SFM-MSV processing of historical aerial photographs: Applications on mountain permafrost in the French Alps

https://meetingorganizer.copernicus.org/EGU21/EGU21-16371.html

Diego Cusicanqui, A. Rabatel, X. Bodin, C. Vincent, E. Thibert, P-A.Duvillard, and A. Revil

a) Raw scanned files available from 1948 until ~2013. Images available at https://remonterletemps.ign.fr/.

b) GCPs collected using IGN Web Map Service (WMS) and a master DEM 5m resolution (BD-Alti-5m) or LiDAR DEM is exist (Laurichard rock glacier case). *GCPs must be identified thought time in all periods.

c) Semi-automatic filter applied to noisy 3D point cloud. Reduce

d) Co-registration stage using Nuth & Kääb (2011) methodology to improve accuracy of older DEMs (Python based automatic workflow).

e) Photogrammetric products are resampled into common grid to keep coherence between historical and recent high resolution products.

f) Methodology applied to three study cases (details are https://meetingorganizer.copernicus.org/EGU21/presentation/EGU21-16371).

Images properties:

- Black & white scanned films (20µm/pix).
- 1/20'000 average scale.
- Standard stereoscopic coverage (60% and 40%, respectively.)
- JP2 format (they need to be on *.tif for processing).
- 30 flights processed.

GCPs identification:

- Over stable areas.
- GCP ± 5m (0.35pix in average) and 0.85pix for older photographs.

Co-registration:

- Recent and accuracy master DEM (LiDAR is exist).
- Filter/mask all objects that can potentially move (i.e. rock glacier, lakes) as well as slopes > 30°.

Using historical aerial imagery to assess multidecadal kinematics and elevation changes. Application to mountain permafrost in the French Alps.

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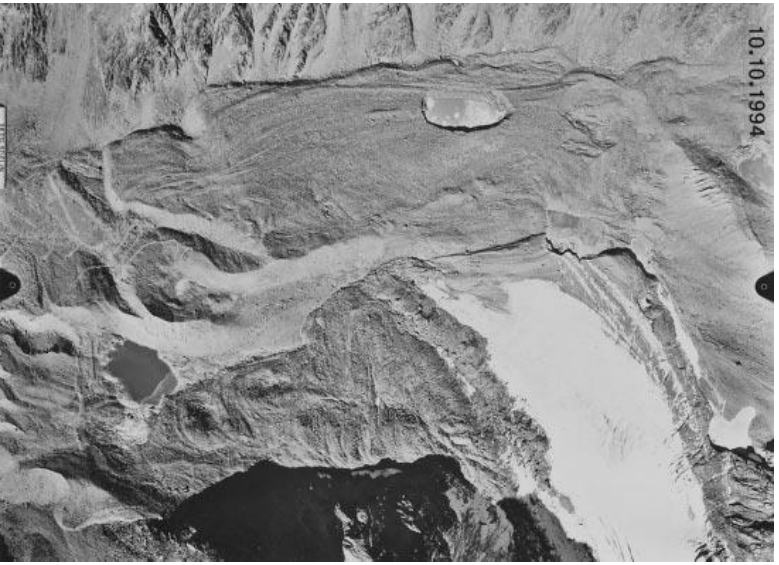
I. Intro – Context



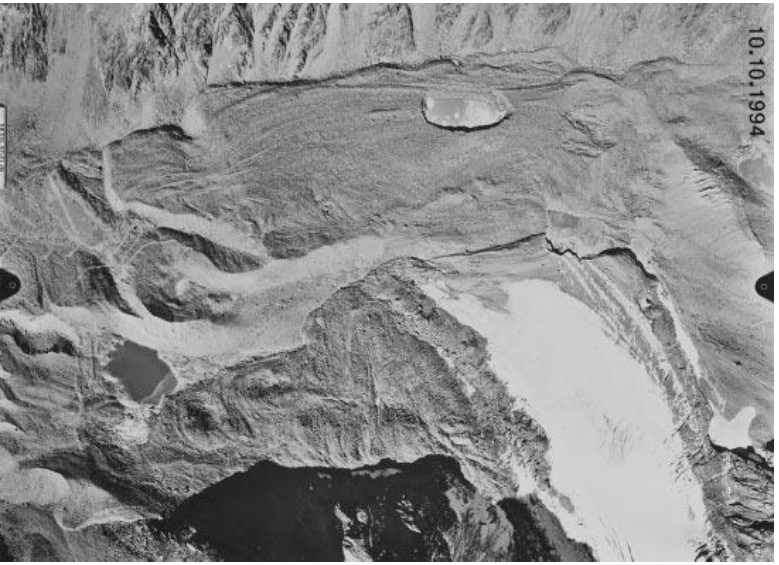
Gruben glacier and rock glacier, Switzerland, 1958 and 1994. *(Kääb et.al., 1997, Haeberli et. al., 2001)*

- Mountain cryosphere has been strongly impacted by global warming over the last three decades (i.e., accelerated rates of glacier retreat). This leads to mountain slopes instabilities amplifying existing hazards (i.e. collapses of high mountain rock walls) or even generating new ones (i.e. debris-flows glacial origin).

- High resolution remote sensing techniques could help to monitoring the phenomena. Nevertheless, it reacts with a rather long response time, which can be several decades depending on their physical characteristics.

- Historical aerial images could fill in the gap. However, processing is challenging.

I. Intro – Goals

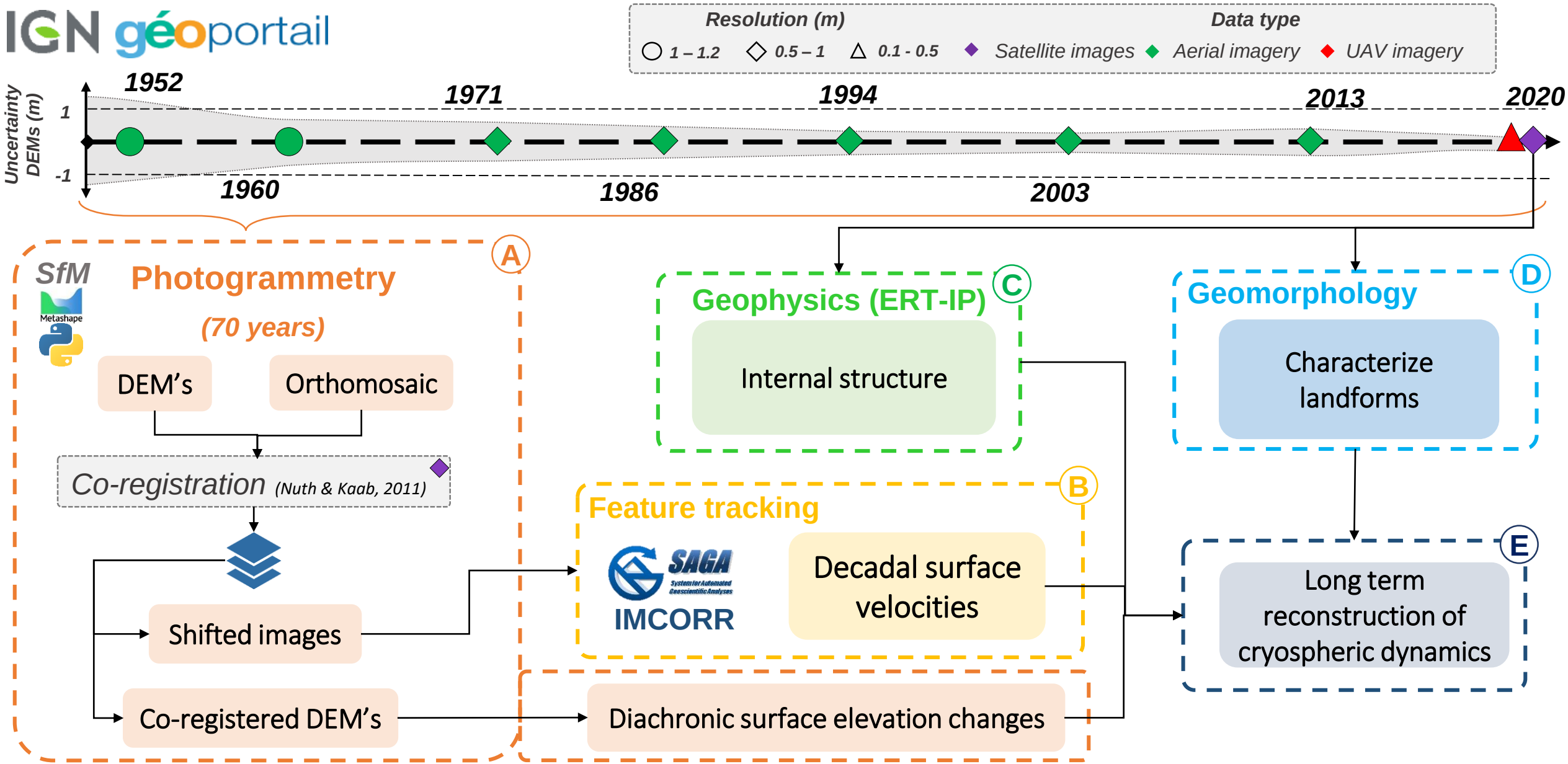


Gruben glacier and rock glacier, Switzerland, 1958 and 1994. *(Kääb et.al., 1997, Haeberli et. al., 2001)*

- **Study the long term behavior of rock glaciers.**
  - Back in time as long as possible using historical aerial photographs.
  - Take advantage of the availability of new accurate data to estimate and quantify surface elevation changes and surface velocities.

Here we present three study cases in order to understand ***How rock glacier are reacting to current climate forcing?***

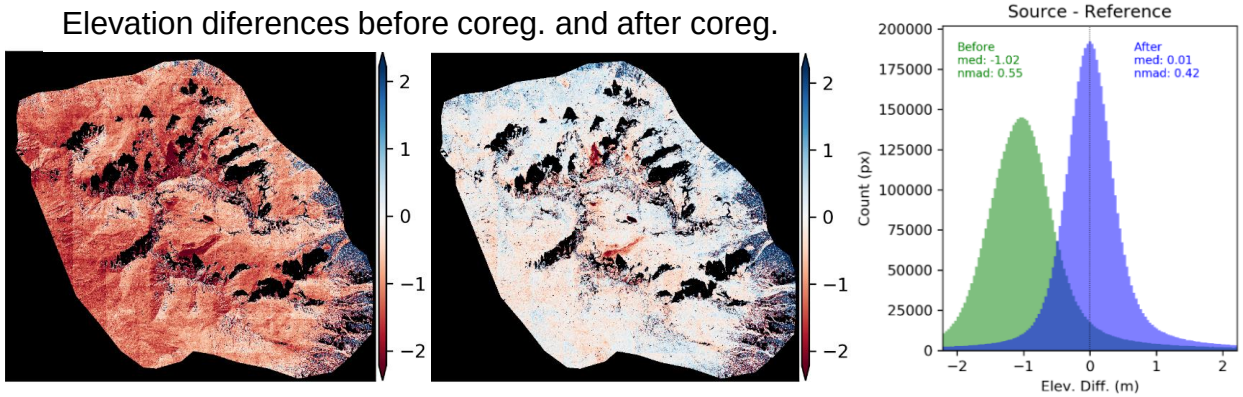
II. Processing – Data and methods



II. Processing – Products evaluation

- Photogrammetric process:
  - Identification of the same GCP's thought time.
  - GCP's coordinates obtained from single master DEM.
  - Correct geometrical distortions of historical images.

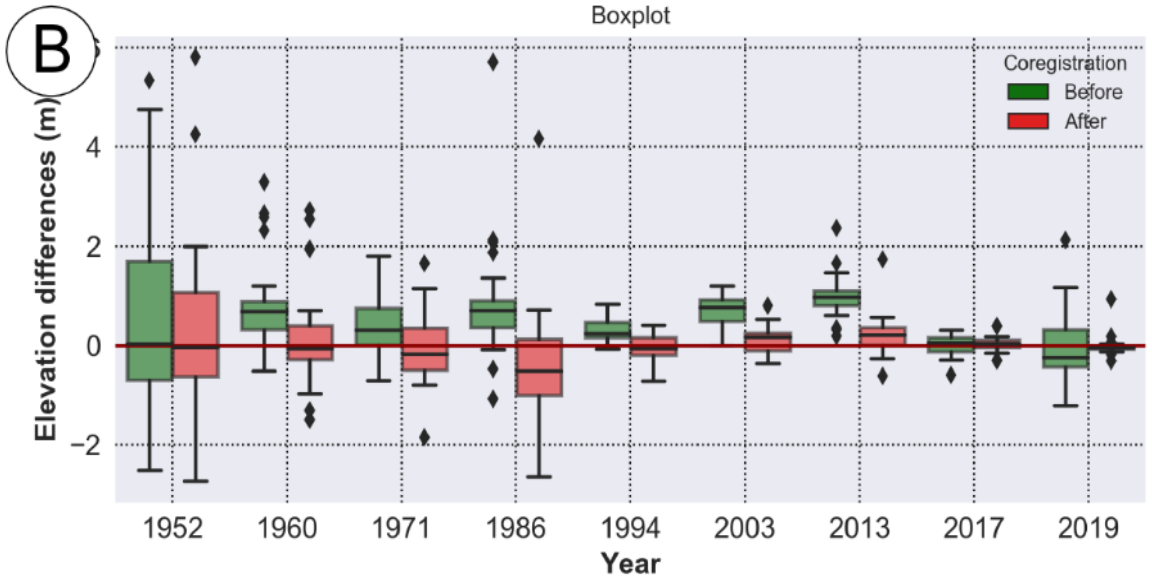
Elevation diferences before coreg. and after coreg.



- **Co-registration over common stable areas**. These areas were delimited as follows:
  - Rock glaciers and foret areas were masked.
  - High slopes (< 30°) were filtered.
  - We use an Aerial or LiDAR DEM as reference for co-registration stage.
- Only, translation shifts (X, Y, Z) was applied.

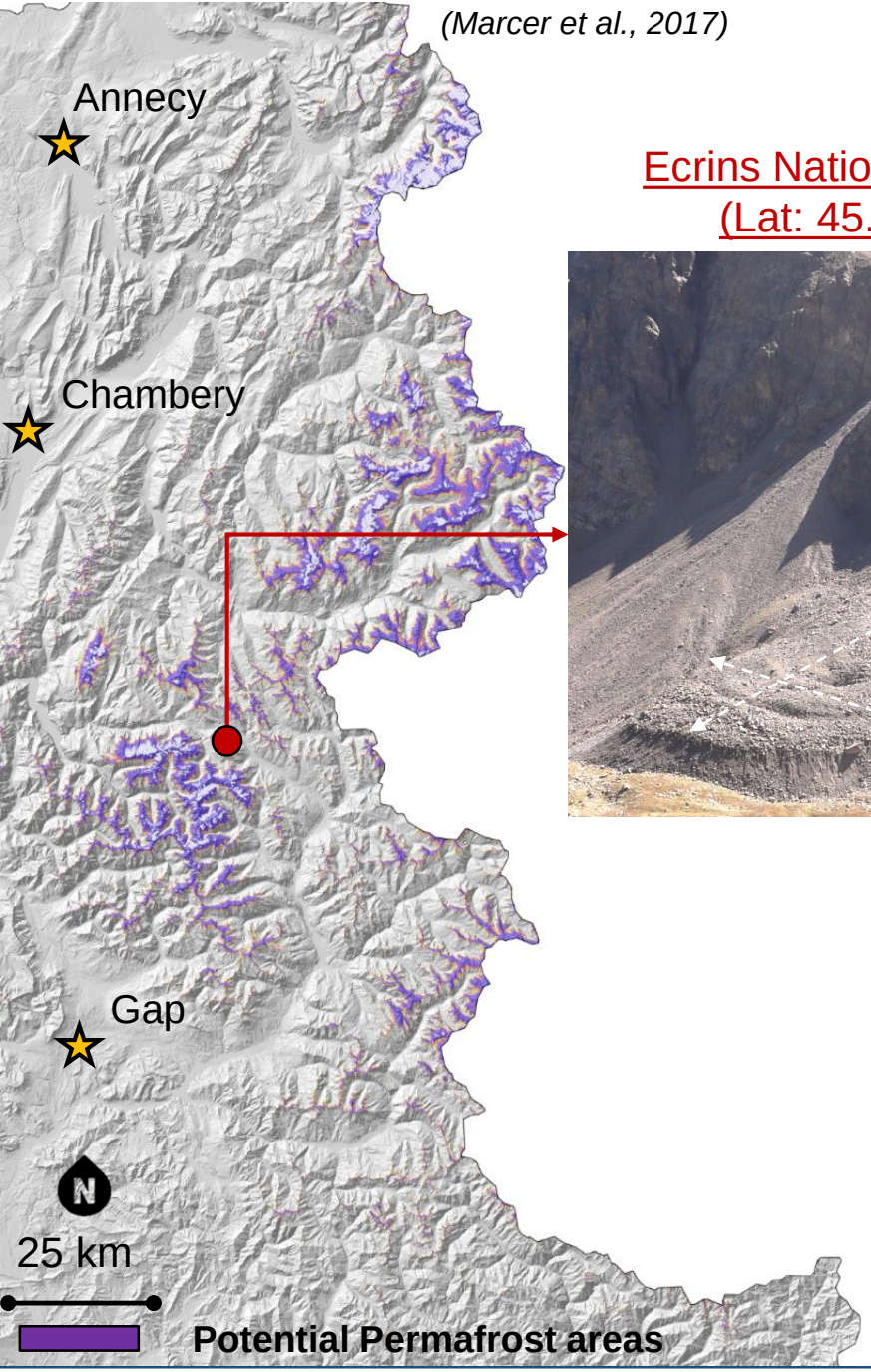
- Low-pass filter was used to reduce noise in oldest DEMs.
- DEMs and ortho-images out into common grid (1-m resolution) to keep coherence with recent products.

Effects of co-registration on DEM's uncertainties

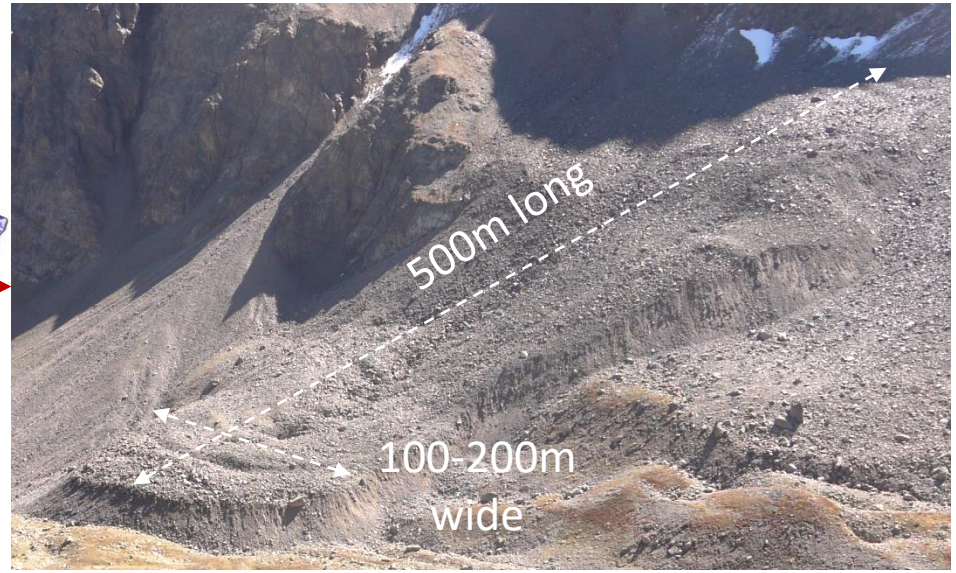


III. Study site – Laurichard rock glacier

(Marcer et al., 2017)



Ecrins National Park, Southern French Alps
(Lat: 45.02; Long: 6.39; Elev: 2520)



The most monitored rock glacier in France:

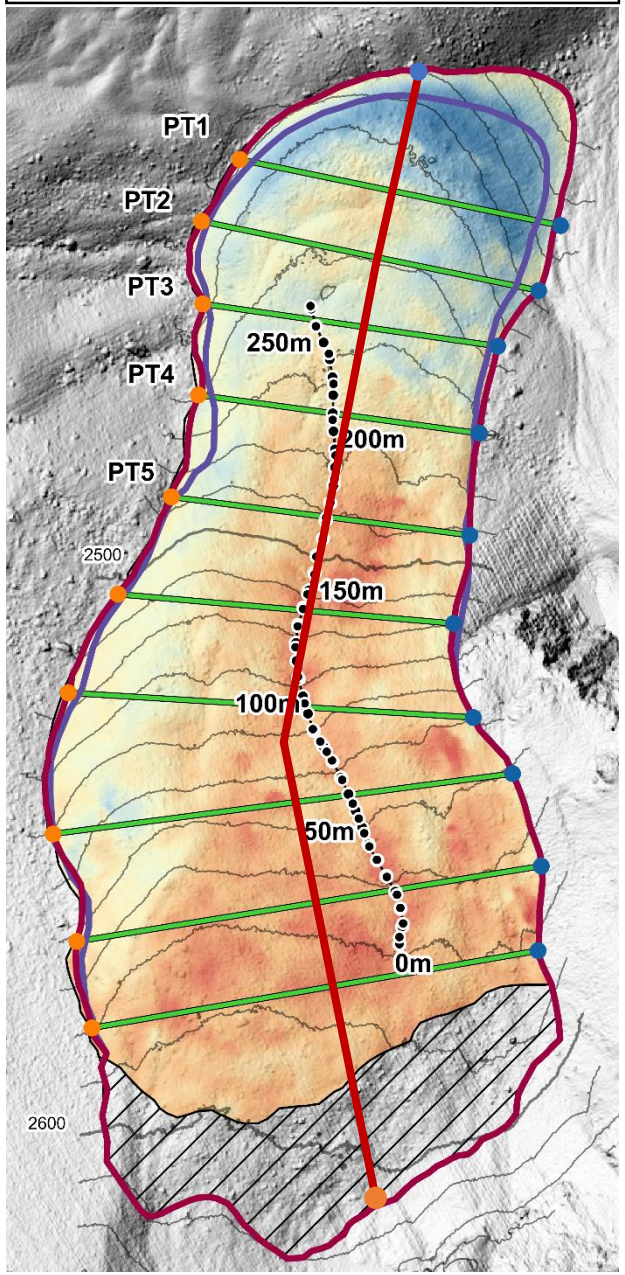
- Geo-electrical surveys *(Bodin et al., 2009)*
- Seismic refraction and GPR *(Guillemot et al., 2020).*
- ~40-yr *in situ* DGPS observations *(Thibert et al., 2018).*
- Daily terrestrial photogrammetric measurements *(Marsy et al., 2020).*

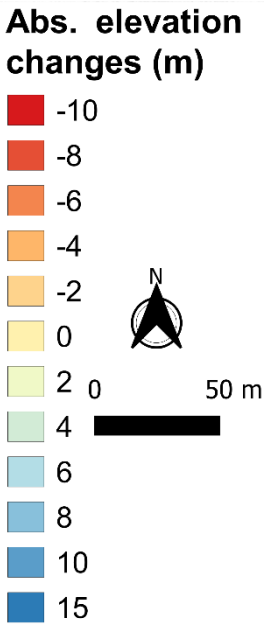
Now:
67 seven years of surface displacements and thickness changes

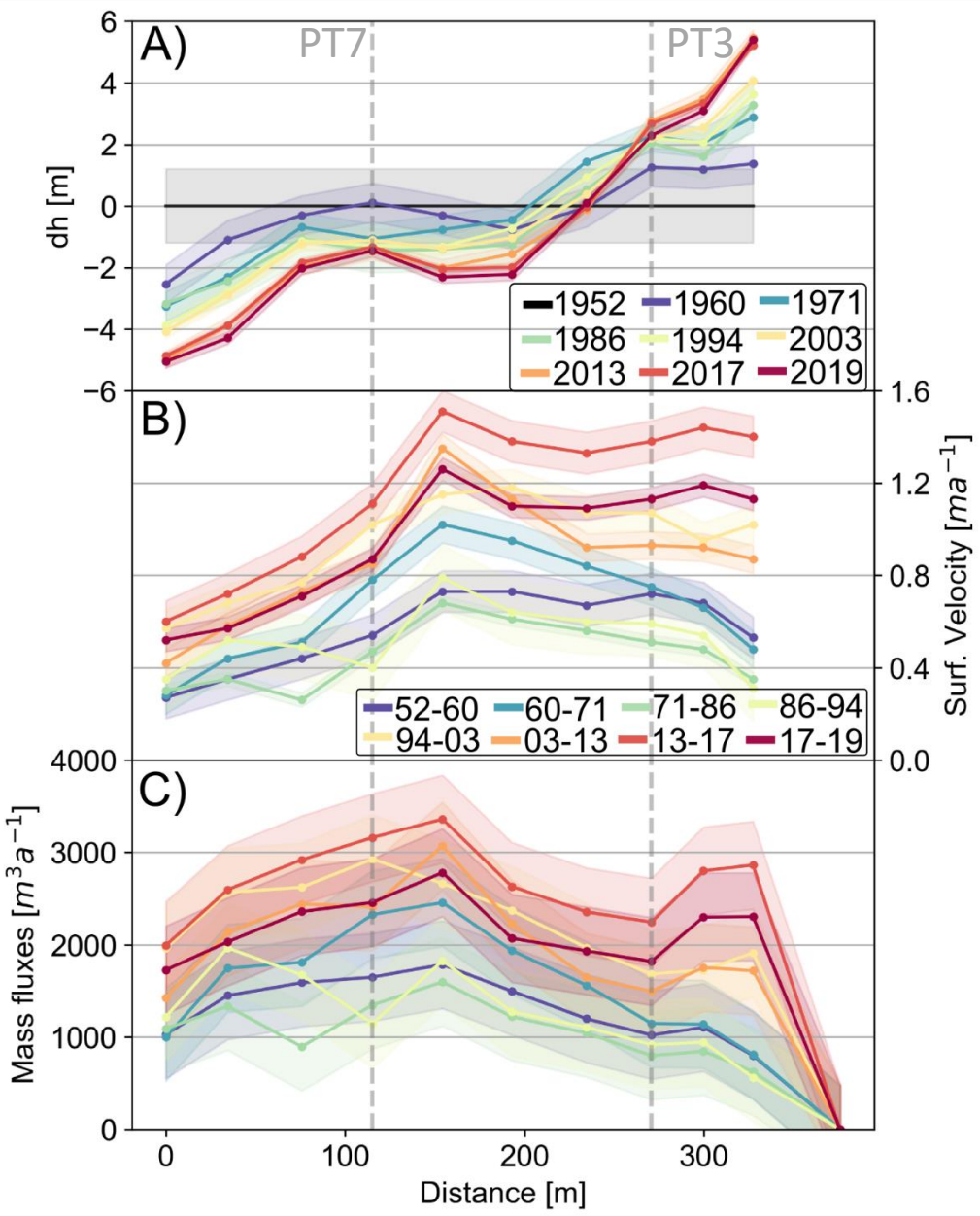
Cusicanqui et al., In review, JGR

III. Laurichard – Thickness changes

1952 - 2019







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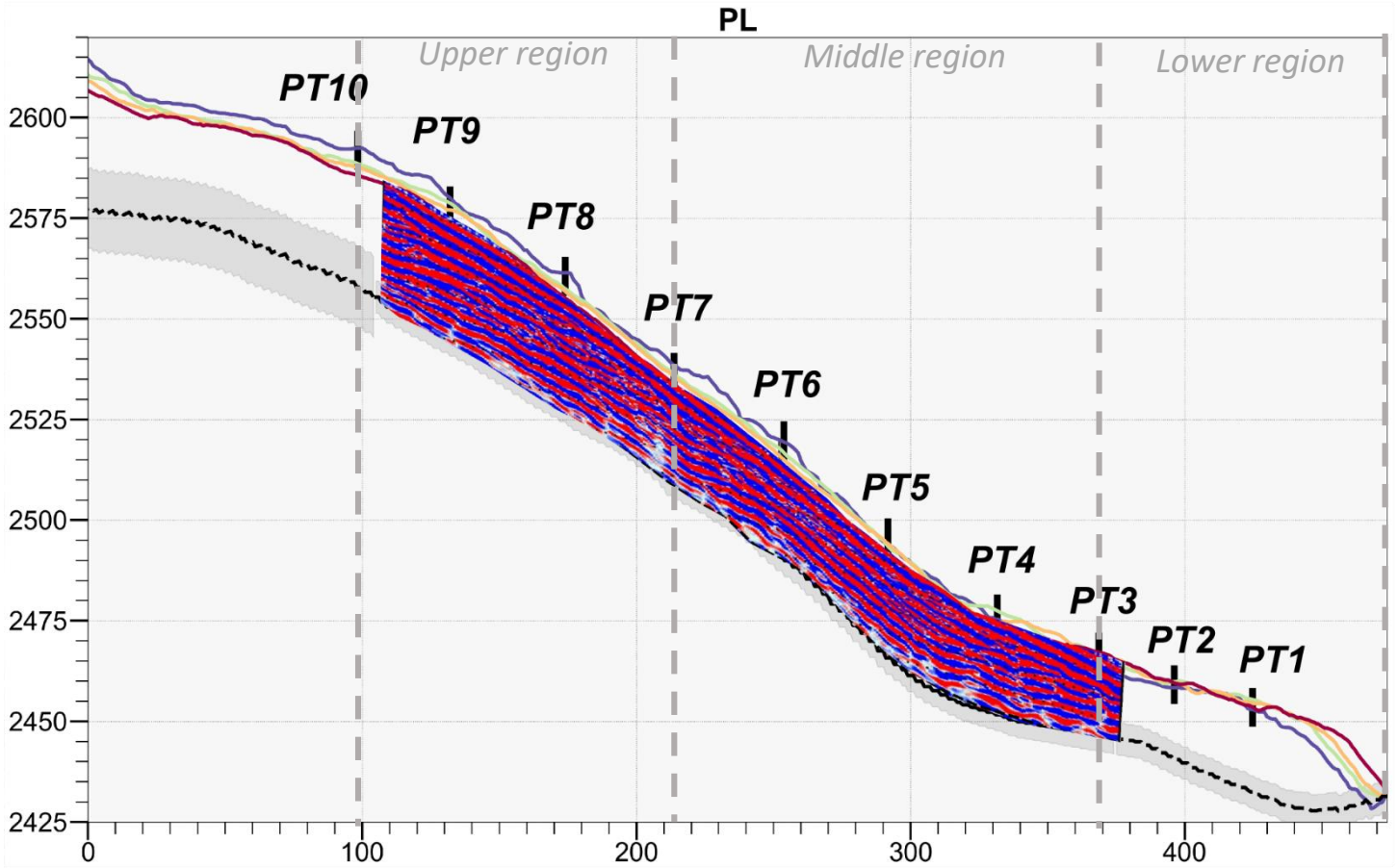
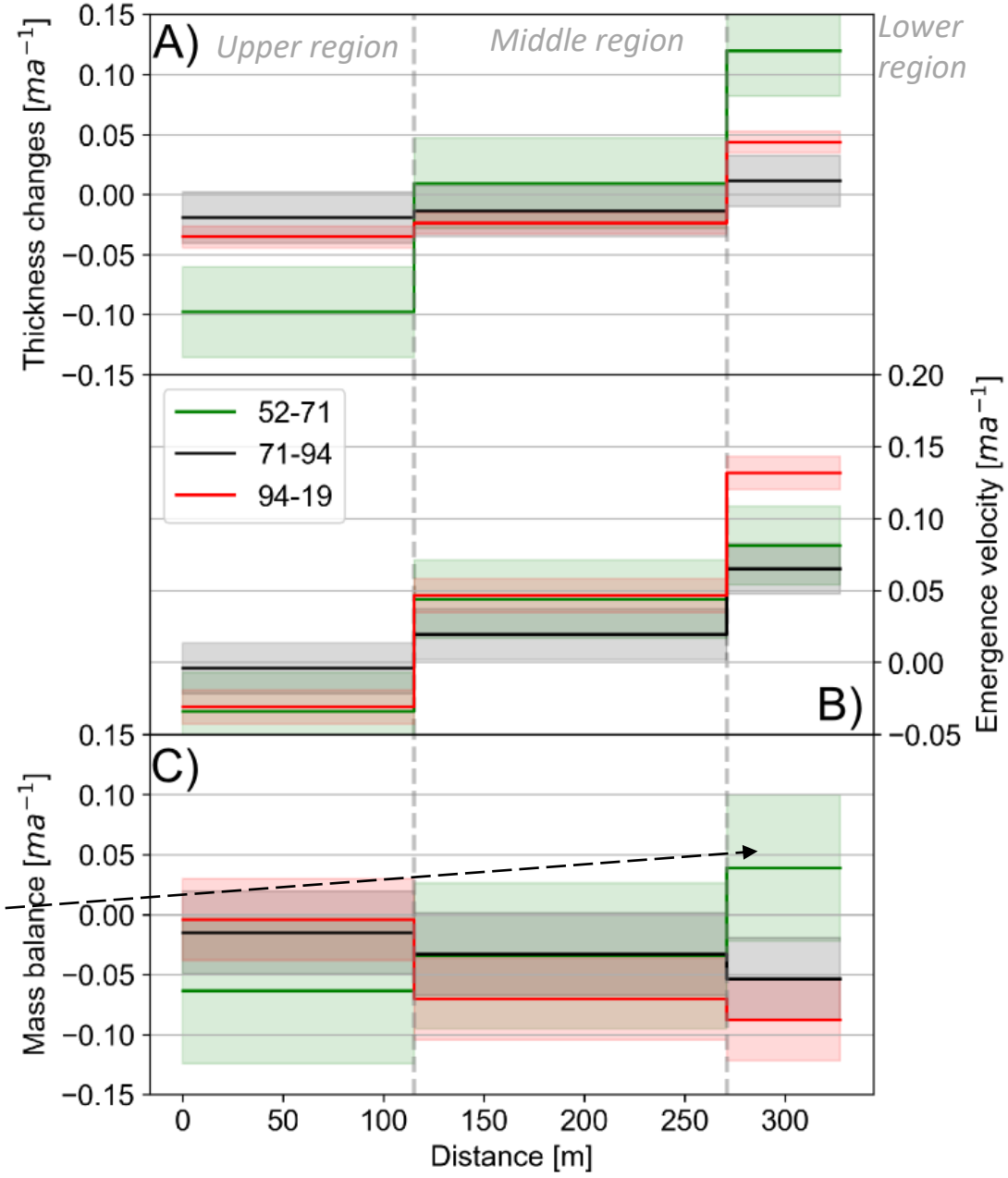
III. Laurichard – Mass balance on rock glaciers



How to explain inverse gradient mass balance



First hypothesis.
Regional avalanche activity was significantly lower during 1950-1970.

Second hypothesis.
Debris input from dominating rock wall. Higher gravitational activity of frozen rock walls in the Alps.

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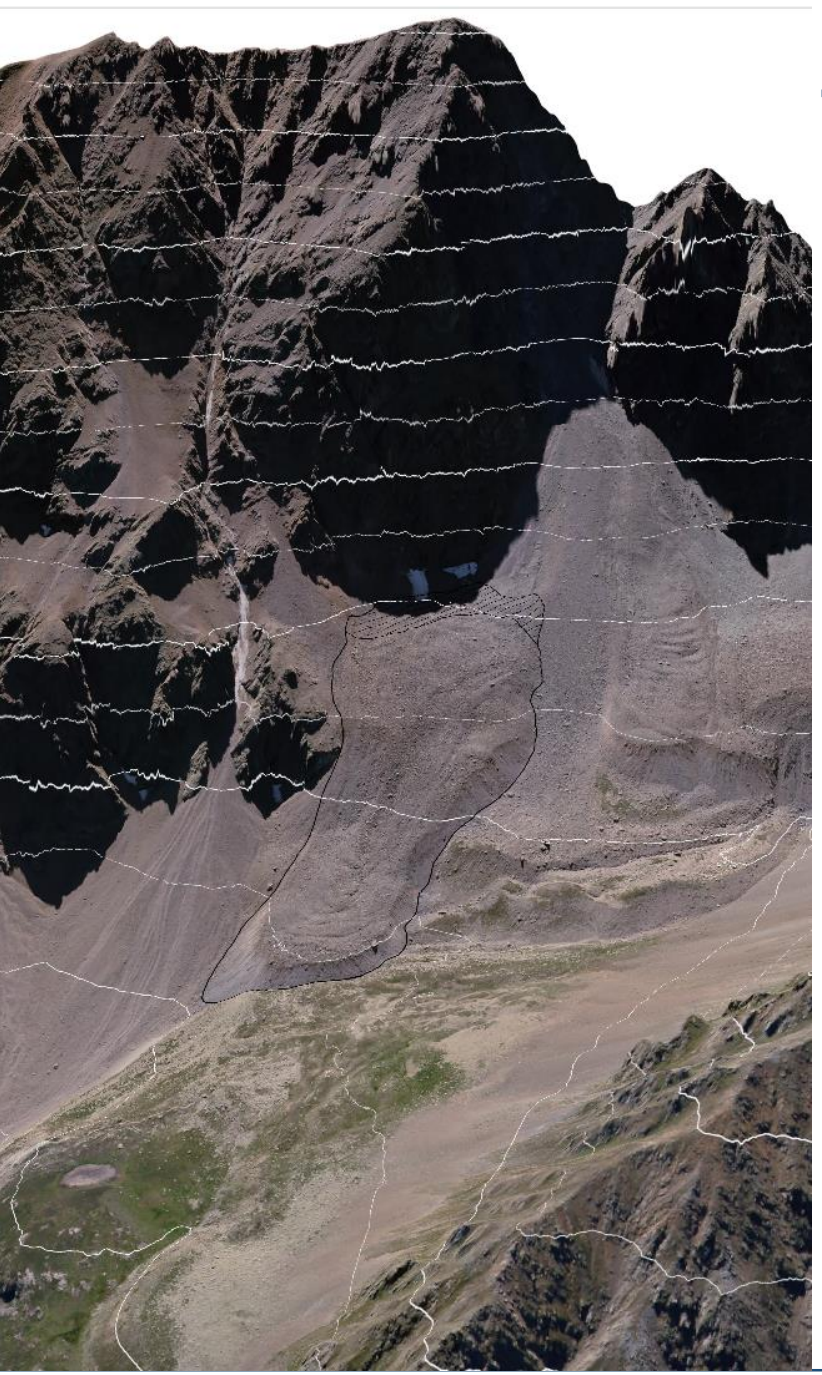

III. Laurichard – Key messages

- For the first on rock glacier, emergence velocities and surface mass balance has been estimated.
- We developed a semi-automatic workflow to compute surface mass balance on rock glacier knowing previously 1) surface velocities; 2) rock glacier thickness; 3) thickness changes. Workflow easily applicable to other rock glaciers.

This part of the presentation id a summary of a paper titled ***"Interpretation of volume and flux changes of the Laurichard rock glacier between 1952 and 2019, French Alps"*** currently in review in *Journal of Geophysical Research.*

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IV. Study sites – Tignes complex glacier

(Marcer et al., 2017)

Annecy

Chambery

25 km

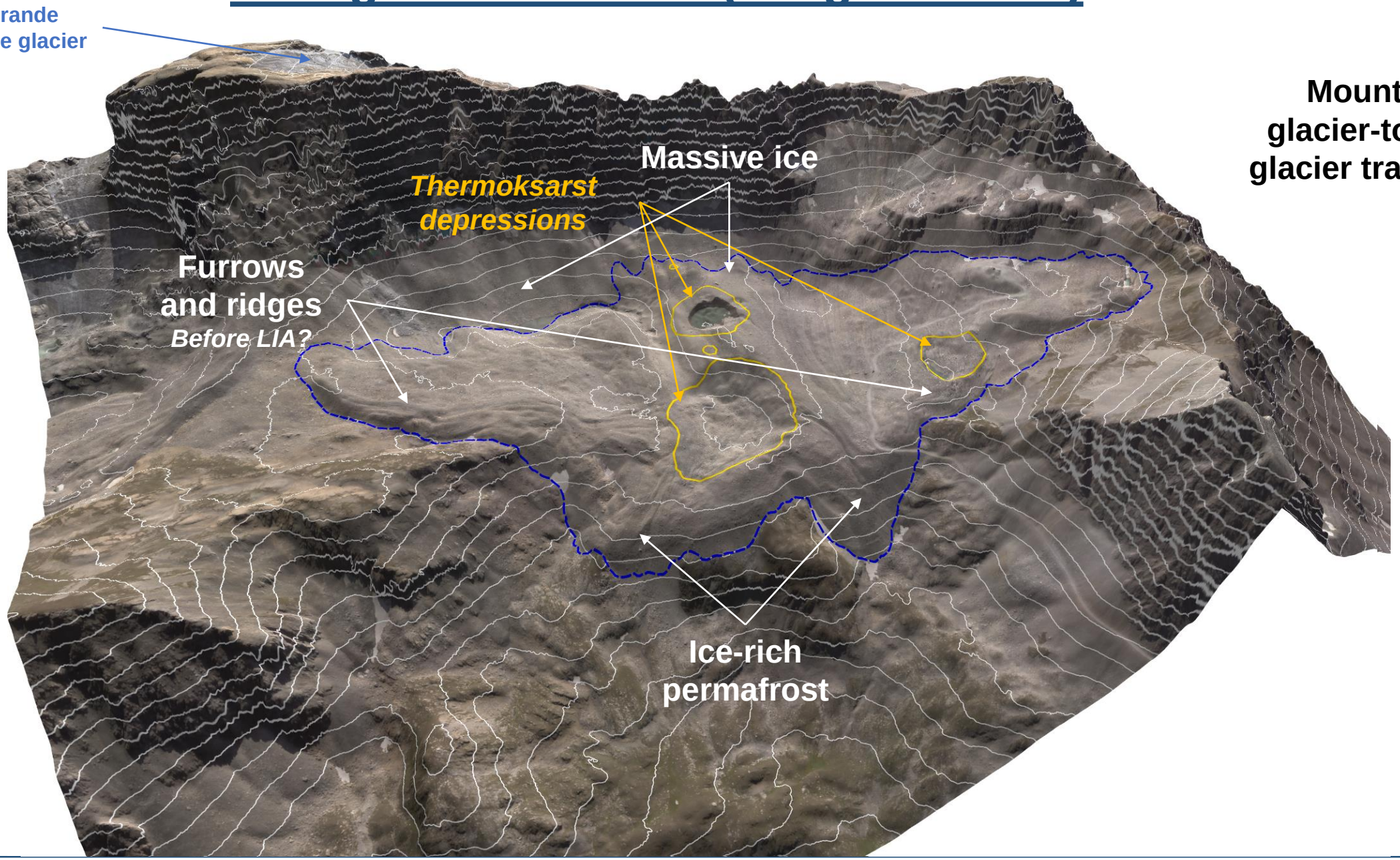
Potential Permafrost areas

Tignes Col de Vés (Lat: 45.44; Long: 6.87; Elev: 2736)

- Long term development of thermokarst lakes.
- Characterize the complex behavior.
- Transition from glacier to debris covered glaciers to rock glacier front.

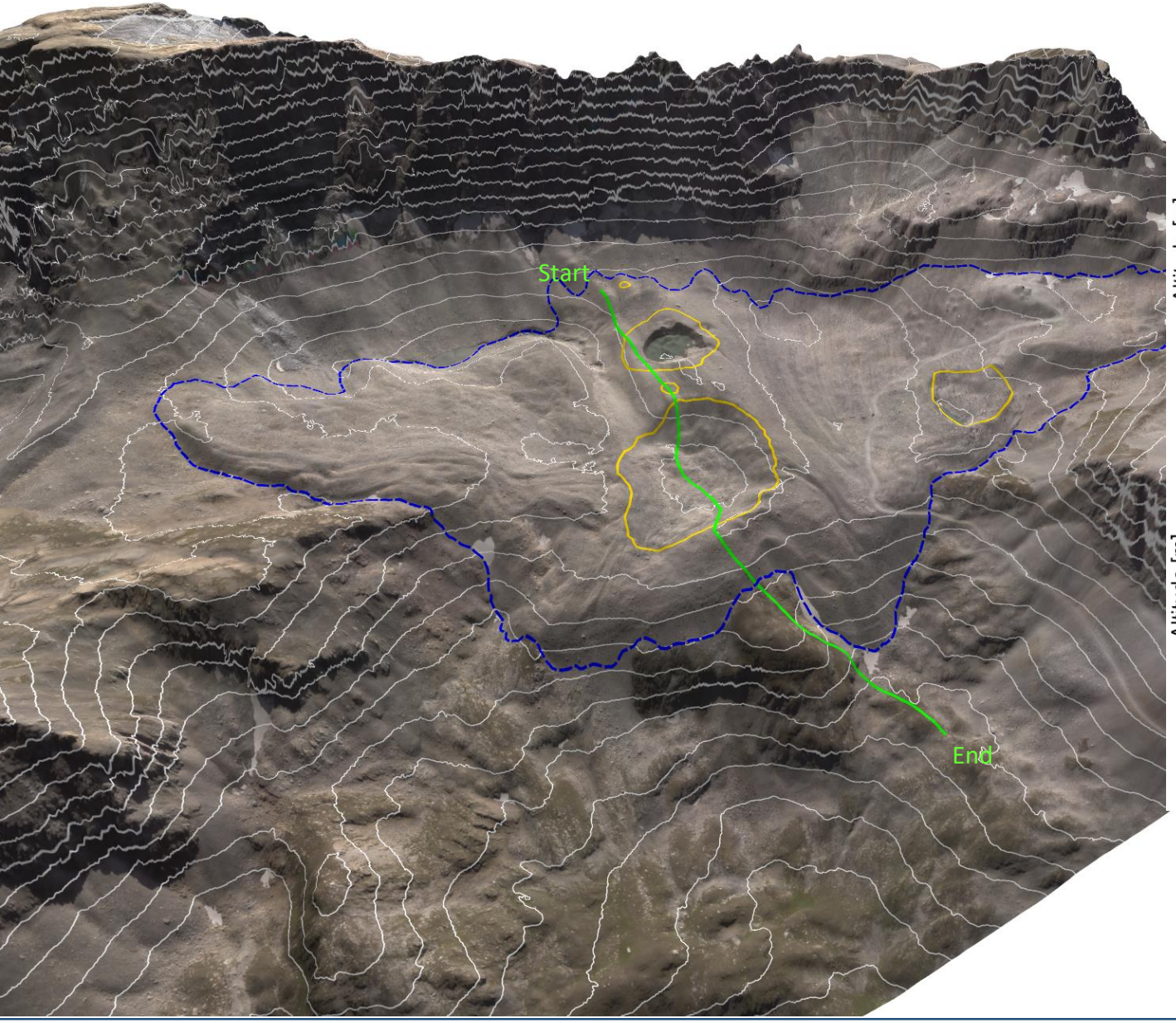
(Duvillard et al., In review)

IV. Tignes – Context (image of 2009)

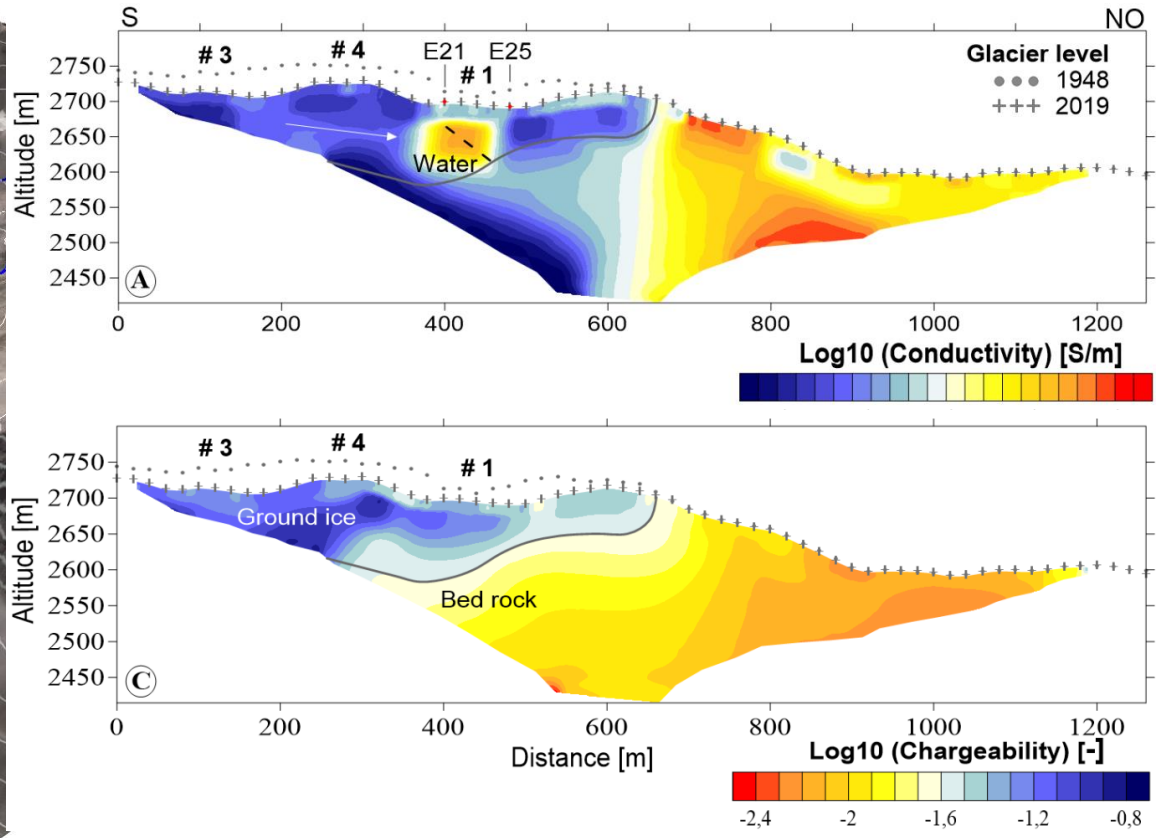


Mountain glacier-to-rock glacier transition

IV. Tignes – Geophysics (ERT-IP)



Large scale longitudinal profile



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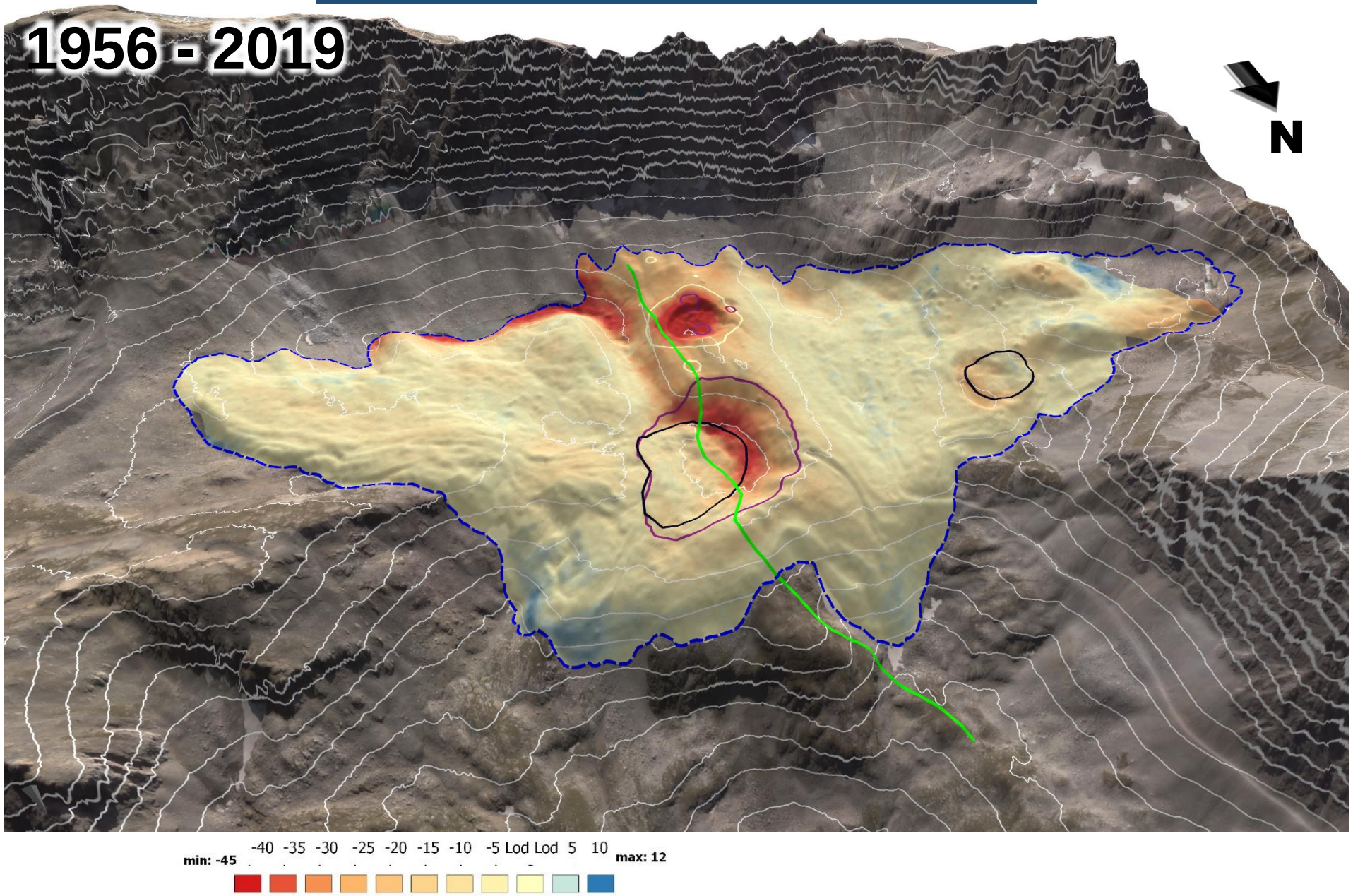
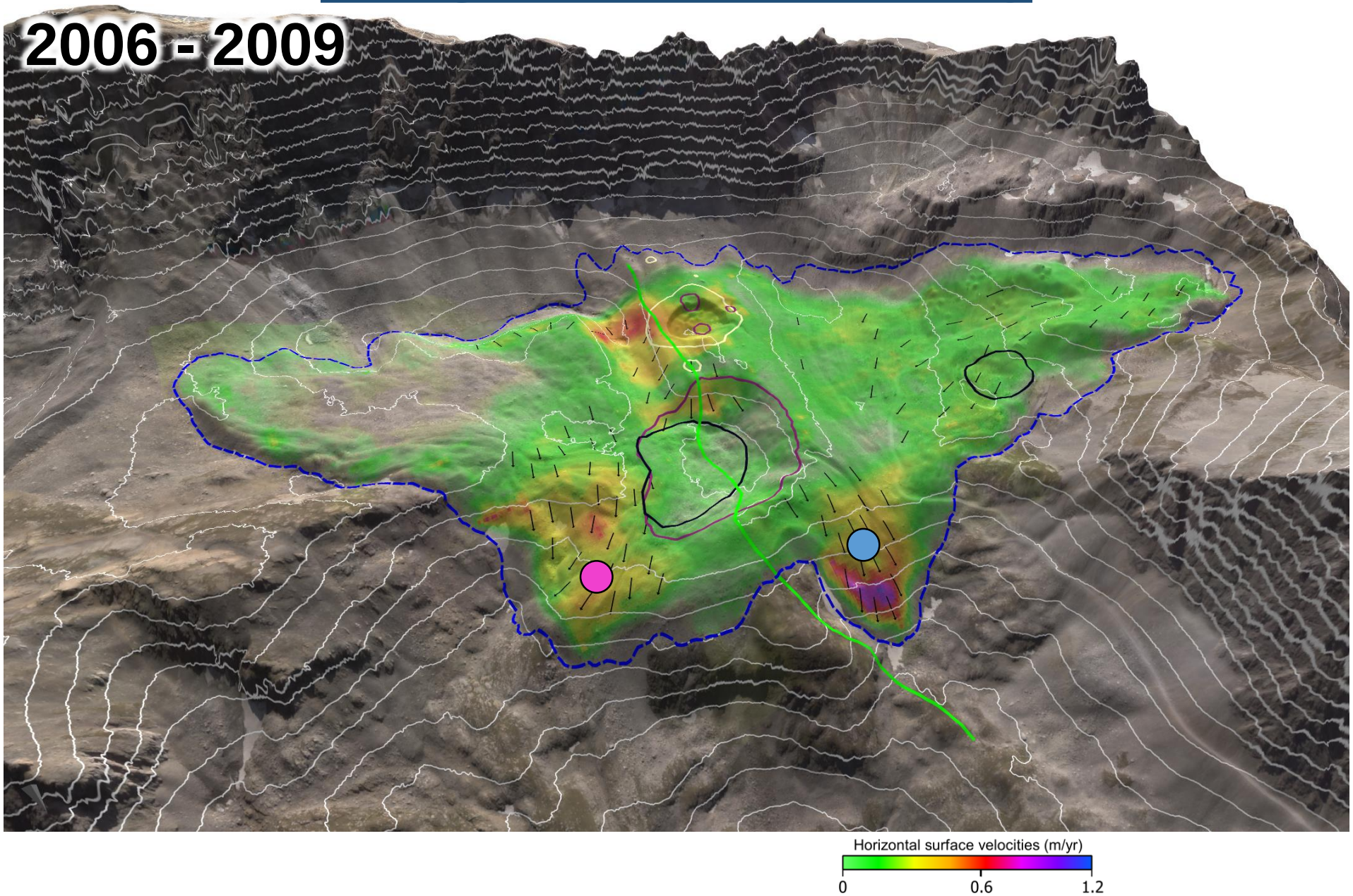
IV. Tignes – volume changes



IV. Tignes – Surface velocity



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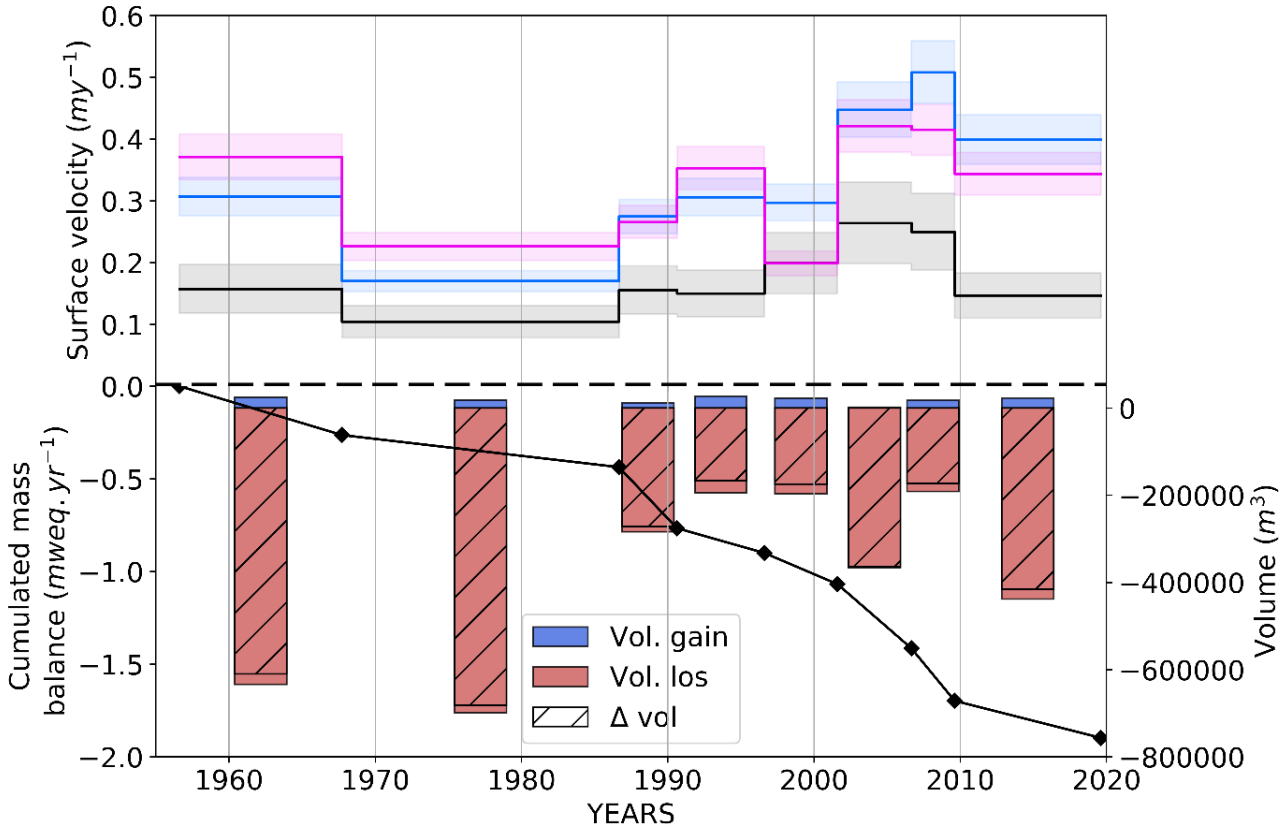
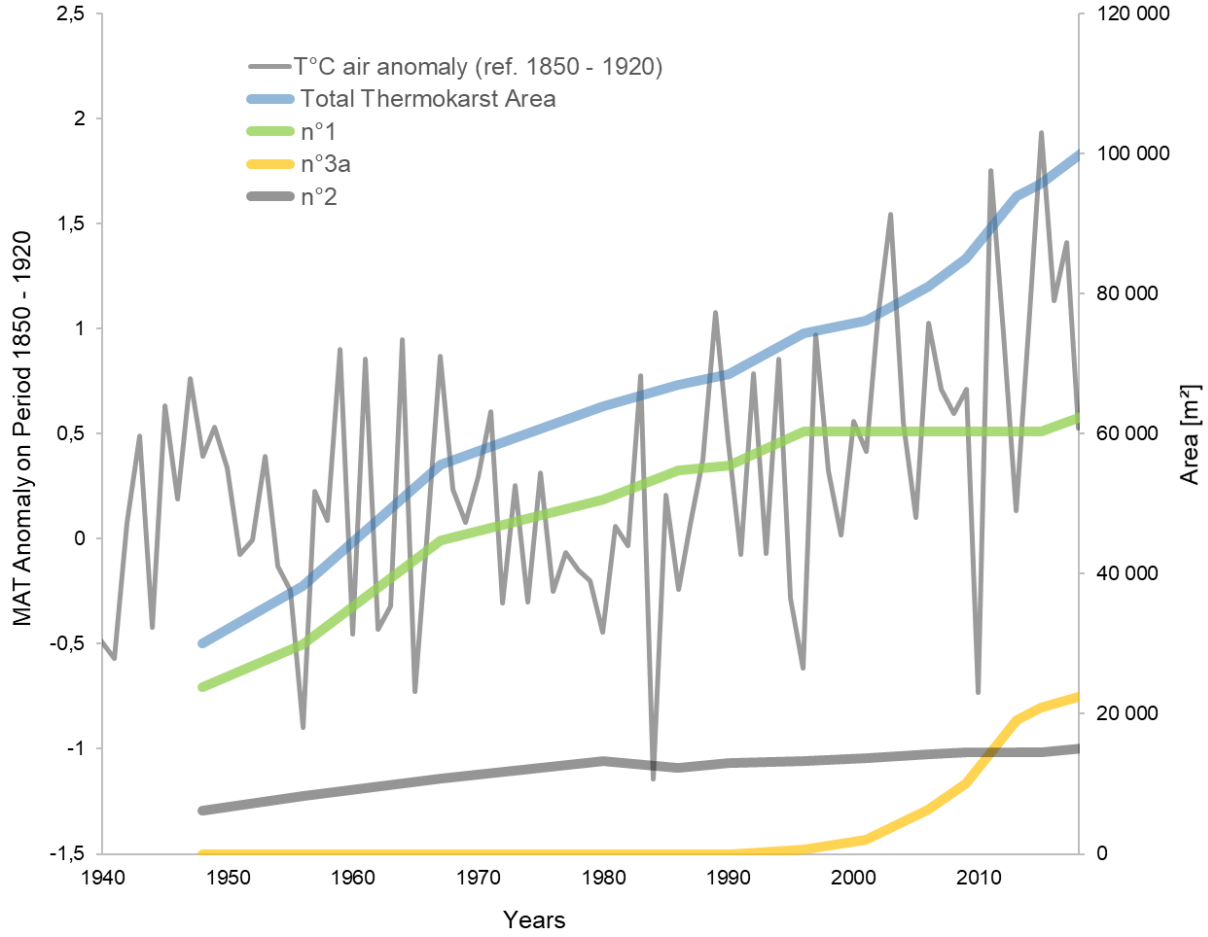
IV. Tignes – thermokarst evolution

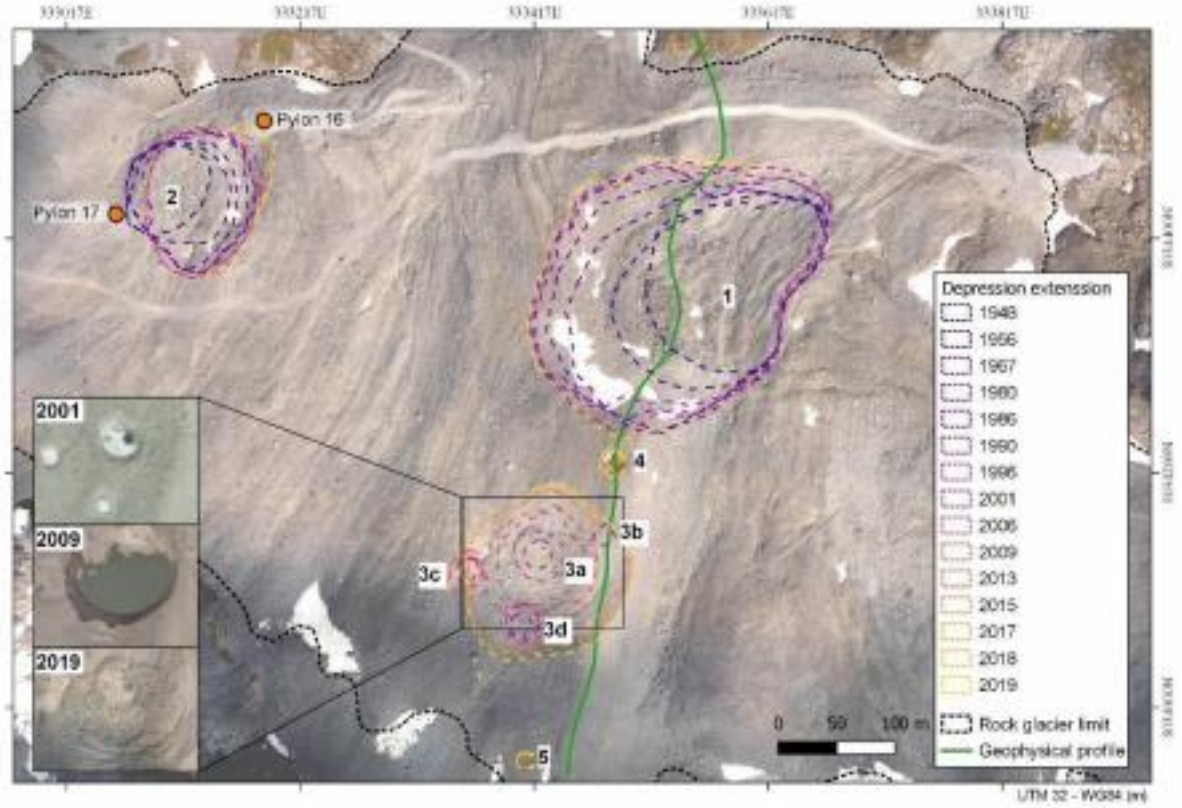




- Correlation between thermokarst lakes growing and temperature increase.
- No traces of floods near to glacier front. Water infiltration thought karstic drainage.

IV. Tignes – Key messages

Extension of thermokarst lakes from 1948 to 2019.



- Correlation between thermokarst lakes growing and temperature increase.
- No traces of floods near to glacier front.
- Water infiltration thought karstic drainage.

This part of the presentation id a summary of a paper titled ***"Evolution of thermokarst over seven decades in an Alpine ice-rich rock glacier / dead ice complex"*** currently in review in *Arctic, Antarctic, and Alpine Research.*

V. Study sites – Mountain thermokarst lakes

(Marcer et al., 2017)

Annecy

Chambery

N

25 km

Potential Permafrost areas

Plan Chauvet

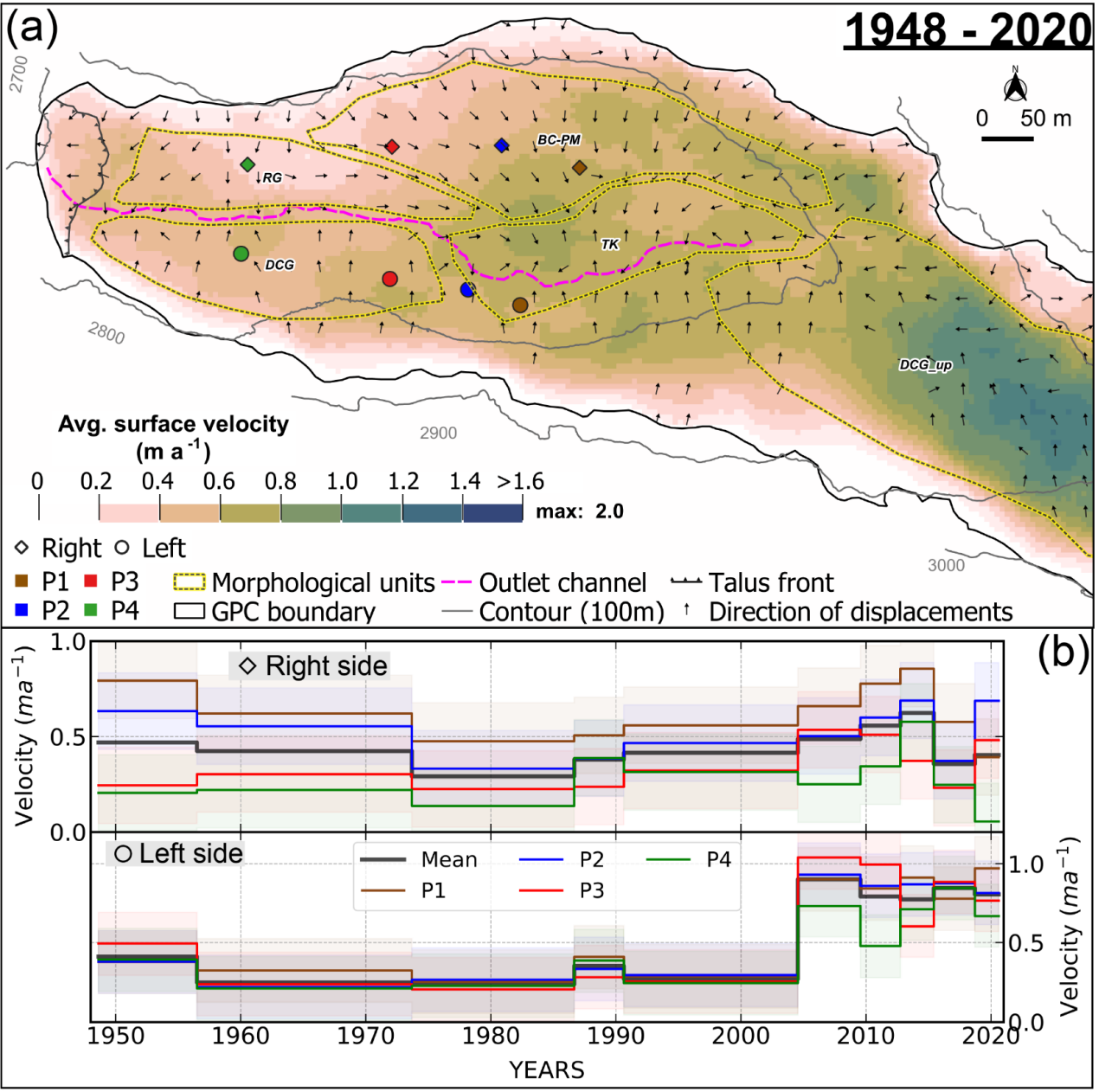
(Lat: 44.55; Long: 6.84; Elev: 2772)

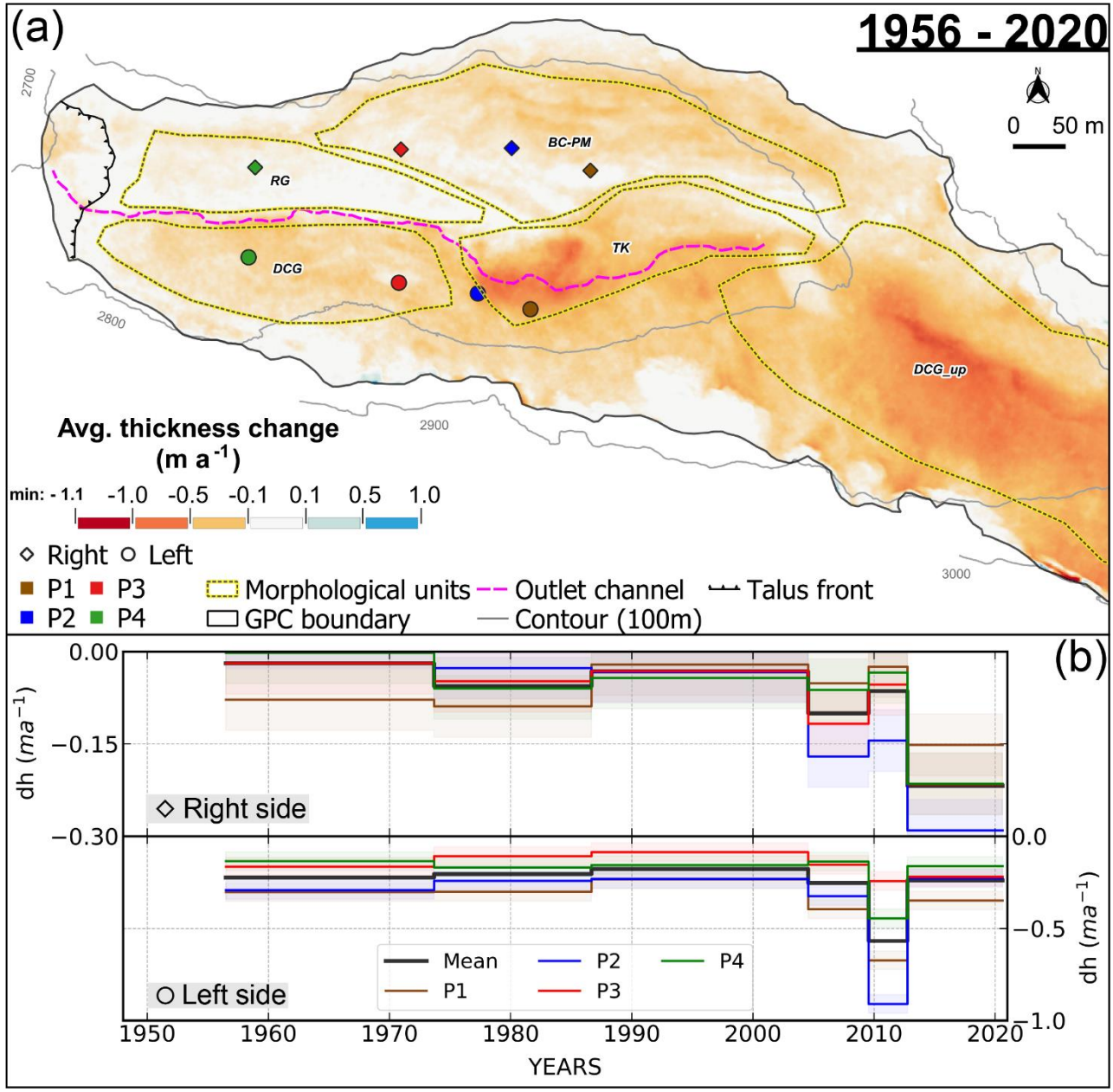
6 violent evacuation occurred (1936, 1956, 1970, 1991, 1997 et 2008)

Cusicanqui et al., In prep.

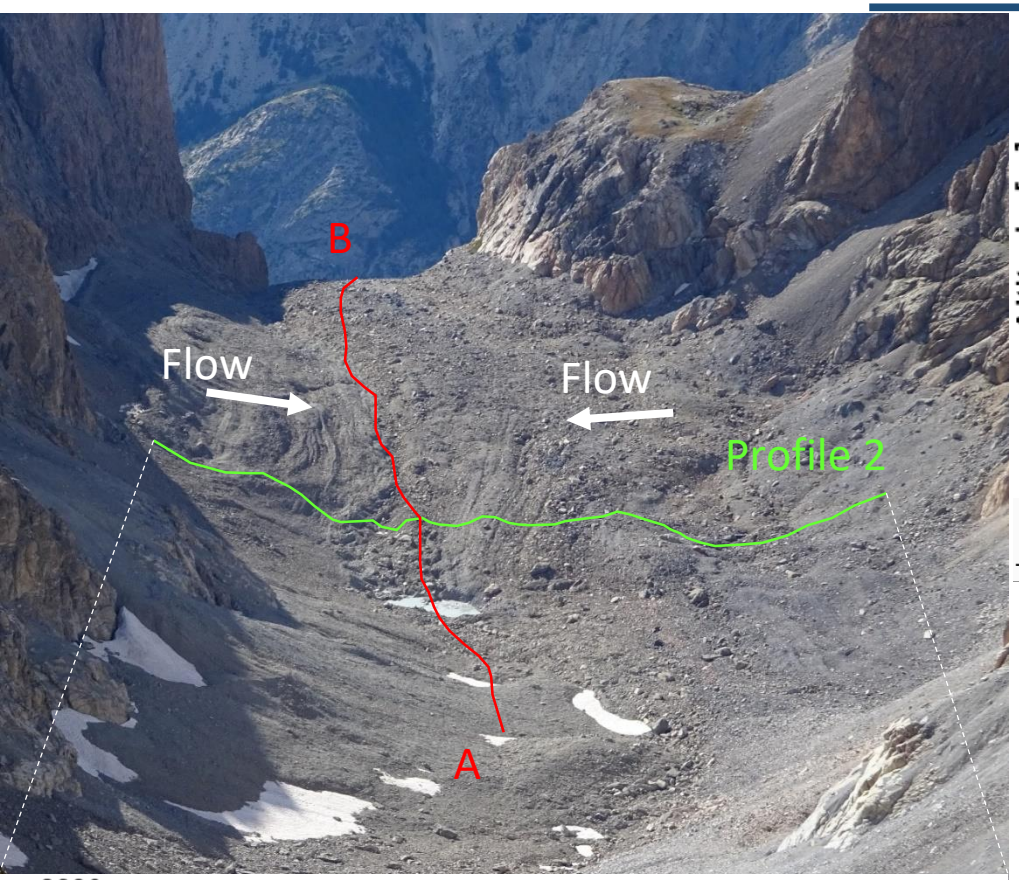
Haute-Ubaye valley

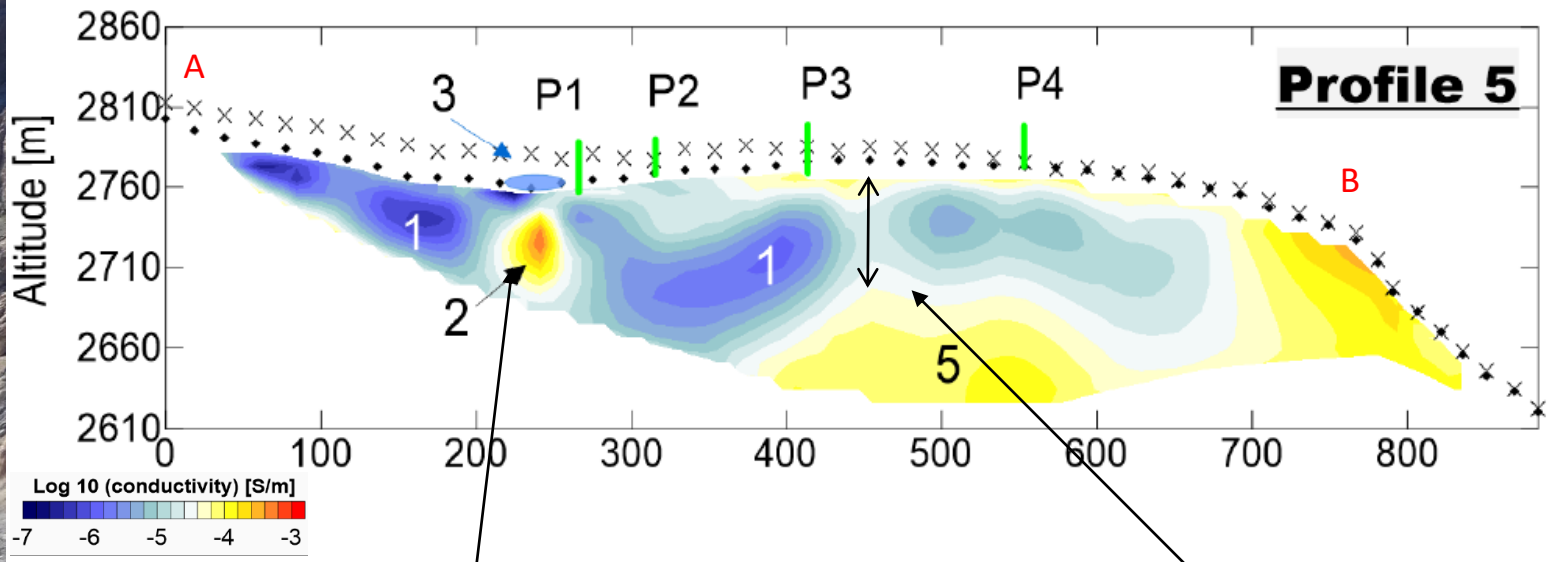
V. Chauvet – Surface velocities and volume changes





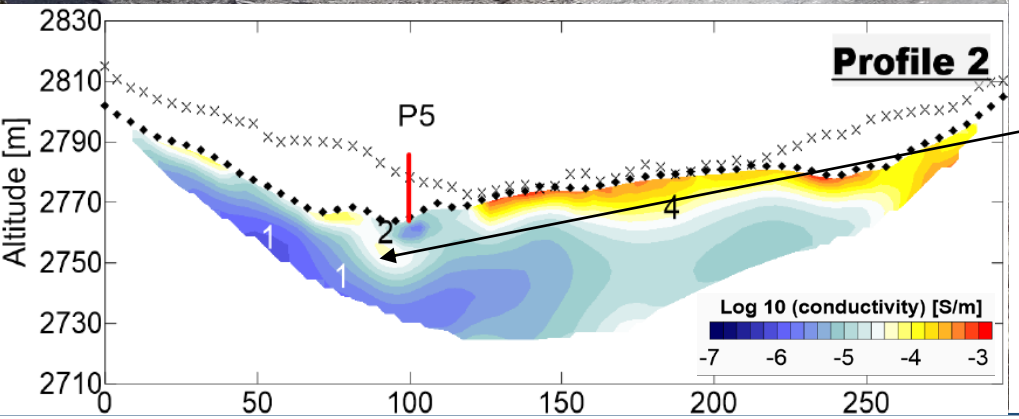
V. Chauvet – Geophysics (ERT-IP)





Geophysics suggest an internal water reservoir.

Geophysics reveals at least 60m of massive ice.

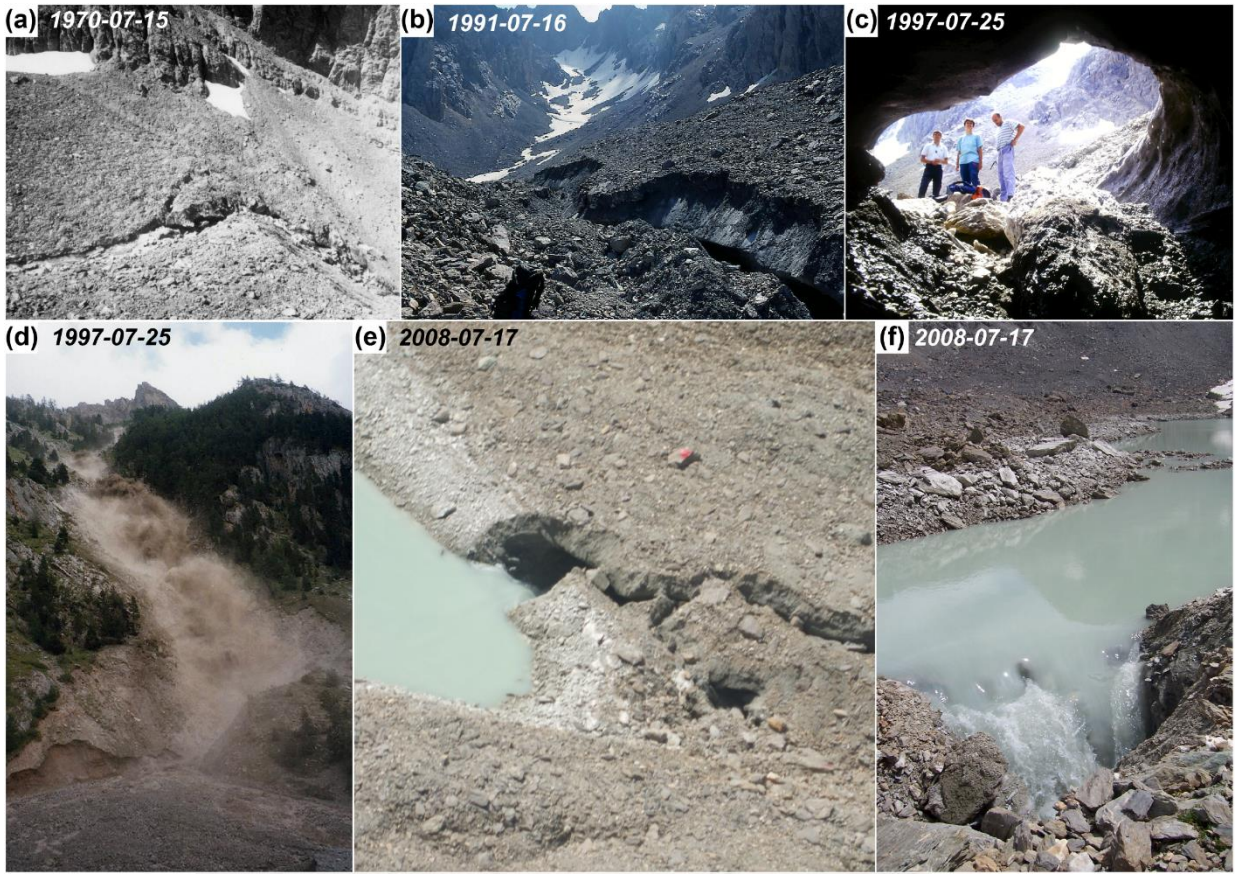


Internal conduit formation?

➡ Blockage of internal conduit remains unclear

1 = massive ice; 2 = Water; 3 = Lake;
4 = Debris covered; 5 = Bedrock

V. Chauvet – Key messages



- Drainage thought an englacial conduit which is currently under developing.
- Strong thickness changes over debris-covered glacier sector.
- Current buckets shape glacier surface could store large quantity of water. Mitigation measurements should be taken urgently.

This part of the presentation id a summary of a paper titled ***"Investigating the multi-decadal (1948-2020) thermokarst dynamicsof the Chauvet glacial and periglacial complex, Southern French Alps"*** currently in preparation to be submitted the next month.

VI. Conclusions

- We successfully quantified 70 years of changes (surface velocity and thickness changes) with high level of confidence.
- Our multidisciplinary approach allow to describe complex behavior.
- A general doubling in flow velocity has been observed after 90's.
- **Laurichard rock glacier:** We developed a semi-automatic workflow to compute surface mass balance on rock glacier easily applicable to other rock glaciers.
- **Tignes complex:** thermokarst are partially correlated with current warming conditions. However, lake drainage can be probably evacuated thought internal karst network drainage.
- **Chauvet complex:** outburst floods causes still remain unclear. However, regarding the current context, new outburst floods can took place in the future.

Thanks for your attention !
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