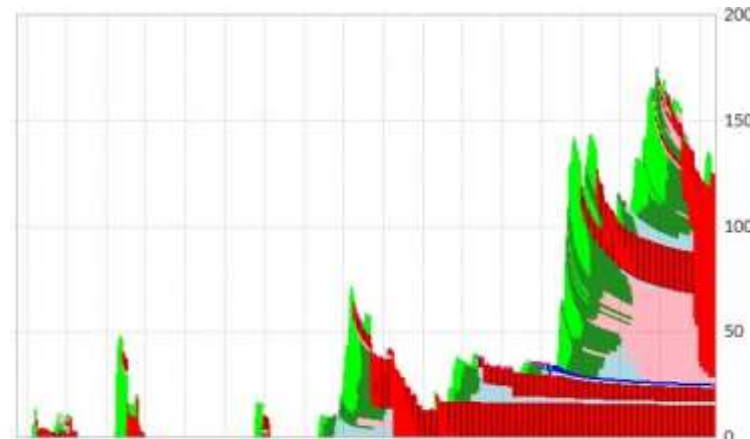Loss of strength due to water infiltration and storage at capillary barriers or base of the snowpack

Very difficult to measure

SNOWPACK: Liquid water content (LWC)

One weather station in Davos

SNOWPACK: LWC_{index}

- Fraction of the snowpack with LWC > 3%
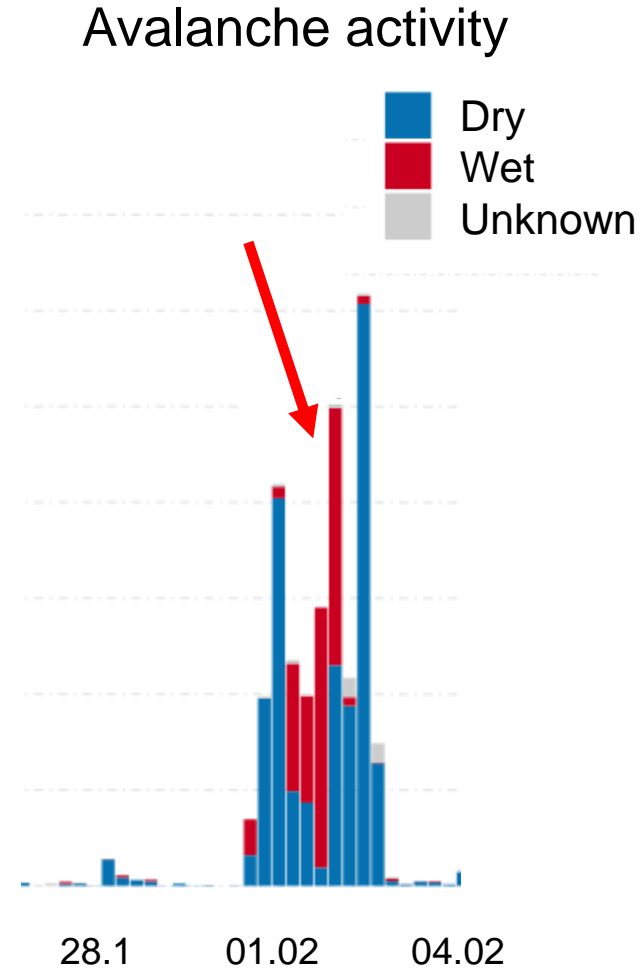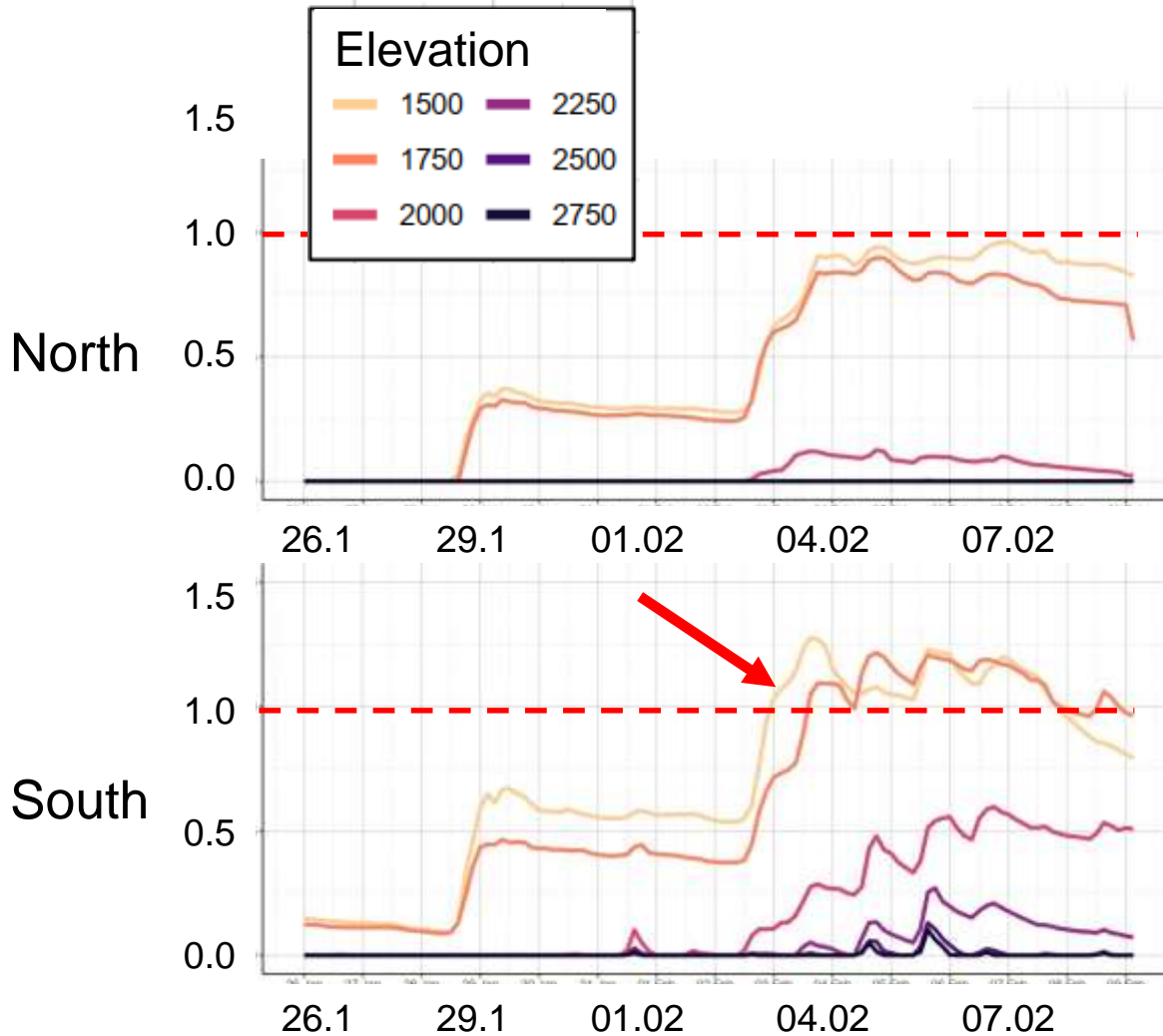
When (and where) will avalanches release?

Models developed over the last decades allow us to:

– Better understand the link between snowpack properties and snow stability

– Predict stability and the danger level based on simulated snow stratigraphy and indices

Models will allow us improve the spatial and temporal resolution of avalanche forecasting