

Corresponding author:
mnicora@fondms.org

# Modelling Glacier Ice Avalanches for Infrastructure Risk Assessment in the Alps

Insights from the PNRR Ecosistema dell'Innovazione
"Nord Ovest Digitale e Sostenibile" Project

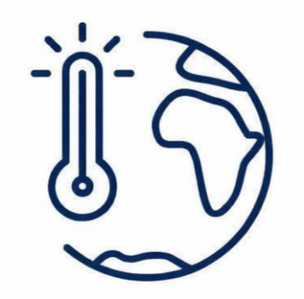
William Boffelli, **Maddalena Nicora**, Fabrizio Troilo, Pietro Di Sopra, Martina Lodigiani, Tommaso Congiu, Federico Rondano, Luca Mondardini, Paolo Perret

FONDAZIONE MONTAGNA SICURA
MONTAGNE SURE

# Context and Aim

Climate change is accelerating cryospheric degradation in the European Alps, increasing the frequency of glacial hazards like ice avalanches.

These events are stochastic and often lack precursory signs, posing a complex threat to high-altitude assets.



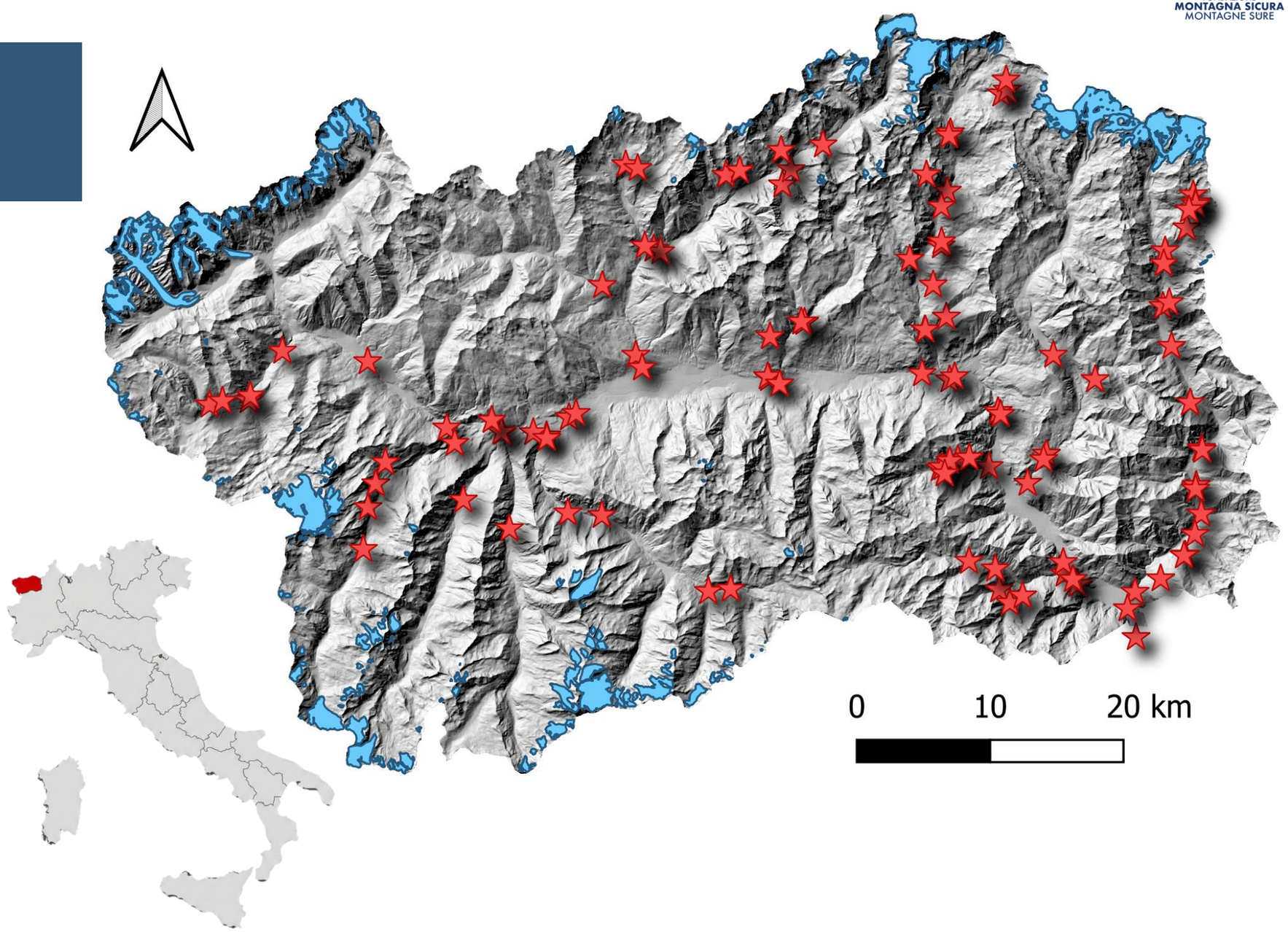
Develop a reproducible workflow to assess vulnerability of hydroelectric infrastructure in Aosta Valley, Italy.

FONDAZIONE
MONTAGNA SICURA
MONTAGNE SÛRE

# Study Area

## Why Aosta Valley?

- Most heavily glaciated region in Italy with over 170 glacial bodies
- Diverse glacier morphology: from small channelized bodies to complex glaciers
- Dense hydroelectric network with high-altitude infrastructure
- Comprehensive glaciological and topographical datasets available



# Methodology

**01**

## Database Construction

Historical ice avalanche data collection and statistical analysis using bootstrap regression

**02**

## Glacier Characterization

Volume estimation via zonal statistics and classification into five volume classes

**03**

## Release Point Definition

Intersection of flowlines with glacier fronts, applying densification strategy

**04**

## Numerical Simulation

r.randomwalk model execution

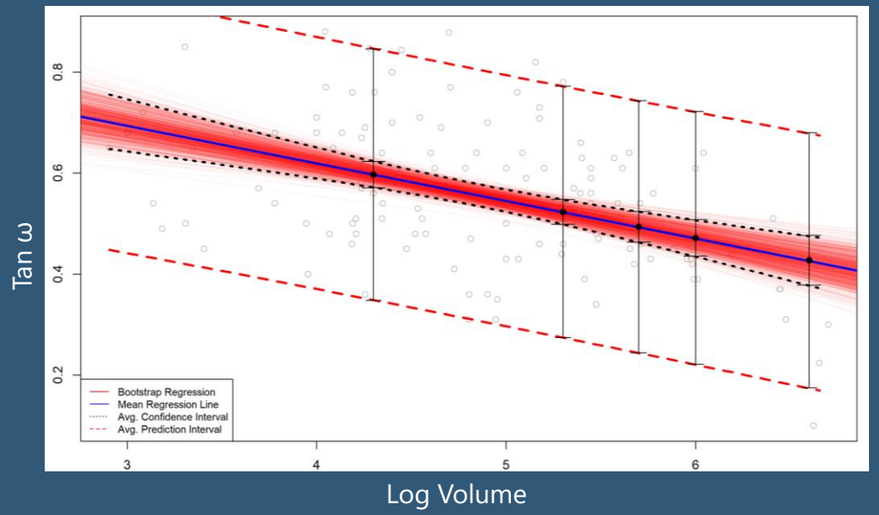
**05**

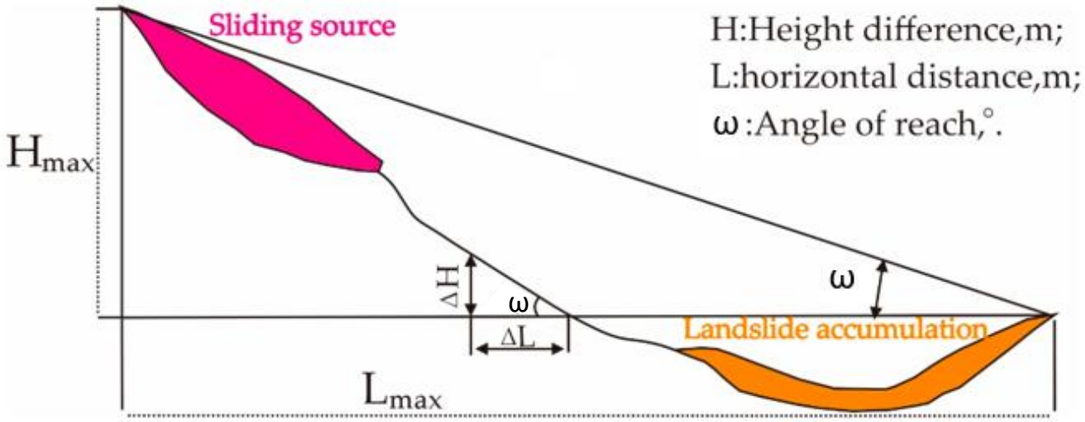
## Impact Assessment

Generation of Impact Frequency maps and spatial analysis of infrastructure interference

# Statistical Analysis

| Ice avalanche | Log V | Tangent of ω | L (km) | H (km) |
|---|---|---|---|---|
| Whymper | 4,447 | 0,844 | 0,17 | 0,13927 |
| Whymper | 4,279 | 0,847 | 0,17 | 0,144392 |
| Triolet | 7,255 | 0,258 | 7,2 | 1,86 |
| Devastation | 7,332 | 0,174 | 7 | 1,22 |
| Huascaran | 7,114 | 0,232 | 7,5 | 0,95 |
| Huascaran | 7,778 | 0,247 | 15,52 | 3,6 |
| Tour | 5,653 | 0,452 | 1,12 | 0,506 |
| Grands Couloirs | 5,301 | 0,463 | 2,202 | 1,02 |
| Grande Motte | 5,301 | 0,543 | 1,563 | 0,848 |
| Taconnaz | 5,447 | 0,564 | 0,479 | 0,27 |
| Taconnaz | 5,447 | 0,607 | 0,672 | 0,408 |
| Bossons | 5,176 | 0,456 | 0,853 | 0,389 |
| Dôme des Ecrins | 5,000 | 0,607 | 0,954 | 0,579 |
| Bionassay | 5,176 | 0,732 | 0,908 | 0,665 |



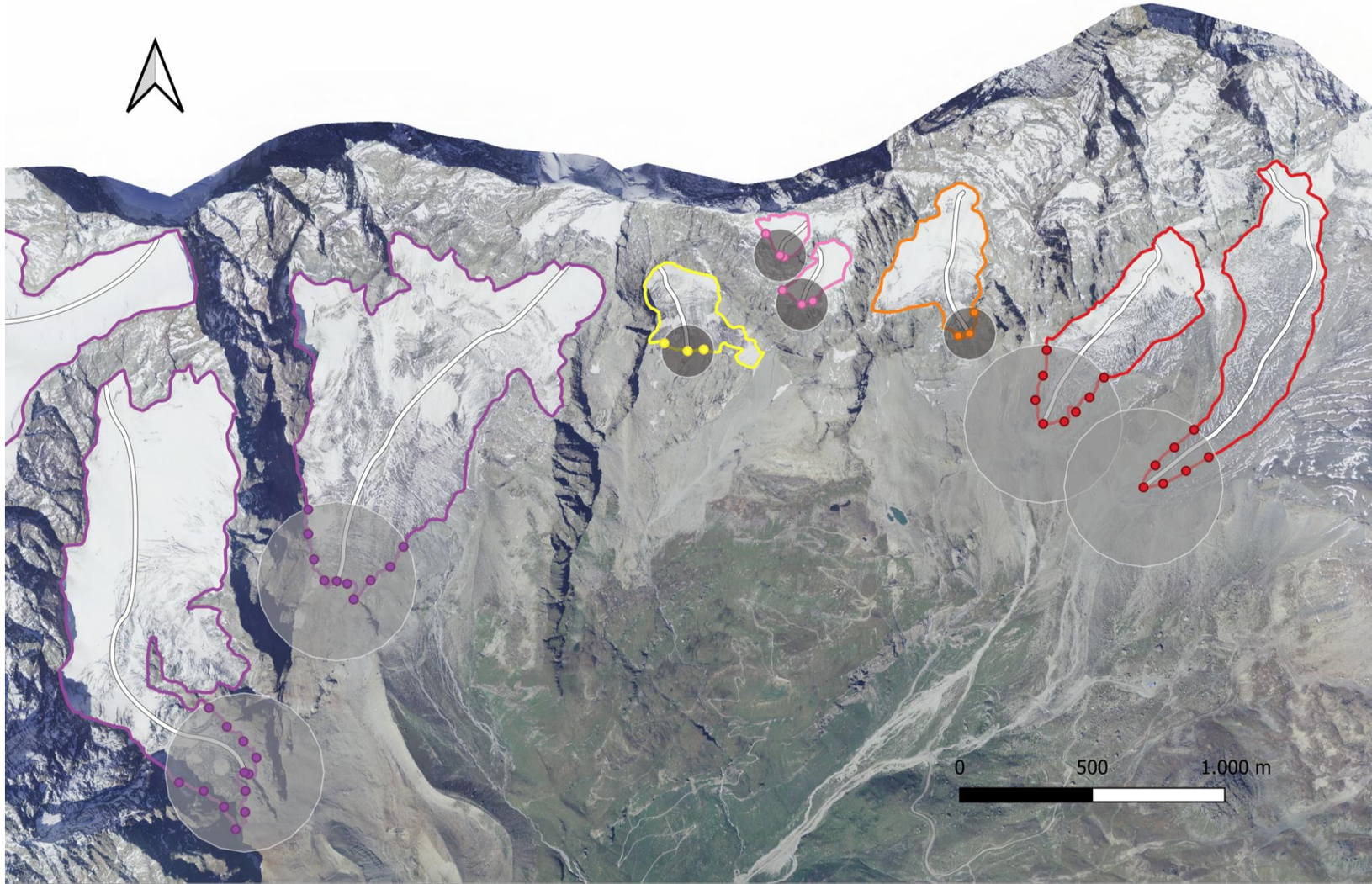

Five volume thresholds defined:

- 50,000 $m^3$
- 200,000 $m^3$
- 500,000 $m^3$
- 1,000,000 $m^3$
- 6,000,000 $m^3$

# Release Point Definition

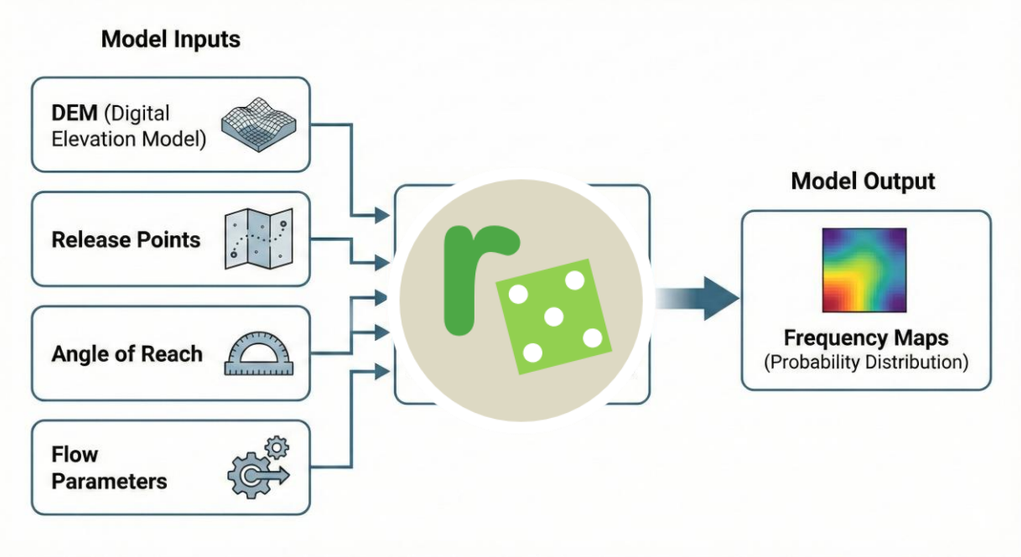
## Point densification strategy

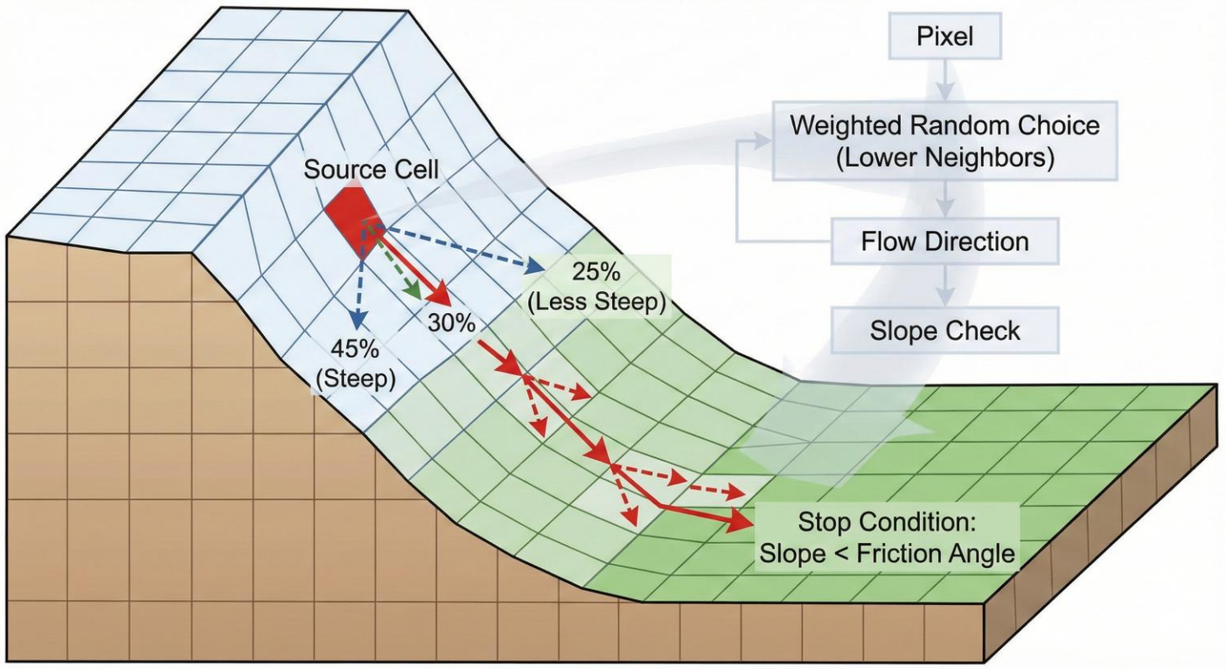
1. Primary point identified at flowline-glacier intersection
2. Additional points generated at 100m intervals along terminus
3. Selection buffer: 300m for large glaciers (>500,000 $m^3$), 100m for smaller bodies
4. Minimum 3 points for small glaciers, more than 7 for large ones



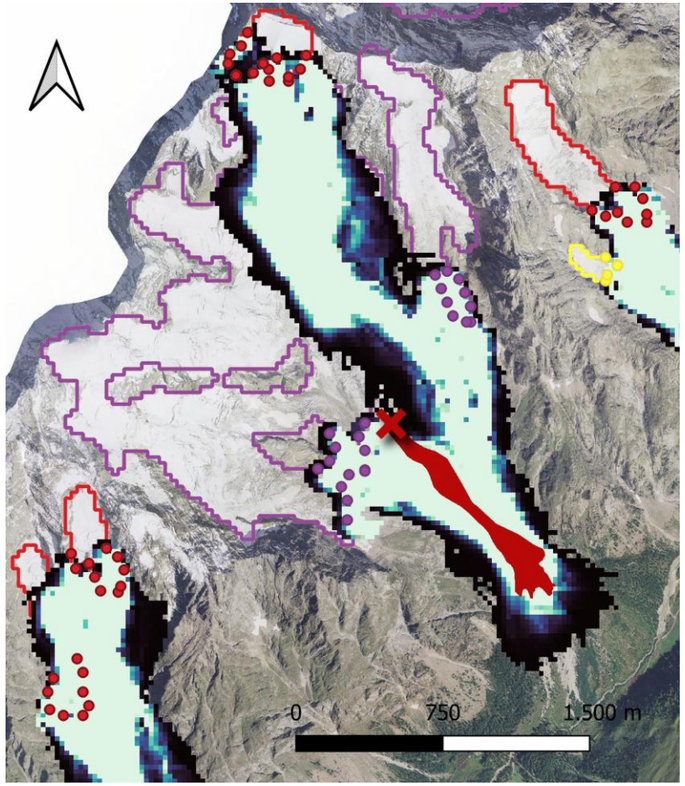
# Propagation Modelling

r.randomwalk

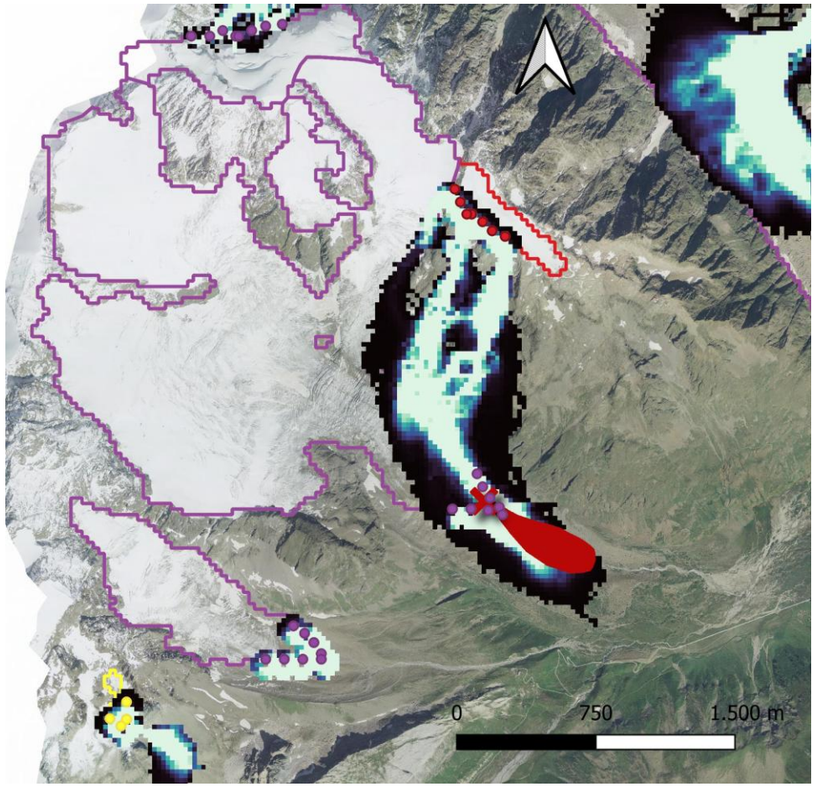


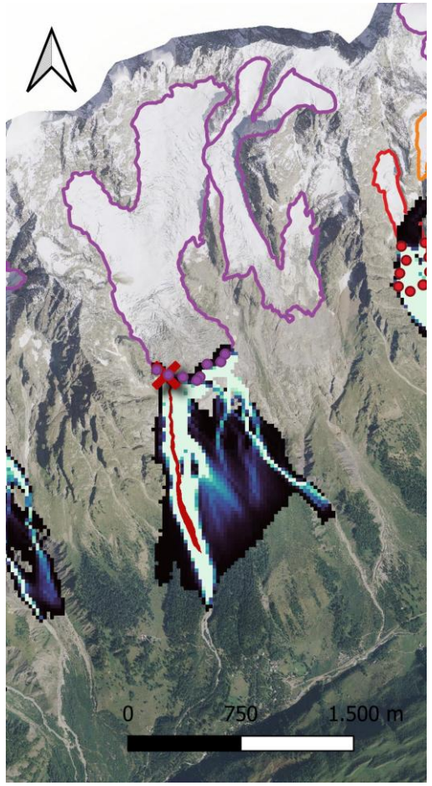
# Model Validation




Frebouze Glacier, 2002



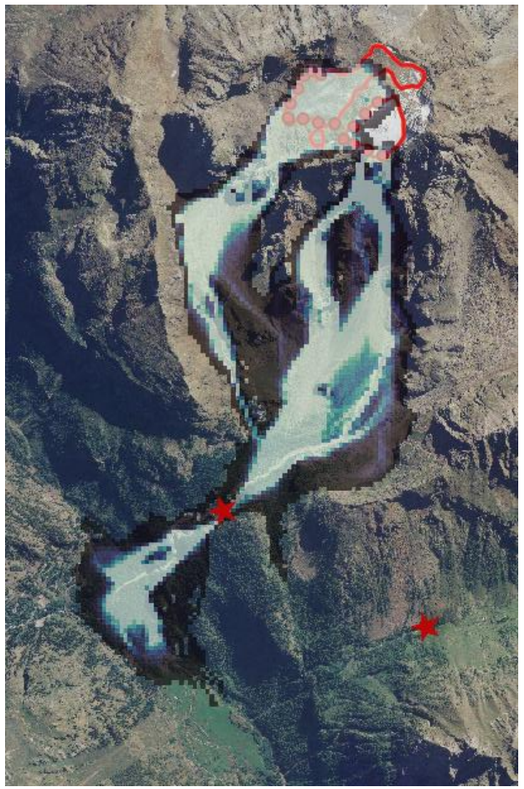

Lex Blanche Glacier, 2004




Planpincieux Glacier, 2017

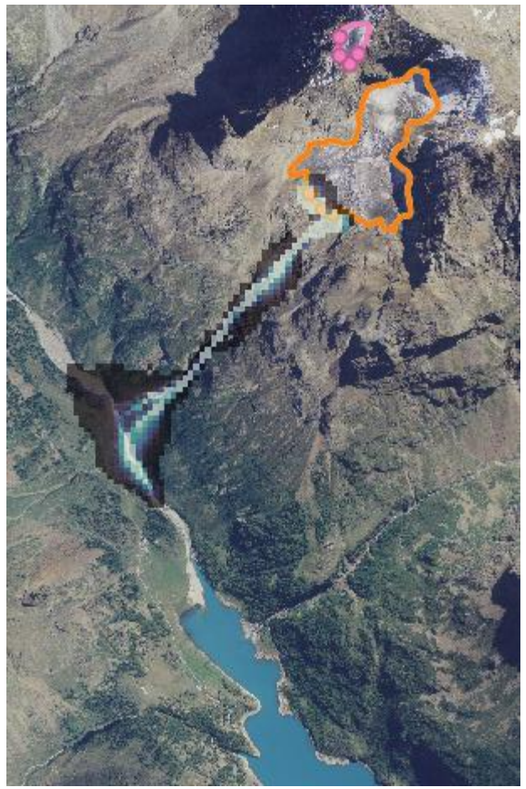
Simulations were validated against well-documented historical avalanches. The comparison showed high consistency between the deposits (in red) and the modelled impact areas.

# Hotspot Identification



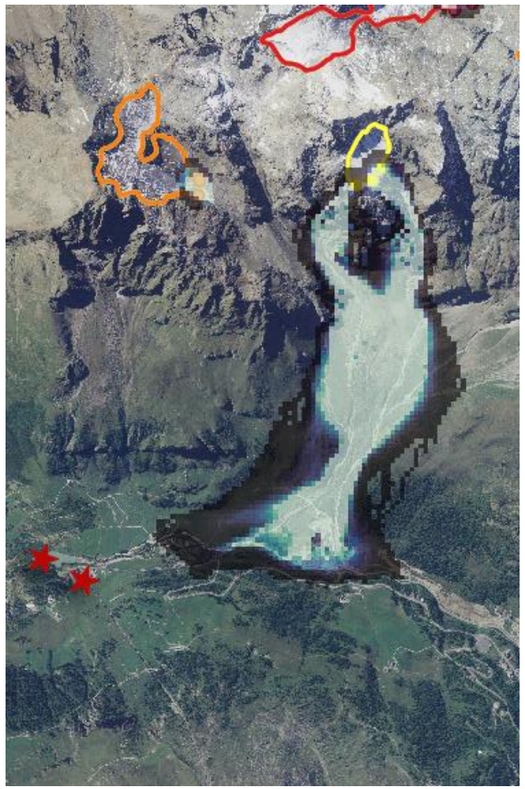
## Luseney Glacier

Collapses from 50.000 to 1.000.000 $m^3$ would reach Arbière stream intake



## Solatset Glacier

High-magnitude event could partially involve Places de Moulin basin, risking Buthier torrent obstruction



## Mont Blanc du Creton Glacier

Collapses could terminate 400-600m from Perrères power plant and dam.

# Conclusions and Future Steps

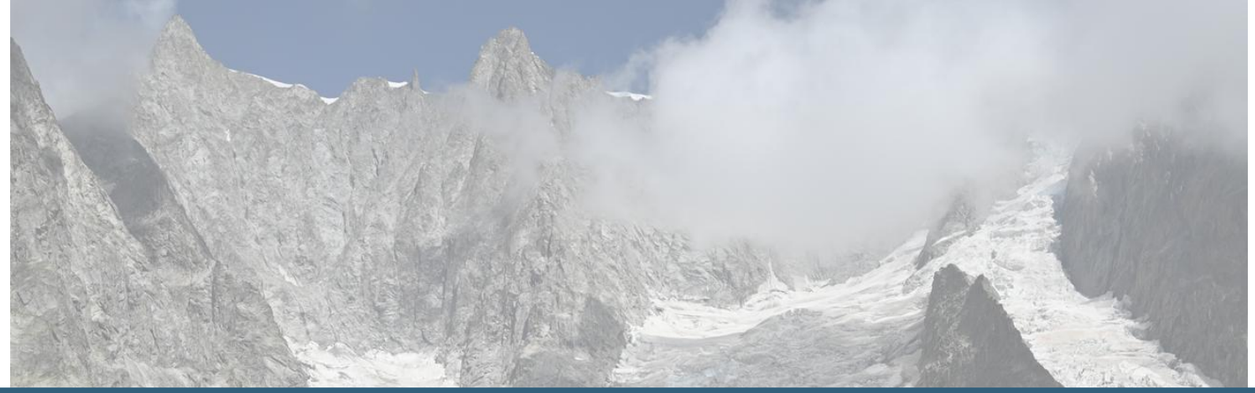
## Key Findings

CVA energy network shows high overall resilience with limited, localized impacts from glacial collapses.

Methodology successfully identifies potential infrastructure interferences and provides foundation for regional risk management.

## Next Steps

- Expand analysis to roads, buildings, and other critical infrastructure
- Investigate cascading phenomena including GLOFs
- Update datasets for high-risk sites with refined topographic and glaciological surveys
- Apply advanced models (r.avaflow) for strategic locations
- Integrate findings into regional prevention and mitigation strategies



# THANK YOU FOR YOUR ATTENTION



Corresponding author:
mnicora@fondms.org

Further acknowledgements: This work was carried out in the framework of the PNRR project “Agile Arvier. La cultura del cambiamento” – WP02 “Green Lab”