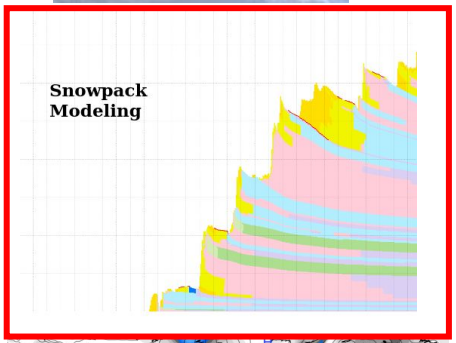
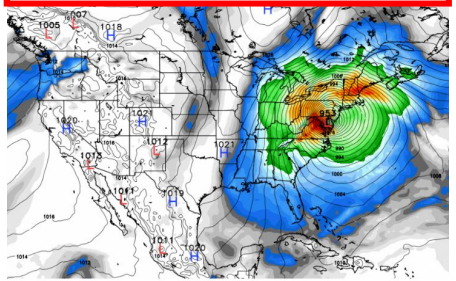




Snow-cover modeling in support of avalanche forecasting

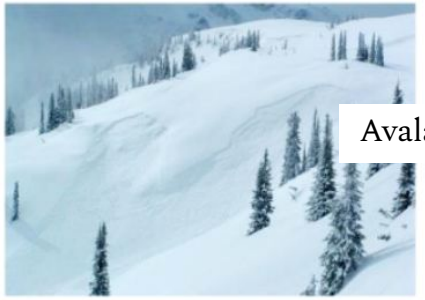
Euregio avalanche forecasters training session–
November 4, 2025

Florian Herla

with Simon Horton, Martin Perfler, and Pascal Haegeli

SFU SIMON FRASER UNIVERSITY
Vancouver BC, Canada

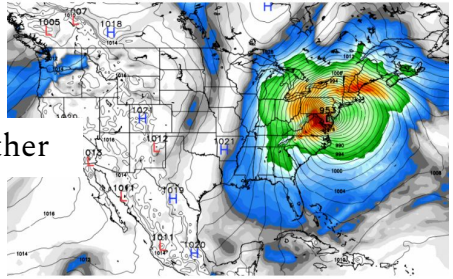
Avalanche Forecasting



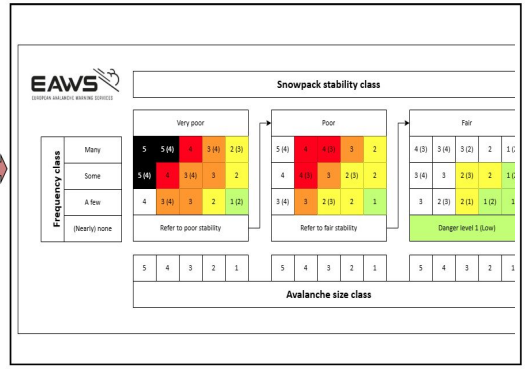
Avalanches

Snowpack

Weather

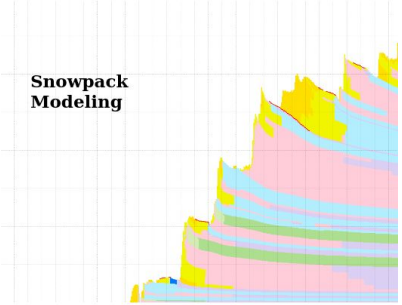


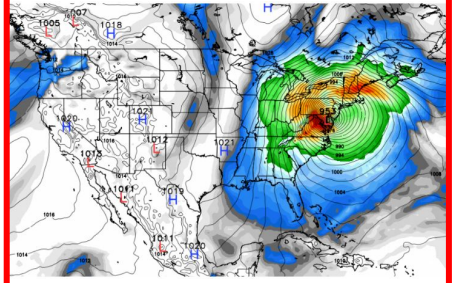
Type of Avalanche Problem → Location



1. **Which Conditions?**
2. **Where?**
3. *How likely?*
4. *How big?*

Avalanche Forecasting

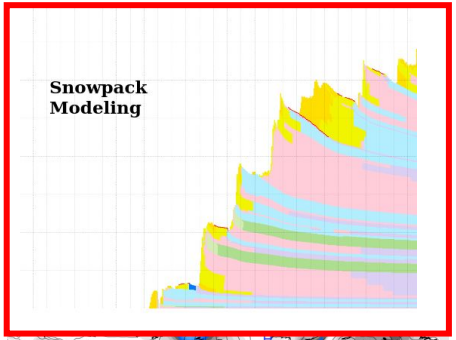


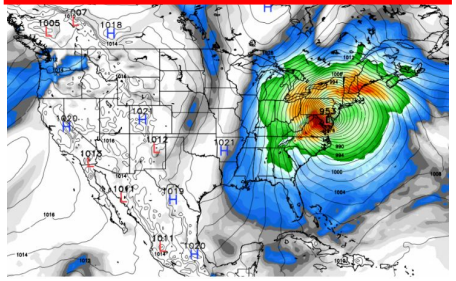


Type of Avalanche Problem → Location

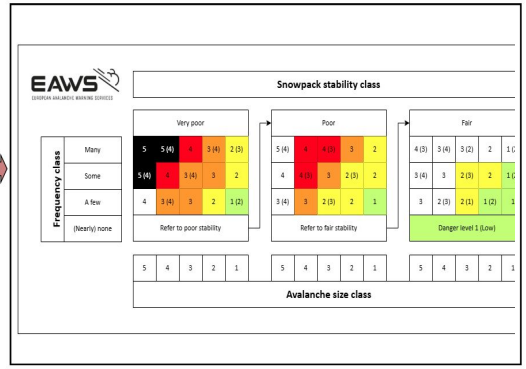
1. **Which Conditions?**
2. **Where?**
3. *How likely?*
4. *How big?*

Avalanche Forecasting

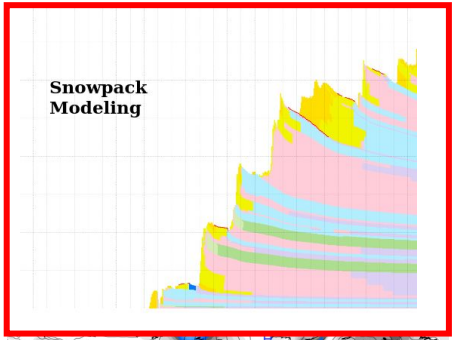


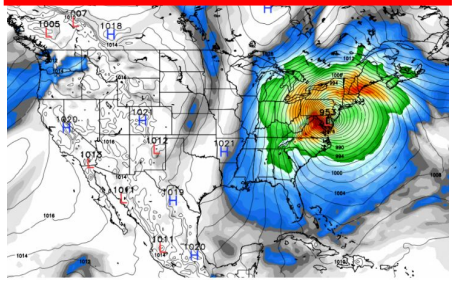


Type of Avalanche Problem → Location



1. **Which Conditions?**
2. **Where?**
3. *How likely?*
4. *How big?*

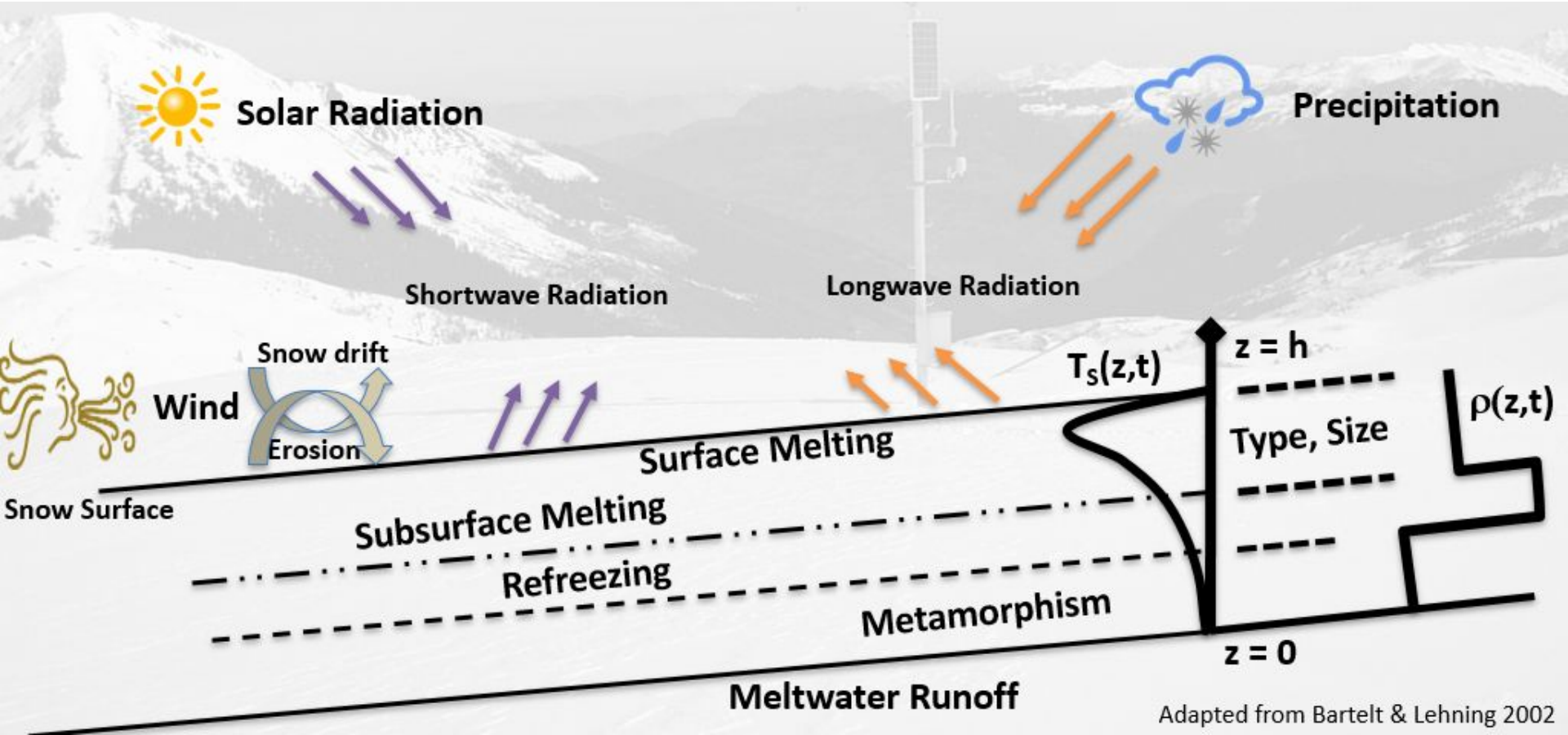




Outline

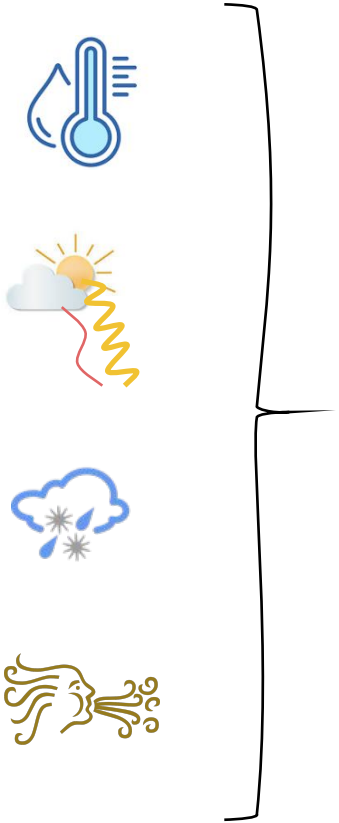
1. Introduction
2. Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard
3. [Hands-on case studies]
4. []

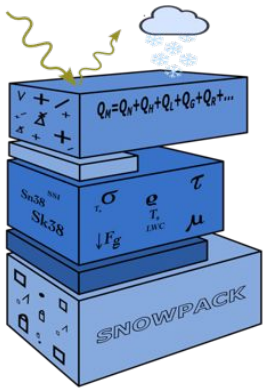
Atmospheric processes shape the alpine snow cover



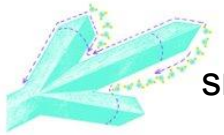
Adapted from Bartelt & Lehning 2002

Detailed snow stratigraphy models solve…



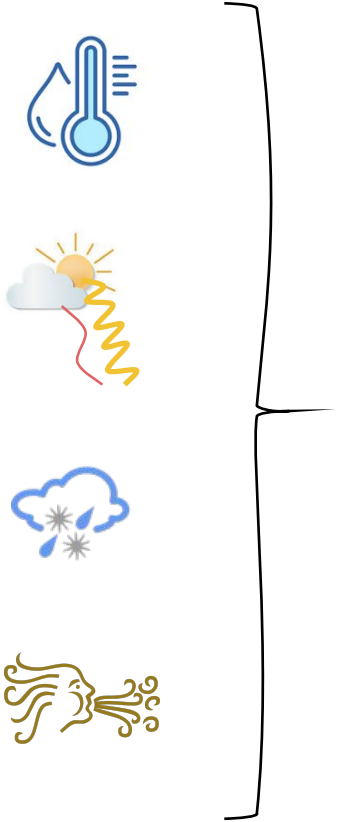


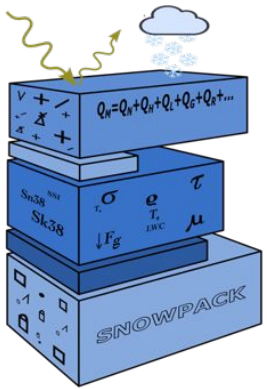
the energy and
mass balances

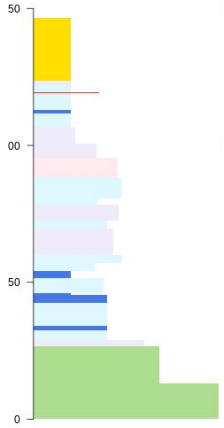


snow metamorphism

Detailed snow stratigraphy models solve…

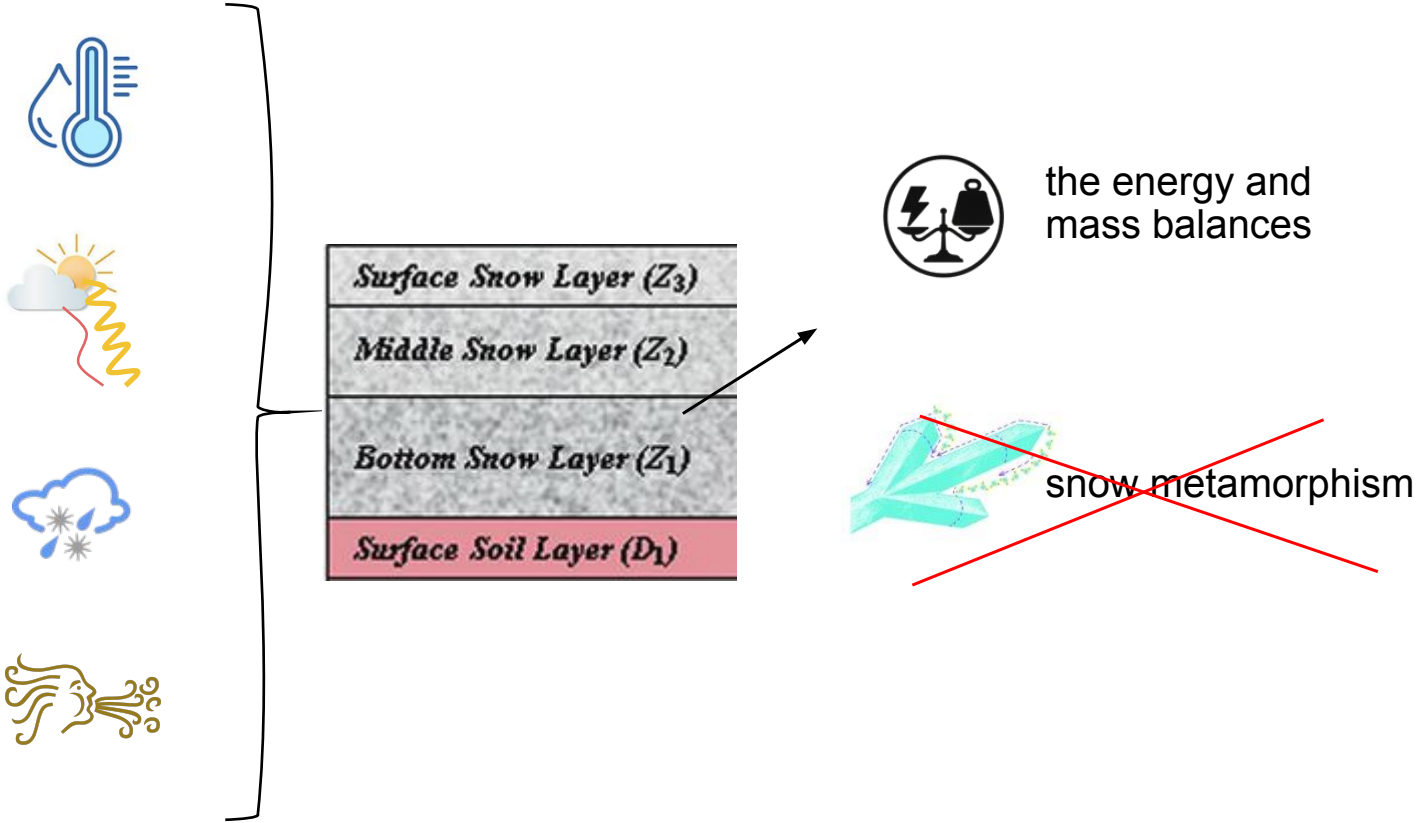




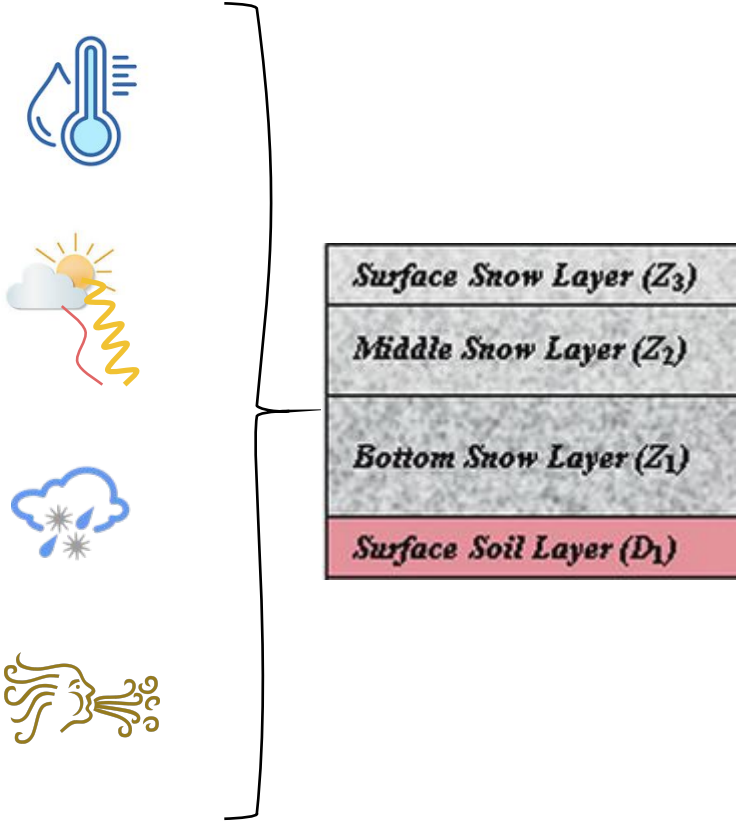


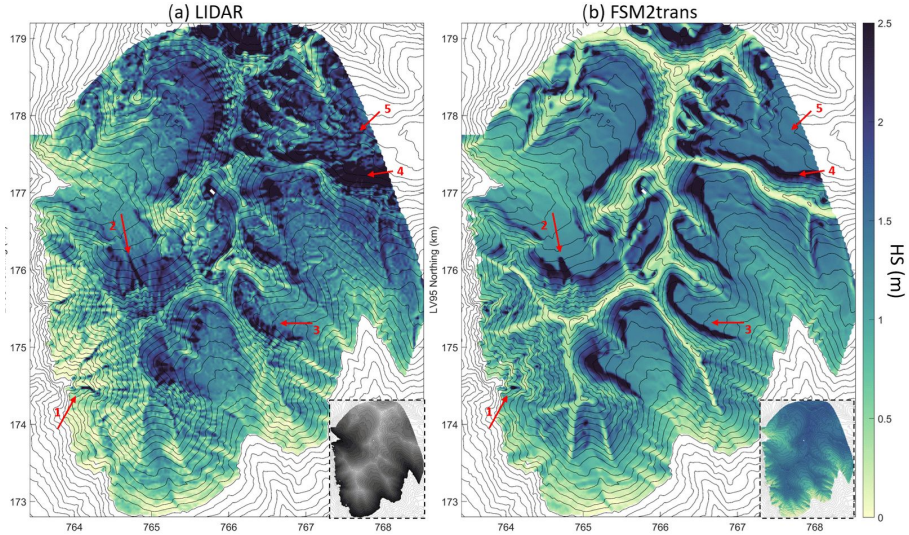
- Expensive
- Thin-layer resolving
- Usually 1D (no horizontal exchange)
- Coarse horizontal coverage

Snow hydrology models solve…



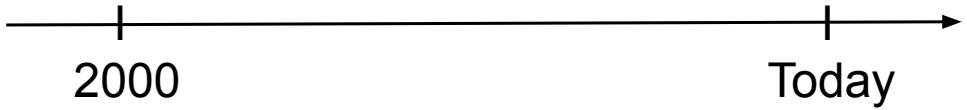
Snow hydrology stratigraphy models solve…



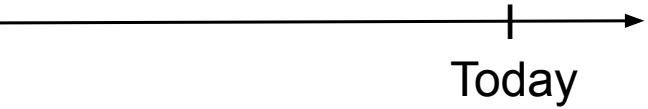


- Cheap
- Simplification of snow layering
- Usually 2D
- High-resolution horizontal coverage

A brief history of snow cover modeling



Avalanche warning agencies world-wide are drafting ambitious visions for employing snow cover simulations



Virtual forecaster

High-res modeling and assimilation framework (as of 2027)

Semi-automated gridded forecasts (within few years)

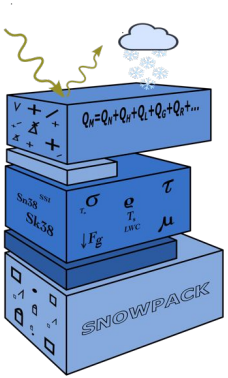
Top modeling pipeline & dashboard

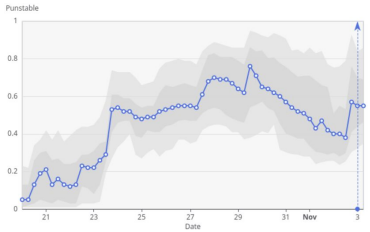
Exciting times!

You can be part of exploring this, but take it with a grain of salt!

- Time to learn about this new information source
- Do not fully depend on it yet for decision making

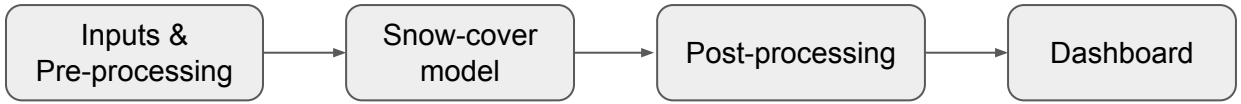
Overview over a comprehensive modeling pipeline





Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

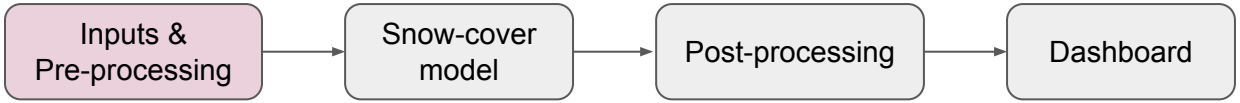
Overview over a comprehensive modeling pipeline



General information

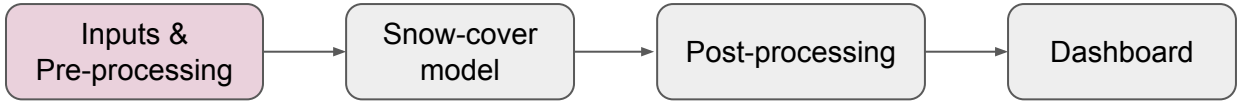
Notable tools and new developments

Challenges and sources of uncertainty



Site-specific or regional-scale applications?

Today, we focus on regional avalanche forecasting!



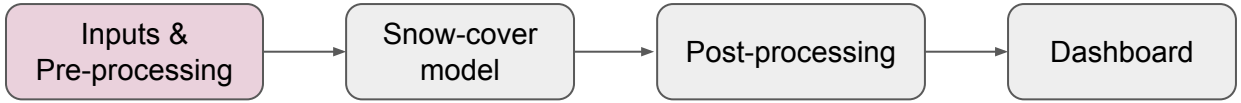
Model chain needs consistent weather timeseries

Temperatur
Humidity

Precipitation

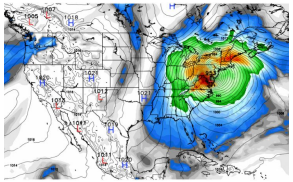
Radiation

Wind



Model chain needs consistent weather timeseries

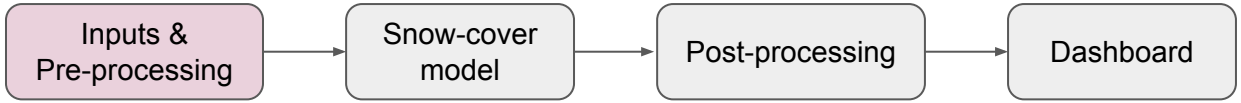
Weather station



Numerical weather prediction (NWP) model

Hybrid

- Station nowcast + NWP forecast
- Patching missing sensors
- Analysis (NWP background field nudged by observations)

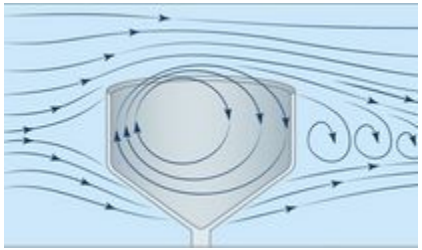


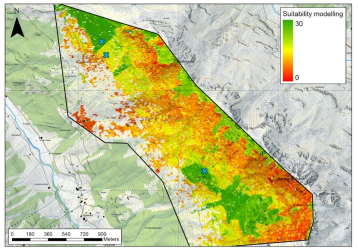
What are the strengths & weaknesses of AWS / NWP?

Group discussion!

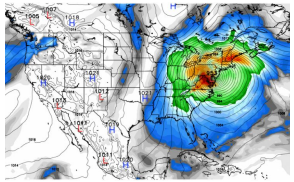
What are the strengths & weaknesses of AWS / NWP?

Measurement



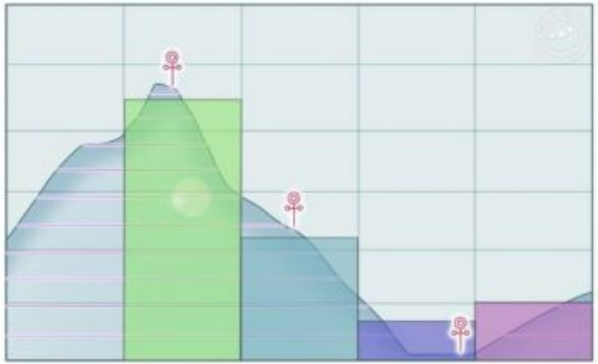


Buehler et al., 2024



Spatial coverage
Forecast

Elevation gradient

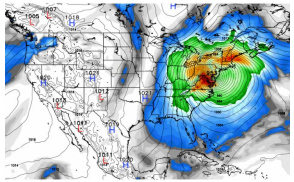


Morin et al., 2020

What are the strengths & weaknesses of AWS / NWP?

Measurement

Measurement errors
Representativeness of location **(= local biases)**
(elevation, terrain, canopy)
Expensive maintenance
Pre-processing-intense (quality control)



Spatial coverage
Forecast

Elevation gradient

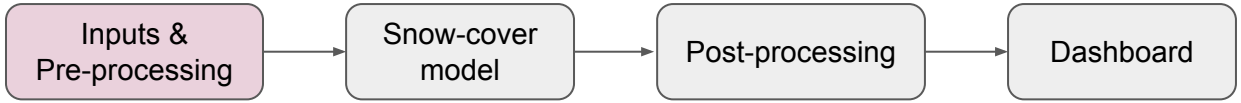
Area-averaged conditions within grid cell

Effective resolution

- Smallest spatial scale at which processes are captured realistically
- ~6-10 x grid spacing

Systematic biases **(larger than AWS)**

- e.g., windward/leeward, elevation



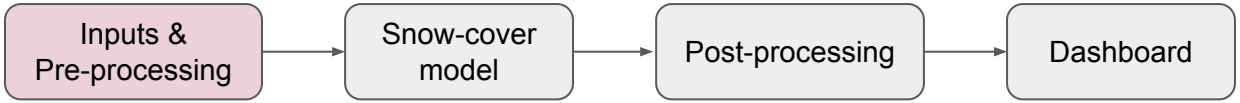
Weather inputs are the largest source of uncertainty for snow cover modeling in support of avalanche forecasting

Temperatur
Humidity

Precipitation

Radiation

Wind



Weather inputs are the largest source of uncertainty for snow cover modeling in support of avalanche forecasting

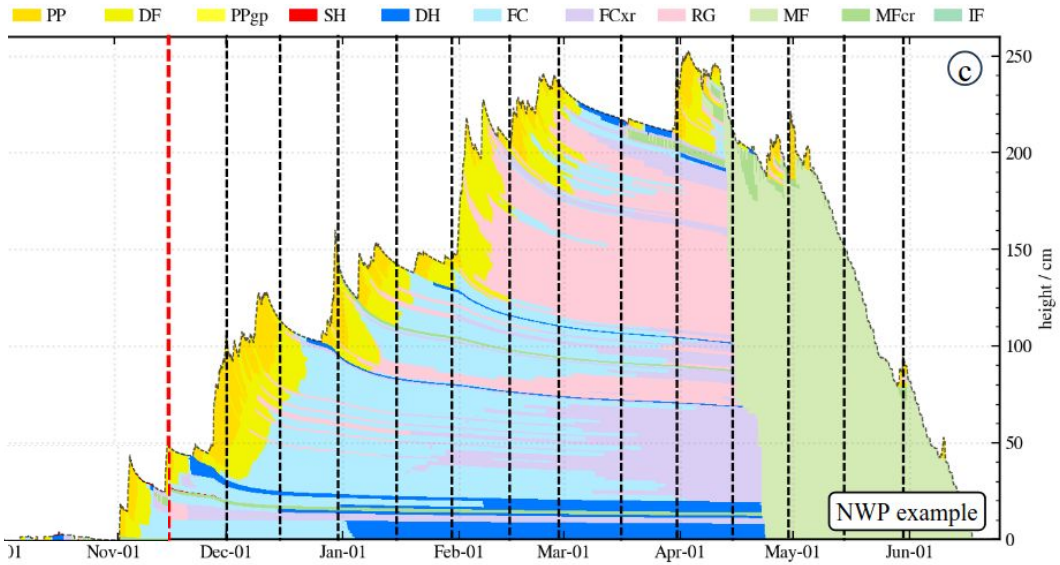
Temperatur
Humidity

Precipitation (amount & phase)

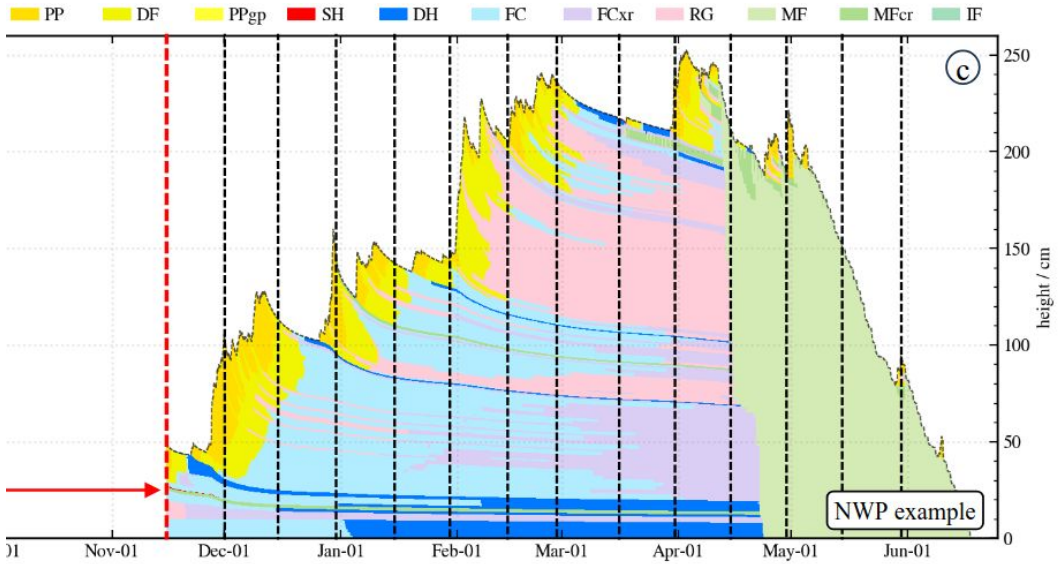
Radiation

Wind

Starting simulations off an observed profile



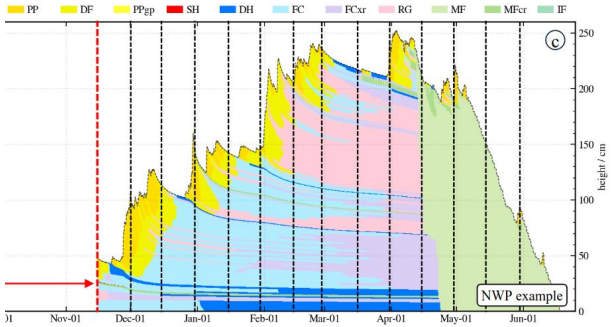
Starting simulations off an observed profile



Binder and Mitterer, 2024

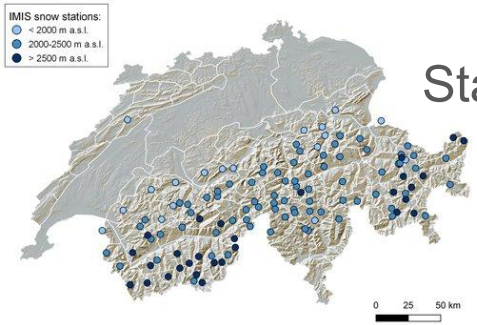
Starting simulations off an observed profile

- Improved stratigraphy for ~ 4 weeks
- Stability predictions → ?? → spin-up time?



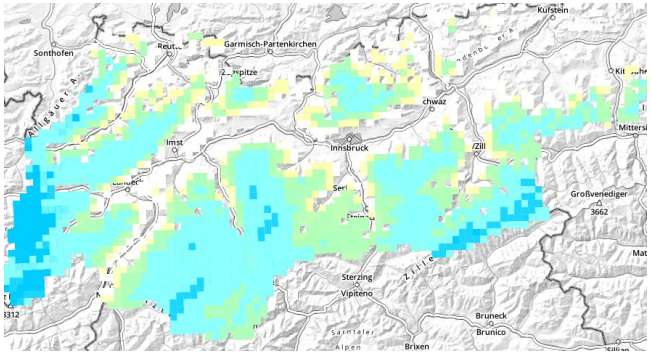
Binder and Mitterer, 2024

How is the model geometry designed?

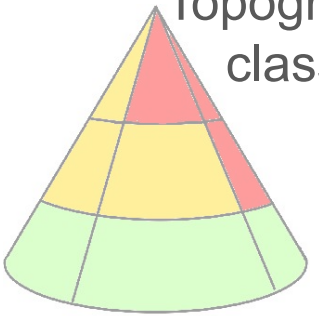


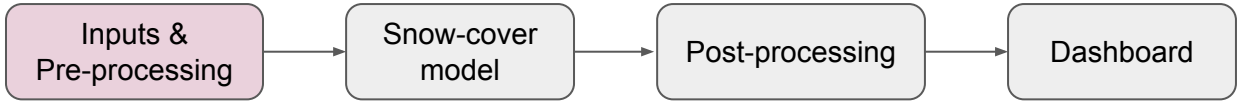
Station network

Gridded



Topographic class

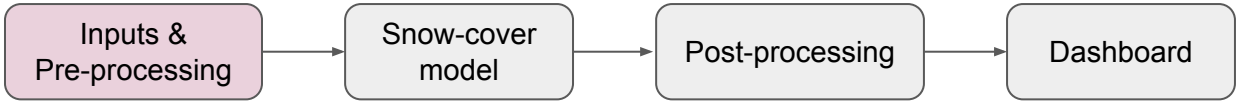




What spatial scale is represented?

Group discussion!

Which spatial scales do we consider? (think of weather, snow cover, & avalanche hazard)
Which small-scale processes have a big impact on regional-scale forecasting?
Do model chain predictions cater to the scale of regional forecasting?
What challenges come to mind that are related to representativeness?

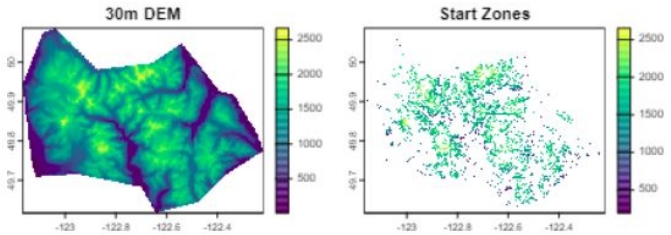


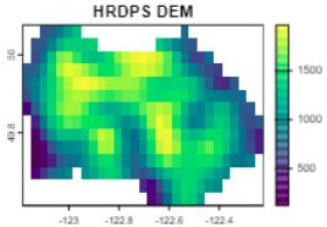
What spatial scale is represented?

- Simulations have a core spatial unit of 1D stratigraphy at a station/vstation/vslope. Pre-processing of weather inputs influences representative scale of this unit.

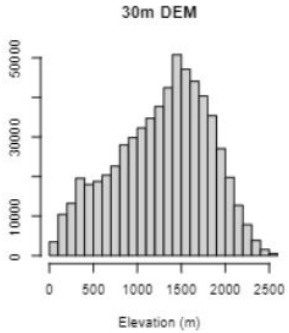
- Sampling biases of gridded geometries
(*What's happening in my avalanche start zones?*)

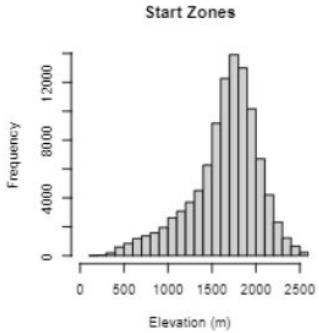
Sampling biases of gridded geometries

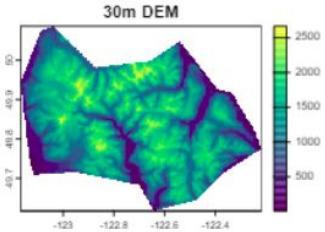


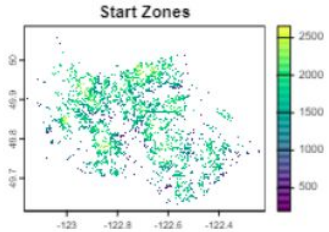


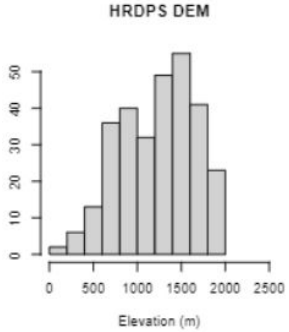
Sampling biases of gridded geometries

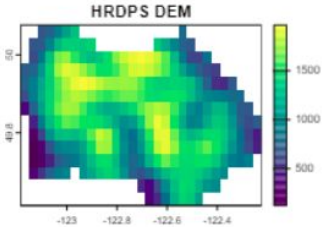




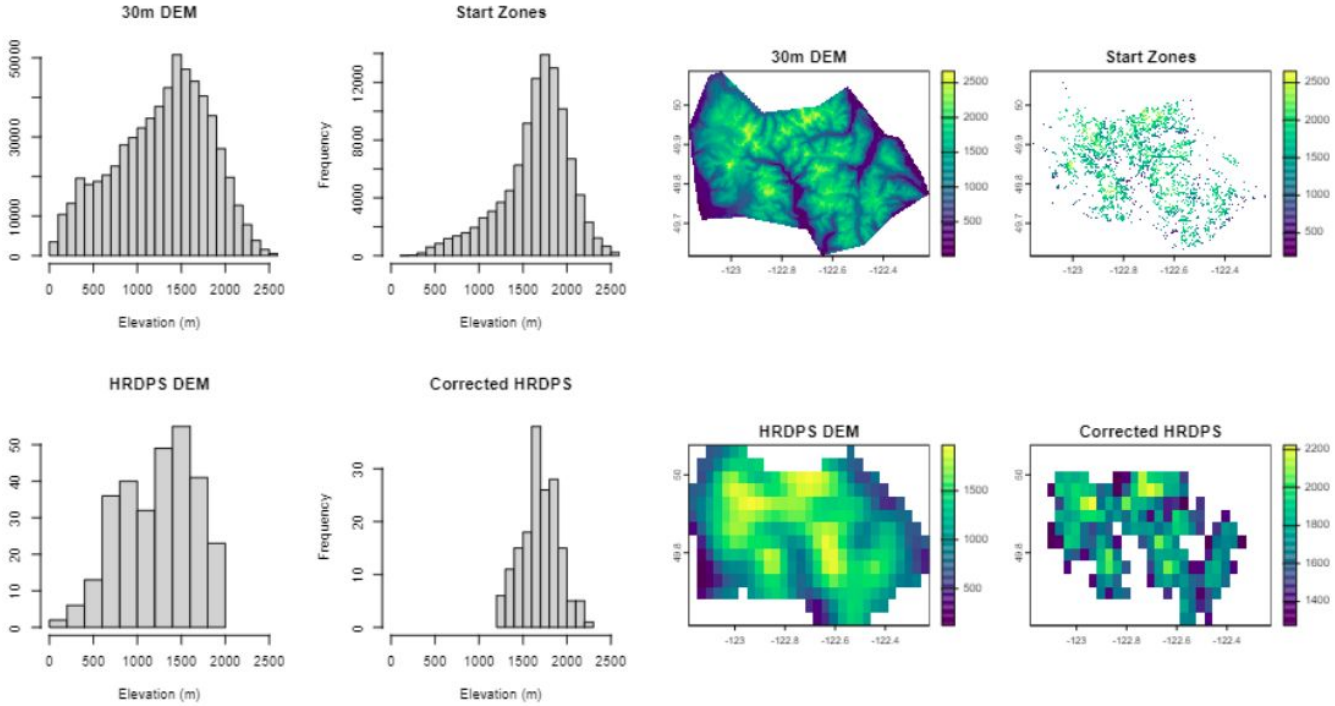




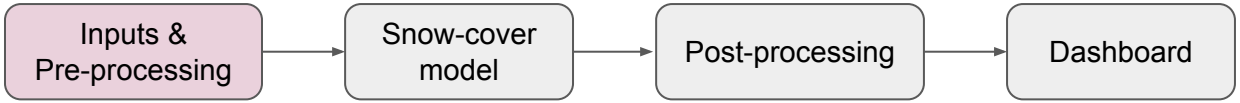




Sampling biases of gridded geometries

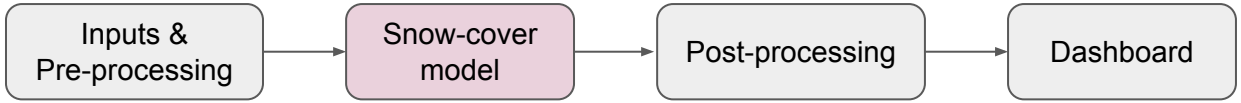


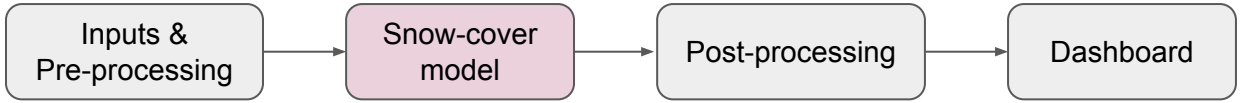
Lapse-rate correct to median start zone elevation



Intermediate Recap

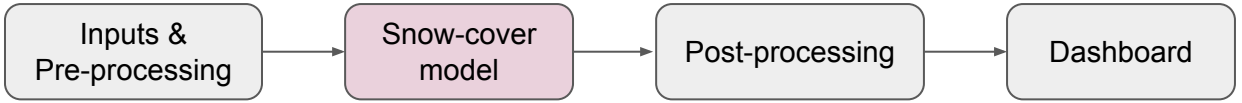
1. Scale: Regional
2. Weather inputs: AWS, NWP, Hybrid
3. Model geometry: Station-based, Gridded, Topo-class


Inputs &
Pre-processing
Snow-cover
model
Post-processing
Dashboard



Snow-cover model: inherent shortcomings

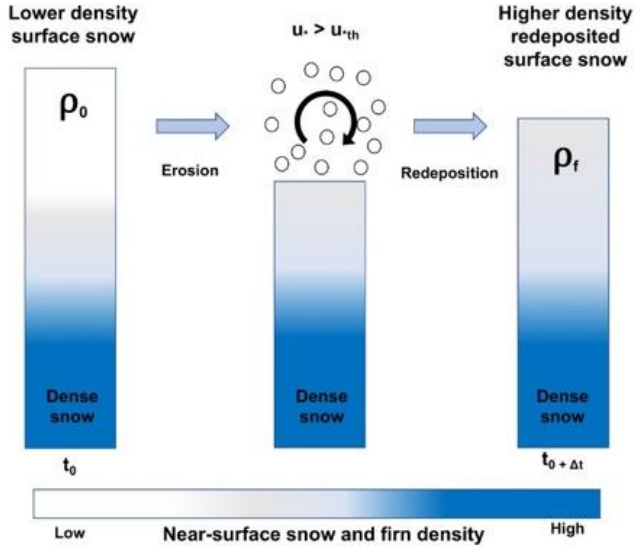
Group discussion!



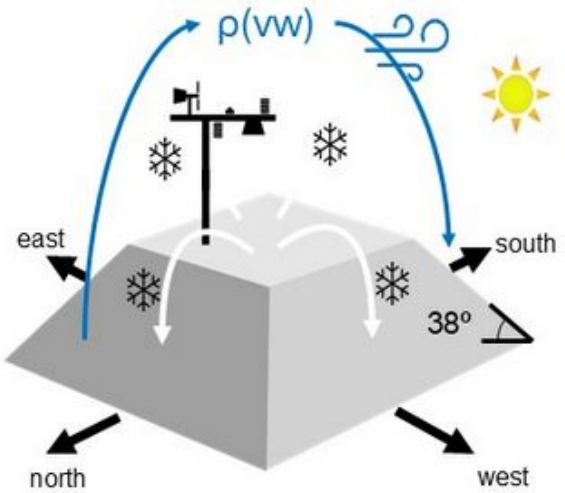
Snow-cover model: inherent shortcomings

- No physics-based link between snow microstructure and snow mechanics. Fracture-mechanical properties are estimated using empirical parametrizations.
- Many empirical parametrizations (density, new snow density, settlement, …)
- Precipitation phase usually as static threshold
- Wind processes (eroded and deposited mass, wind slab density)

Wind processes: redeposition as wind slabs



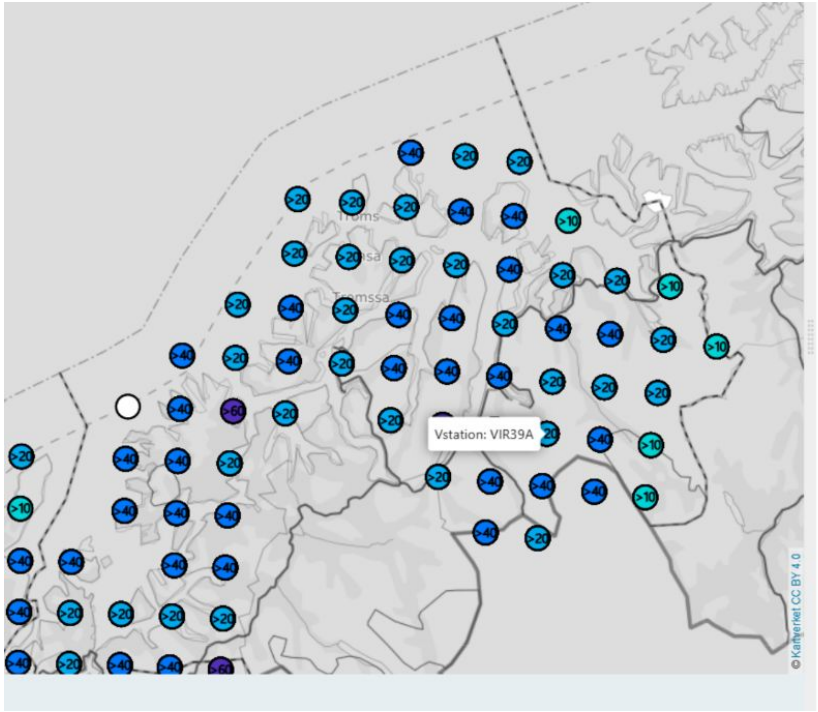
Keenan et al., 2021

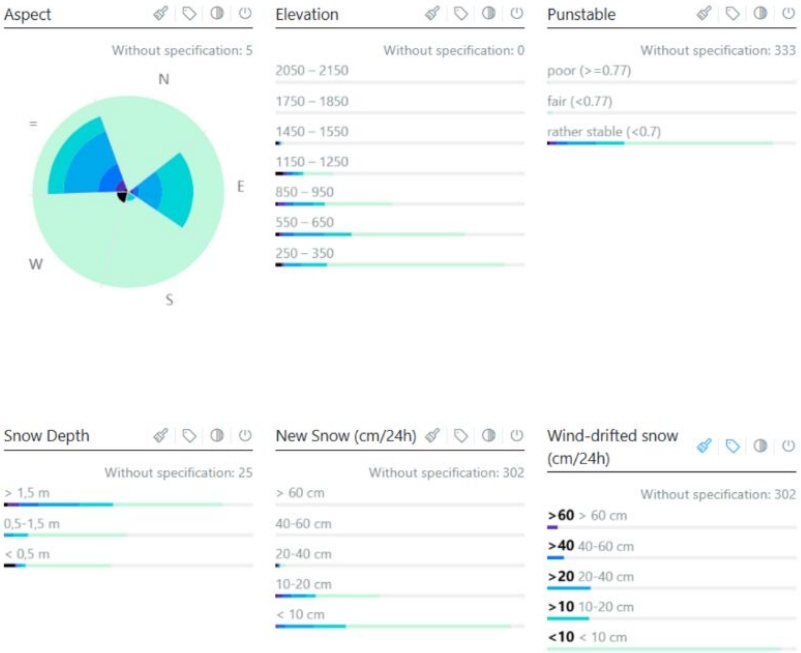


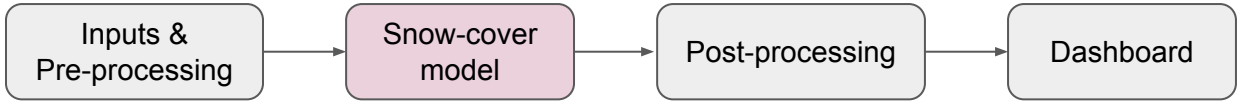
avacollabra.org/wind_in_snowpack

Wind processes: an improved wind-drift index

(by Bert Kruyt at NVE)



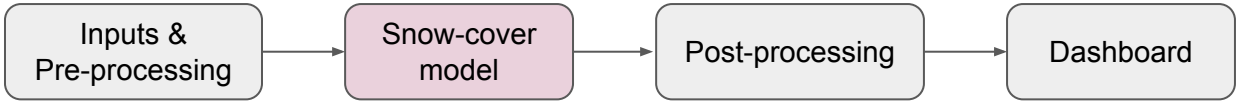




Wind processes improved

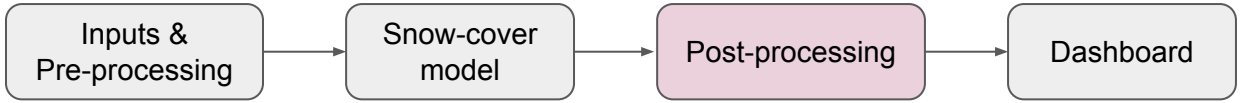
- Wind slab densities
- Drift index more interpretable
- Drift index separate for each virtual slope

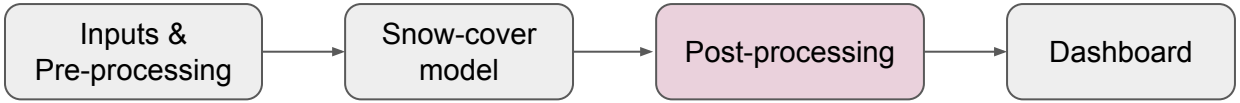
How much mass to transport from windward- to leeward side?



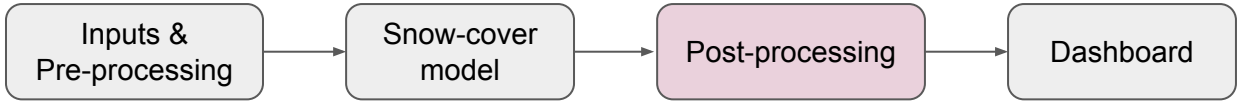
Intermediate Recap

1. Many processes are parametrized
2. Wind processes

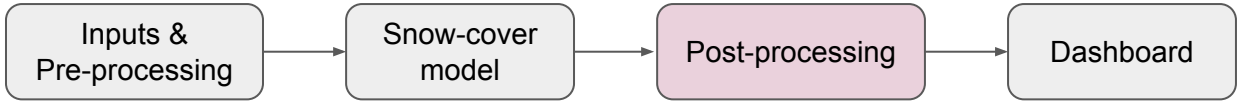

Inputs &
Pre-processing
Snow-cover
model
Post-processing
Dashboard



Post-processing — What is that? Why is it useful?



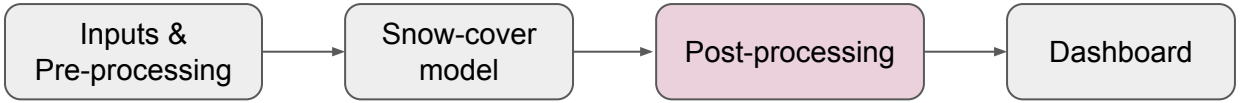
Facilitating **low-barrier access** to **relevant** information
for avalanche forecasting



Facilitating **low-barrier access** to **relevant** information
for avalanche forecasting

Goal:

- Additional information source
- Second, independent opinion
- Automation of simple tasks / support for bulletin generation

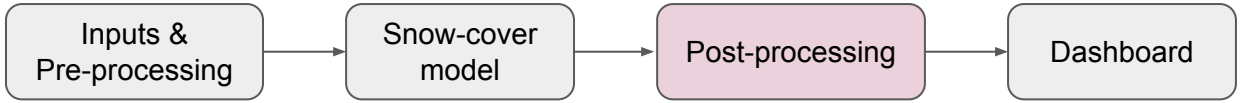


Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

Information about the **snow-cover** and **avalanche hazard**

Goal:

- Additional information source
- Second, independent opinion
- Automation of simple tasks / support for bulletin generation



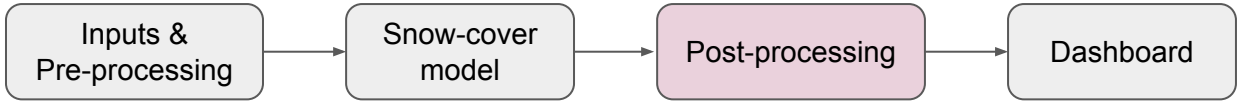
Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the **snow-cover** and **avalanche hazard**

<u>Goal:</u>

- Additional information source
- Second, independent opinion
- Automation of simple tasks / support for bulletin generation



Post-processing — What kind of tools exist?

Facilitating low-barrier access to **relevant** information: **point scale**

Instability indices & models

- How trigger-prone is a specific layer?
- Am I expecting avalanches at the profile location?
- Physics-based and data-driven solutions
- Different situations: type of slab and trigger

Facilitating low-barrier access to **relevant** information: **point scale**

Instability indices & models

trigger \ slab	dry	wet
artificial	Monti et al. (2016) *SK38* Richter et al. (2019) *CCL* Mayer et al. (2022) *Punstable* Borsotti et al. (in prep.) *SK38-CCL*	
natural	Reuter et al. (2021) *time-to-failure* Mayer, Techel et al. (2023)	Mitterer et al. (2013) *LWC index* Hendrick et al. (2022)

physics-based
data-driven

Facilitating low-barrier access to **relevant** information: **point scale**

Instability indices & models

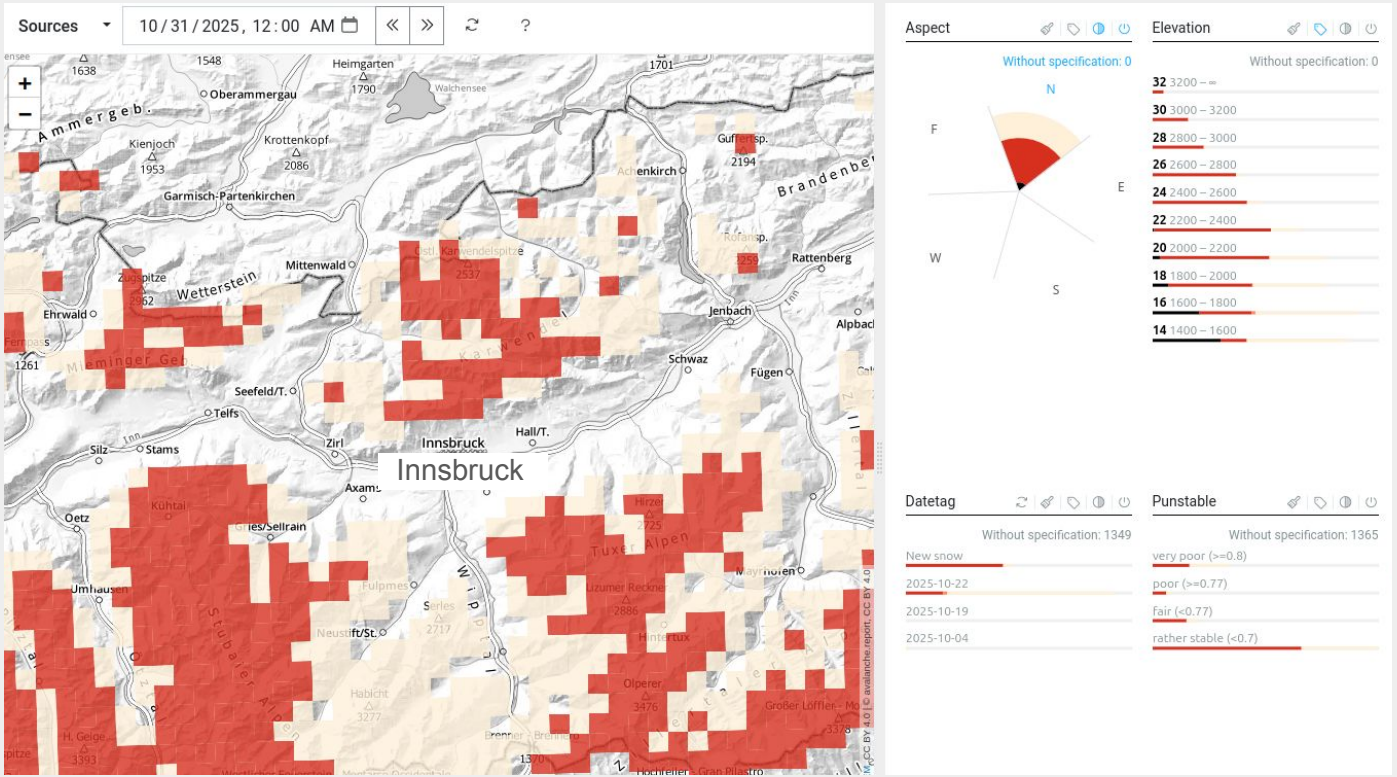
slab / trigger	dry	wet
artificial	(*)Monti et al. (2016) *SK38* (*)Richter et al. (2019) *CCL* (*)Mayer et al. (2022) *Punstable* (*)Borsotti et al. (in prep.) *SK38-CCL*	
natural	(*)Reuter et al. (2021) *time-to-failure* Mayer, Techel et al. (2023)	(*)Mitterer et al. (2013) *LWC index* Hendrick et al. (2022)

physics-based
data-driven
(*) AWSOME

Facilitating low-barrier access to **relevant** information: **regional scale**

Instability indices & models

“Overview first, details on demand”

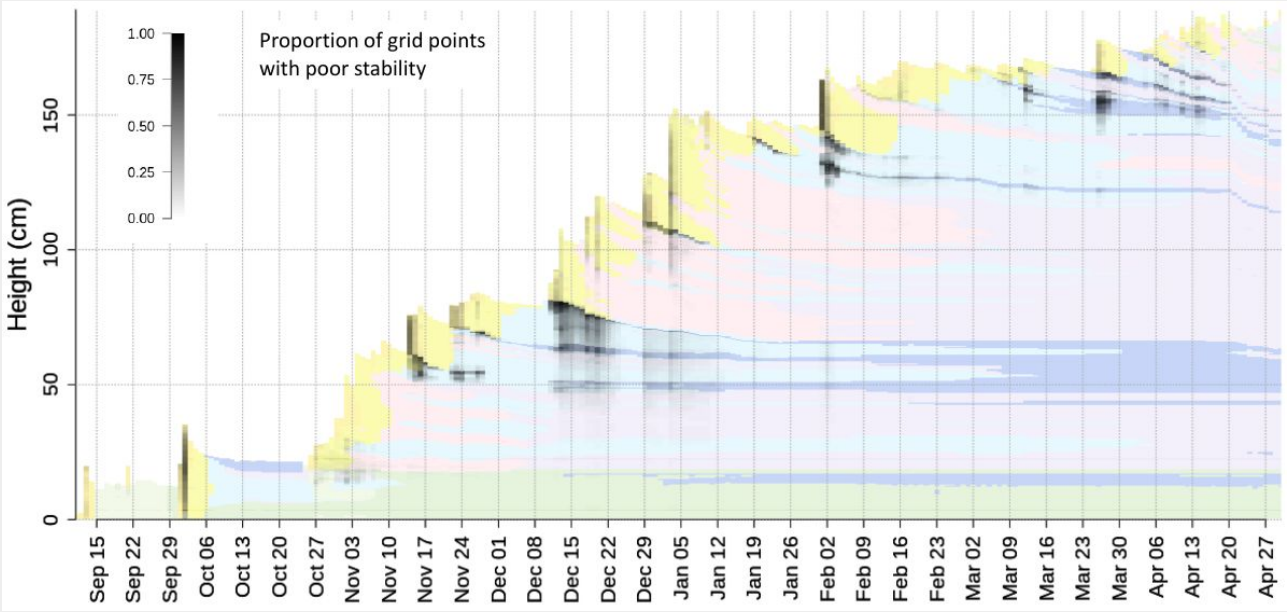


Facilitating **low-barrier** access to relevant information: **regional scale**

Instability indices & models

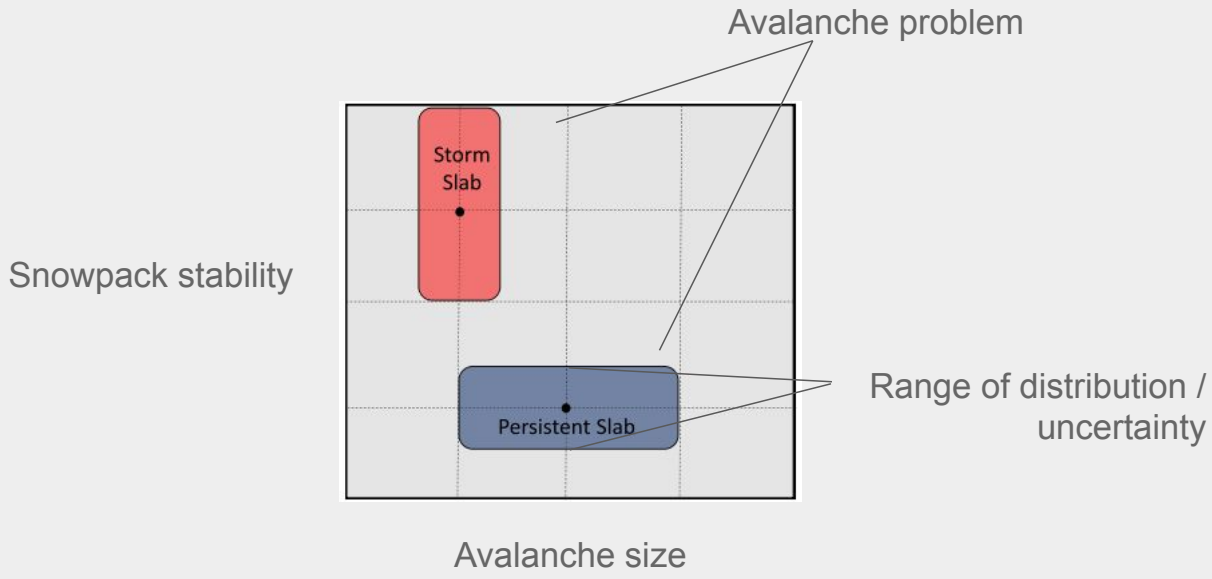
"Overview first, details on demand"

Representative profile per region – elevation band – aspect



Facilitating low-barrier access to relevant information: regional scale

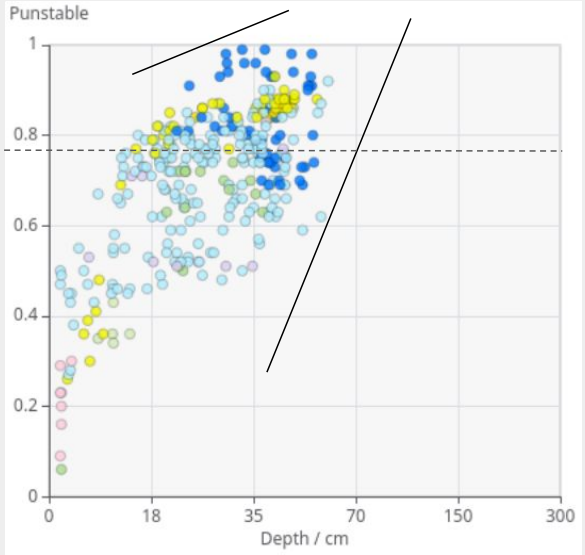
Hazard chart



Facilitating low-barrier access to relevant information: regional scale

Hazard chart

Frequency distribution



Poor

Fair

Rather stable

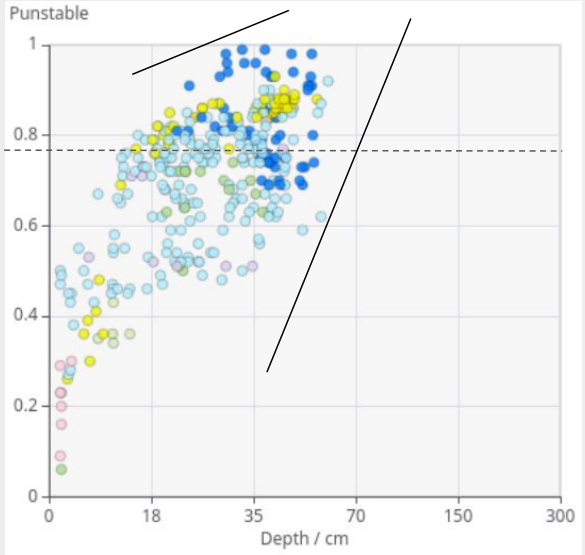
Snowpack stability

Anticipated failure depth (cm)
~ Avalanche size

Facilitating low-barrier access to relevant information: regional scale

Hazard chart

Frequency distribution



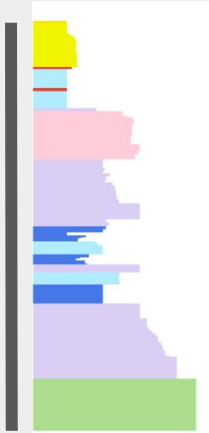
Poor

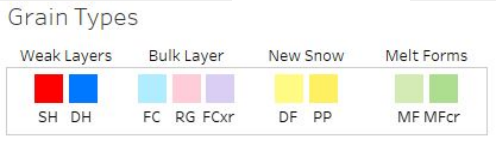
Fair

Rather stable

Snowpack stability

Anticipated failure depth (cm)
~ avalanche size

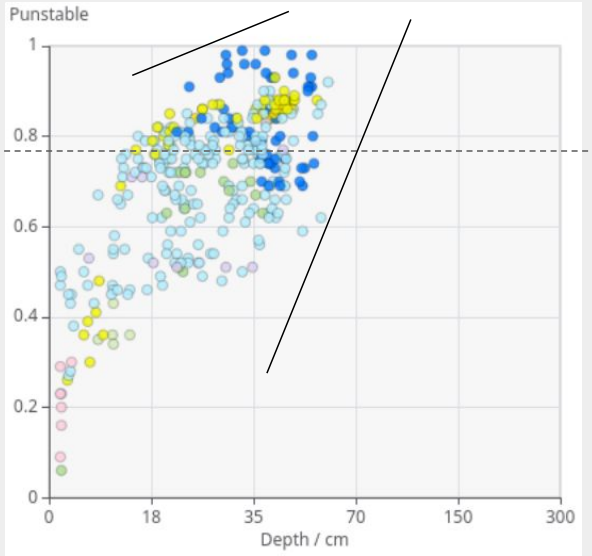


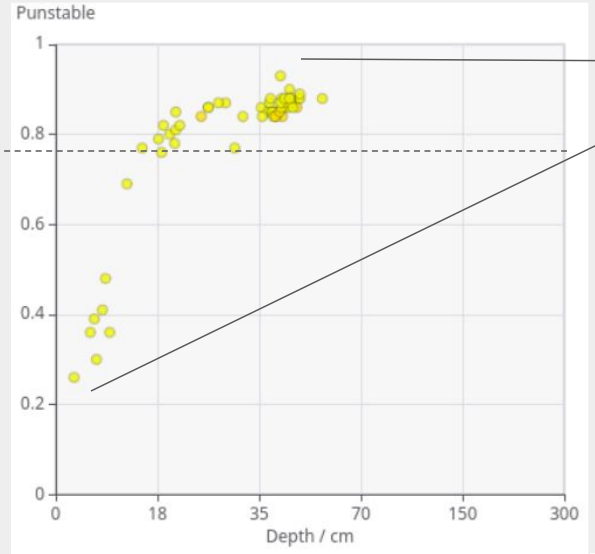


Facilitating low-barrier access to relevant information: **regional scale**

Hazard chart

Frequency distribution





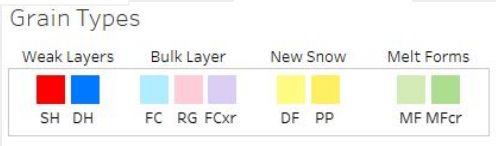
Poor

Fair

Rather stable

Snowpack stability

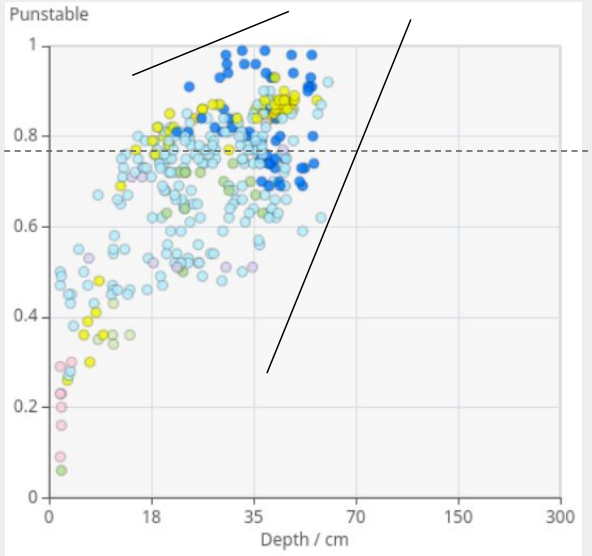
Anticipated failure depth (cm)
~ avalanche size

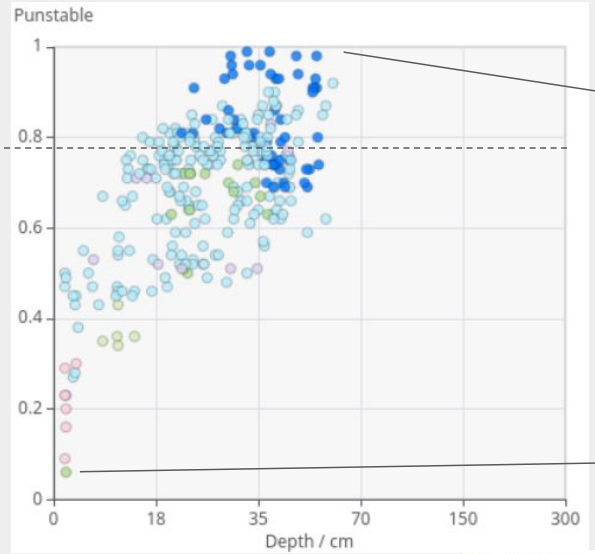


Facilitating low-barrier access to relevant information: **regional scale**

Hazard chart

Frequency distribution





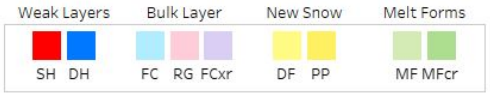
Poor

Fair

Rather stable

Snowpack stability

Grain Types

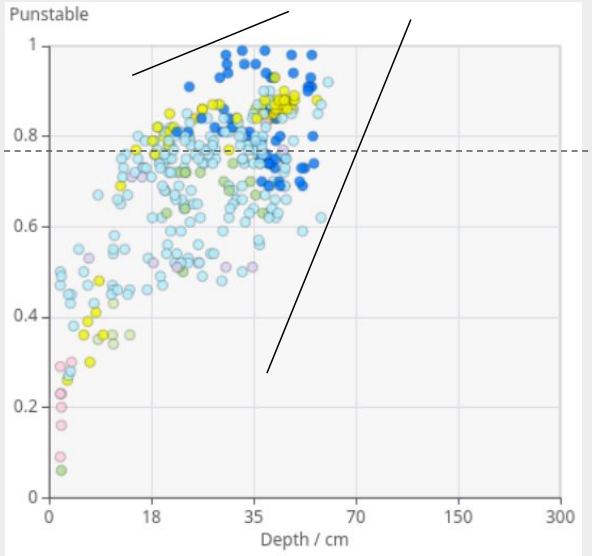


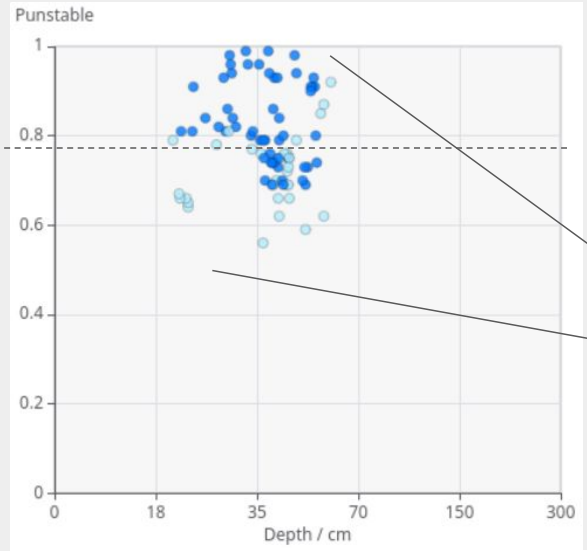
Anticipated failure depth (cm)
~ avalanche size

Facilitating low-barrier access to relevant information: **regional scale**

Hazard chart

Frequency distribution





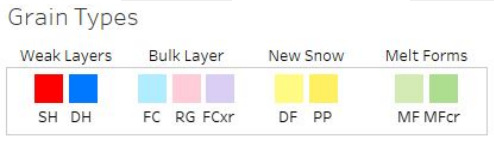
Poor

Fair

Rather stable

Snowpack stability

Anticipated failure depth (cm)
~ avalanche size

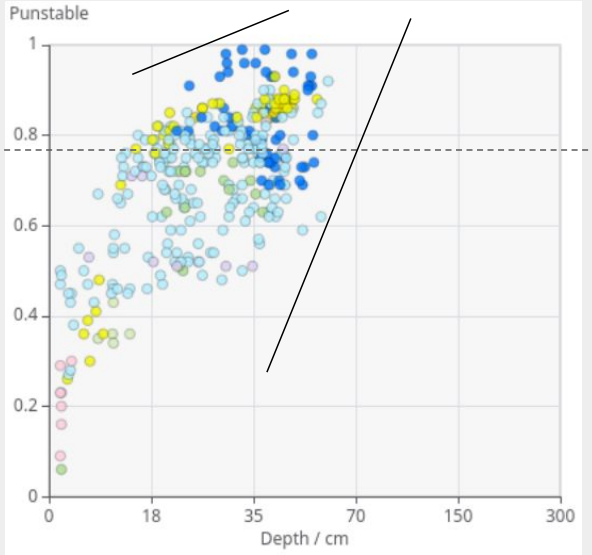


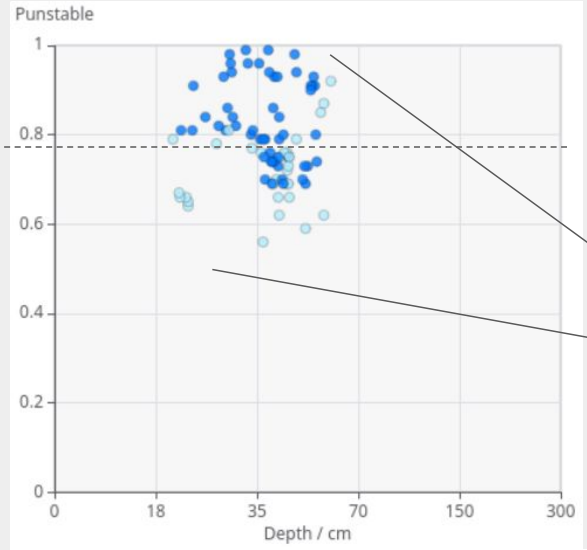
Facilitating low-barrier access to relevant information: regional scale

Hazard chart

"Overview first, details on demand"

Frequency distribution





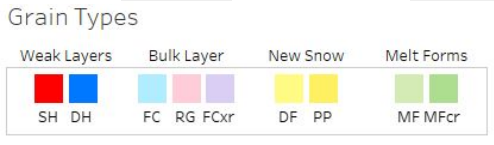
Poor

Fair

Rather stable

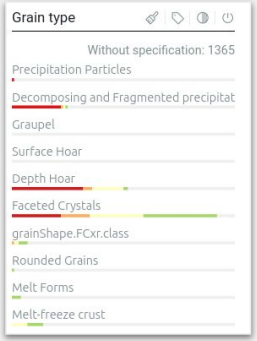
Snowpack stability

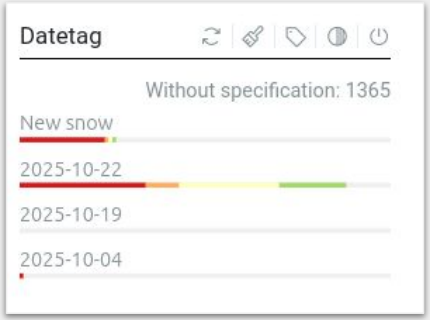
Anticipated failure depth (cm)
~ avalanche size

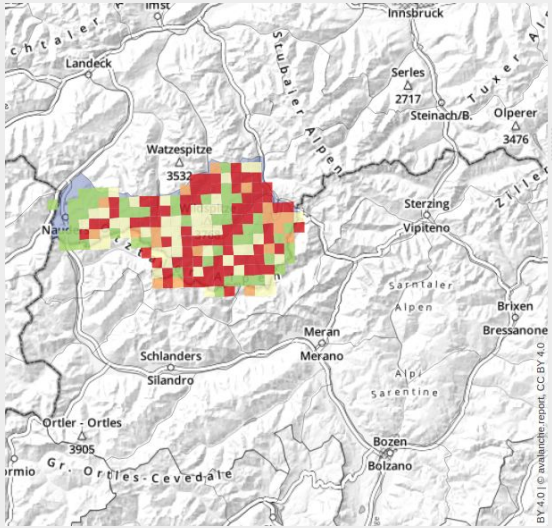


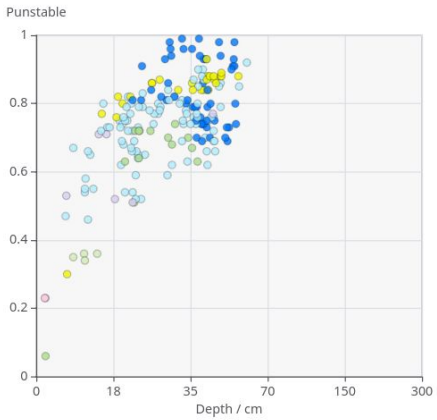
Facilitating low-barrier access to relevant information: regional scale

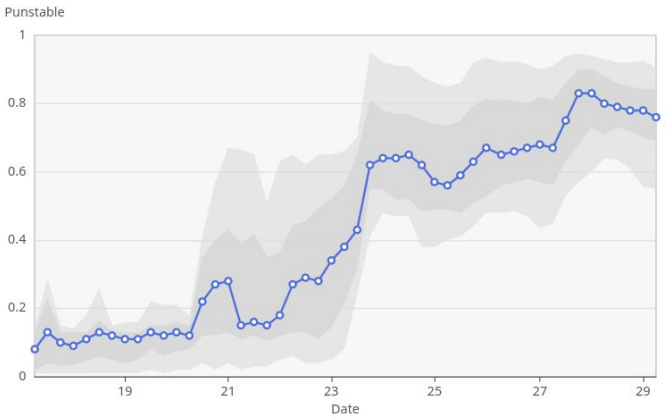
Hazard chart





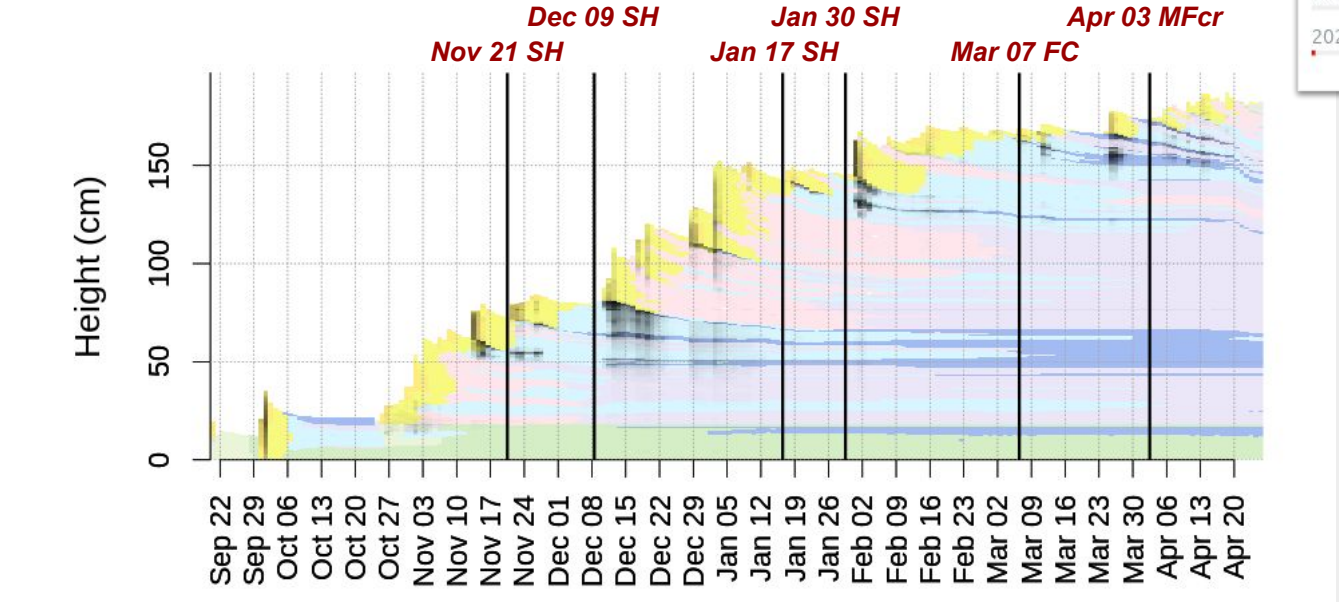


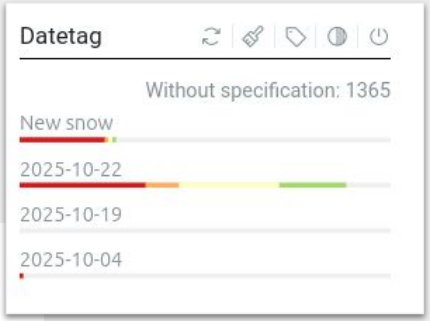


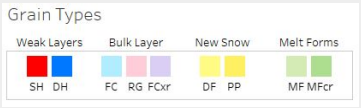


Facilitating low-barrier access to **relevant** information: **regional scale**

Datetags represent burial dates of the old snow surface

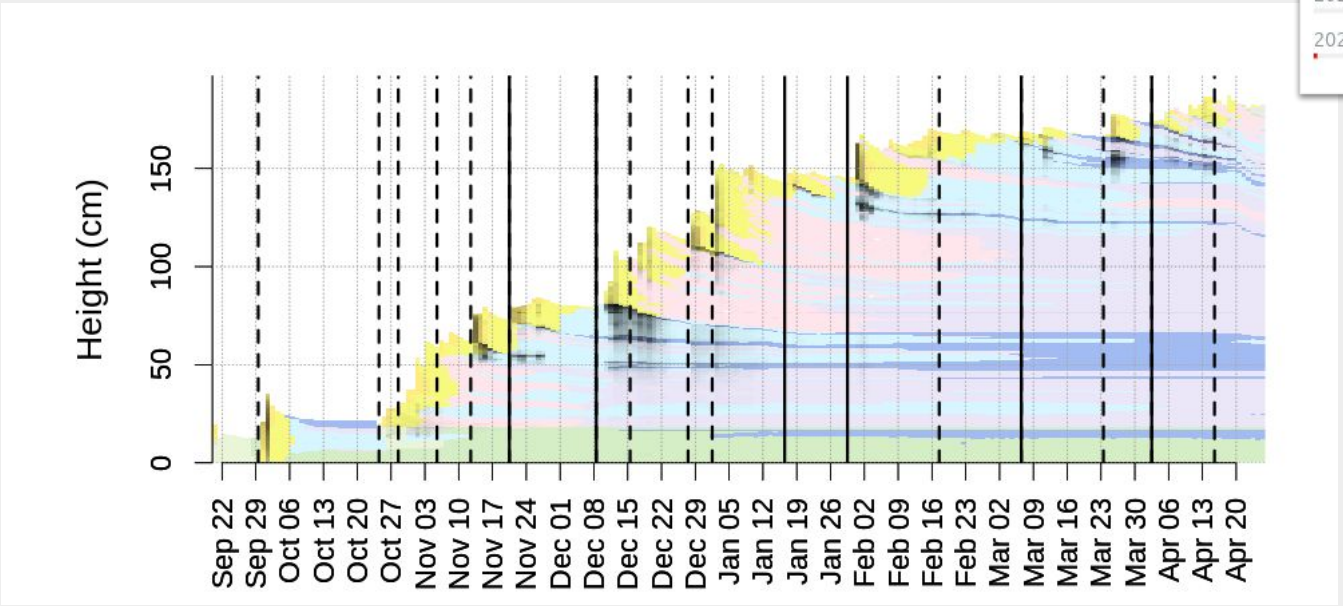


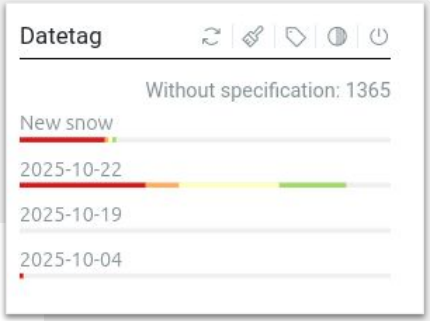


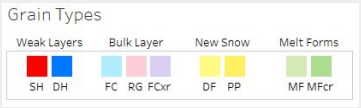


Facilitating low-barrier access to **relevant** information: **regional scale**

Datetags represent burial dates of the old snow surface

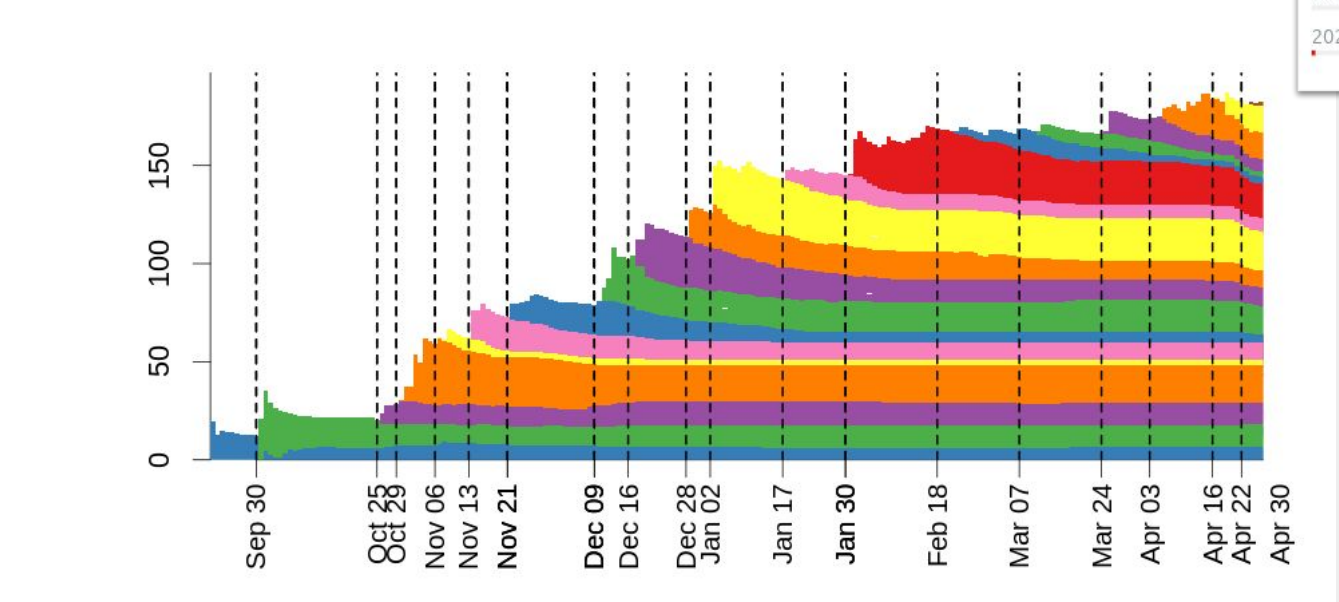


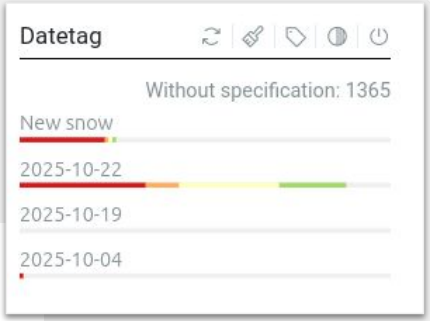


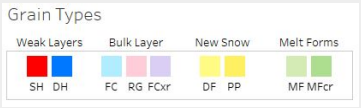


Facilitating low-barrier access to **relevant** information: **regional scale**

Datetags represent burial dates of the old snow surface

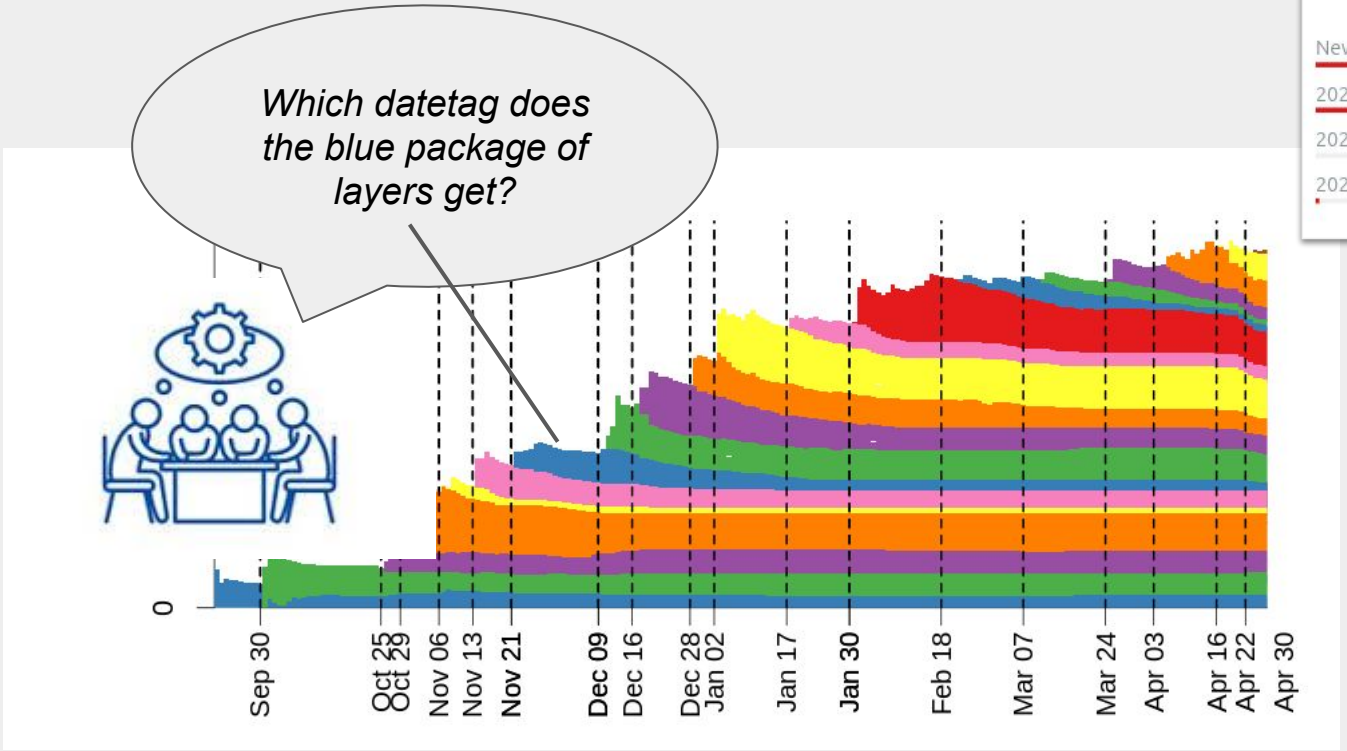


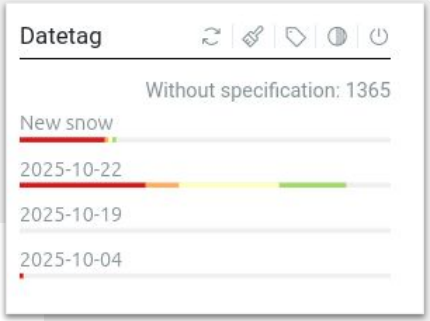


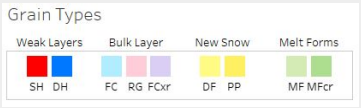


Facilitating low-barrier access to **relevant** information: **regional scale**

Datetags represent burial dates of the old snow surface







Facilitating low-barrier access to **relevant** information: **point scale**

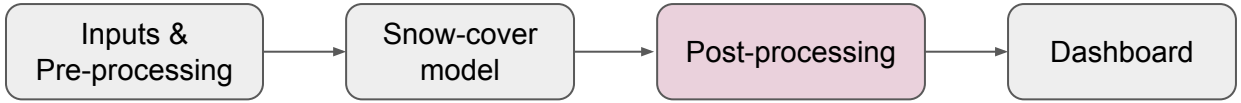
Danger rating

- Which danger level am I expecting in the microregion that a simulated profile belongs to?
- Perez et al. (2022)
  - Data-driven approach

Facilitating low-barrier access to **relevant** information: **regional scale**

Danger rating

- Interpolation from point values to full topography
- Virtual forecaster at SLF
  - Model prediction as equal opinion



Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the **snow-cover** and **avalanche hazard**

<u>Goal:</u>

- Additional information source
- Second, independent opinion
- Automation of simple tasks / support for bulletin generation

Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- ~~Summarize data flood~~
- Transformation Point → Region
- ~~*"Overview first, details on demand"*~~

Information about the **snow-cover** and **avalanche hazard**

<u>Goal:</u>

- Additional information source
- Second, independent opinion
- Automation of simple tasks / support for bulletin generation

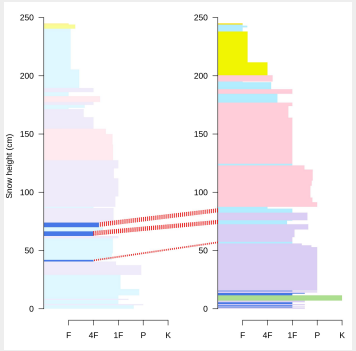
Facilitating low-barrier access to relevant information:

Where are my **region boundaries?**

Facilitating low-barrier access to relevant information: Where are my **region boundaries?**

Clustering (an optimization algorithm)

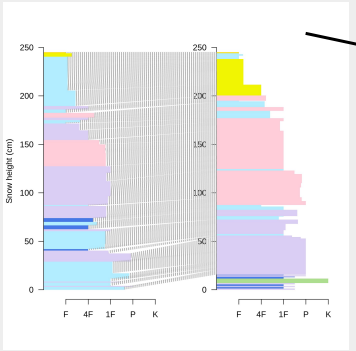
Layer matching (or feature matching)

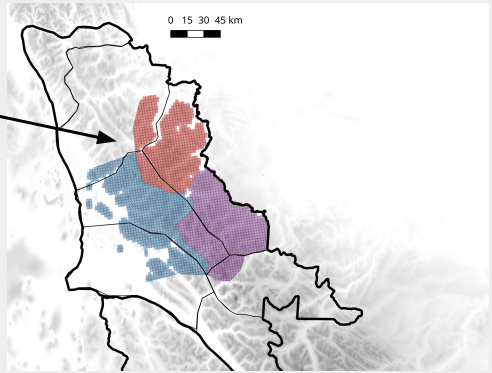


Facilitating low-barrier access to relevant information: Where are my **region boundaries?**

Clustering (an optimization algorithm)

Similarity assessment

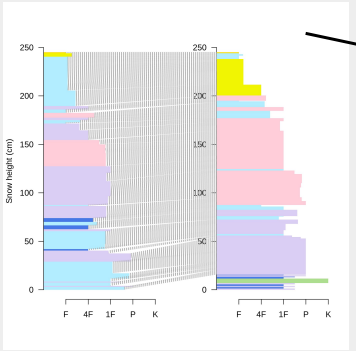


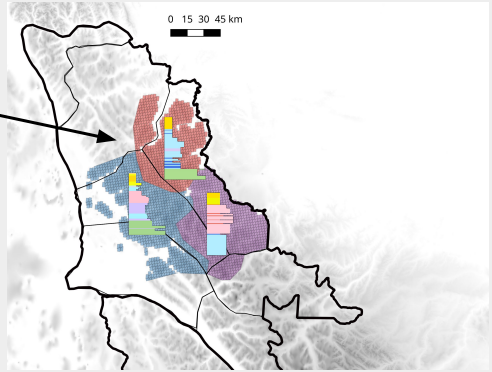


Facilitating low-barrier access to relevant information: Where are my **region boundaries?**

Clustering (an optimization algorithm)

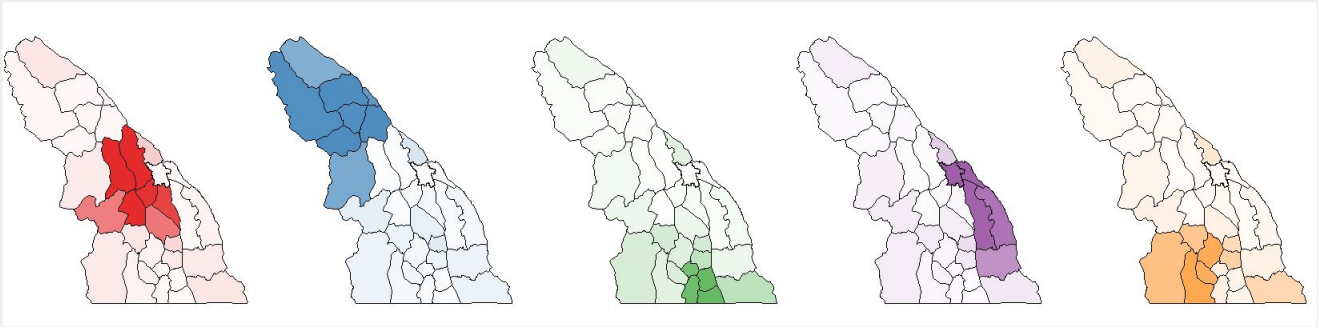
Similarity assessment



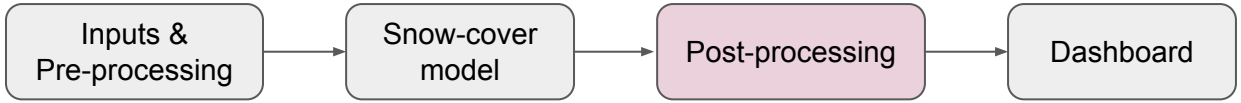


Facilitating low-barrier access to relevant information: Where are my **region boundaries?**

Clustering (an optimization algorithm)



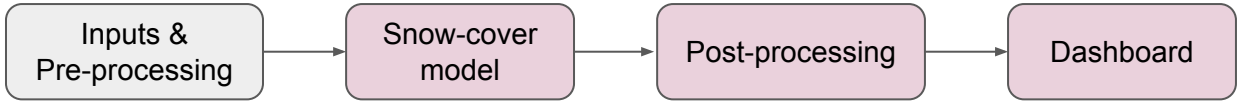
Horton et al. (2024)



Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the
snow-cover and **avalanche hazard**



Facilitating **low-barrier access** to **relevant** information
for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the
snow-cover and **avalanche hazard**

Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

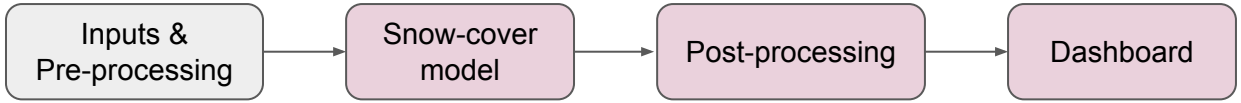
Facilitating **low-barrier access** to **relevant** information
for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the
snow-cover and **avalanche hazard**

Profiles and wind drift index

Snow-cover model



Facilitating **low-barrier access** to **relevant** information
for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Information about the
snow-cover and **avalanche hazard**

Profiles and wind drift index — Snow-cover model

Stability
Frequency distribution
Avalanche size — Post-processing

Datetags

Avalanche problems

Danger rating

Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *“Overview first, details on demand”*

Map, filters, details view — Dashboard

Information about the **snow-cover** and **avalanche hazard**

Profiles and wind drift index — Snow-cover model

Stability
Frequency distribution
Avalanche size — Post-processing

Datetags

Avalanche problems

Danger rating

Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

Facilitating **low-barrier access** to **relevant** information for avalanche forecasting

- Summarize data flood
- Transformation Point → Region
- *"Overview first, details on demand"*

Map, filters, details view — Dashboard

Representative profile
- Profile view across space/time

Post-processing

Hazard chart
- Layer-level visualization across space/time
- Features all three components of avalanche danger
- Drill-down into layer tracking via datetags

Clustering into dynamic forecast regions

Information about the **snow-cover** and **avalanche hazard**

Profiles and wind drift index — Snow-cover model

Stability
Frequency distribution
Avalanche size

Post-processing

Datetags → danger sources

Avalanche problems

Danger rating

Summary: Major sources of uncertainties

Group discussion!

Summary: Major sources of uncertainties

(1) Weather inputs

(3) Scale mismatch

(1) Wind

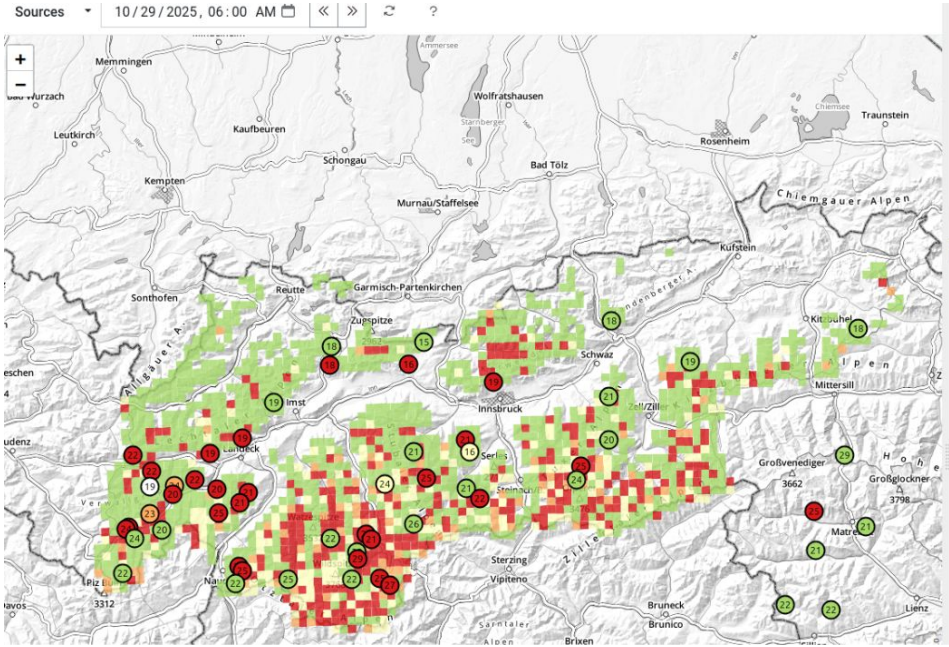
(2) Parametrizations, Training data

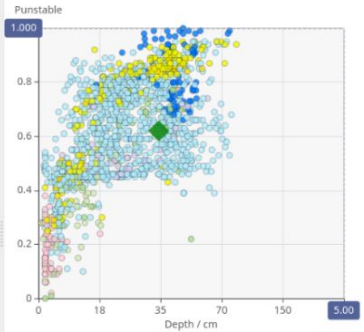
(2) Parametrizations, Training data

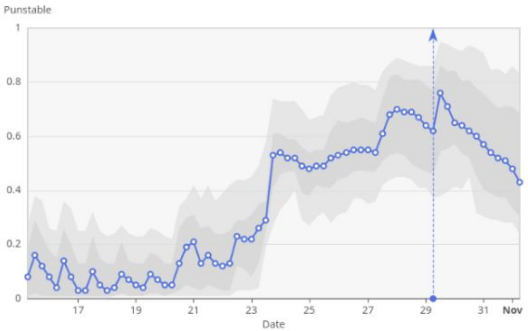
Each stage introduces errors that propagate downstream and influence overall results!

Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

https://admin.avalanche.report/dev/#/modelling/awsome



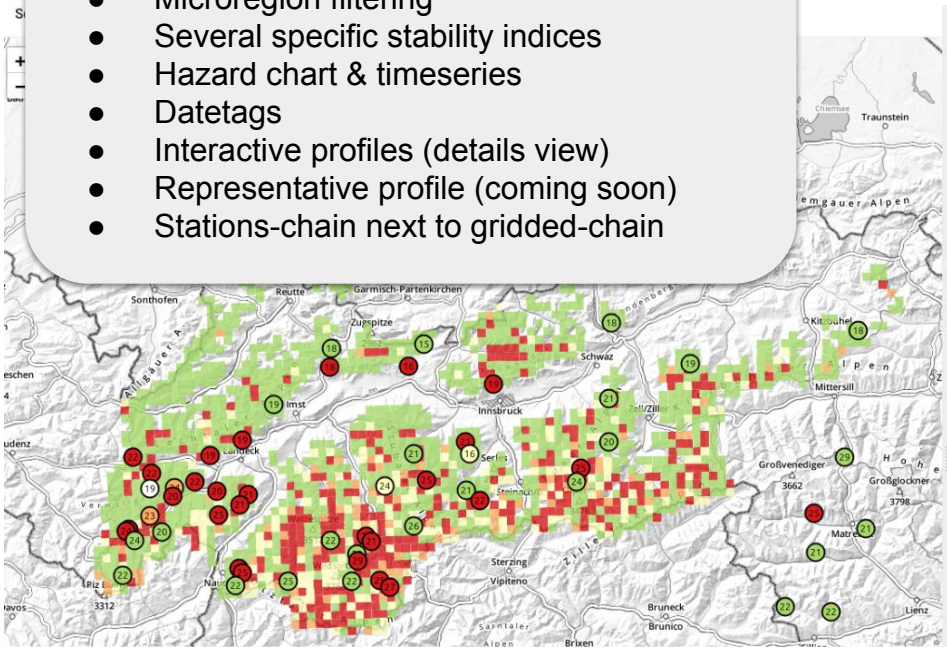


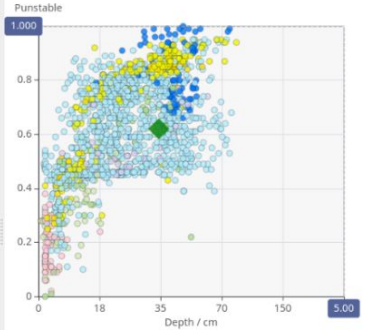


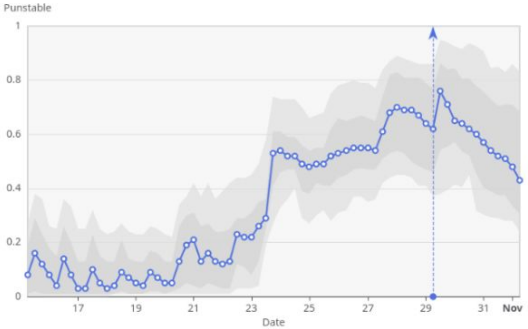
Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

https://admin.avalanche.report/dev/#/modelling/awsome

- Filters show distributions
- Microregion filtering
- Several specific stability indices
- Hazard chart & timeseries
- Datetags
- Interactive profiles (details view)
- Representative profile (coming soon)
- Stations-chain next to gridded-chain

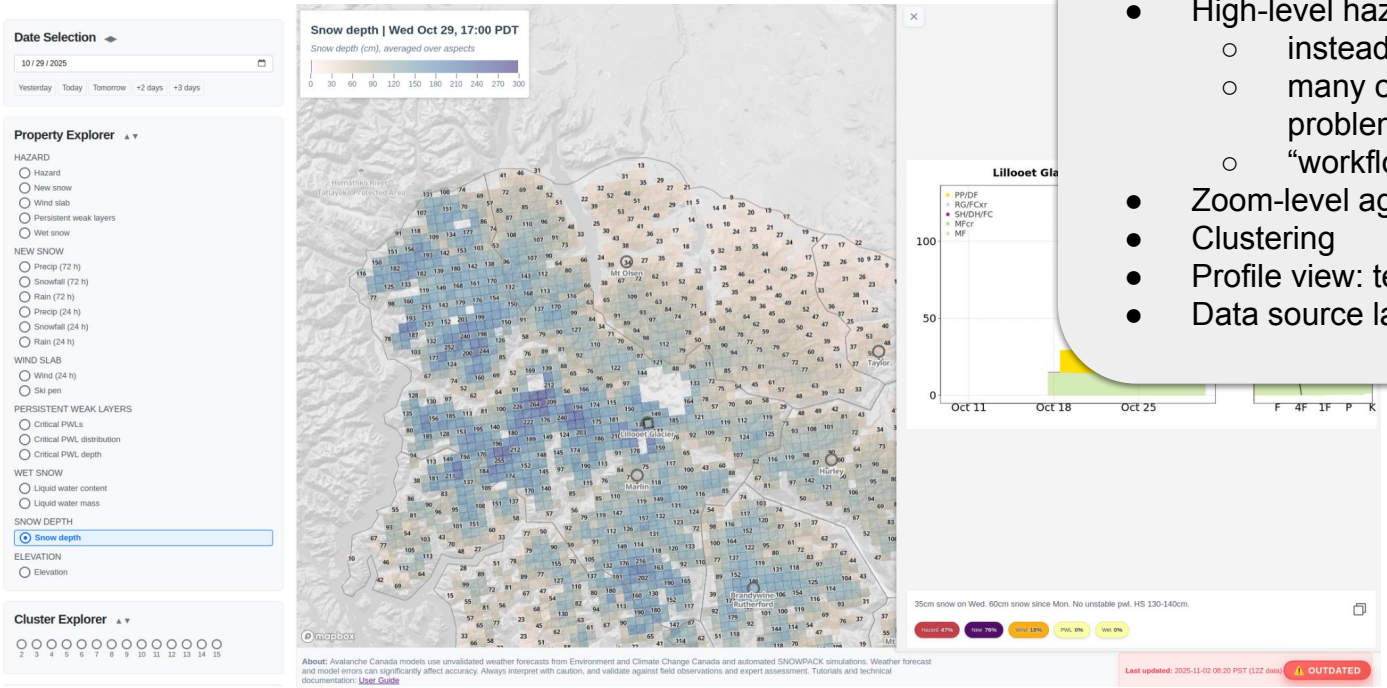




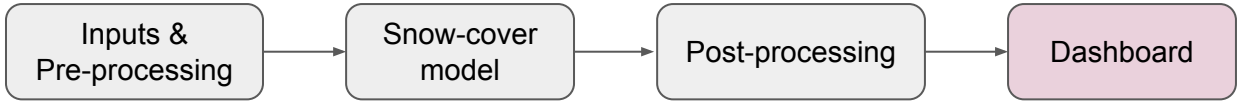


Inputs & Pre-processing → Snow-cover model → Post-processing → Dashboard

https://snowpack.avalanche.ca/



- Static property explorer
- High-level hazard metrics
  - instead of explicit indices
  - many of them, grouped by problems
  - “workflow”
- Zoom-level aggregation
- Clustering
- Profile view: text & metrics summary
- Data source label



Explore the dashboards and give us your feedback!

Try to scrutinize and critically reflect on:

https://admin.avalanche.report/dev/#/modelling/awsome

- Filters show distributions
- Microregion filtering
- Several specific stability indices
- Hazard chart & timeseries
- Datetags
- Interactive profiles (details view)
- Representative profile (coming soon)
- Stations-chain next to gridded-chain

https://snowpack.avalanche.ca/

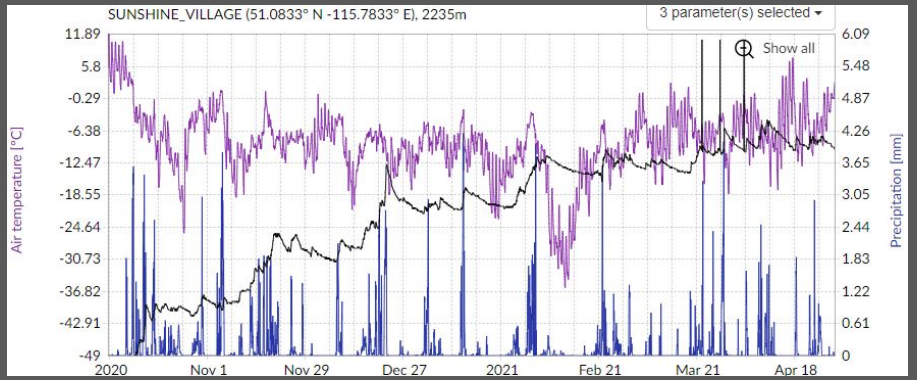
- Static property explorer
- High-level hazard metrics
  - instead of explicit indices
  - many of them, grouped by problems
  - “workflow”
- Zoom-level aggregation
- Clustering
- Profile view: text & metrics summary
- Data source label

Group discussion!

Everybody please post a summary of their thoughts into chat:

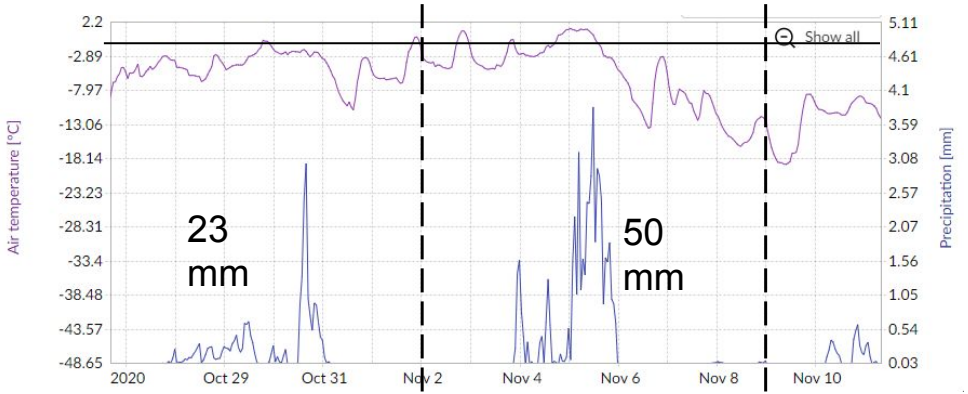
“I like xyz, because..”
“I am missing xyz. This would help me to assess …”
“I find confusing …”

Isolated hands-on exercises



Early season storms

Oct 28
HS = 35 cm

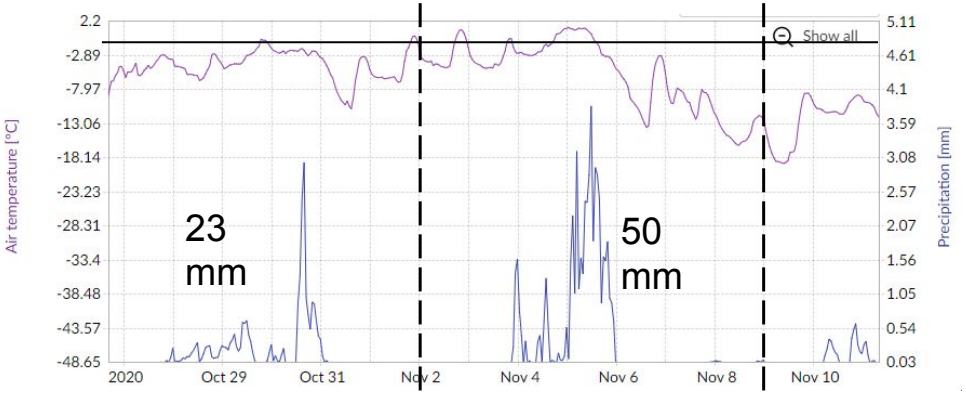


Nov 9
HS = ?

	QPF (mm)	Tmin	Tmax
2020-10-28	3	-7	-3
2020-10-29	6	-5	-1
2020-10-30	14	-3	-2
2020-10-31	1	-11	-3
2020-11-01	0	-7	0
2020-11-02	0	-5	1
2020-11-03	2	-5	0
2020-11-04	7	-3	1
2020-11-05	43	-4	1
2020-11-06	0	-14	-3
2020-11-07	0	-13	-5
2020-11-08	0	-16	-12
2020-11-09	0	-19	-9
2020-11-10	4	-12	-9

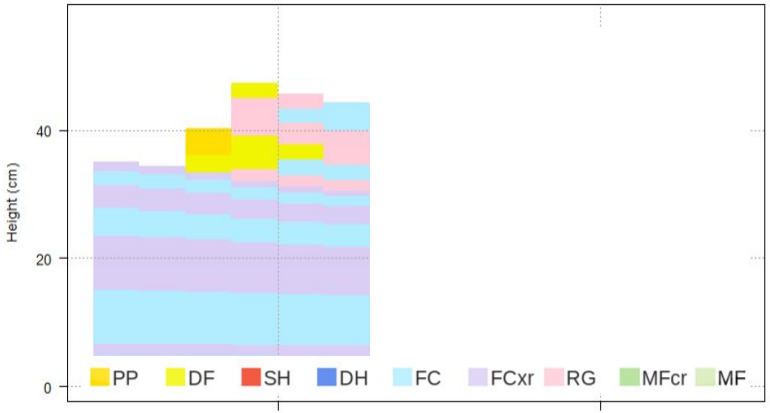
Early season storms

Oct 28
HS = 35 cm



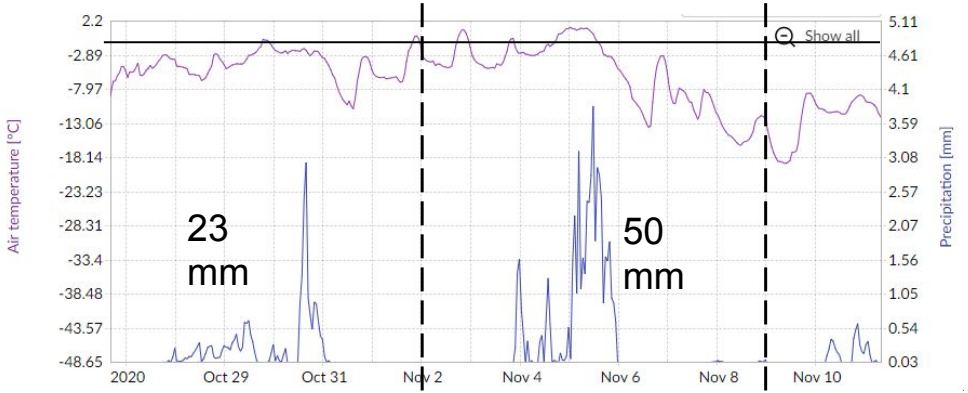
Nov 9
HS = ?

	QPF (mm)	Tmin	Tmax
2020-10-28	3	-7	-3
2020-10-29	6	-5	-1
2020-10-30	14	-3	-2
2020-10-31	1	-11	-3
2020-11-01	0	-7	0
2020-11-02	0	-5	1
2020-11-03	2	-5	0
2020-11-04	7	-3	1
2020-11-05	43	-4	1
2020-11-06	0	-14	-3
2020-11-07	0	-13	-5
2020-11-08	0	-16	-12
2020-11-09	0	-19	-9
2020-11-10	4	-12	-9



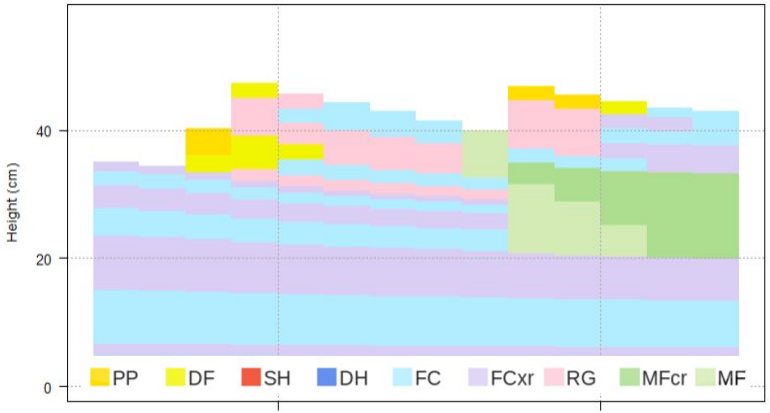
Early season storms

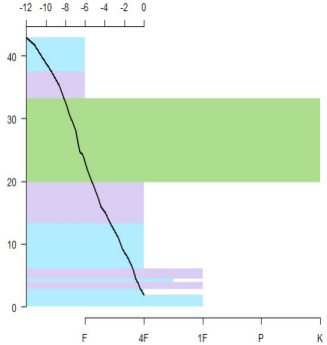
Oct 28
HS = 35 cm



Nov 9
HS = ?

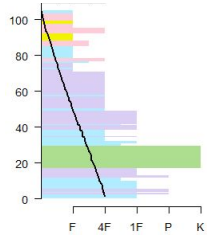
	QPF (mm)	Tmin	Tmax
2020-10-28	3	-7	-3
2020-10-29	6	-5	-1
2020-10-30	14	-3	-2
2020-10-31	1	-11	-3
2020-11-01	0	-7	0
2020-11-02	0	-5	1
2020-11-03	2	-5	0
2020-11-04	7	-3	1
2020-11-05	43	-4	1
2020-11-06	0	-14	-3
2020-11-07	0	-13	-5
2020-11-08	0	-16	-12
2020-11-09	0	-19	-9
2020-11-10	4	-12	-9

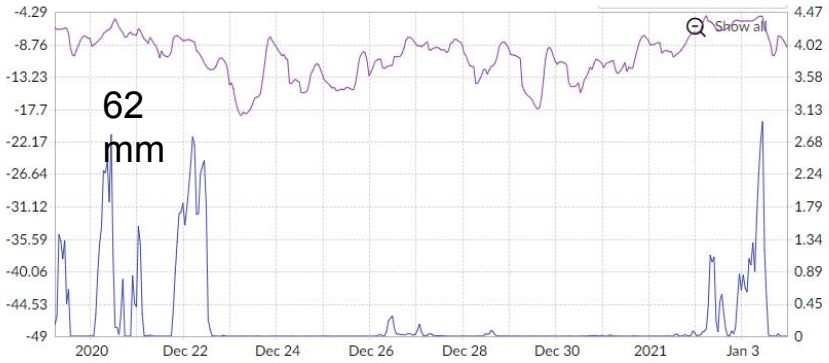


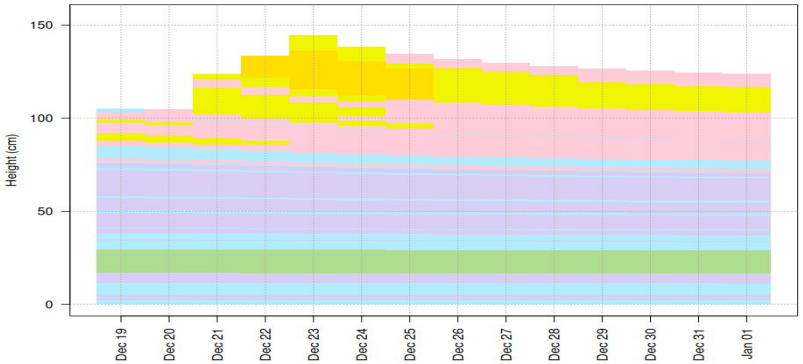


Christmas storm

Dec 19
HS = 105 cm



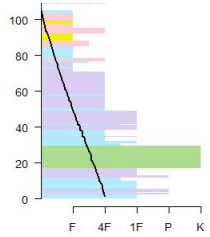


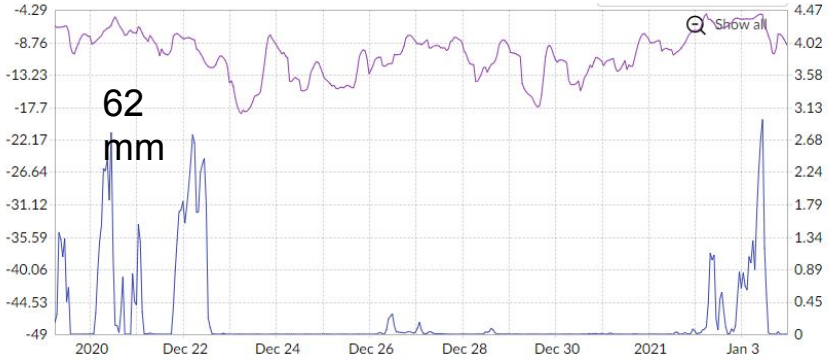


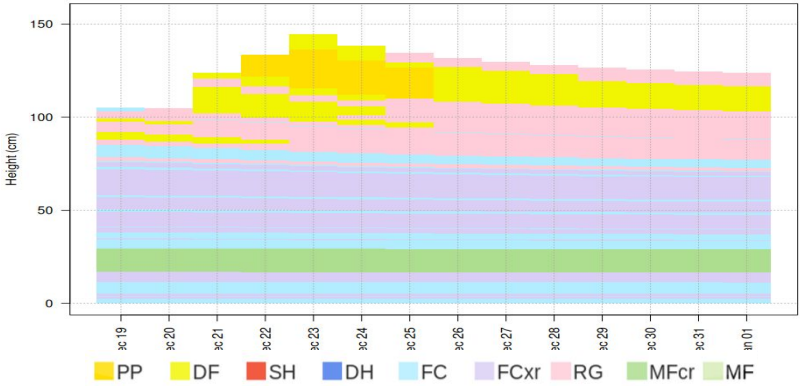
	QPF	Tmin	Tmax
2020-12-19	7	-10	-7
2020-12-20	19	-9	-5
2020-12-21	9	-11	-7
2020-12-22	27	-12	-8
2020-12-23	0	-19	-8
2020-12-24	0	-15	-9
2020-12-25	0	-15	-10
2020-12-26	1	-13	-8
2020-12-27	0	-10	-8
2020-12-28	0	-14	-8
2020-12-29	0	-18	-9
2020-12-30	0	-15	-11
2020-12-31	0	-13	-8
2021-01-01	0	-11	-7
2021-01-02	7	-7	-5

Christmas storm

Dec 19
HS = 105 cm



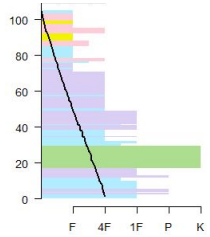


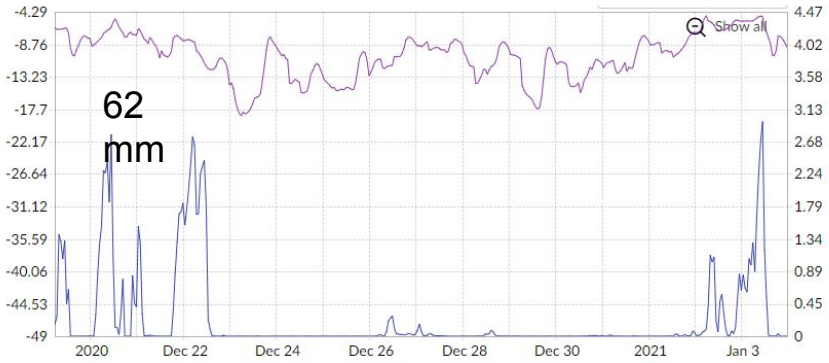


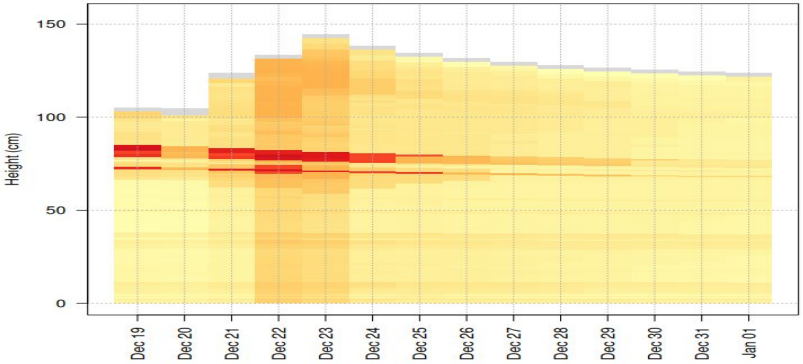
	QPF	Tmin	Tmax
2020-12-19	7	-10	-7
2020-12-20	19	-9	-5
2020-12-21	9	-11	-7
2020-12-22	27	-12	-8
2020-12-23	0	-19	-8
2020-12-24	0	-15	-9
2020-12-25	0	-15	-10
2020-12-26	1	-13	-8
2020-12-27	0	-10	-8
2020-12-28	0	-14	-8
2020-12-29	0	-18	-9
2020-12-30	0	-15	-11
2020-12-31	0	-13	-8
2021-01-01	0	-11	-7
2021-01-02	7	-7	-5

Christmas storm

Dec 19
HS = 105 cm

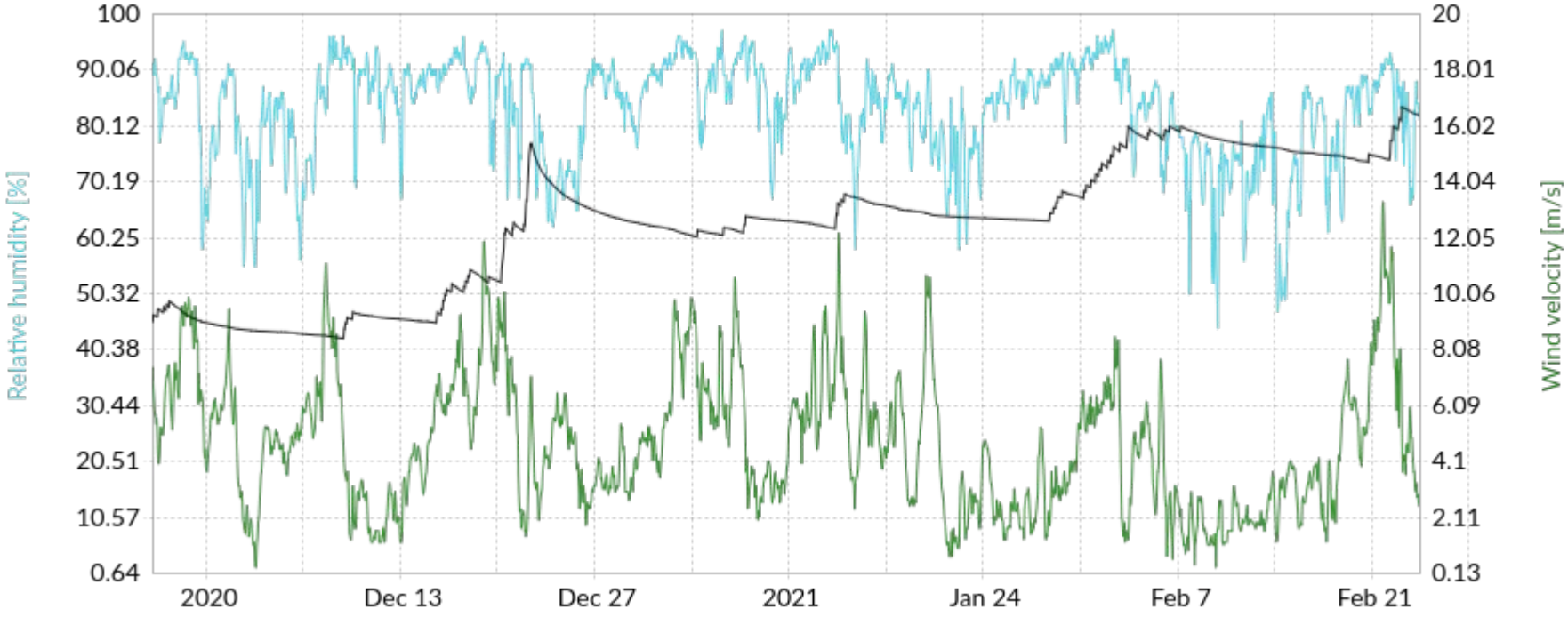




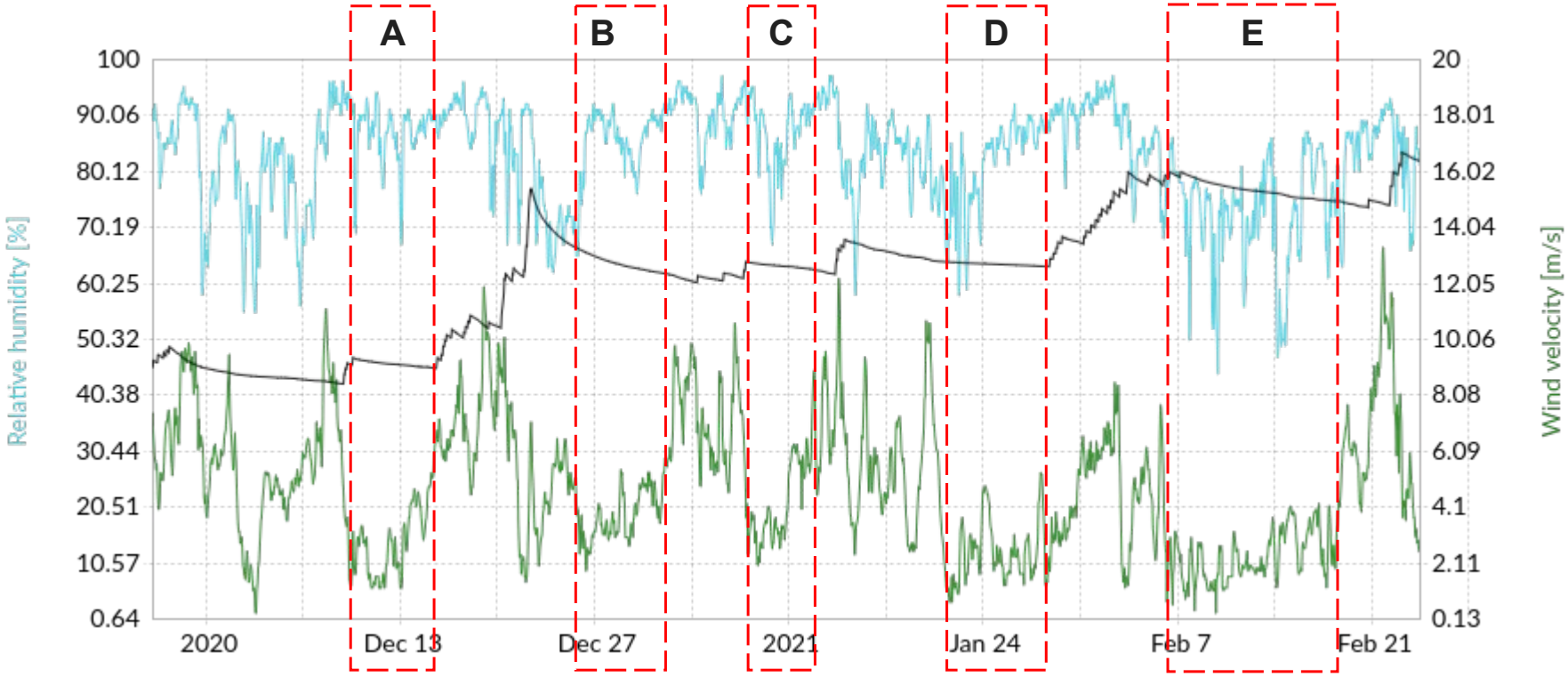


	QPF	Tmin	Tmax
2020-12-19	7	-10	-7
2020-12-20	19	-9	-5
2020-12-21	9	-11	-7
2020-12-22	27	-12	-8
2020-12-23	0	-19	-8
2020-12-24	0	-15	-9
2020-12-25	0	-15	-10
2020-12-26	1	-13	-8
2020-12-27	0	-10	-8
2020-12-28	0	-14	-8
2020-12-29	0	-18	-9
2020-12-30	0	-15	-11
2020-12-31	0	-13	-8
2021-01-01	0	-11	-7
2021-01-02	7	-7	-5

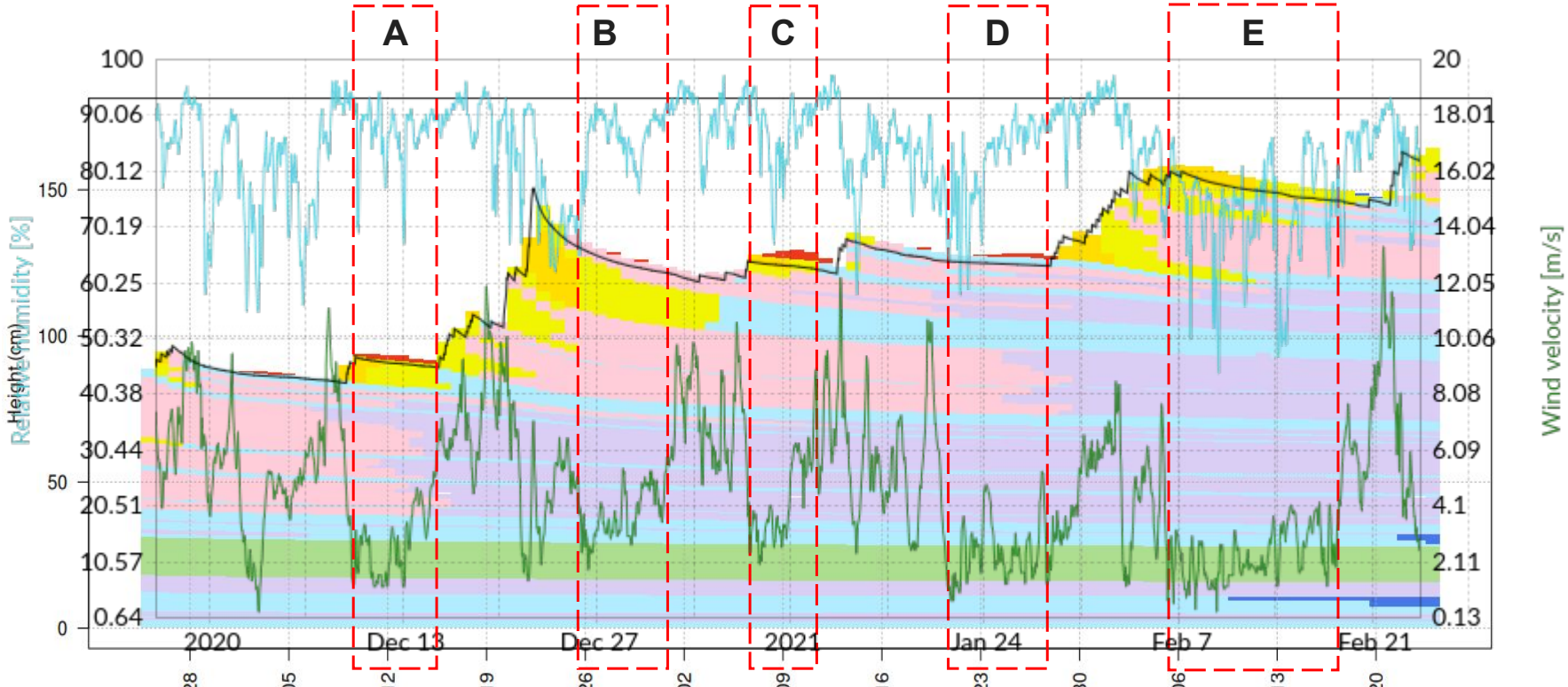
When might SH form?



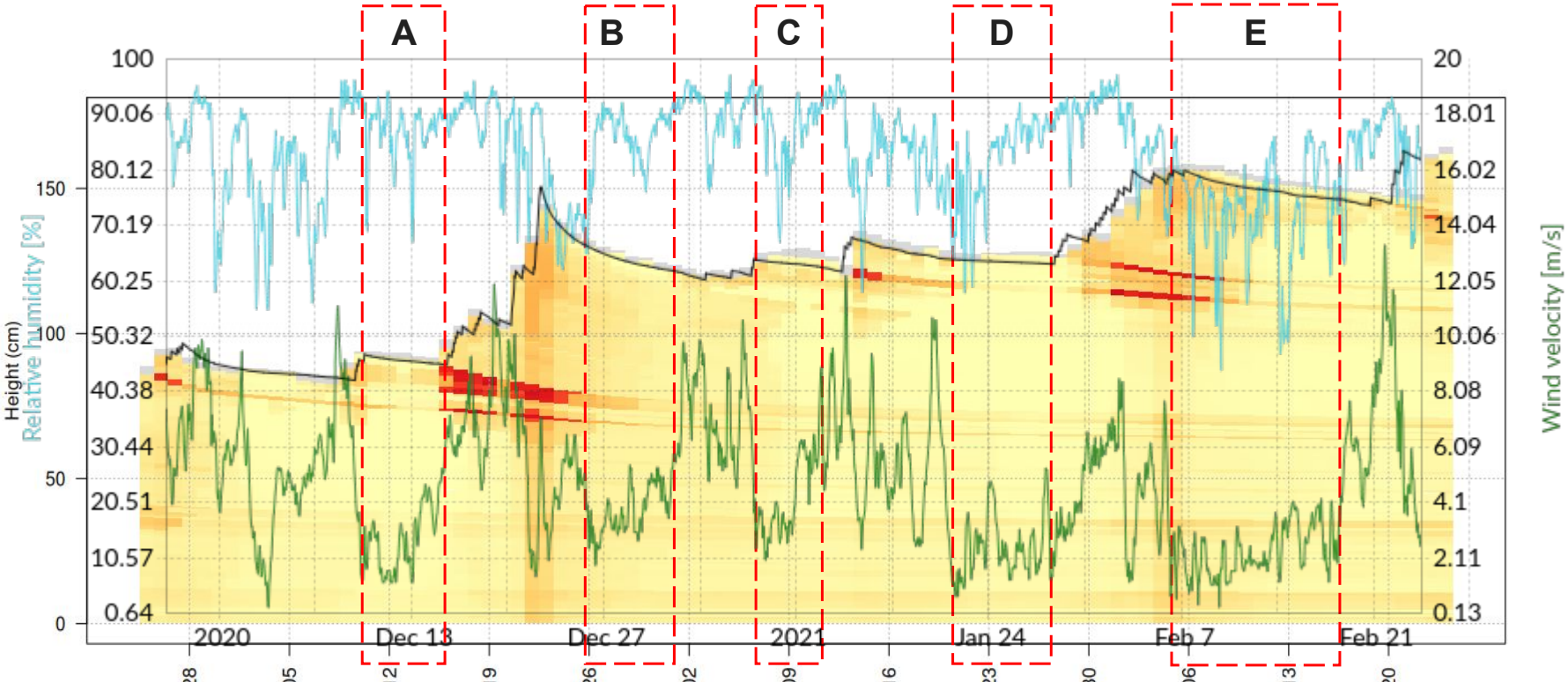
When might SH form?



When might SH form?



When might SH form?




Validation?

Model validation is challenging

- What validation data to use?
  - Type: Weather, Snowpack, Avalanche, Hazard, Impact
  - Origin: Instrument, Event, Synthesis, Assessment

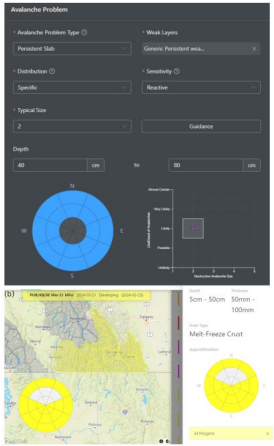
- How to evaluate?
  - Approach: Calibration,
    Quantitative or qualitative validation,
    Sensitivity, Uncertainty, Inter-comparison,
    Impact

- Scale mismatch

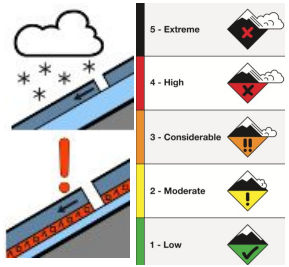
Validation studies

Snow depth

Weak layer assessments



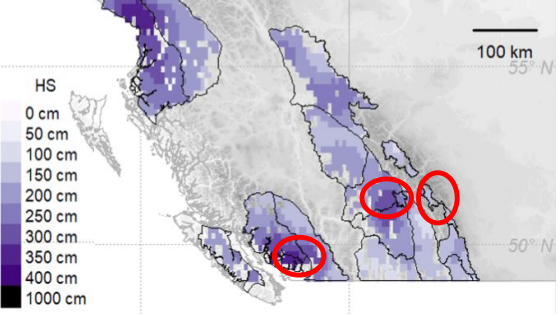
Problems/danger



Avalanche occurrences

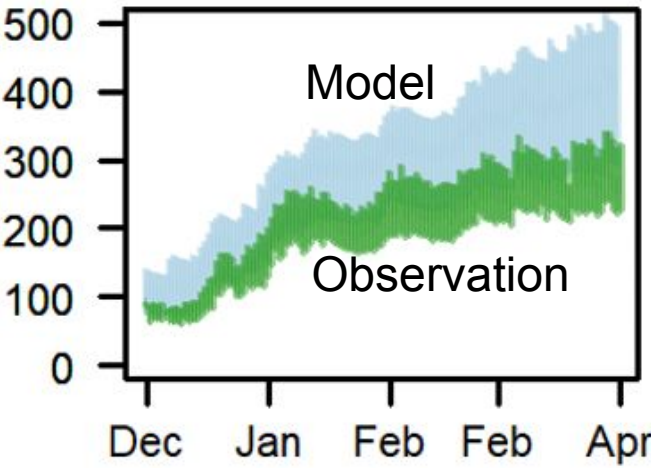
Snow depth validation

Does the total snow depth seem right?



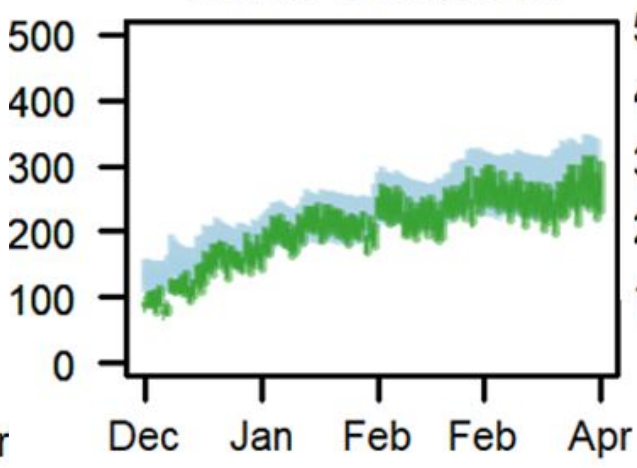
Coast Mountains

Sea To Sky



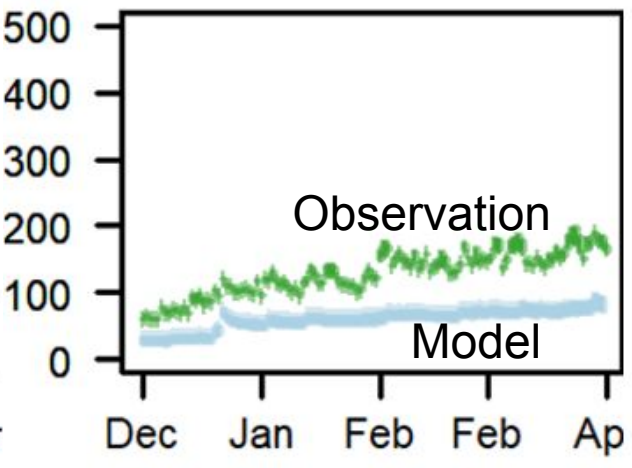
Columbia Mountains

North Columbia



Rocky Mountains

Kananaskis



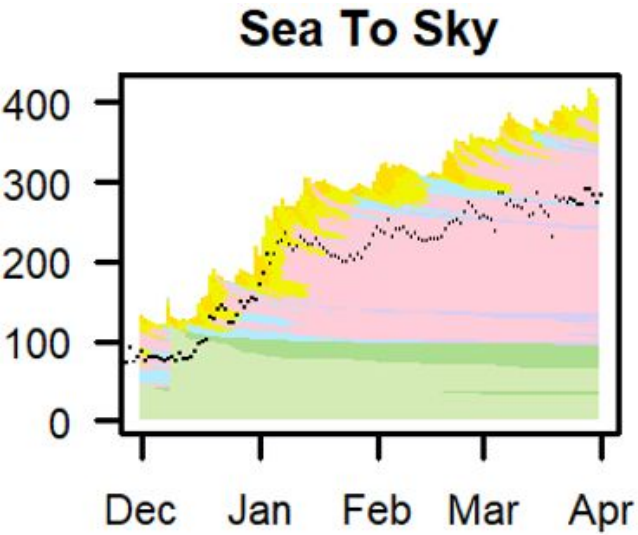
Upscaled observation

Model

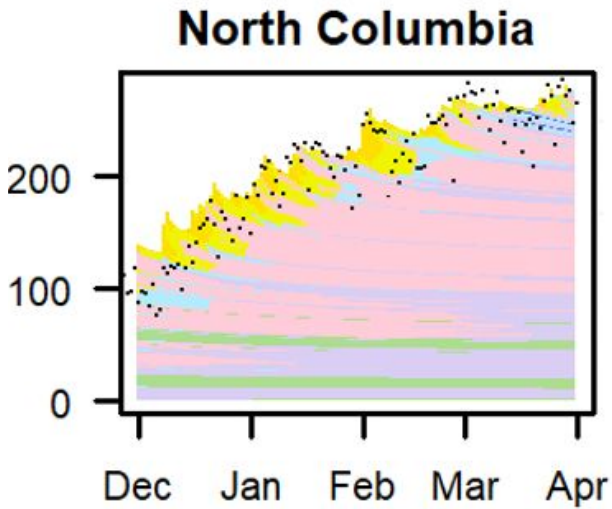
HS errors just stretch or compress the structure

HS errors can have severe impact on faceting

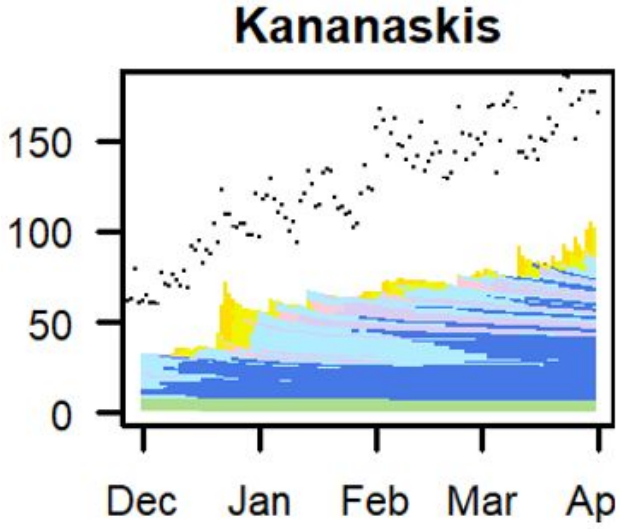
Coast Mountains



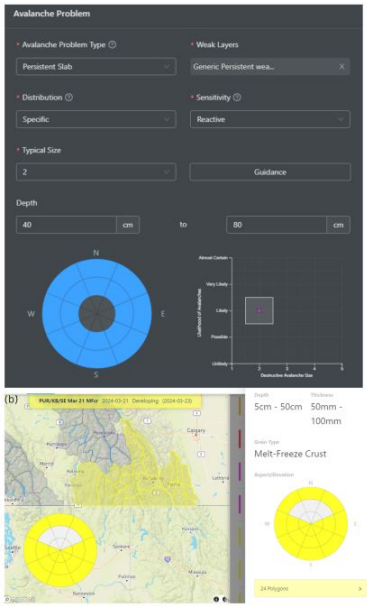
Columbia Mountains

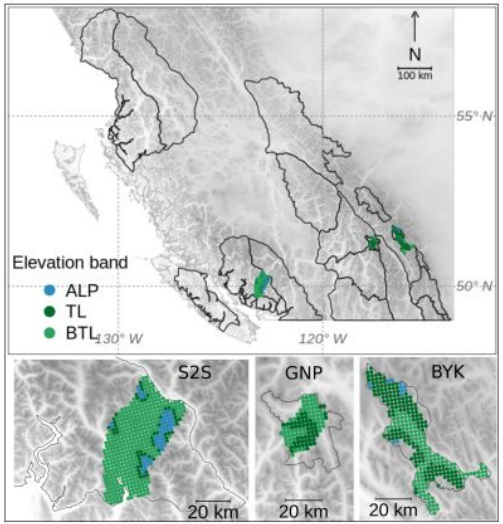


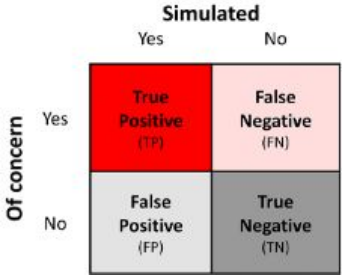
Rocky Mountains



Weak layer assessments





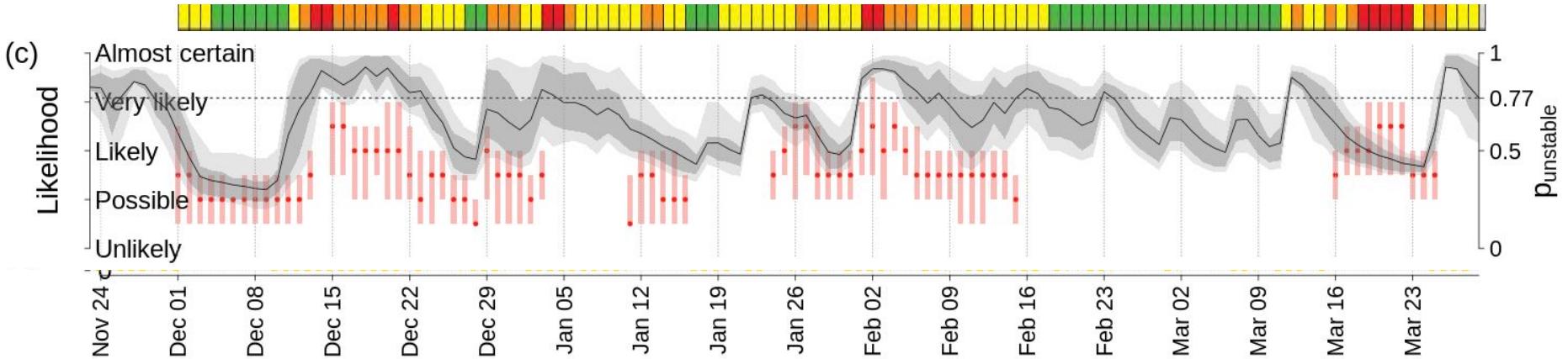


75% probability of detection
30% false alarm

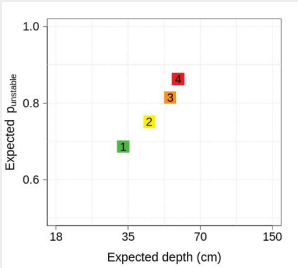
Weak layer assessments

- **SH:** few false alarms, best when formed over long periods (>7 d)
- **FC:** many false alarms
- **MFcr:** poorly matched with assessments, better with early season rain/temp crusts than sun crusts

Problems and danger



Good **seasonal** agreement



Highly variable **daily** agreement

- best for high-level assessments
- models sensitive to change

Real-time model evaluation

- Compare simulation against observations and your mental model
- Compare recent trends (simulation vs assessments)
- Scrutinize and critically reflect