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An altitudinal transition in rock glacier dynamics detected through integration of geomorphologic mapping and InSAR-based kinematic information

PermaCOST Training School
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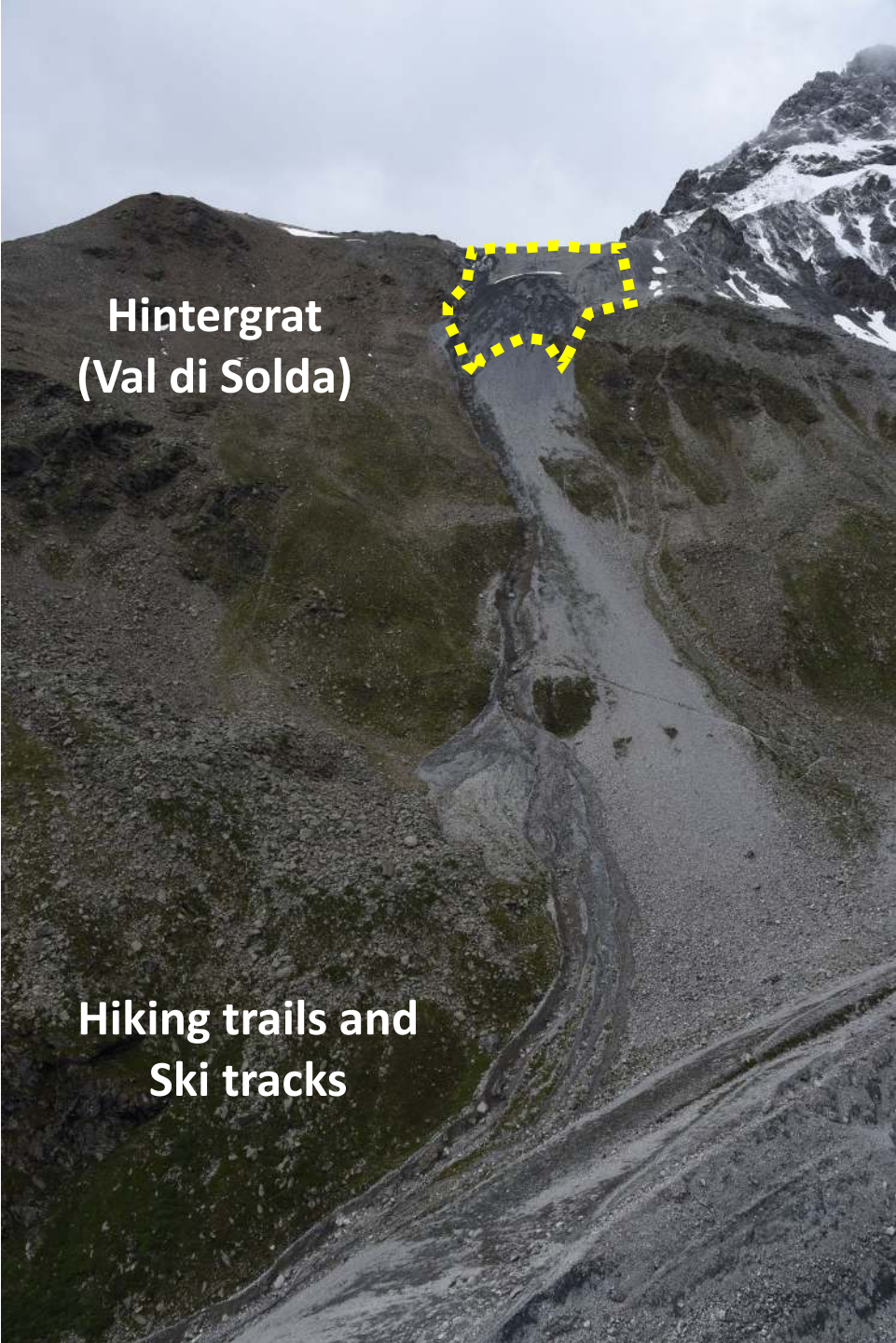
1. University of Bologna; 2. Province of Bolzano; 3. Gamma Remote Sensing

Statement of the problem

“Traditional” inventories display **high variability** with respect to the **morphologic discrimination** between intact (**active** + **transitional**) and relict rock glaciers:

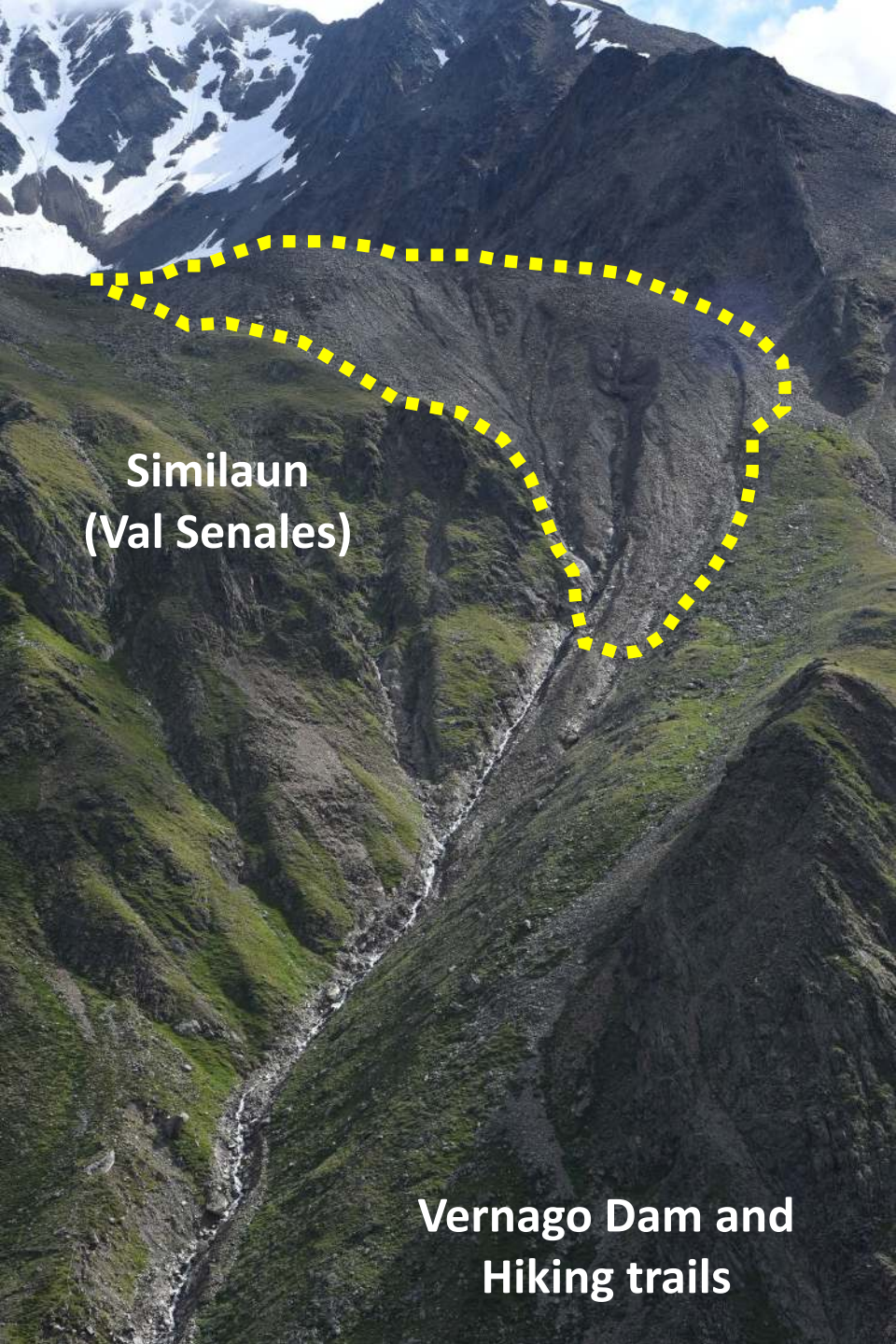
1) This is a problem for evaluating **permafrost distribution** and geohazard potential, since the altitudinal transition between intact and relict rock glaciers sits at the **fringe** of permafrost-bearing terrain;





Hintergrat
(Val di Solda)

Hiking trails and
Ski tracks



Similaun
(Val Senales)

Vernago Dam and
Hiking trails



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Statement of the problem

“Traditional” inventories display **high variability** with respect to the **morphologic discrimination** between intact (**active** + **transitional**) and relict rock glaciers:

- 1) This is a problem for evaluating **permafrost distribution** and geohazard potential, since the altitudinal transition between intact and relict rock glaciers sits at the **fringe** of permafrost-bearing terrain;
- 2) A **systematic evaluation** of the improvements gained through the integration of a traditional geomorphologic inventory and InSAR technology over **broad spatial scales** is missing.

Objectives

In western South Tyrol, starting from a recent geomorphologic inventory (Scotti et al, 2024), we aim to:

- (i) Characterize the **kinematics** of InSAR-based moving areas and hosting rock glaciers;
- (ii) Evaluate InSAR-derived improvements, in terms of **completeness** and **uncertainty reduction**, in the detection and activity classification of rock glaciers (**TECHNICAL OBJECTIVE**)
- (iii) Explore how the velocity and spatial distribution of moving areas varies with simple topographic variables (known to exert first-order controls on incoming solar radiation and ground temperature) such as **elevation** and **aspect** (**PROCESS-BASED OBJECTIVE**)



Study area (970 km²)

The NE portion of **Ortles-Cevedale massif**:

- (i) the southern side of Venosta Valley
- (ii) five tributary valleys

Elevation: 500 – 3905 m a.s.l.

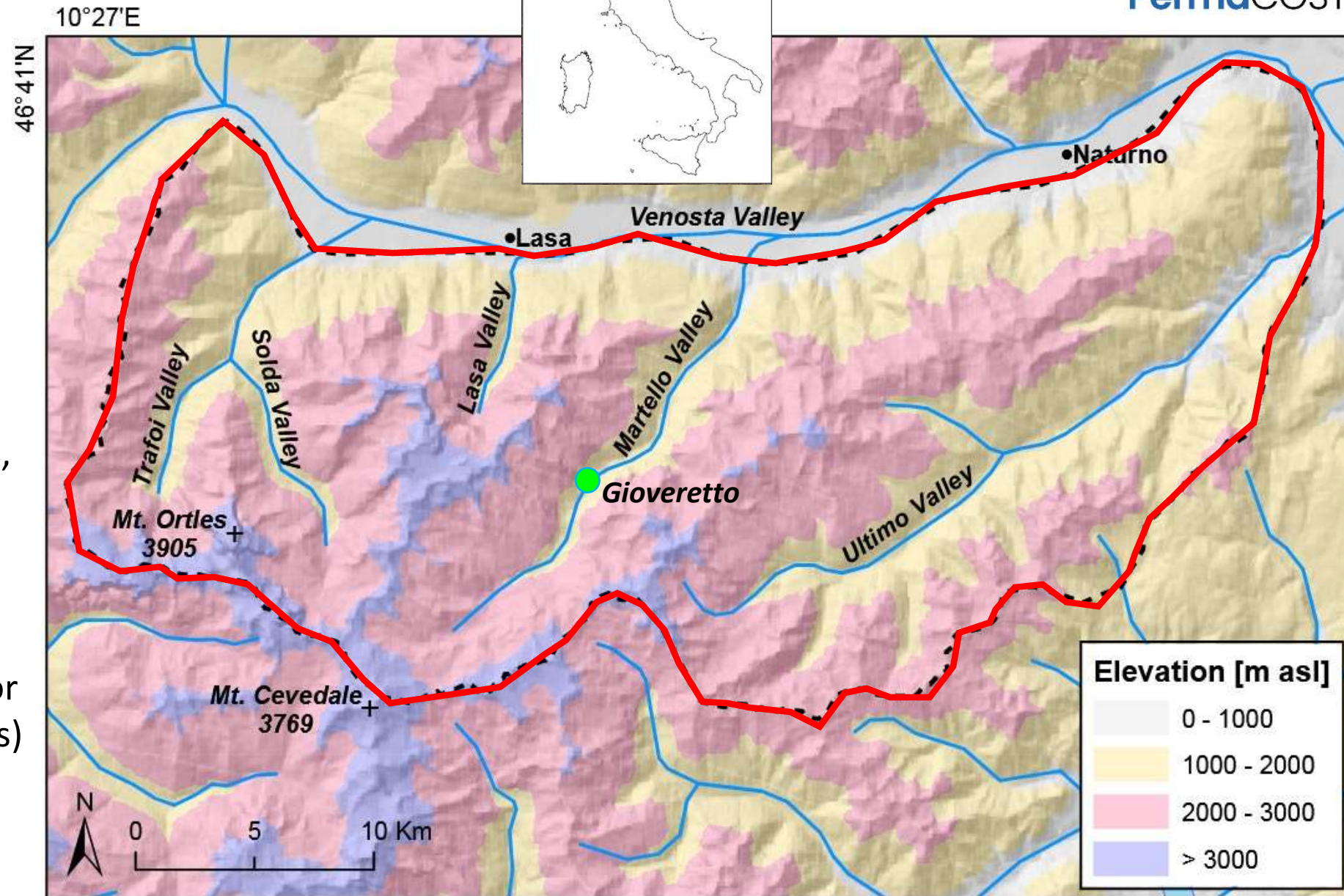
Geology:

Dominant **metamorphic rocks**, lesser granite and limestone-dolostone

MAP (1921/1972-2022):

506 mm @ Venosta valley floor
(Silandro/Shlanders)

779 mm @ **Gioveretto dam**



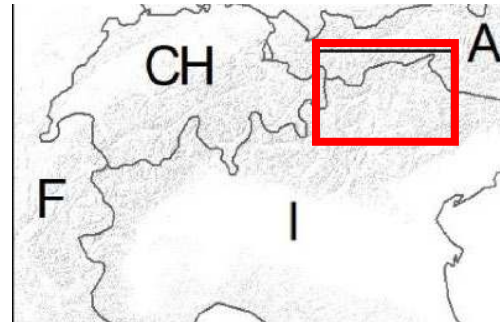
Study area



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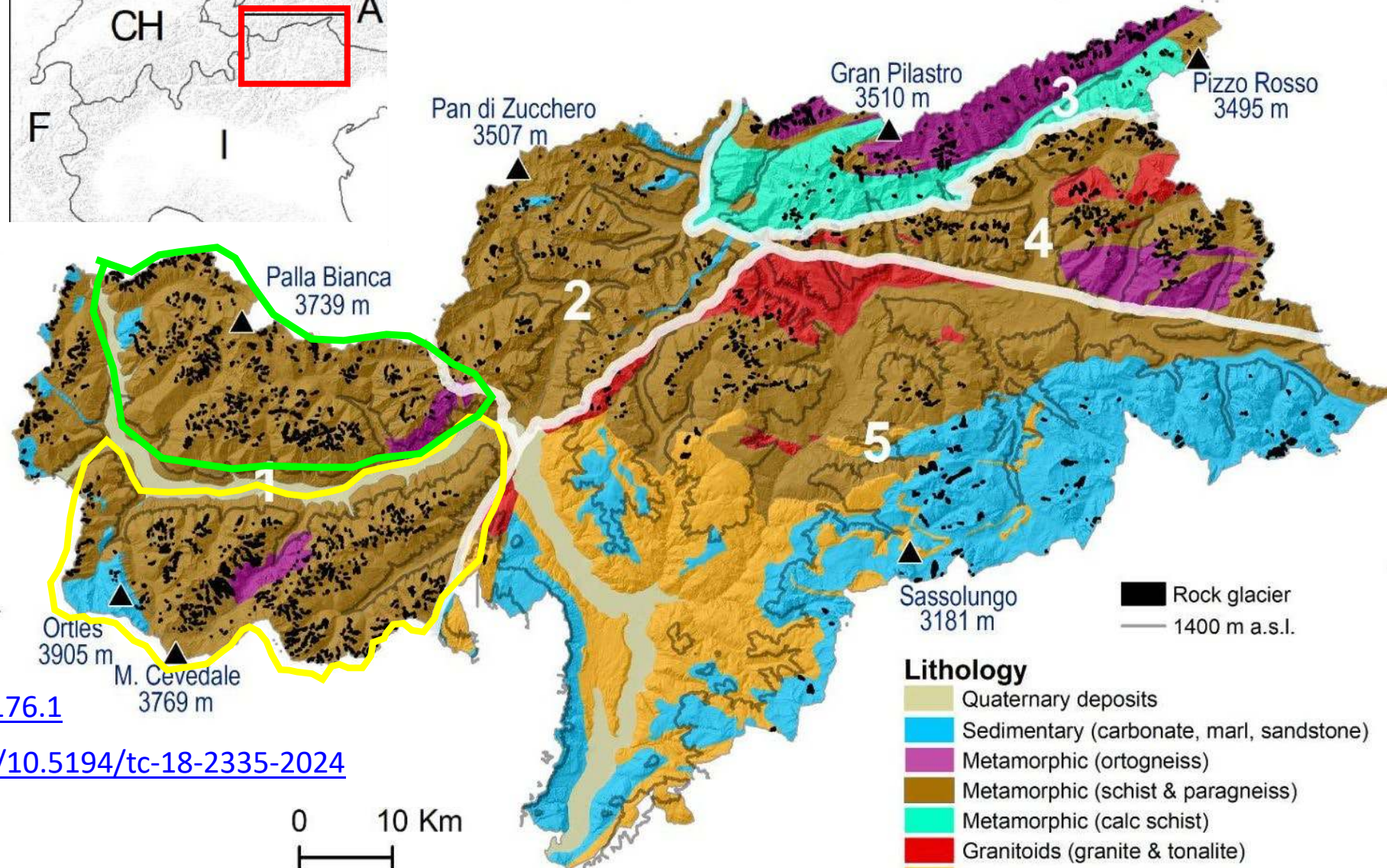
Physiographic zones

- 1 Western Austroalpine
- 2 Central Austroalpine
- 3 Penninic
- 4 Eastern Austroalpine
- 5 Southalpine



NORTHERN Venosta →

SOUTHERN Venosta →



Scotti et al (2024)

Scotti et al. 2024

<https://doi.org/10.52381/ICOP2024.176.1>

Bertone et al. 2024 <https://doi.org/10.5194/tc-18-2335-2024>

Data collection: Geomorph RG inventory



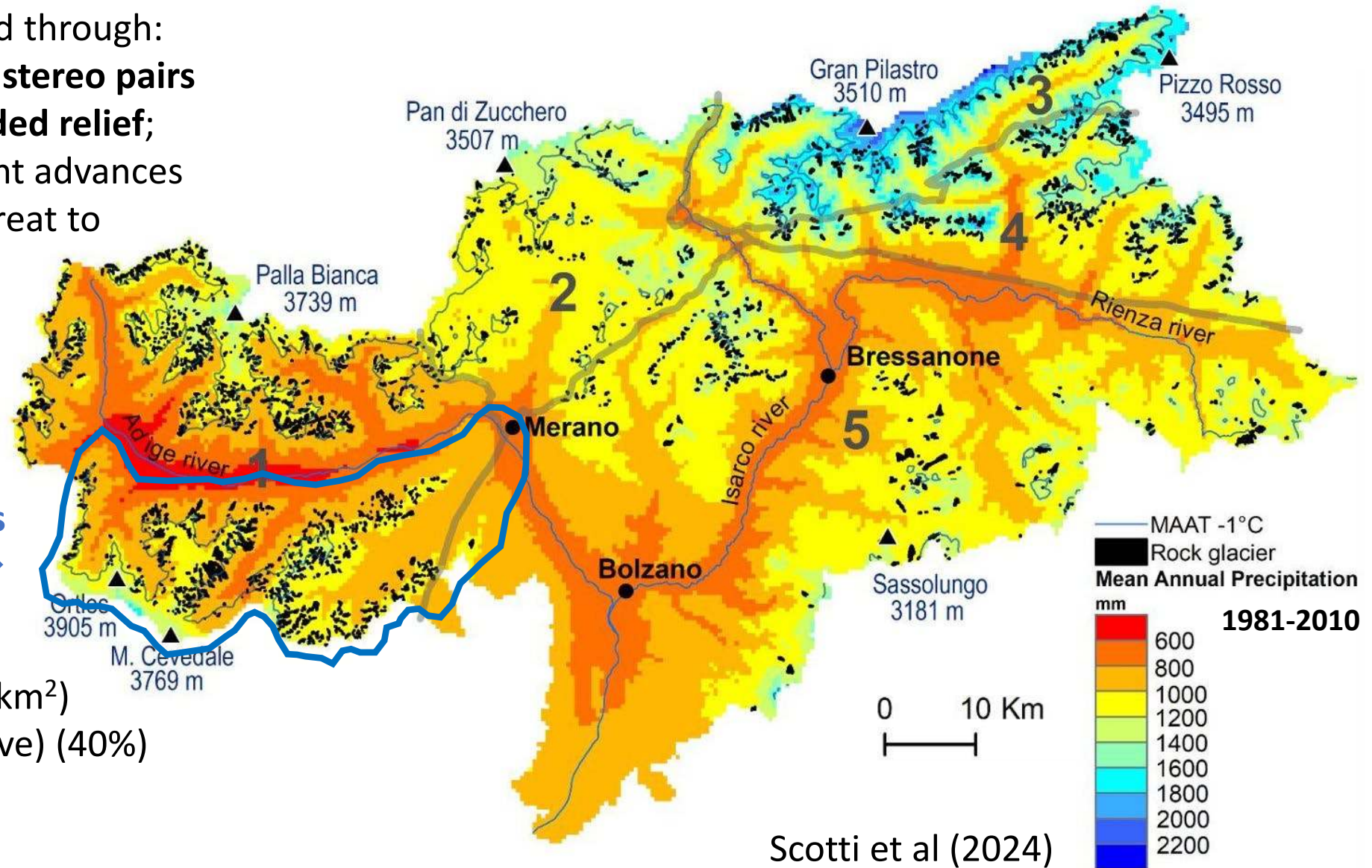
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The inventory was compiled through:

- Interpretation of **photo stereo pairs** and **LiDAR-derived shaded relief**;
- **Local reports** on RG front advances that caused damage/threat to infrastructure

789 rock glaciers
in 970 km² →

2796 rock glaciers (→ 146 km²)
1117 intact (active & inactive) (40%)
1679 relict (60%)



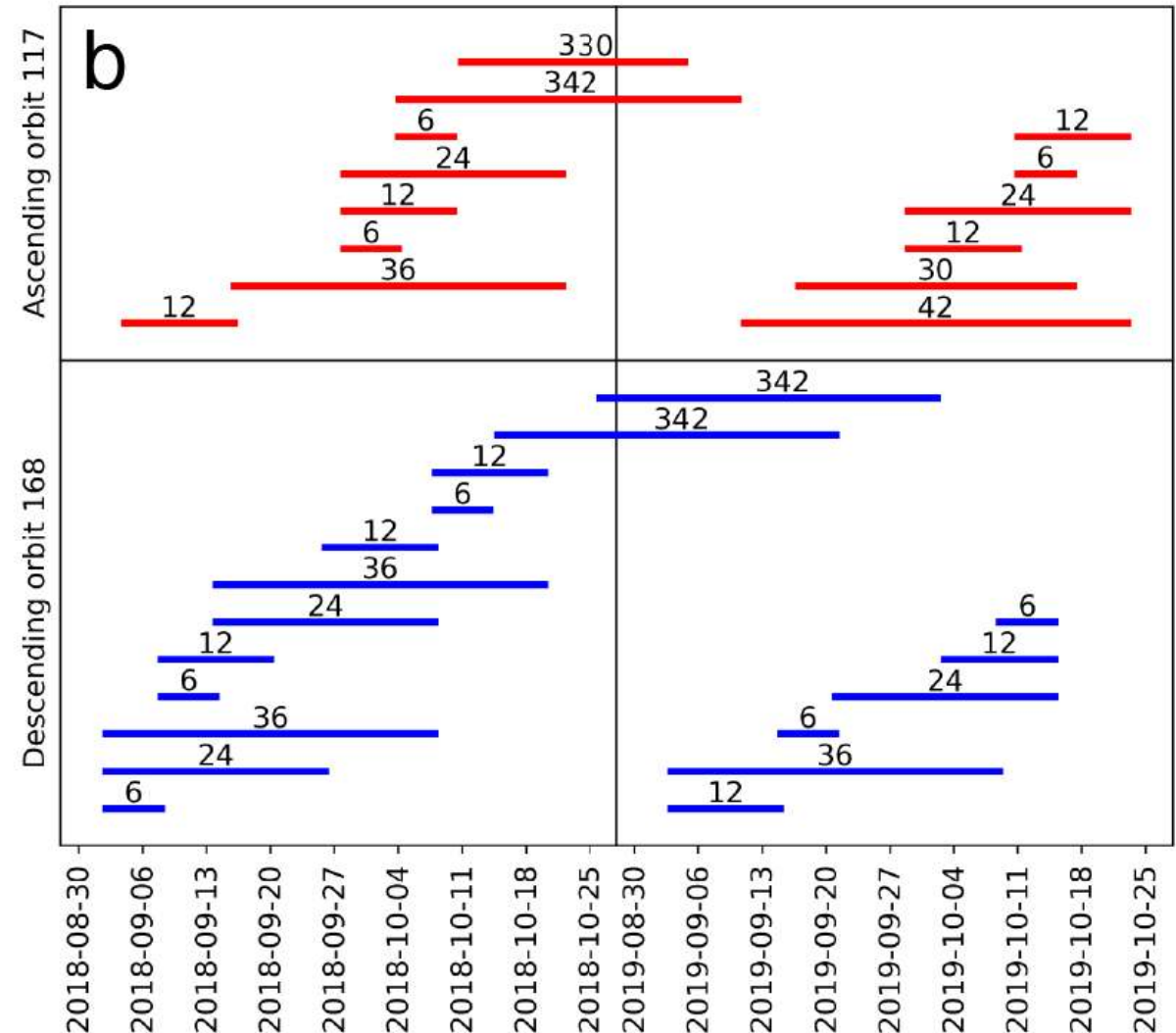
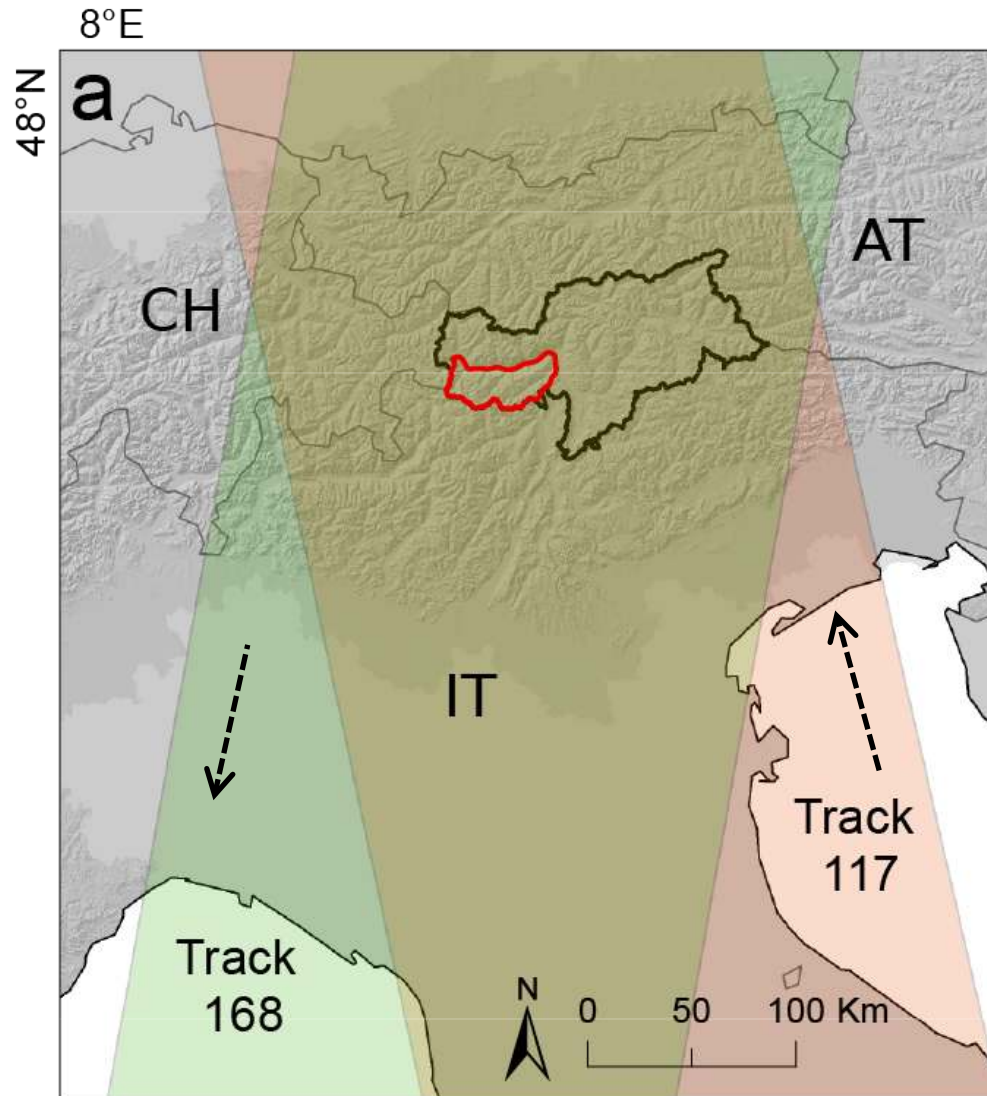
Scotti et al (2024)

Data collection: InSAR kinematic characterization



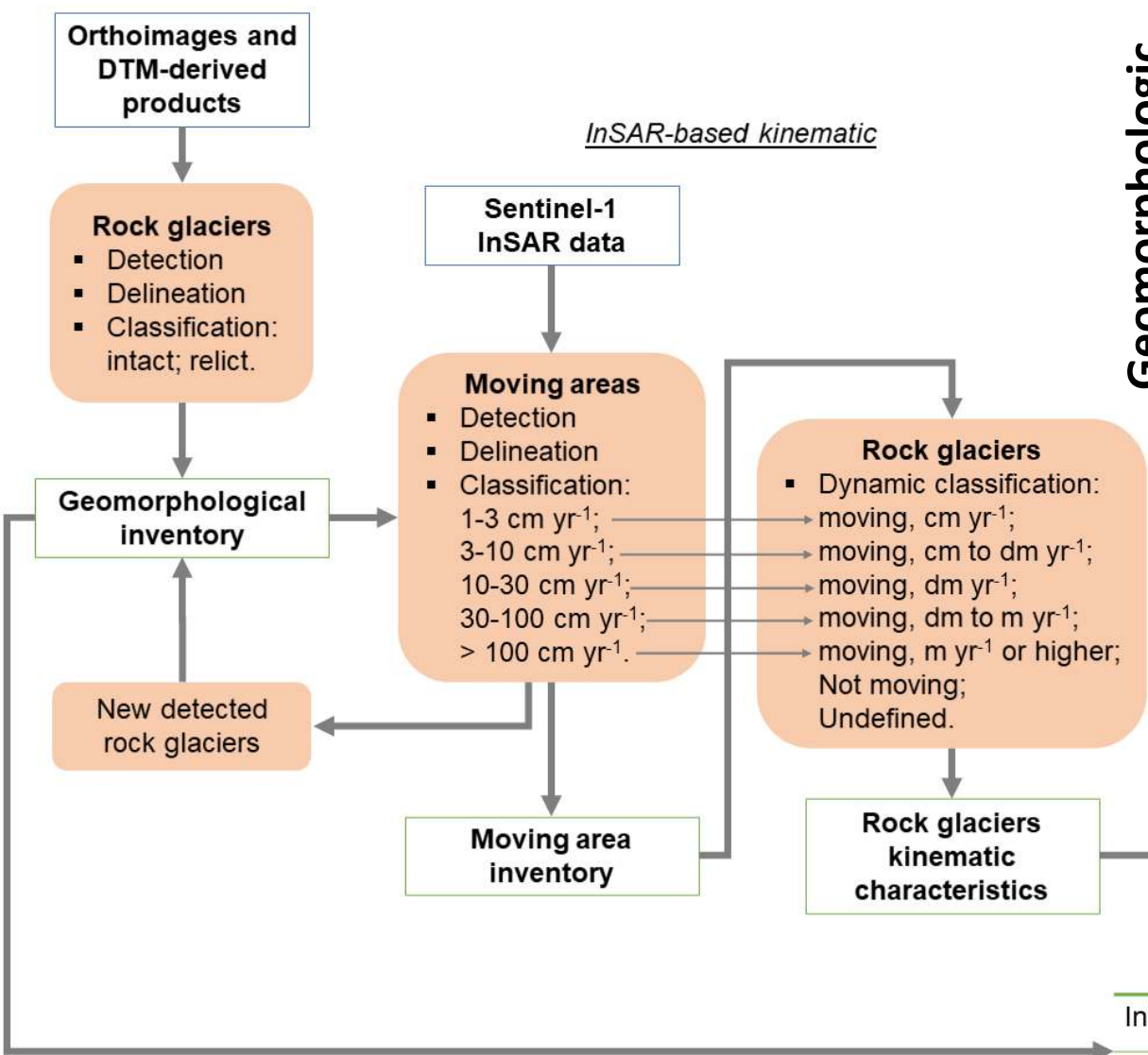
Using **Sentinel-1**, InSAR data acquired between **Sept 2018** and **Oct 2019**, both in **ascending** and **descending** mode, we selected **34 wrapped interferograms** over 6, 12, 24, 30, 36, 42, 330 and 342 days

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Data integration and decision rules

Geomorphologic analyses



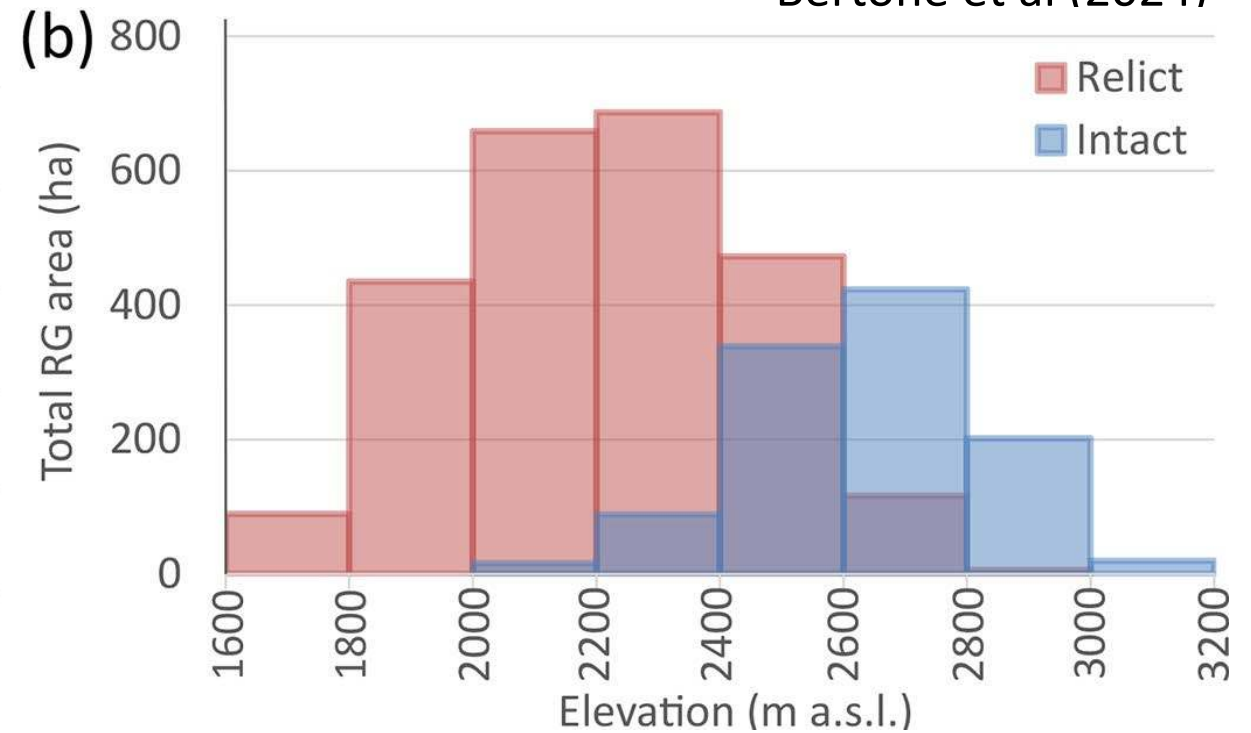
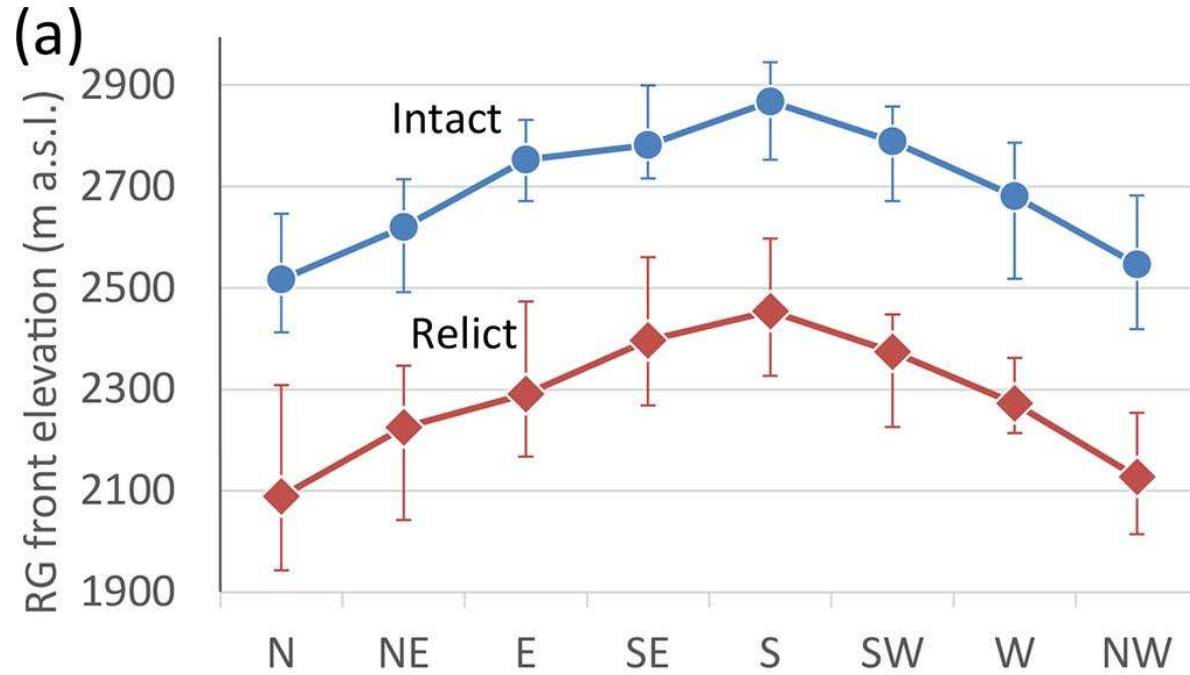
Geomorphologic

InSAR classification

	Moving	Not moving	Undefined
Intact	Intact	Relict	Intact
Relict	Intact	Relict	Relict
New	Intact	-	-

Geomorph results:

Relict and intact RGs across elevations and aspects

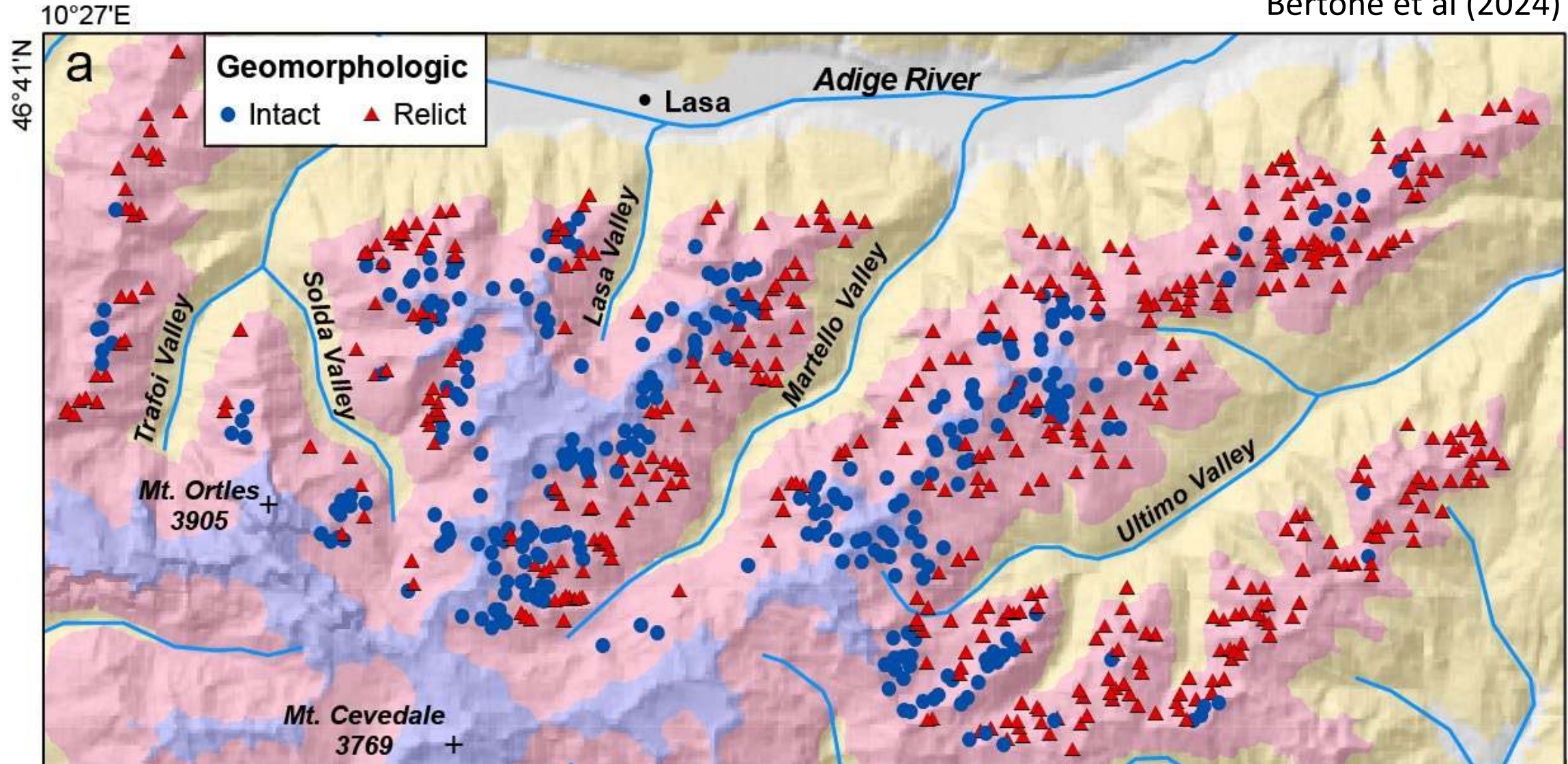


Valley-wide products: Geomorph inventory



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Bertone et al (2024)

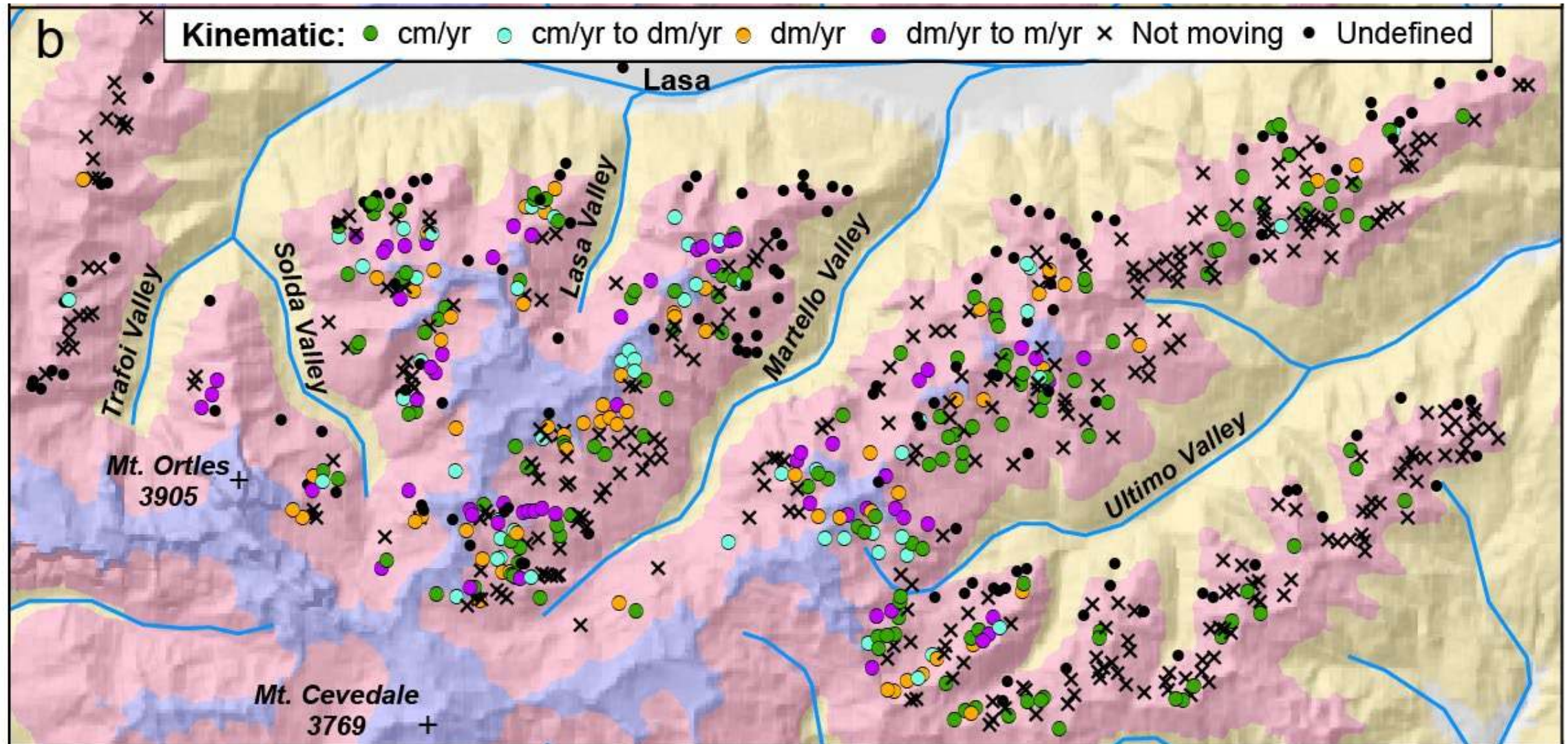


Valley-wide products: InSAR-based Kin Attribute



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Bertone et al (2024)

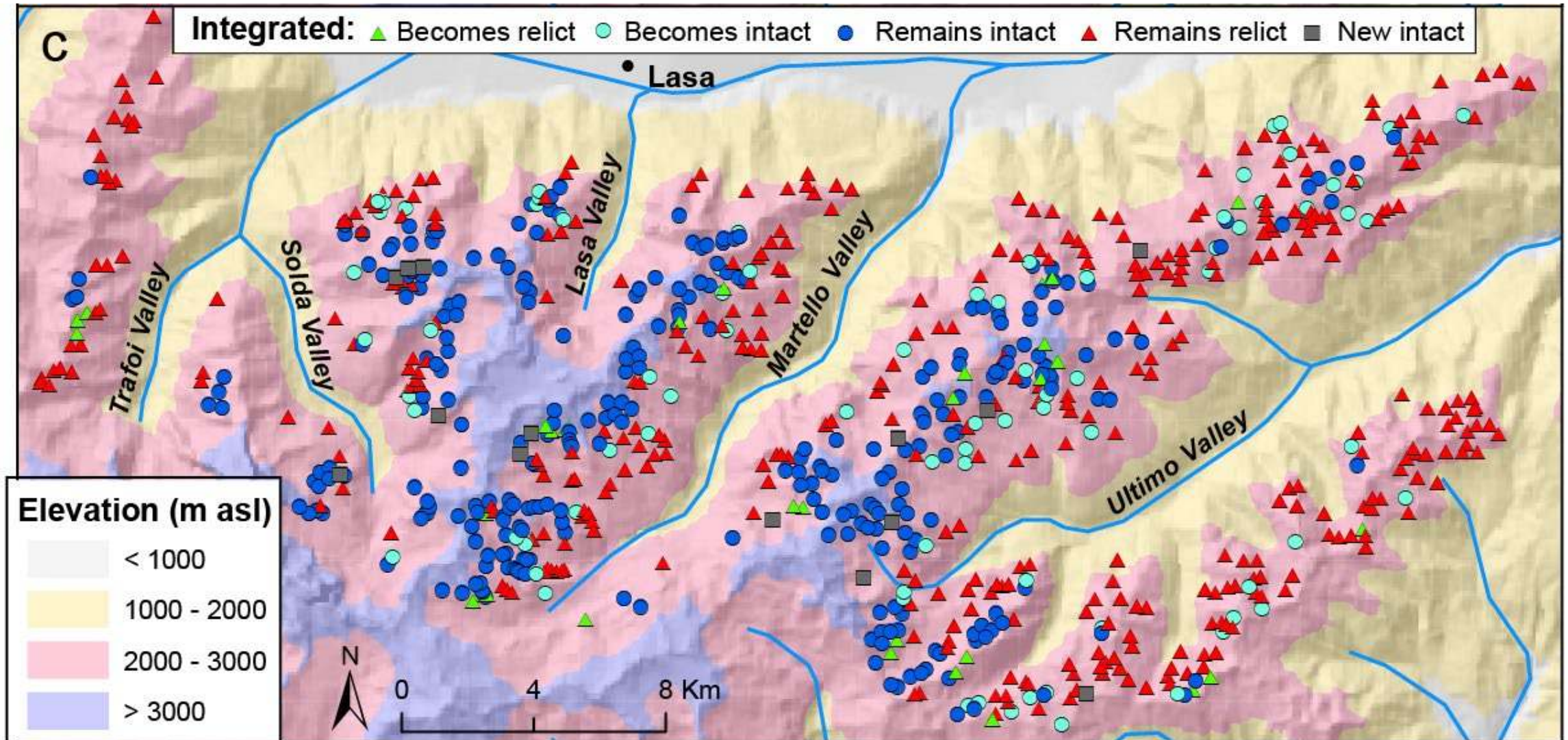


Valley-wide products: Integrated inventory



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Bertone et al (2024)



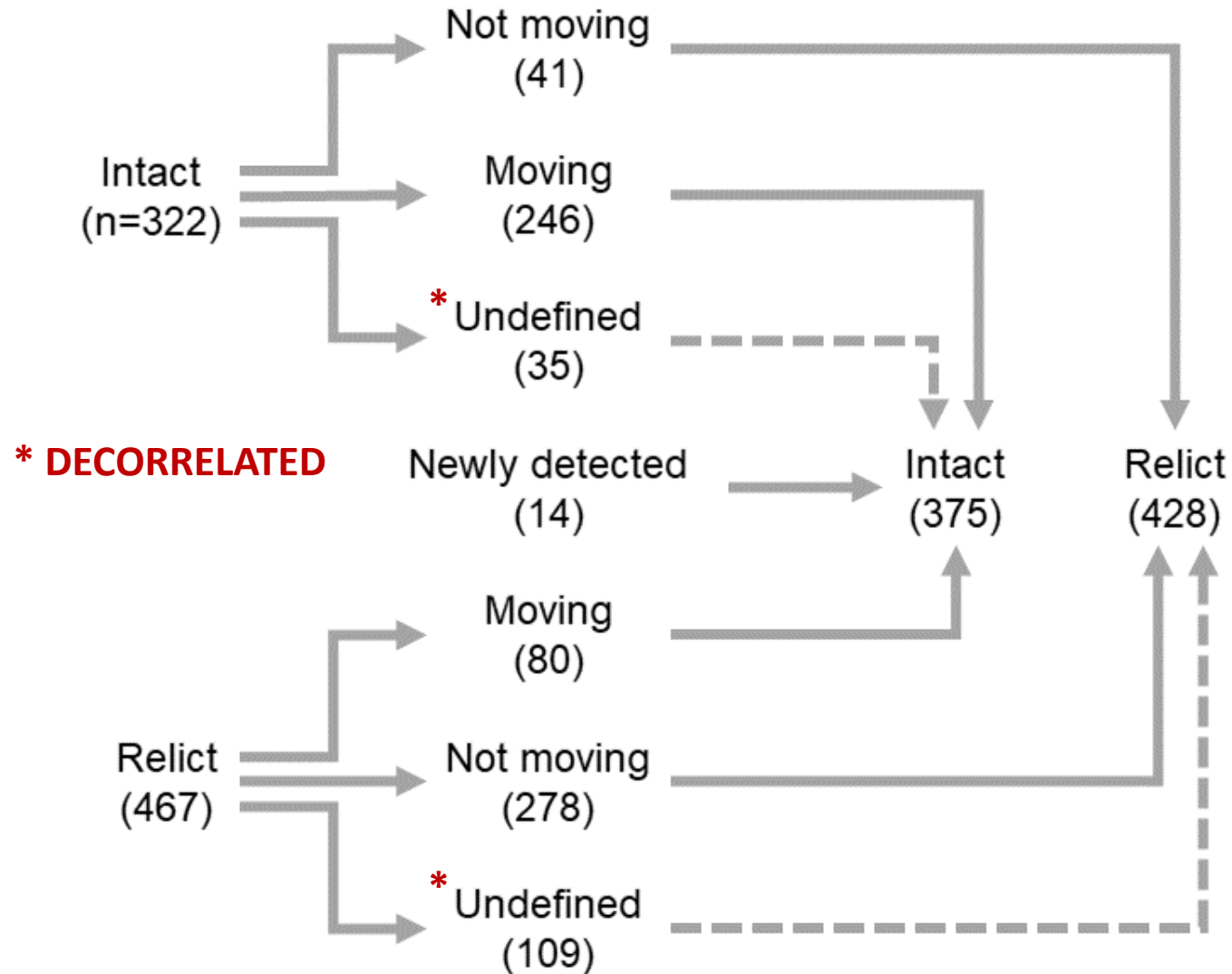
Membership changes across classification approaches

Geomorphologic

Kinematic

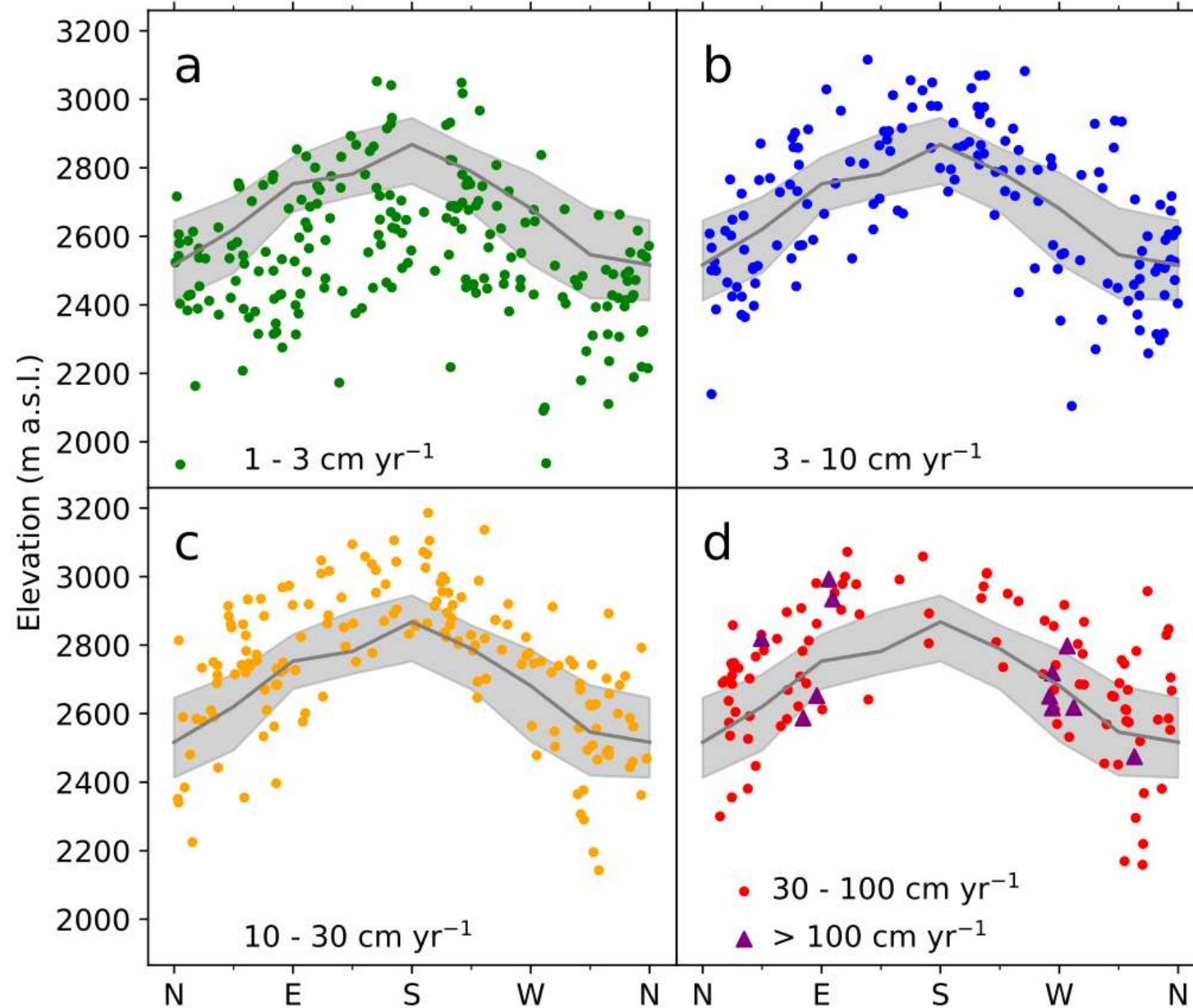
Integrated

Bertone et al (2024)



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How moving areas distribute across the landscape?

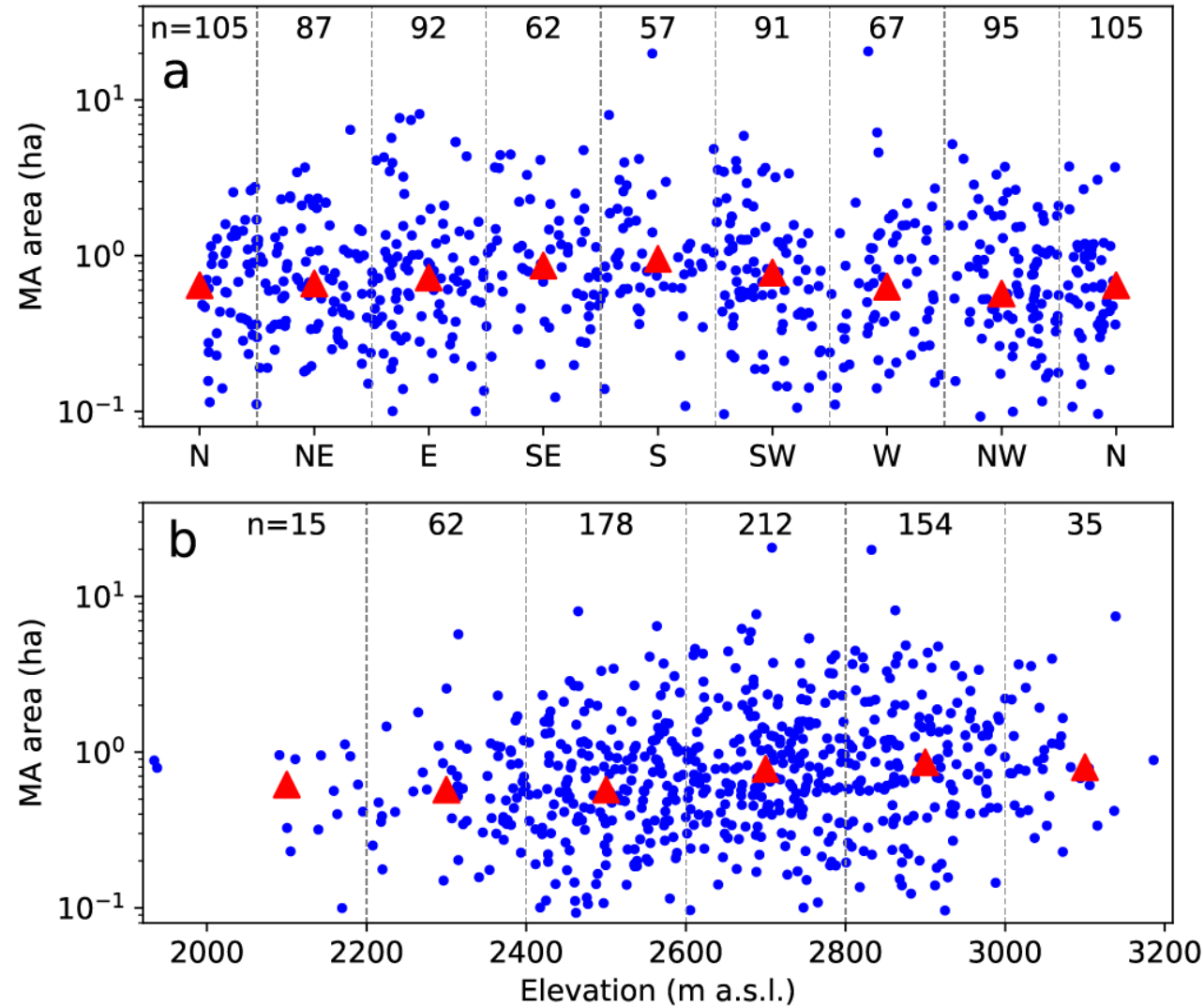


Bertone et al (2024)



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Is moving area size influenced by topography?



Bertone et al (2024)

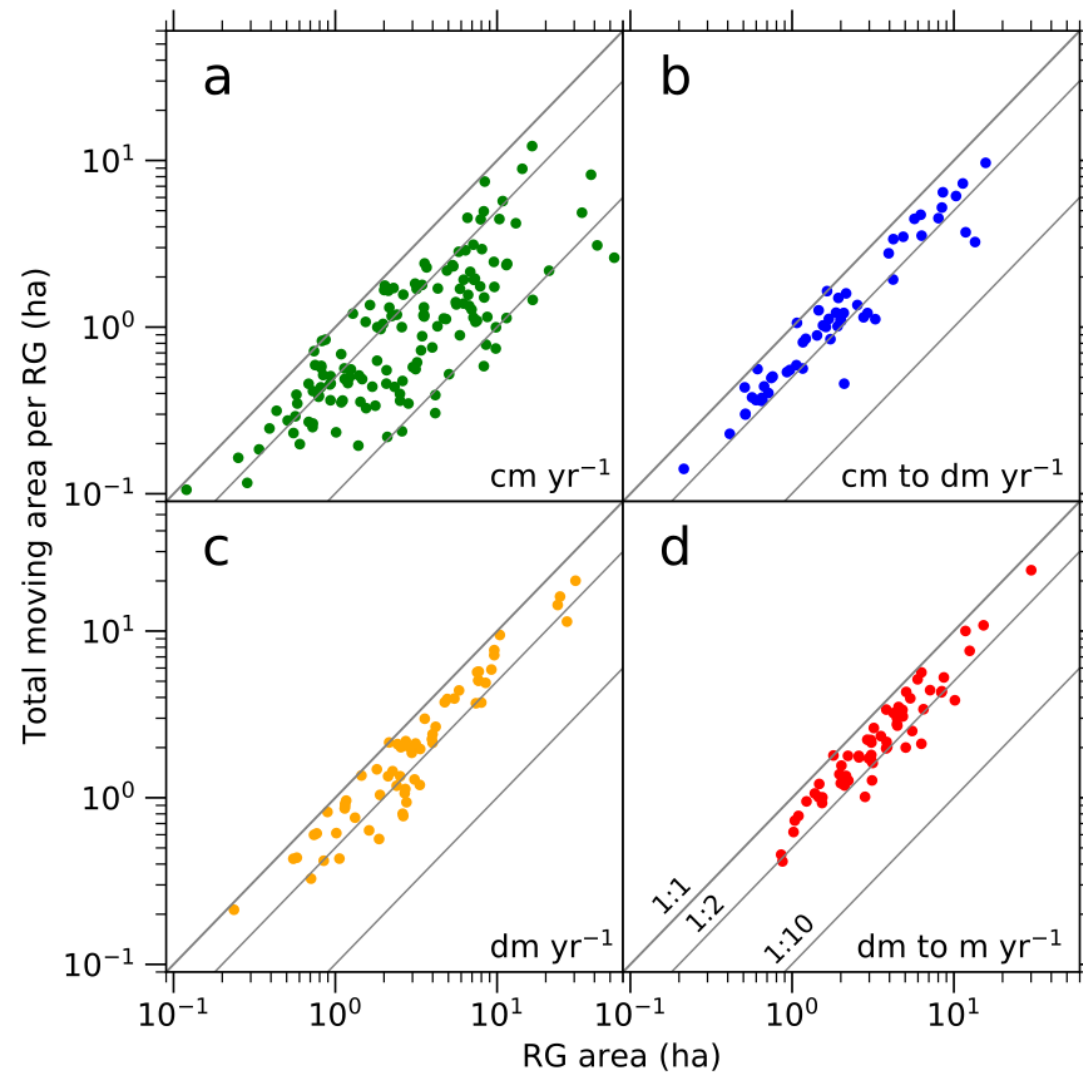
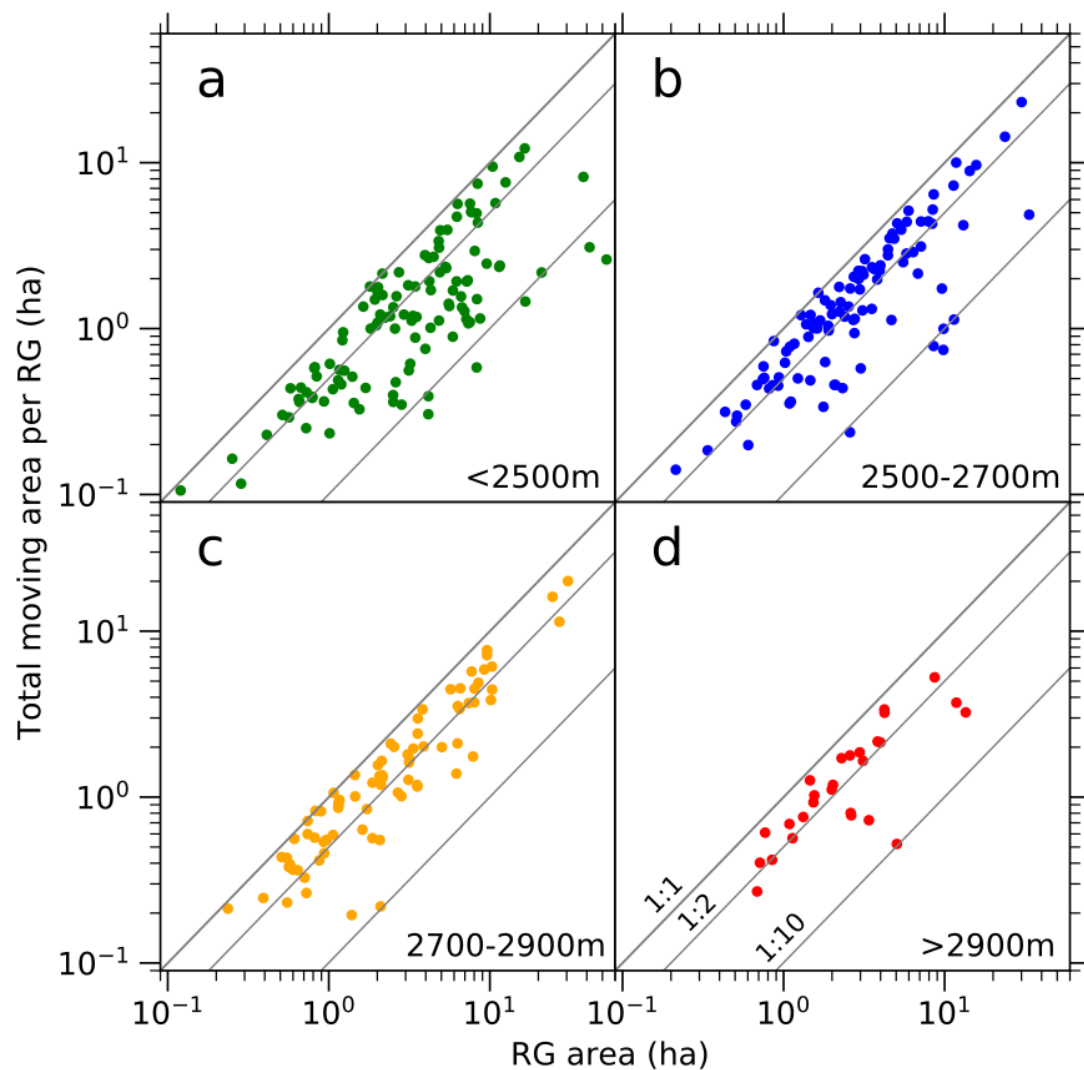


Which proportion of a RG moves and how fast?



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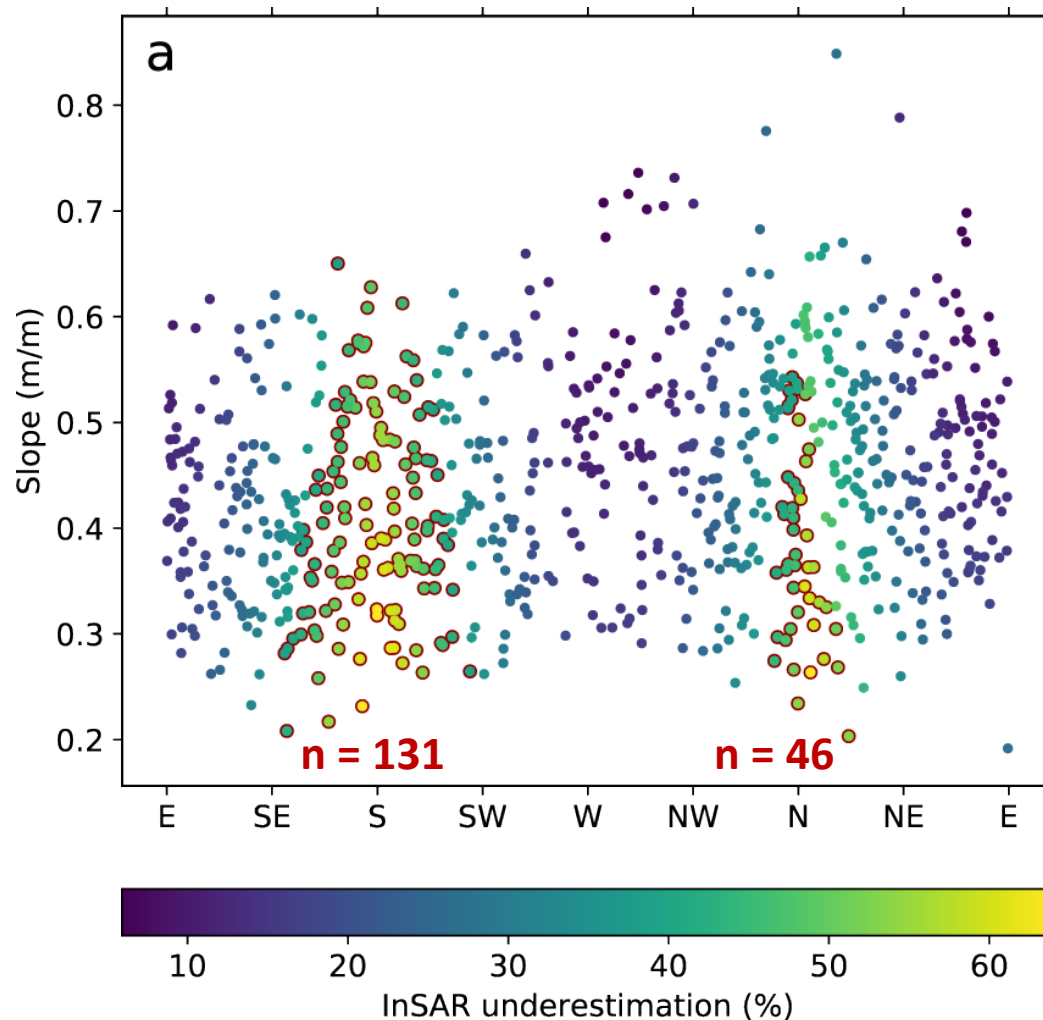
Bertone et al (2024)



InSAR geometry and displacement underestimation



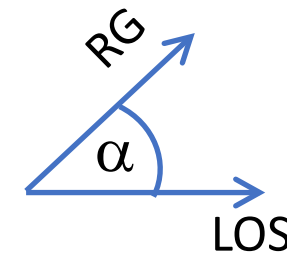
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ASSUMPTION: the downslope direction (ie, the **main flow line**) is representative of the real three-dimensional movement of a rock glacier (Liu et al., 2013; Barboux et al., 2014)

UNDERESTIMATION (U) of measured ground deformation along the LOS can be evaluated by computing **the α angle between the downslope direction of a RG and the LOS**

$$U = (1 - \cos\alpha) \cdot 100$$



When $U > 50\%$, which corresponds to $\alpha > 60^\circ$ we consider the InSAR measurements UNRELIABLE

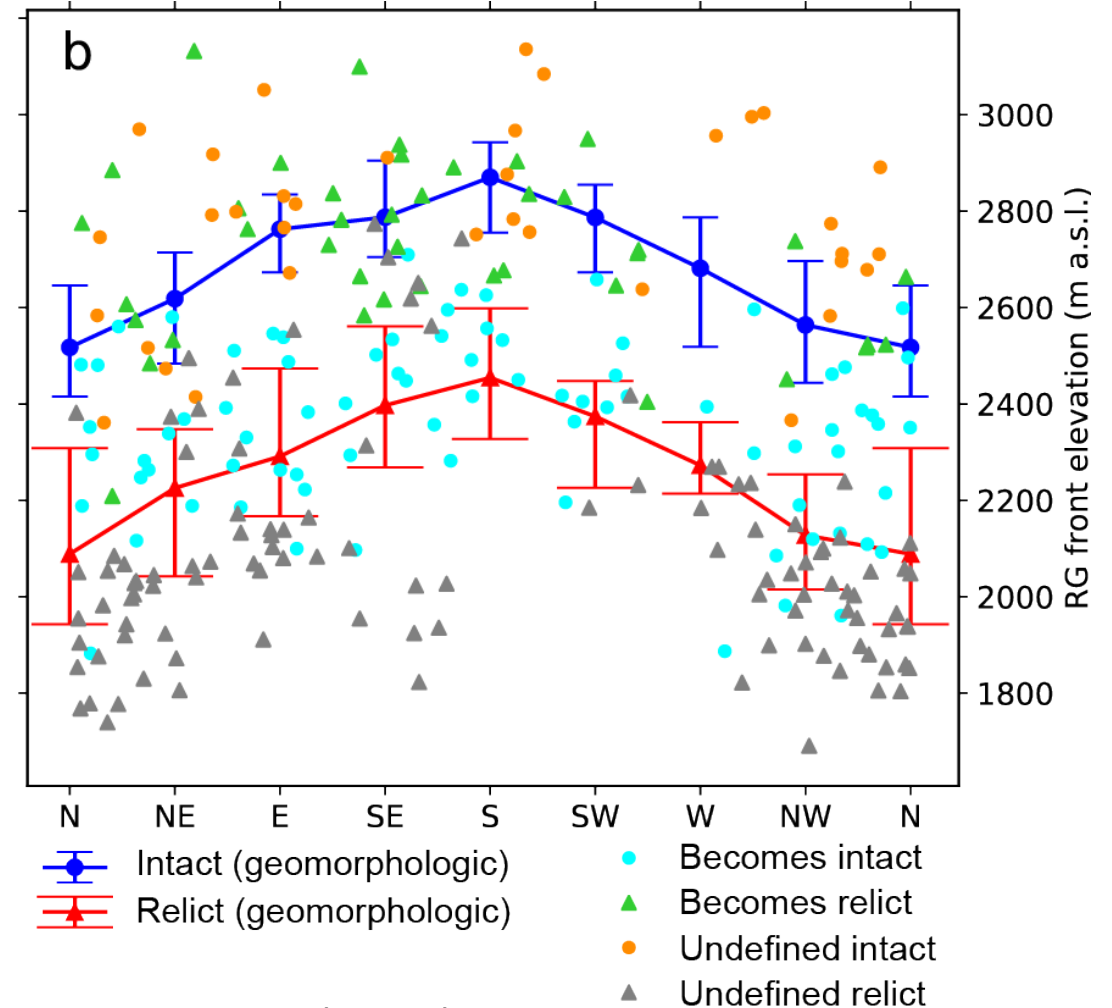
RG main flow line: dominant slope aspect
Bertone et al (2024)

InSAR-based reclassification of RGs weakens dependence on elevation

Note the altitudinal position of:

1. the cluster of RGs that becomes intact
2. the cluster of RGs that becomes relict

Note elevation of undefined RGs



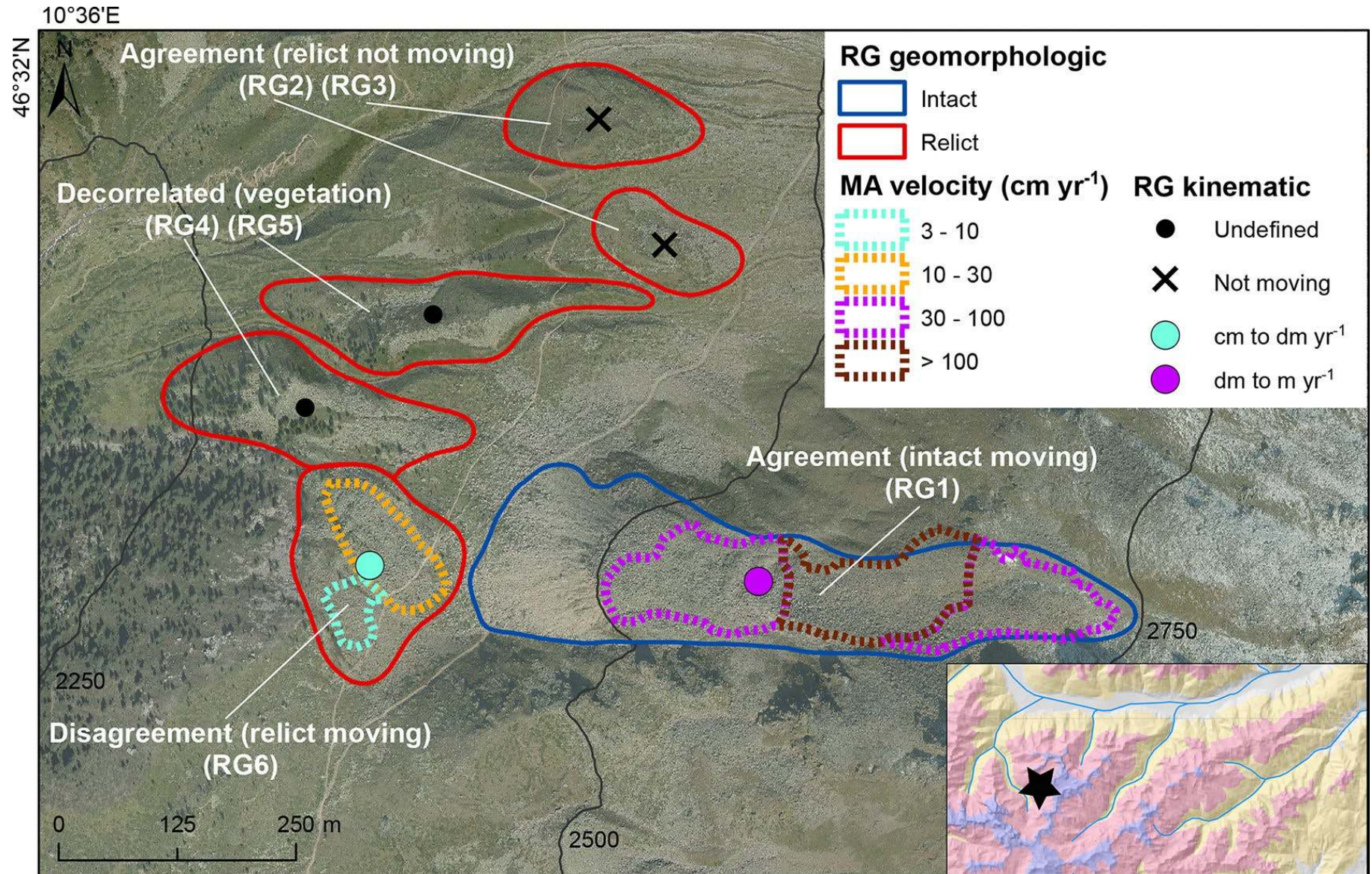
Bertone et al (2024)



Mapping examples

Val Solda/Suldental

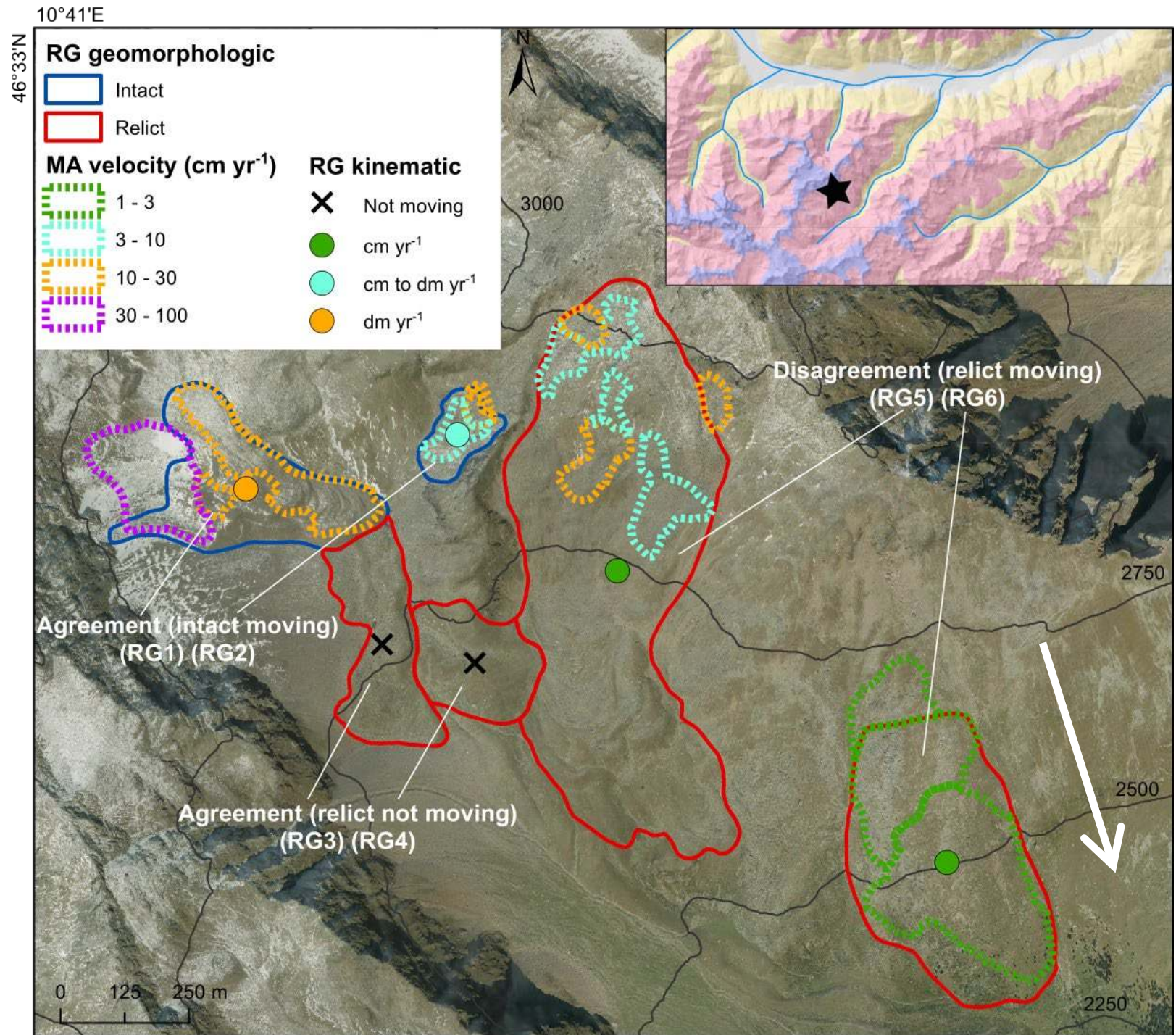
$U < 20\%$



Mapping examples

Val Martello/Martellital

$38\% < U < 46\%$



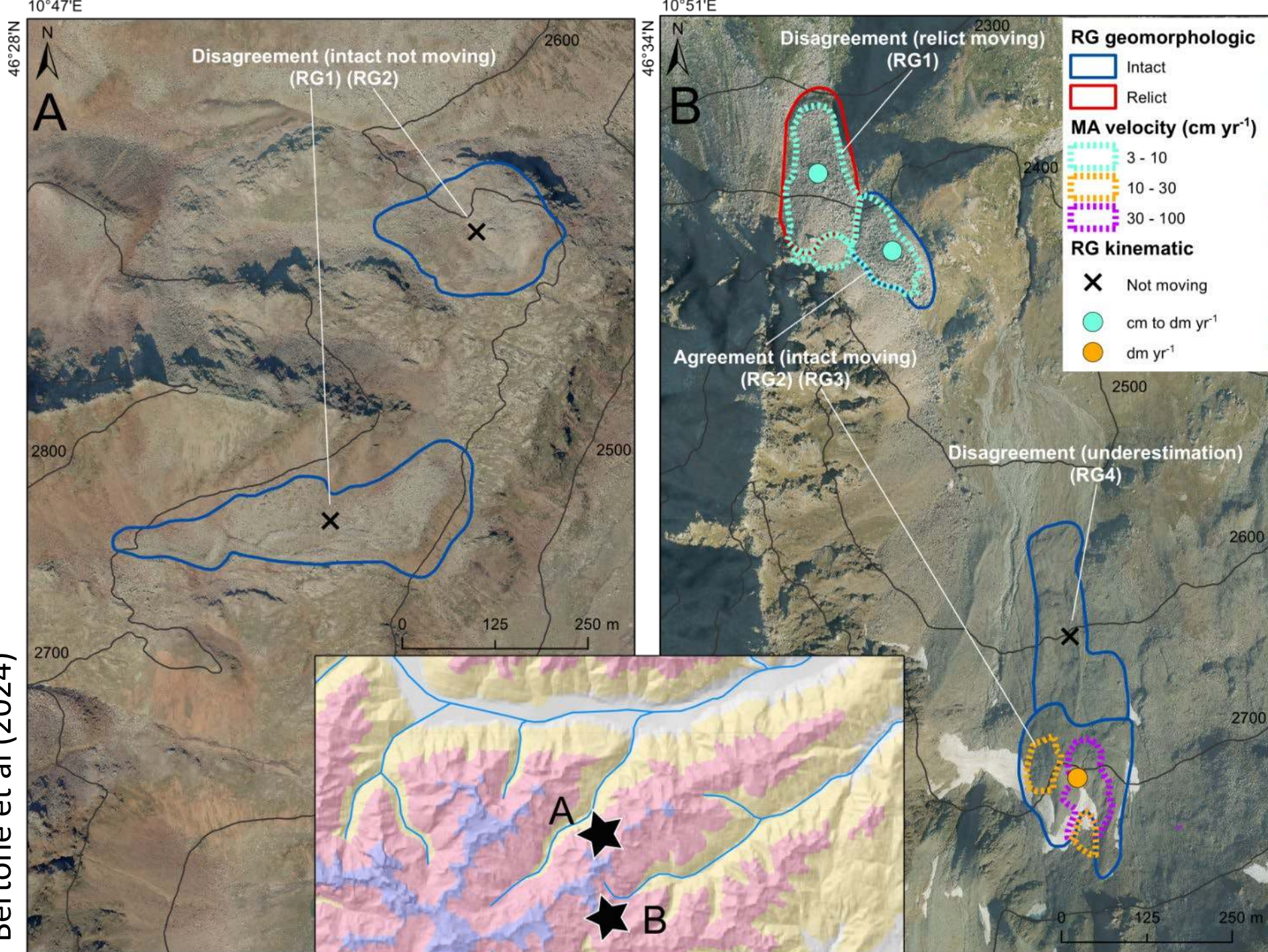
Mapping examples

A) Ultental/
Val d'Ultimo

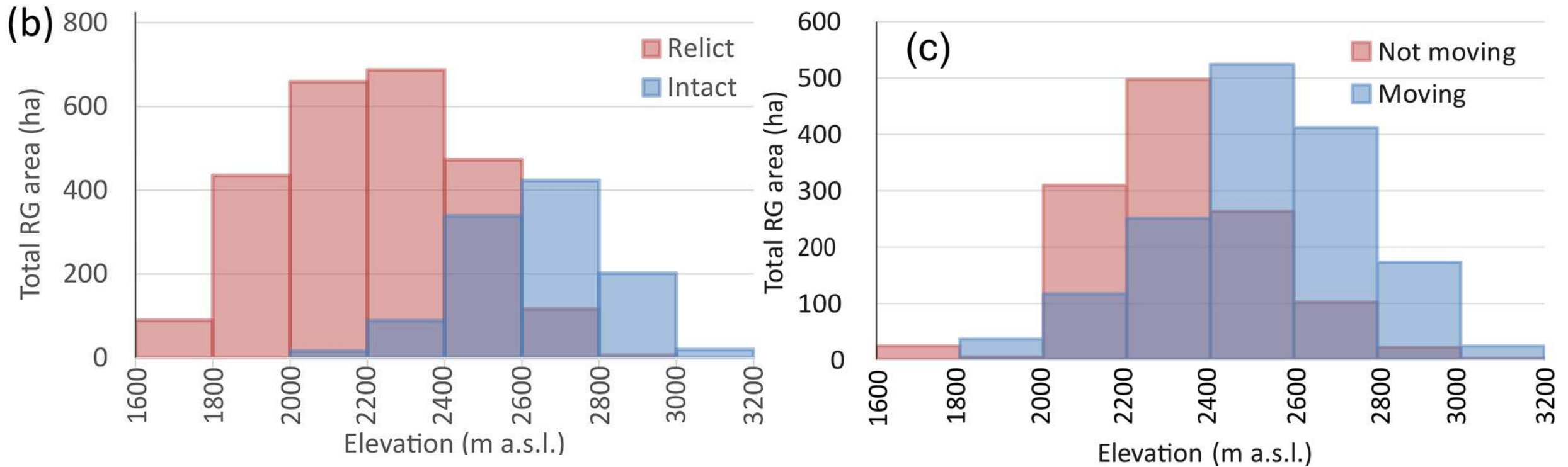
$U < 20\%$

B) Martelltal/
Val Martello

$39\% < U < 57\%$



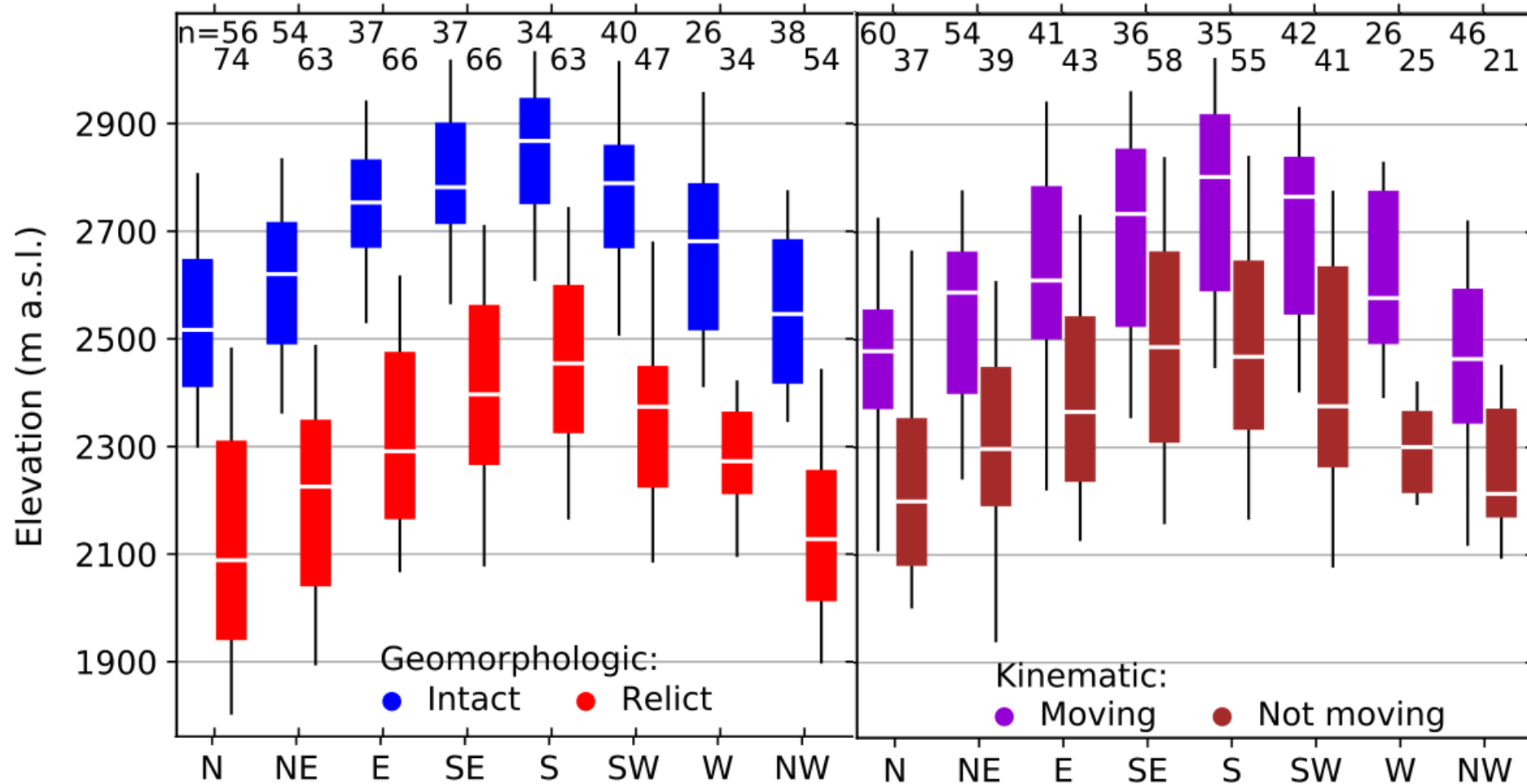
InSAR-based reclassification of RGs enhances altitudinal overlap in RG area



Excluding kinematic undefined RGs



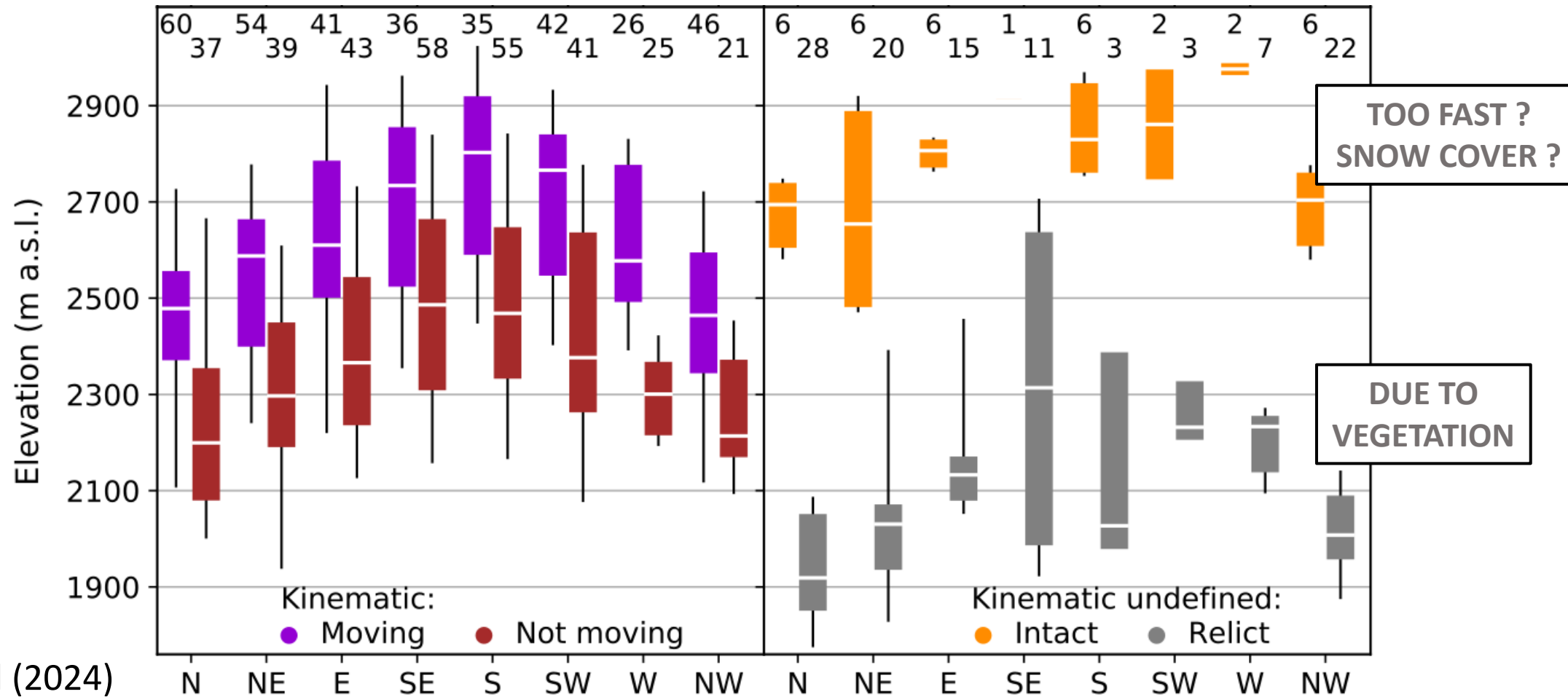
Reclassification imparts changes in altitudinal distribution: intact-relict overlap increases



Excluding kinematic undefined RGs



Undefined rock glaciers are well separated in Asp-Elev



TOO FAST ?
SNOW COVER ?

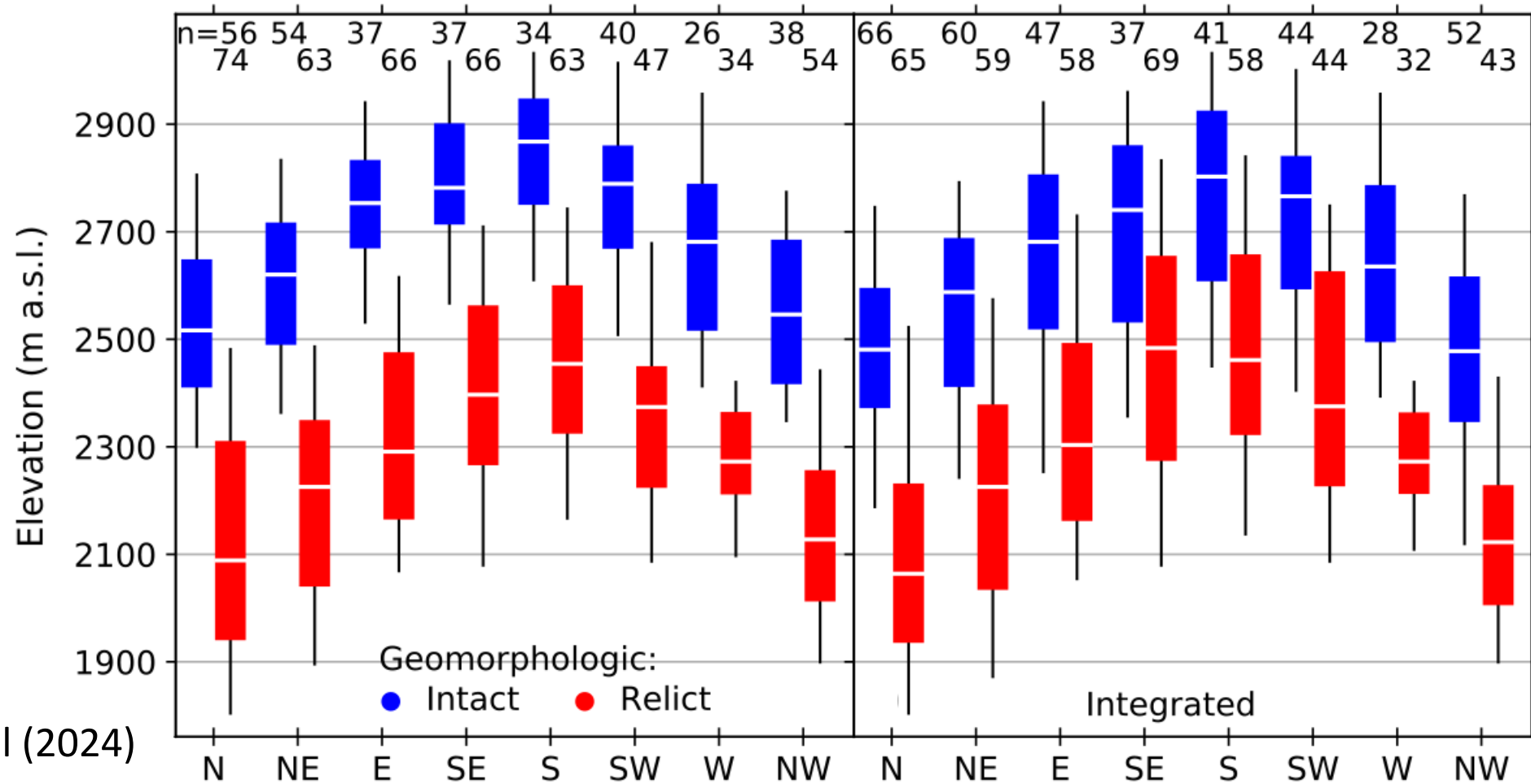
DUE TO
VEGETATION

Bertone et al (2024)

Despite being simplistic, decision rules adopted for **UNDEFINED** (i.e., **DECORRELATED**) rock glaciers appears reasonable



Reclassification leads to increased altitudinal overlapping



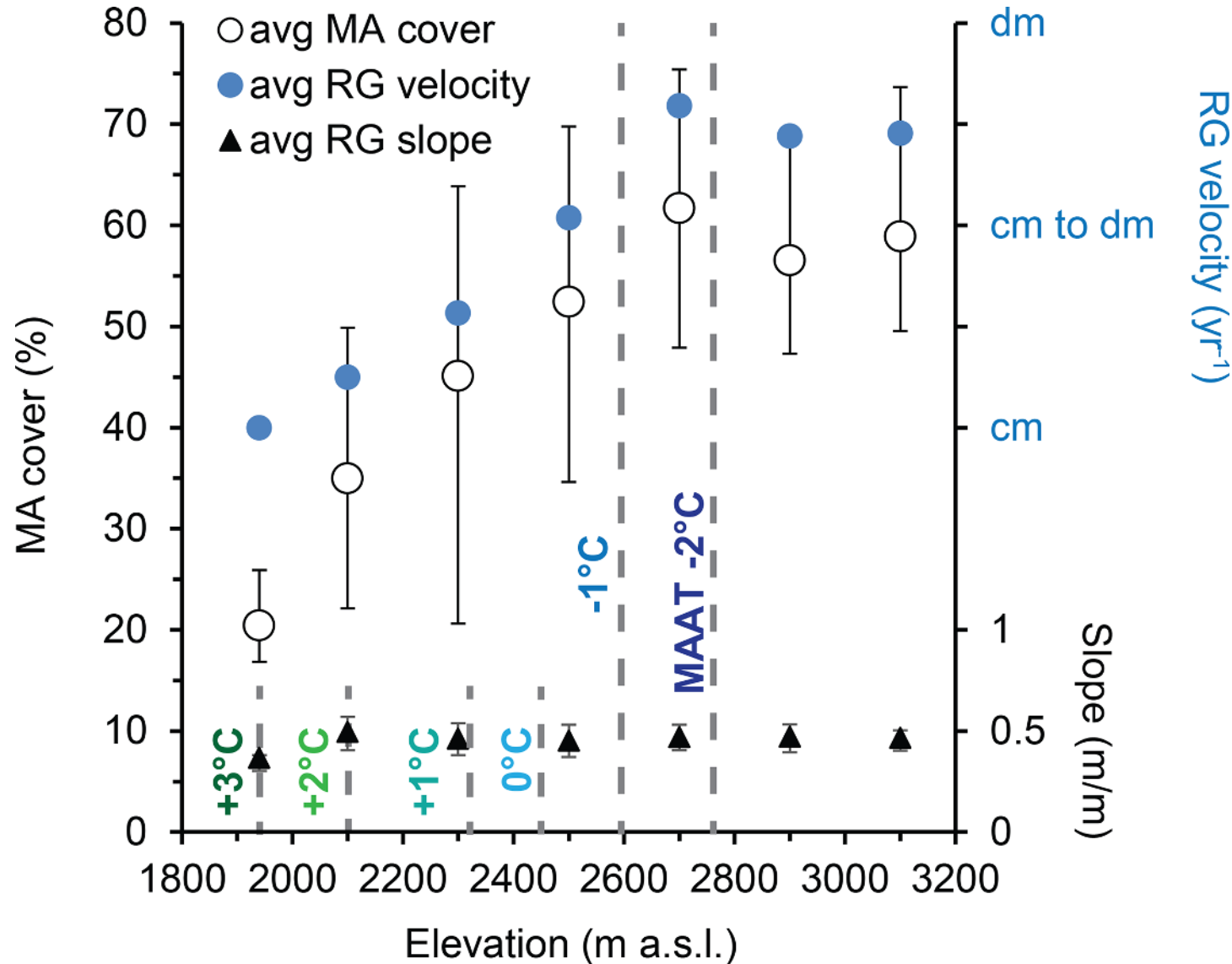
Bertone et al (2024)

Data integration leads to an **increased altitudinal overlapping between** intact and relict rock glaciers:

- **South facing RELICT RGs** tend to extend to higher elevations
- Altitudinal drop across aspects of the **lower INTACT RGs**



An altitudinal transition in rock glacier dynamics



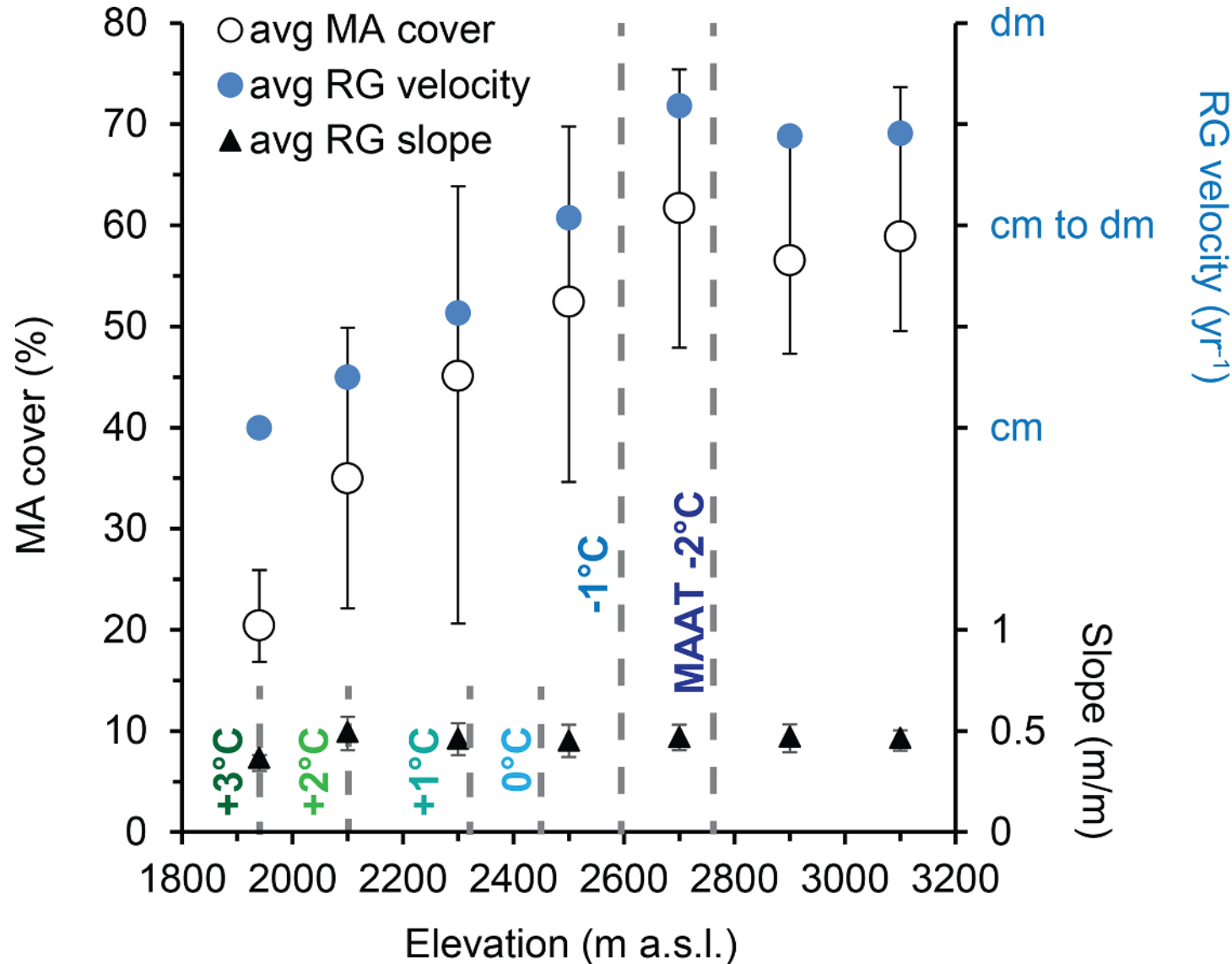
INFLECTION at 2600-2800 m

→ **between MAAT -1°C and -2°C**

lower boundary for discontinuous permafrost occurrence (Haeberli, 1983; Haeberli et al., 1989)

→ Consistent slope across elevations, which therefore is not a factor

An altitudinal transition in rock glacier dynamics



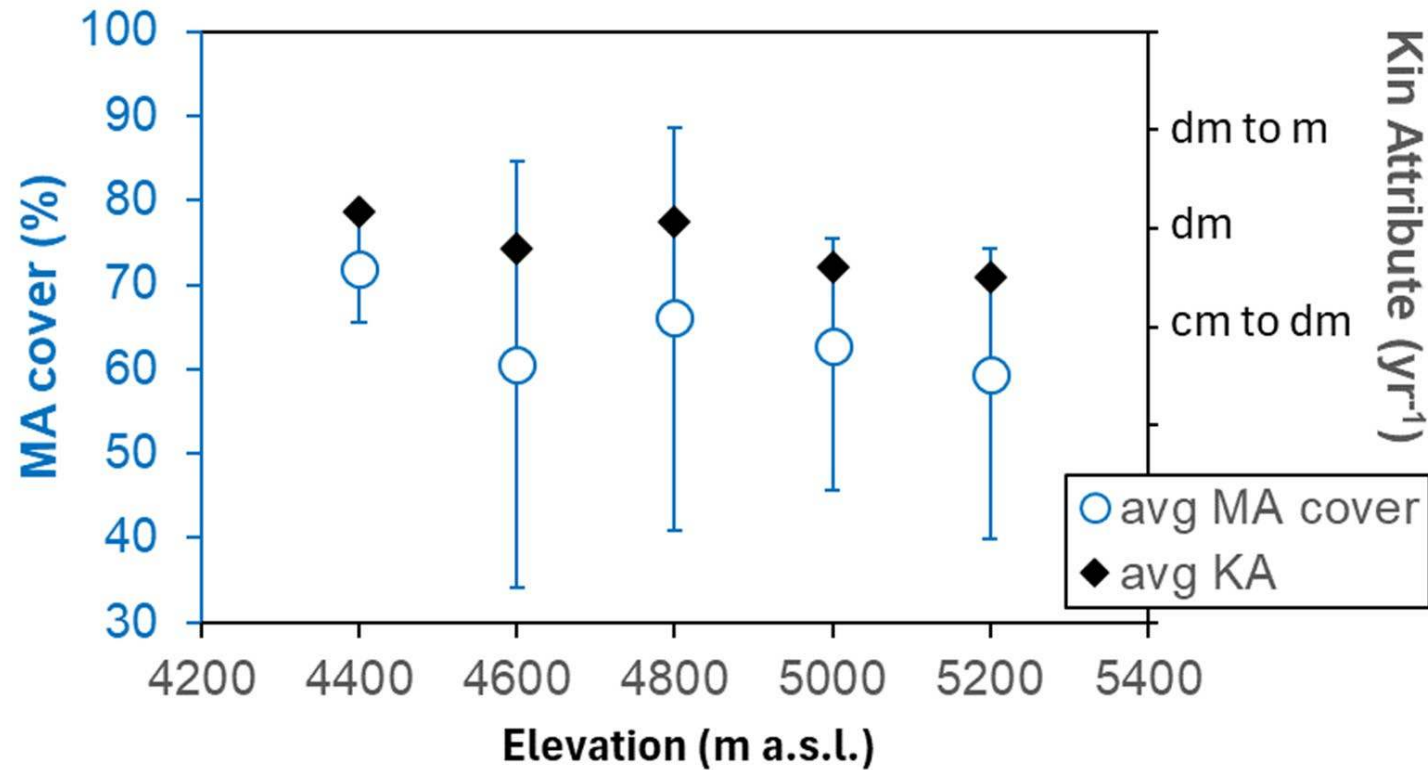
INFLECTION at 2600-2800 m

→ **between MAAT -1°C and -2°C**

lower boundary for **discontinuous** permafrost occurrence (Haeberli, 1983; Haeberli et al., 1989)

INTERPRETATION:
this altitudinal pattern represents a **geomorphic signature**: the dynamic expression of increasing permafrost distribution, from sporadic to discontinuous

Himachal-Ladakh (India) border: No altitudinal transition



NO CLEAR ALTITUDINAL PATTERN

Is this an expression of discontinuous permaforst occurrence across the entire range of elevations?

Need to recover MAAT or MAGT grids