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Triggering and runout conditions of two rock slope failures in the French Alps: Vallon d'Étache and Crête des Grangettes

Maëva Cathala, Josué Bock, Florence Magnin, Ludovic Ravel, Matan Ben-Asher, Guillaume Chambon, Philip Deline, Thierry Faug, Kim Génuite, Jean-Yves Josnin, et al.

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Triggering and runout conditions for the little rock avalanche of June 2020 in Vallon d'Étache (Savoy, France).

An approach combining various cutting-edge methods.

Cathala M.^{1,2}, Bock J.¹, Magnin F.¹, Ravanel L.¹, Ben Asher M.¹, Chambon G.³, Deline P.¹, Faug T.³, Génuite K.⁴, Josnin J.-Y.¹, Revil A.¹, Richard J.¹



¹ EDYTEM Lab. (UMR 5204), USMB - CNRS, France

² Alpes Ingé, Saint Vincent de Mercuze, France

³ INRAE, Grenoble, France

⁴ PACEA, Archeology, Bordeaux, France



OBJECTIVES

In high mountain environments, permafrost degradation causes rockwall instabilities, sometimes leading to rock slope failures. These processes could be a threat for human lives and activities, it is therefore essential to improve our knowledge about their triggering and propagation mechanisms.

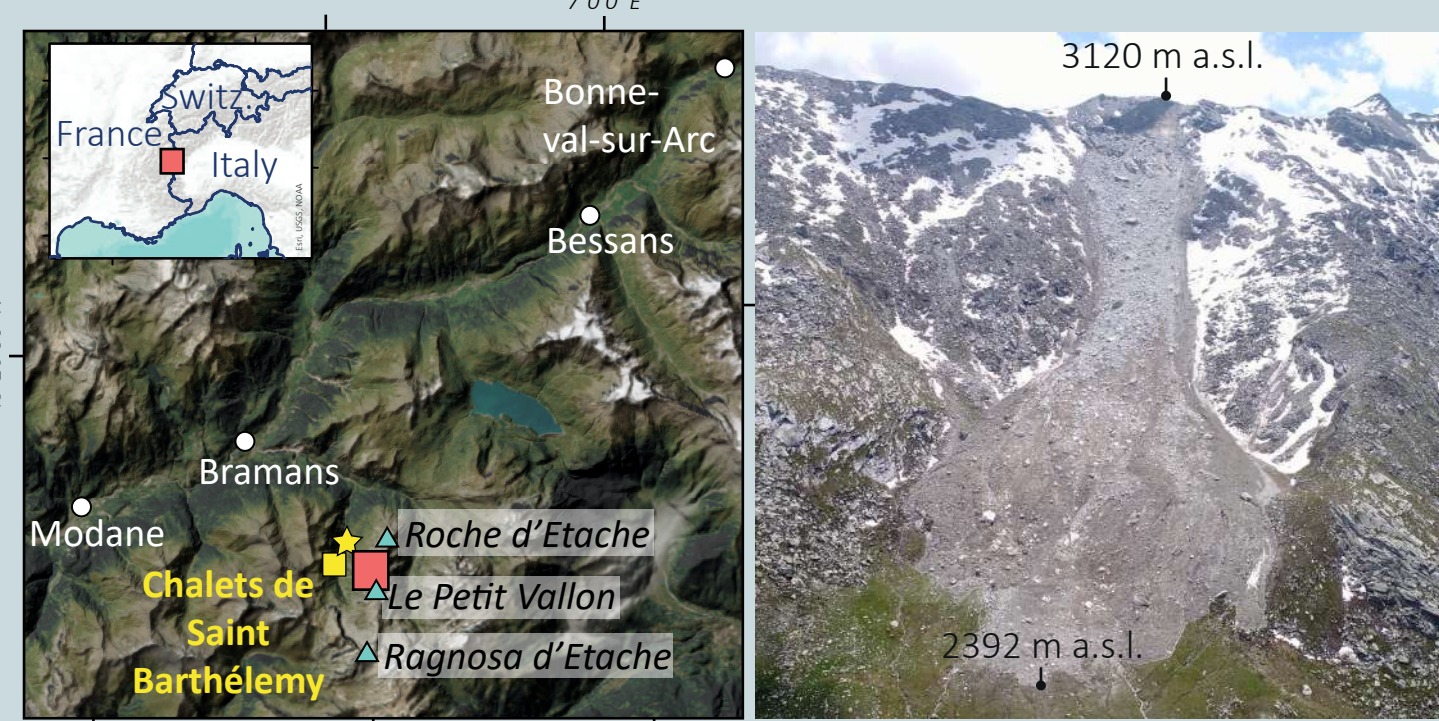
This study focuses on a rock slope failure which occurred in the Vallon d'Étache (Maurienne Valley, France) in 2020. The aims of this study are (i) to **assess thermal conditions in which the rock avalanche was triggered** and (ii) to **model its propagation**. To do so, we propose a method that combines **rockwalls temperature monitoring, statistical modelling of permafrost distribution, geophysical surveys** (Electrical Resistivity Tomography) and **laboratory measurements** (petrophysical model) to explain the **thermal conditions under which the rock avalanche occurred**.

This multi-method approach allows to understand the context and the processes leading to rock slope failure triggering of Vallon d'Étache rock slope failure.

STUDY AREA

CHARACTERISTICS OF THE EVENT

The rock avalanche occurred on June 18, 2020, from the crest line (3126 m) in Etache Valley. The deposit extends 600 m above the farm, the parking area, and the hiking trails. **Ice in the rockfall scars** suggests the presence of permafrost, but its local distribution remains to be confirmed.



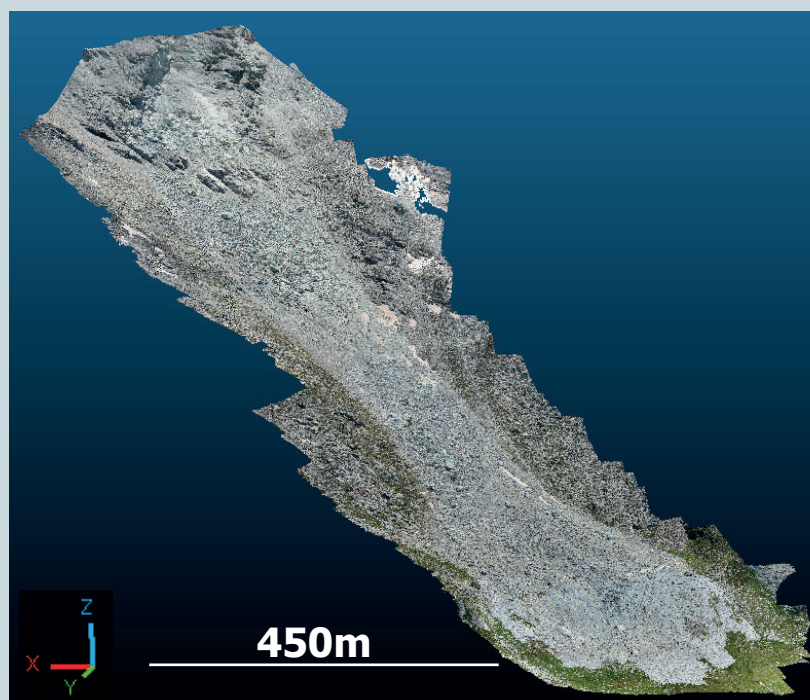
- Building
- Visible fracture
- Study area
- Visible ice coating
- Parking
- Liquid water

VOLUMES : 3D RECONSTRUCTION

The scar :

- Width: 180 m
- Max depth: 46.5 m
- Average depth: 14.7 m.

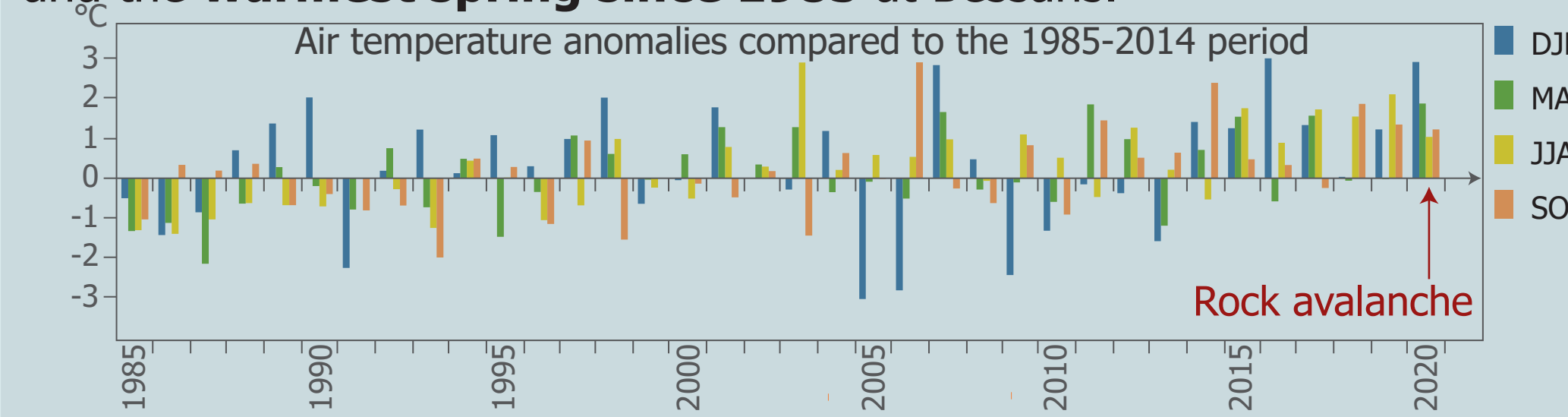
Estimated volume:
221,000-229,000 m³



METEOROLOGICAL CONTEXT

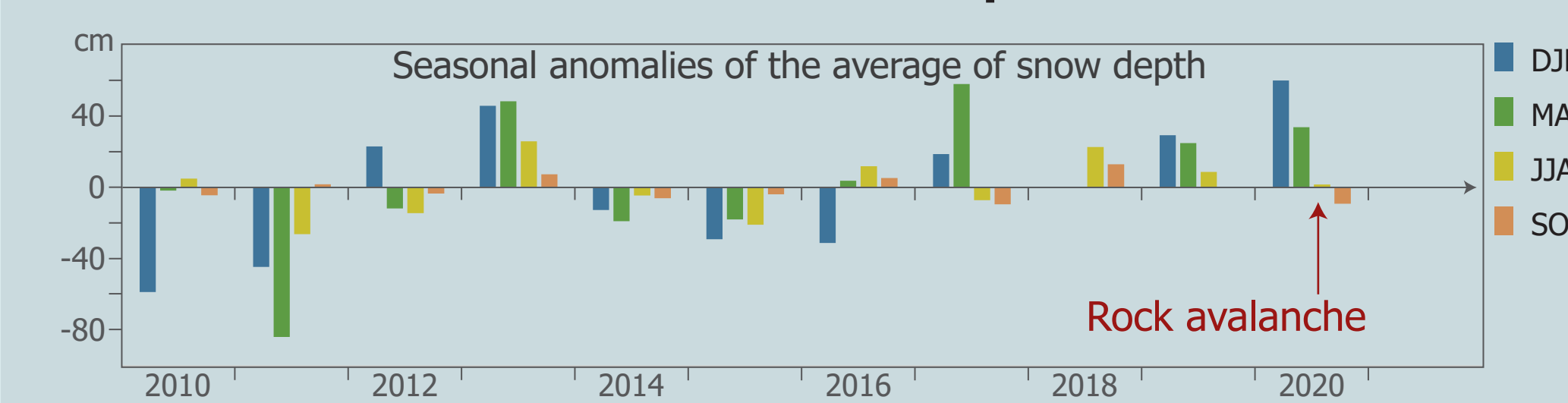
Air temperature anomalies:

- 2020 annual average air temperature: **the warmest in the 1985-2014 period.**
- The 6 month period prior to the event: the **second warmest winter and the warmest spring since 1985** at Bessans.



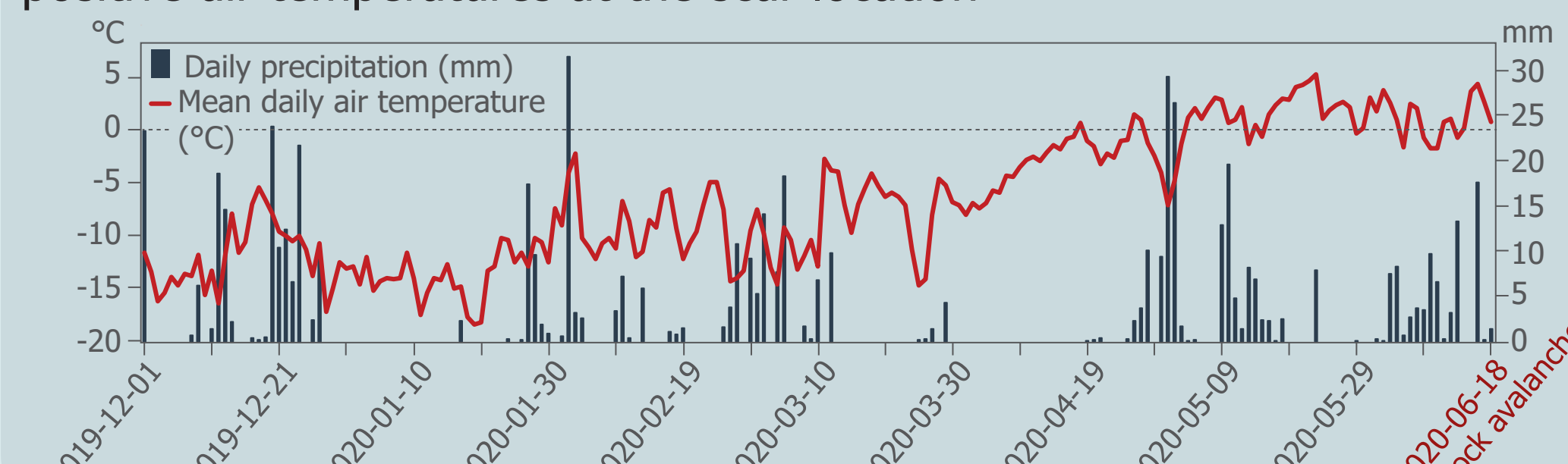
Snow anomalies:

- Average snow depth over the winter period: 186 cm = **48% (60 cm) more snow than the 2010-2019 winter periods** at Bonneval-sur-Arc.



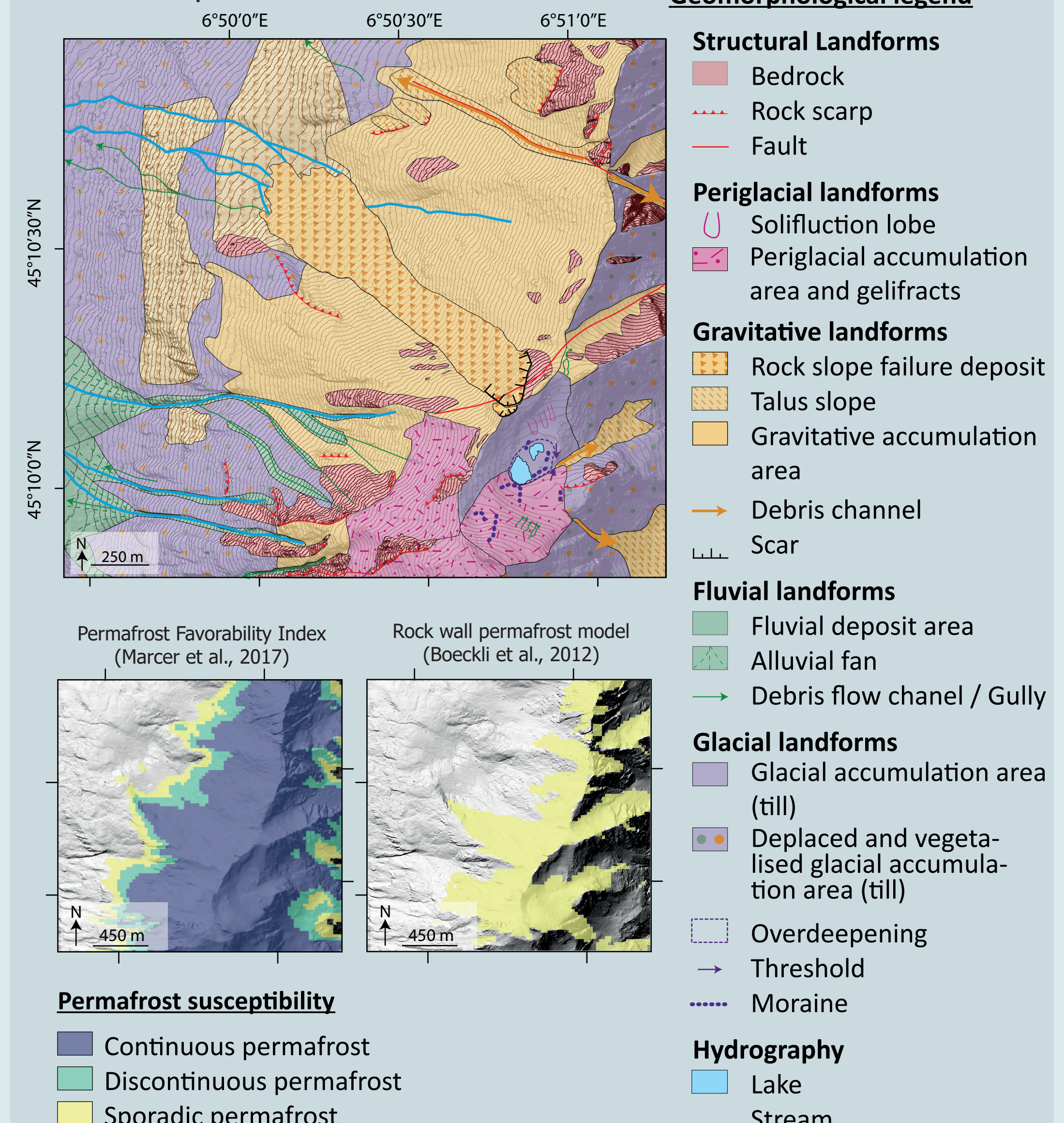
Precipitation prior to the rock avalanche:

- **Significant rainfall** the week prior to the event (15 % of the spring 2020 rainfall in Bessans).
- **Significant input of water (snow melt and rainfall)** suggested by positive air temperatures at the scar location



GEOMORPHOLOGICAL AND GEOLOGICAL SETTINGS

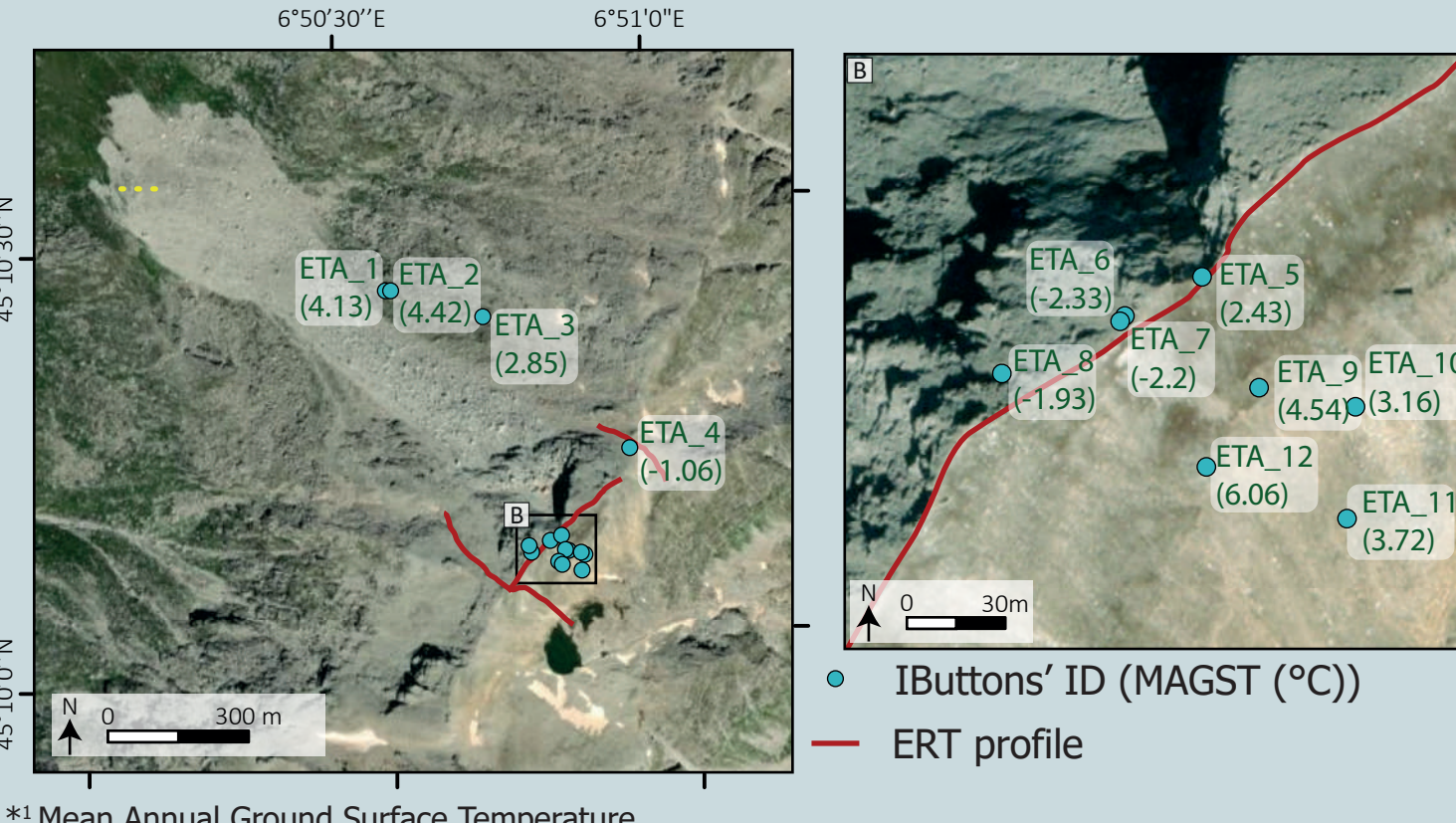
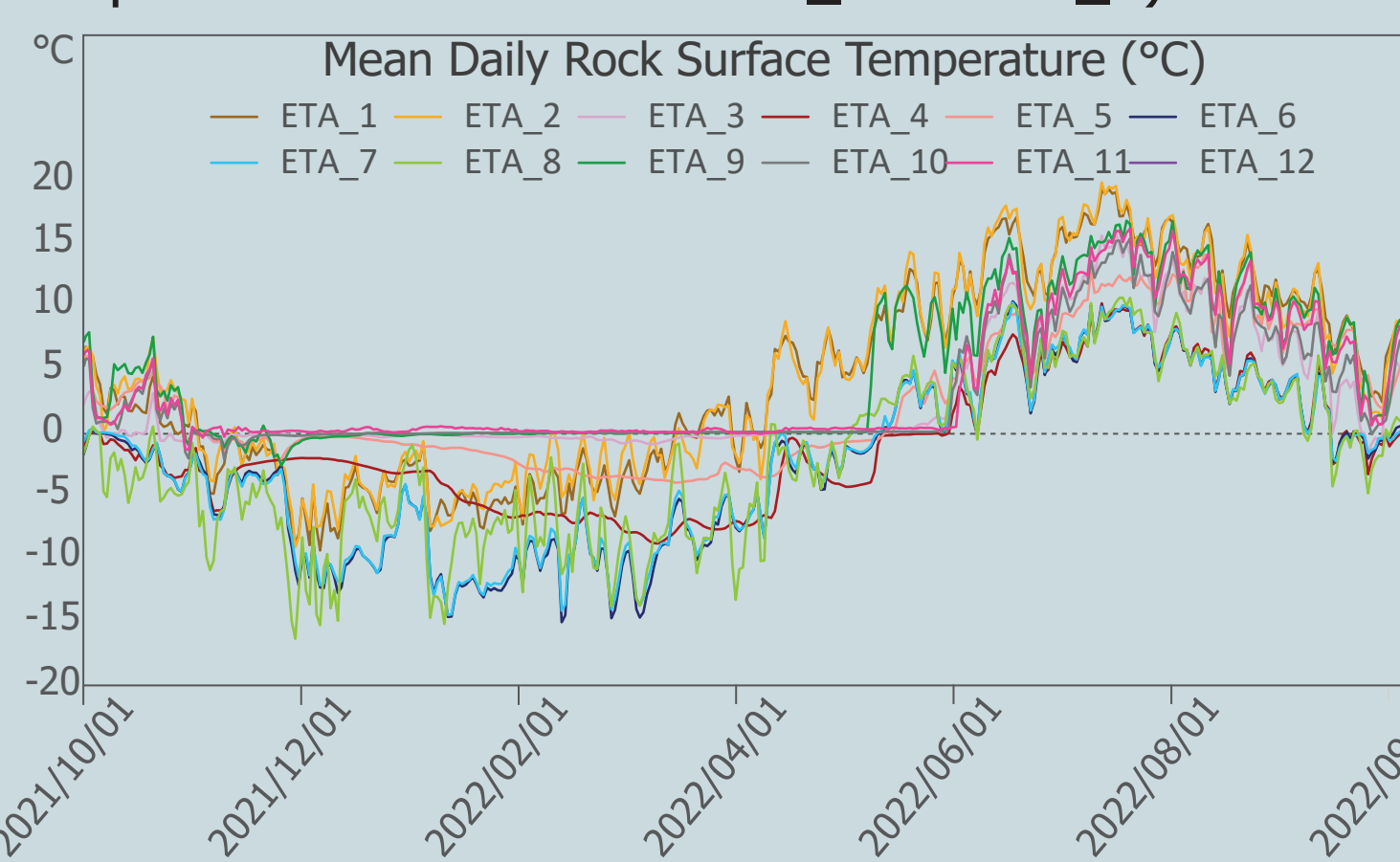
The geomorphological analysis of the Etache valley shows that this area is widely in a **periglacial context**, which could explain the **gravitational activity and the triggering of the rock avalanche**. A **fault** oriented NE-SW is located on the failure scar, with a contact between micashistes on the NE and quartzite on the SW.



GROUND THERMAL CONDITIONS

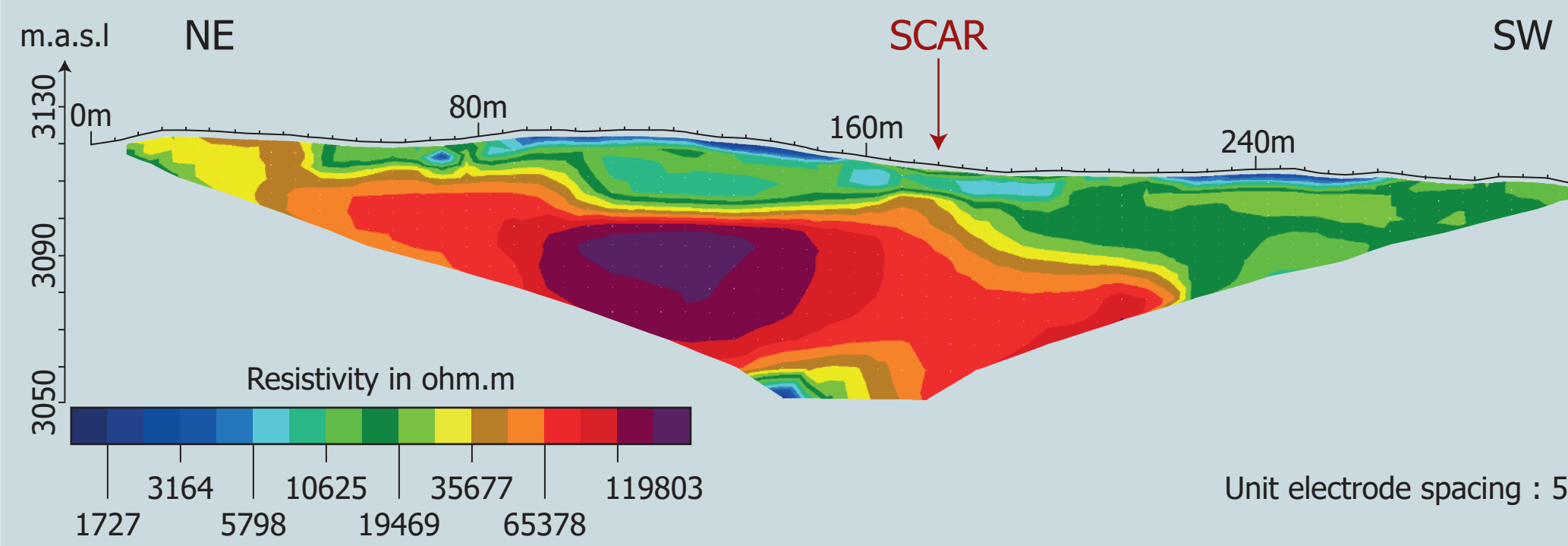
GROUND TEMPERATURE MEASUREMENTS

- **12 loggers installed** (c. 10 cm below the surface)
 - elevation range from 2675 m to 3116 m asl.
 - different ground conditions and sun-exposure.
 - data recorded from 2021/10/01 to 2022/09/30.
- **MAGST***1: ranges from -2.3 to 6.1°C
- **Sensors affected by snow** (dampened daily oscillation and persistent sub-zero temperature in winter and spring).
- **Effect of permafrost at depth** (suggested by low temperature in winter for ETA_4 & ETA_5)



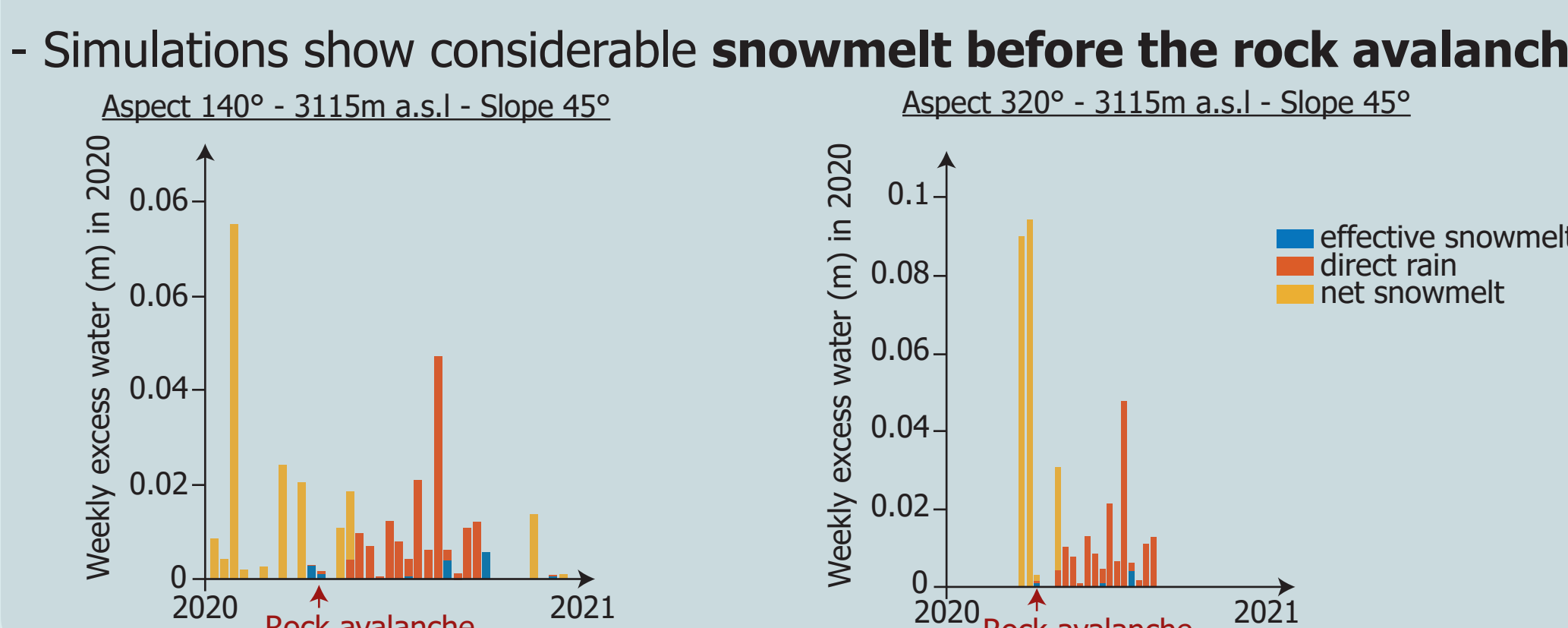
GEOELECTRICAL SURVEY

- **High resistivity values** suggest the **presence of permafrost** in the rock avalanche scar location.
- A sub-vertical discontinuity can be observed on this profile near the scar.



ENERGY BALANCE MODELLING

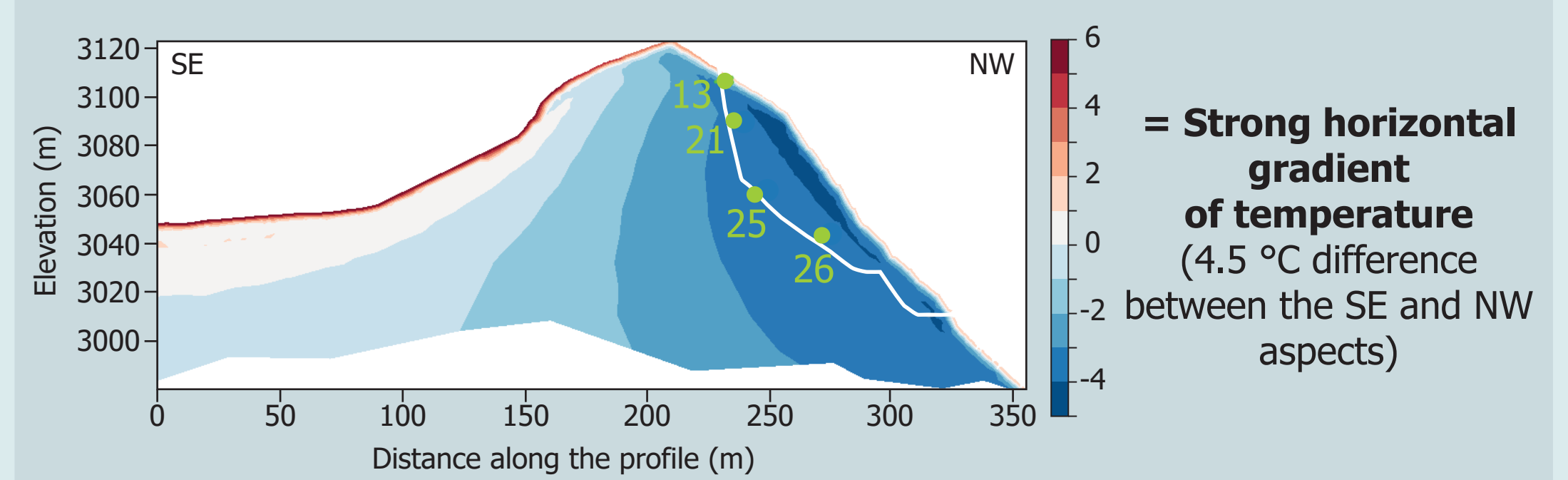
- The **CryoGrid** model (Westermann et al., 2022) was used to simulate the **energy and water mass balances and estimate rock surface temperature and water fluxes from snowmelt and rainfall.**



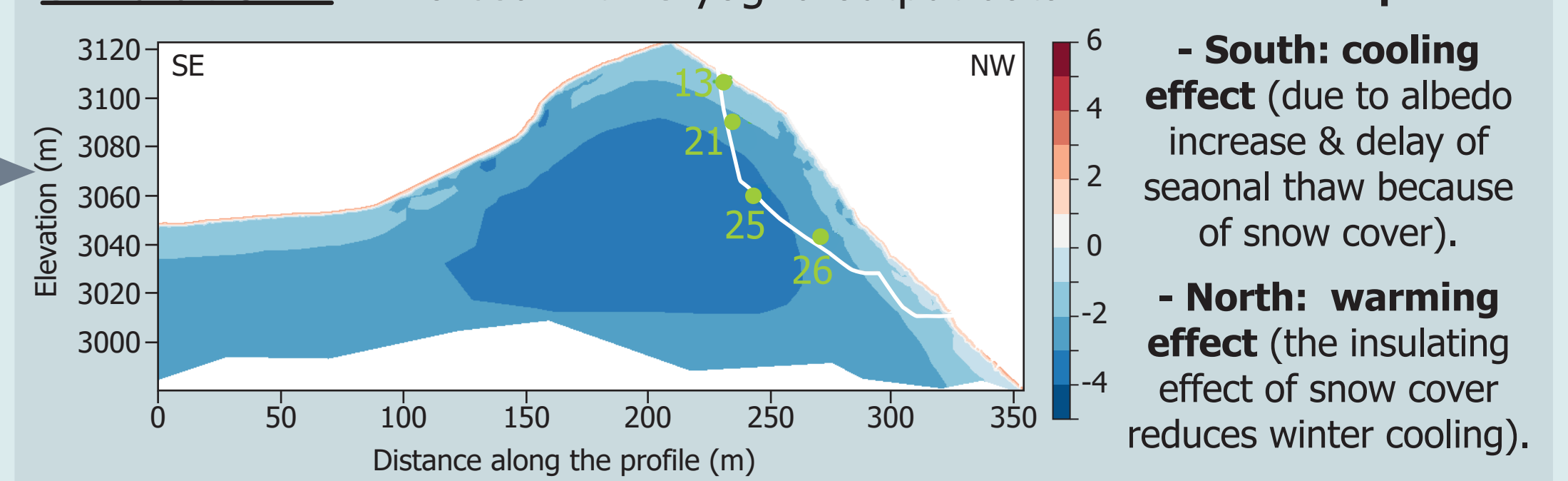
PERMAFROST MODELLING

In order to estimate **the thermal state of the release area** when the rockfall happened we performed two simulations with FEFLOW.

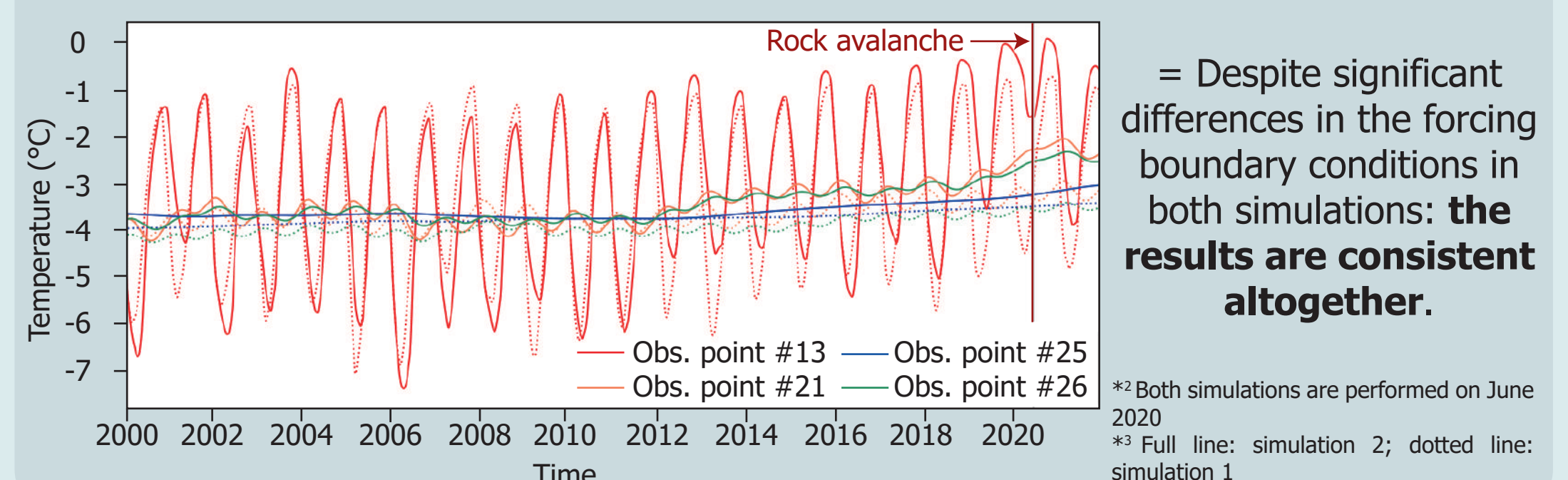
Simulation 1*2: Forced with rock surface temperature deduced from air temperature (does not account for the presence of snow.)



Simulation 2*2: Forced with Cryogrid output data.



Timeseries of temperature at 4 observation points close to the rockfall scar, for both simulations*3.



CONCLUSIONS & OUTLOOK

- The weather conditions the month prior to the event highlight a **possible relationship of the failure with air temperature, precipitation, and snowmelt**
- Energy balance model (CryoGrid) show that **water input from precipitation and snowmelt are consistent** in the weeks before the rock avalanche is triggered.
- Permafrost modelling results (Feflow) strongly support **the hypothesis of a rockfall triggered by a warming of cold permafrost**, both by heat conduction as simulated by the models, but also possibly reinforced by heat advection from water infiltration (likely leading to the thawing of areas that have never experienced conditions above freezing point, which could also lead to high hydrostatic pressure).
- The **methods** used in this work are **complementary** and provide both a qualitative and quantitative assessment of permafrost distribution.
- **High-resolution DEMs** (acquired by photogrammetry) will provide provide consistent inputs for **runout modelling**.

DISCUSSIONS

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Graham Cogley Award candidate

