Assessing Rock Glacier Activity In Val Senales By Exploiting Multiband Sar Data Through Differential Sar Interferometry And Offset Tracking

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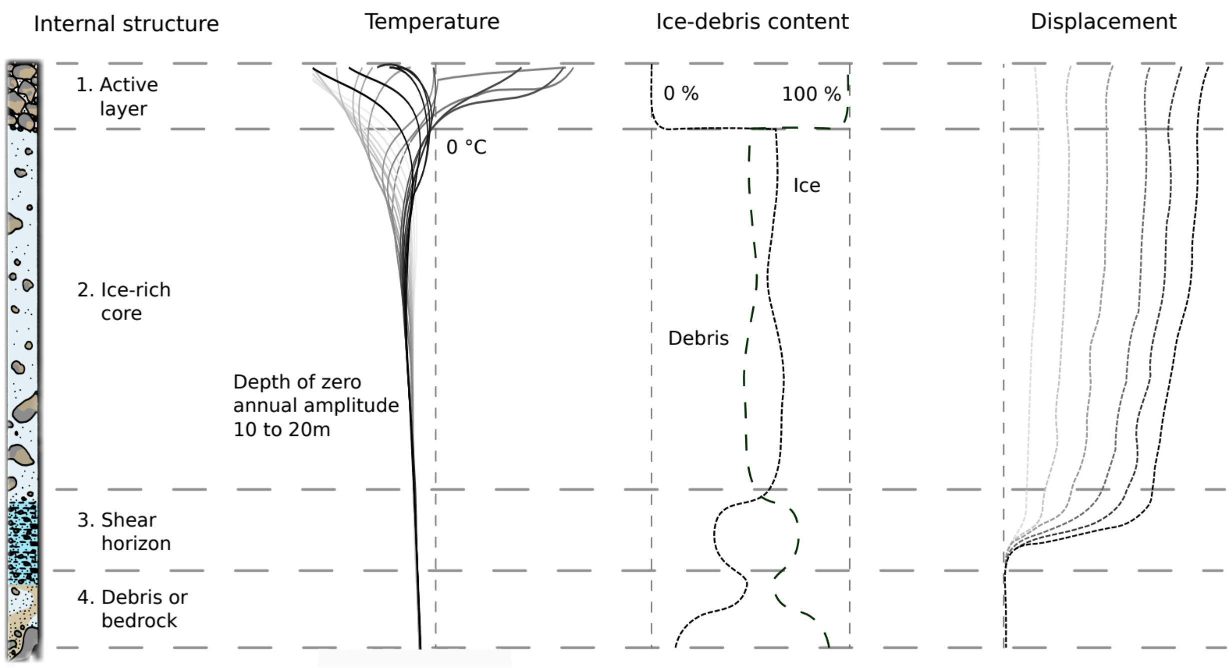
→ THE EUROPEAN SPACE AGENCY

Outline

- ✓ Introduction
- ✓ Displacements from MTInSAR
- ✓ Rock glacier classification
- ✓ Lazaun test case
- ✓ Intensity tracking
- ✓ Result analysis and comparison
- ✓ Final comments

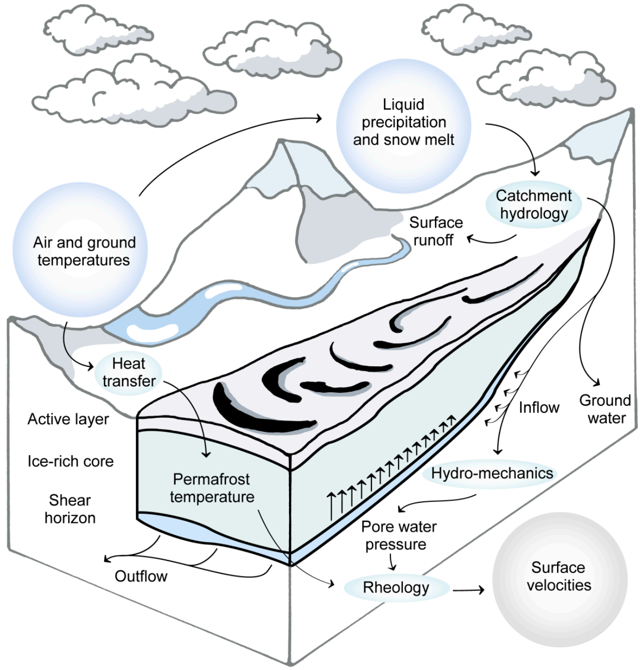
Rock Glacier Stability

- ✓ Rock glaciers are characterised by a mix of ice and rock, related to the presence of permafrost in mountainous areas, and represent an important water source particularly in drought-prone regions.
- ✓ The rock glacier kinematics is controlled by the water content along the shear layer(s). The external temperature is considered one of the most important factors controlling rock glacier flow variation, showing mean velocities ranging from centimeters to meters per year. Because of relationship among temperature, liquid water content and rock glacier flow, it is relevant to classify rock glaciers according to their kinematics.



Conceptualized vertical profile of a typical rock glacier

Ref. [A. Cicoira et al., Permafrost and Periglac Process. 2021;32:139–153]

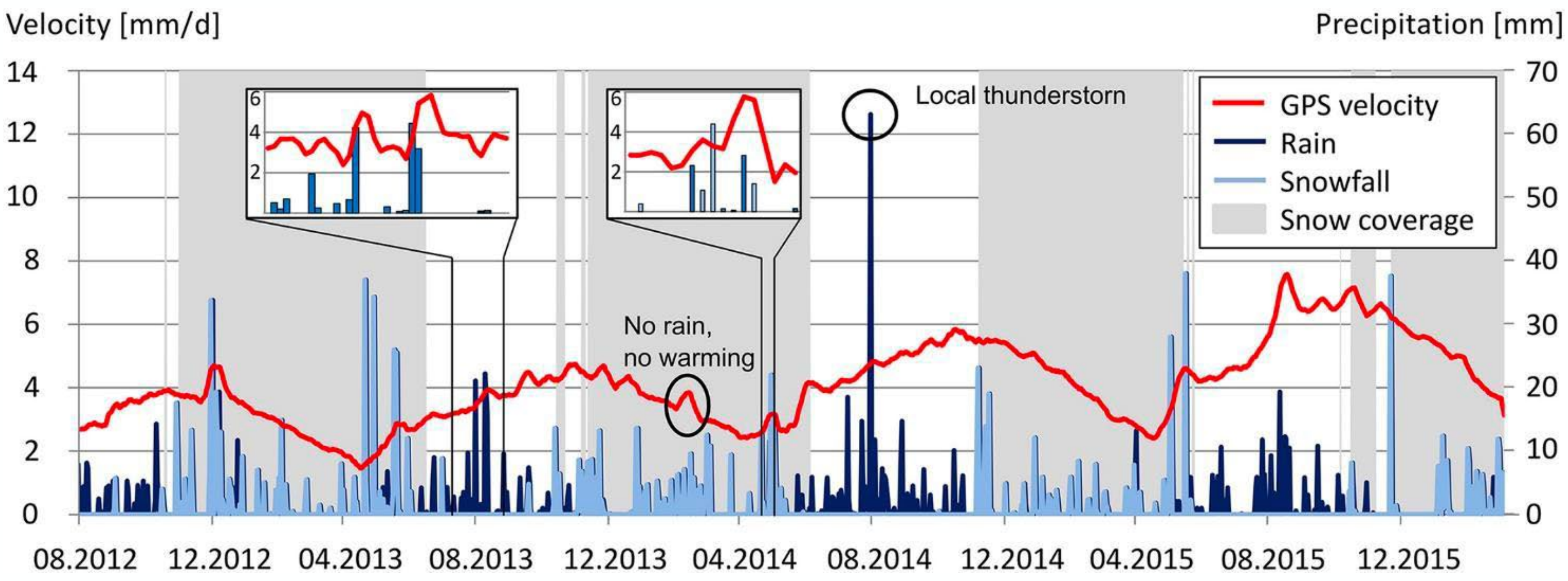


Conceptualization of the model of the moving rock glacier

Ref. [A. Cicoira et al., Earth and Planetary Science Letters. 2019; 528: 115844]

DInSAR vs Rock Glacier Analysis

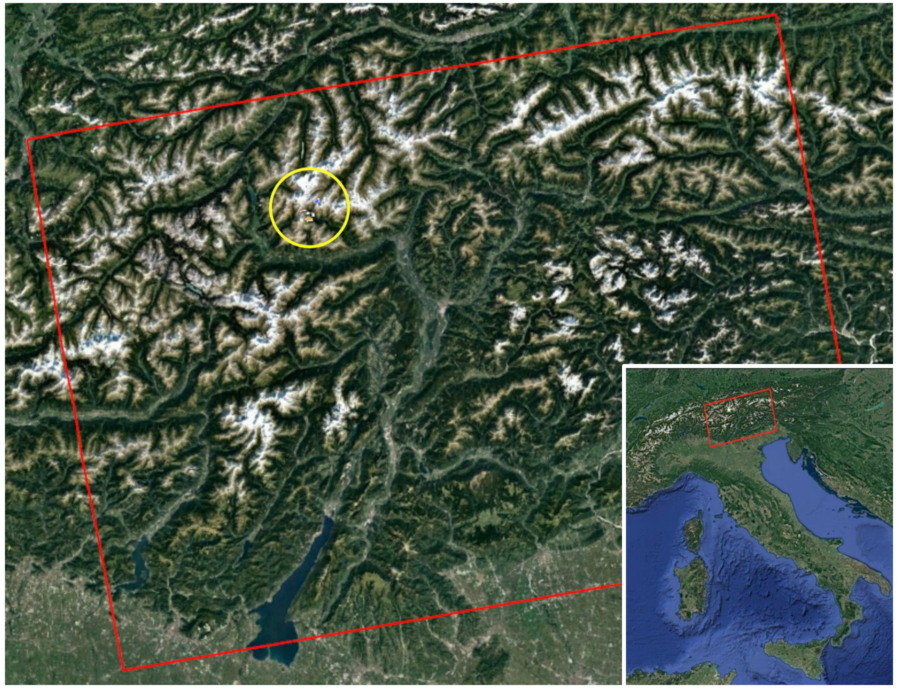
- ✓ Despite multi-temporal differential SAR interferometry (MTInSAR) is a very effective tool for measuring ground stability, its application to rock glacier monitoring poses critical issues relate to:
  - the steep topography may lead to unfavorable illuminating conditions in terms of either unfeasible detection over layover and shadow areas, or low sensitivity to the ground displacement;
  - signal decorrelation due to changeable snow cover conditions;
  - displacement kinematic characterised by linear and non-linear components, and high displacement rates leading to aliasing.



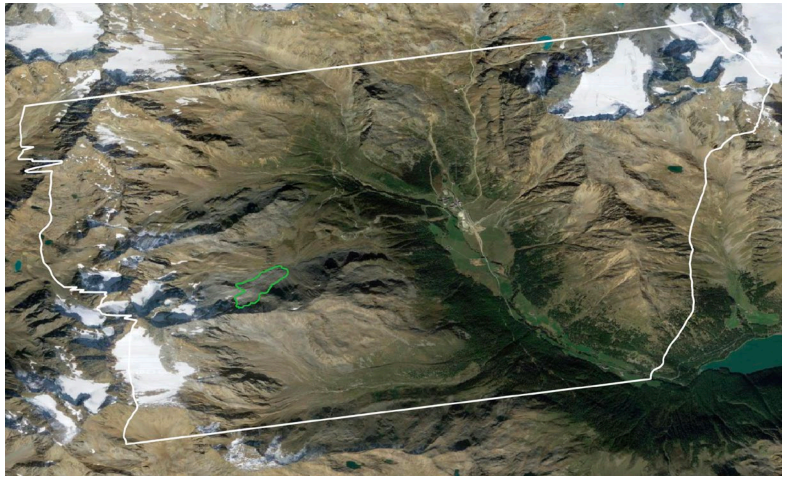
Ref. [R. Kenner R. et al. (2017). Factors Controlling Velocity Variations at Short-Term, Seasonal and Multiyear Time Scales, Ritigraben Rock Glacier, Western Swiss Alps. Permafrost and Periglacial Processes, 28(4), 675–684.]

Test Site & Datasets

- ✓ This work investigates the rock glacier stability in Val Senales (Italian Alps) by processing a dataset of 345 Sentinel-1 SAR images acquired between 04.2015 and 05.2022.
- ✓ Focus on Lazaun, a tongue-shaped active rock glacier, 660 m long and 200 m wide, with interannual and seasonal displacement rates up to few mm/day (from GNSS, inclinometers, and both ground based and spaceborne SAR systems).



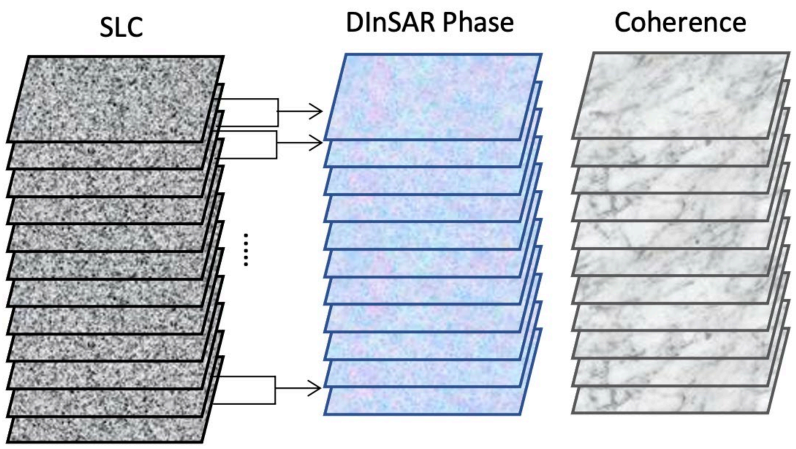
Sentinel-1 Frame (Ascending, Orb. 117)



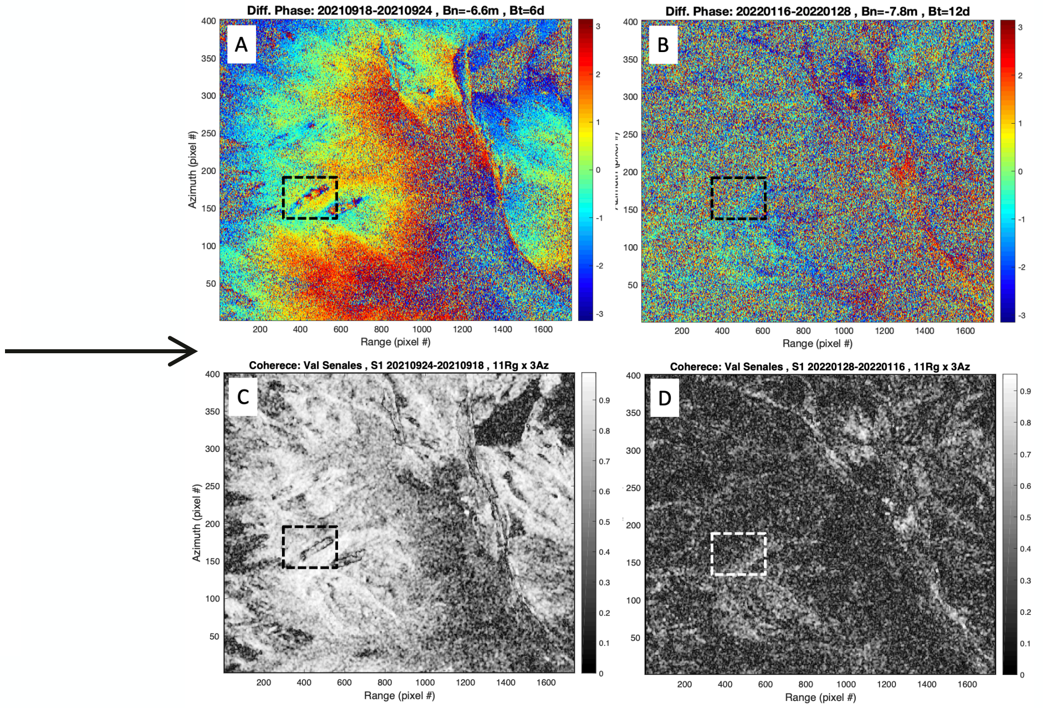
AOI

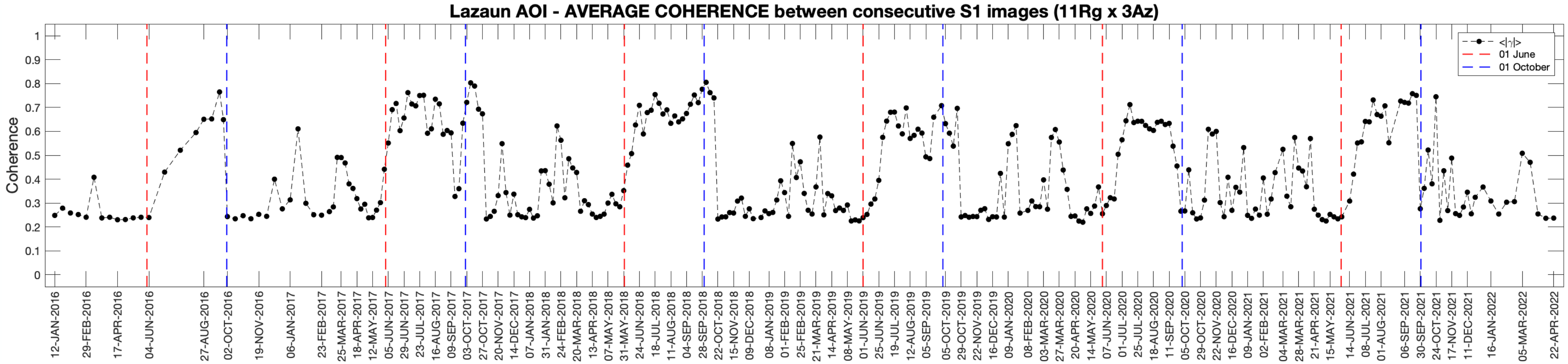
Lazaun

DInSAR vs Rock Glacier Analysis



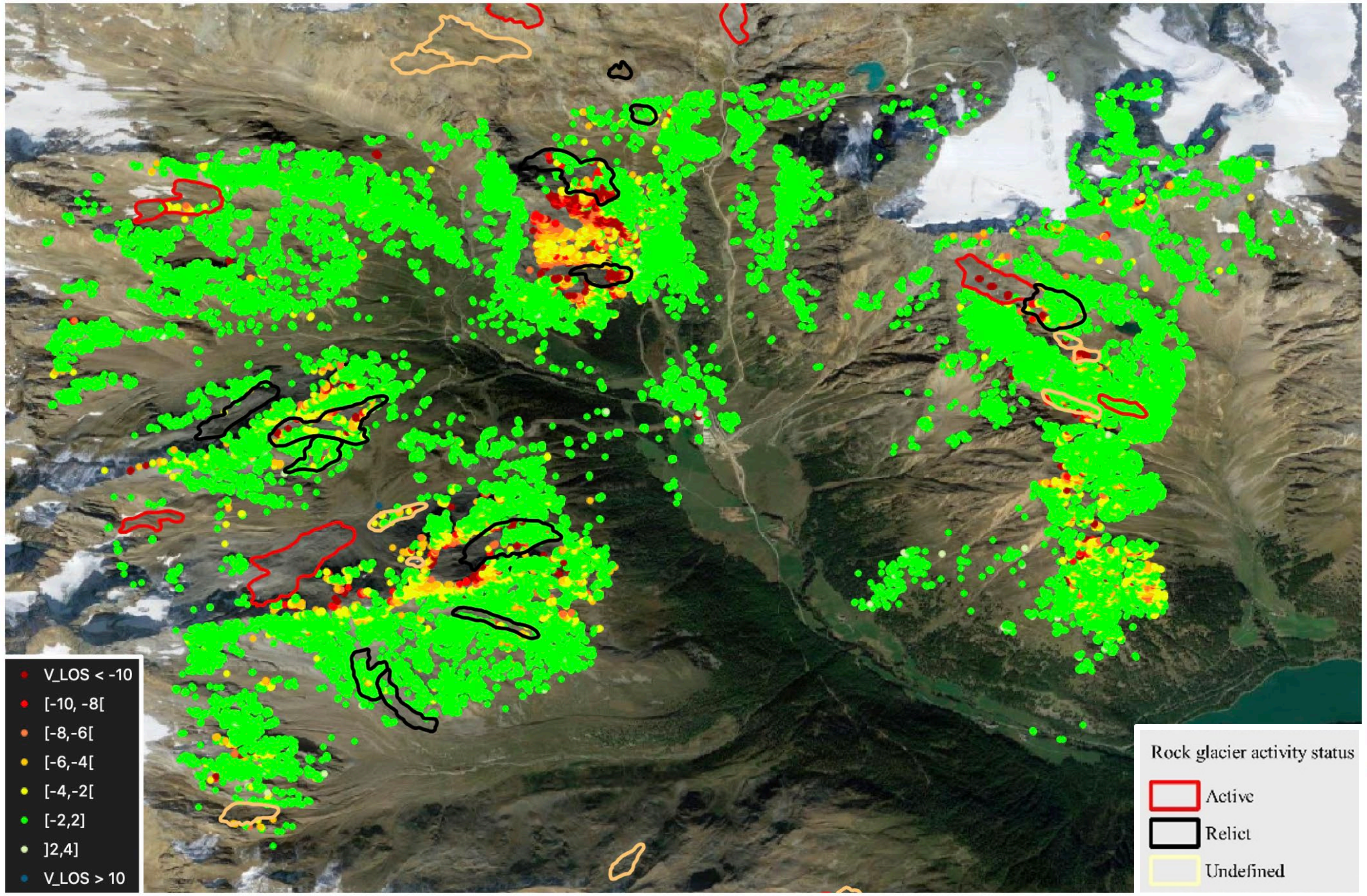
$$\mathrm{INT}_i = \mathrm{SLC}(t_{i+1}) \cdot SLC^*(t_i) \quad i = 1{:}\,\mathrm{N}_i - 1$$





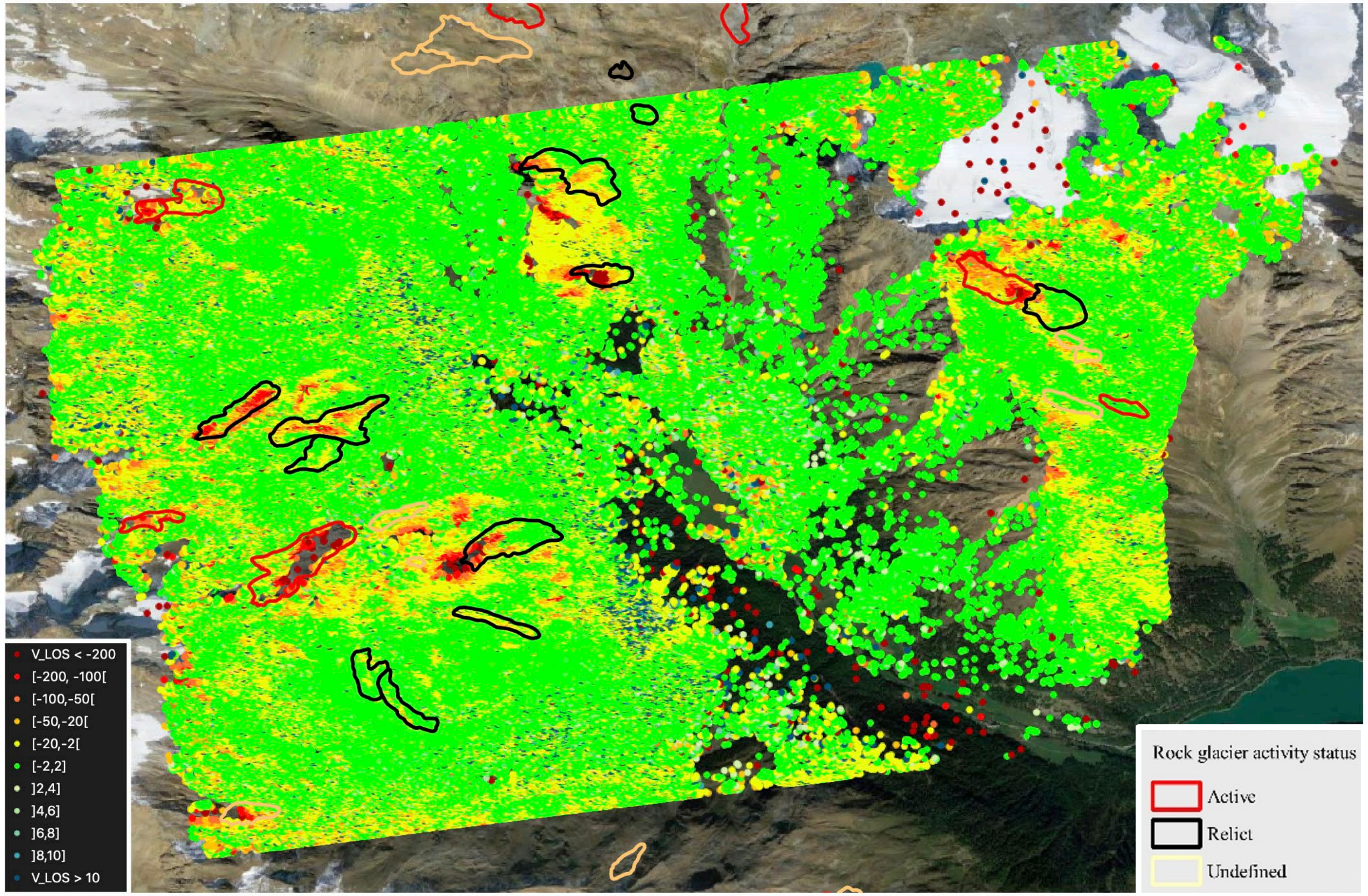
MTInSAR Results: Standard Processing

- ✓ By using the standard MTInSAR processing, several areas are lacking of targets leading unfeasible the stability analysis for several rock glaciers within the AOI.
- ✓ The rock glacier polygons sketched in the figure map are from a regional inventory map.



MTInSAR Results: Advanced Processing

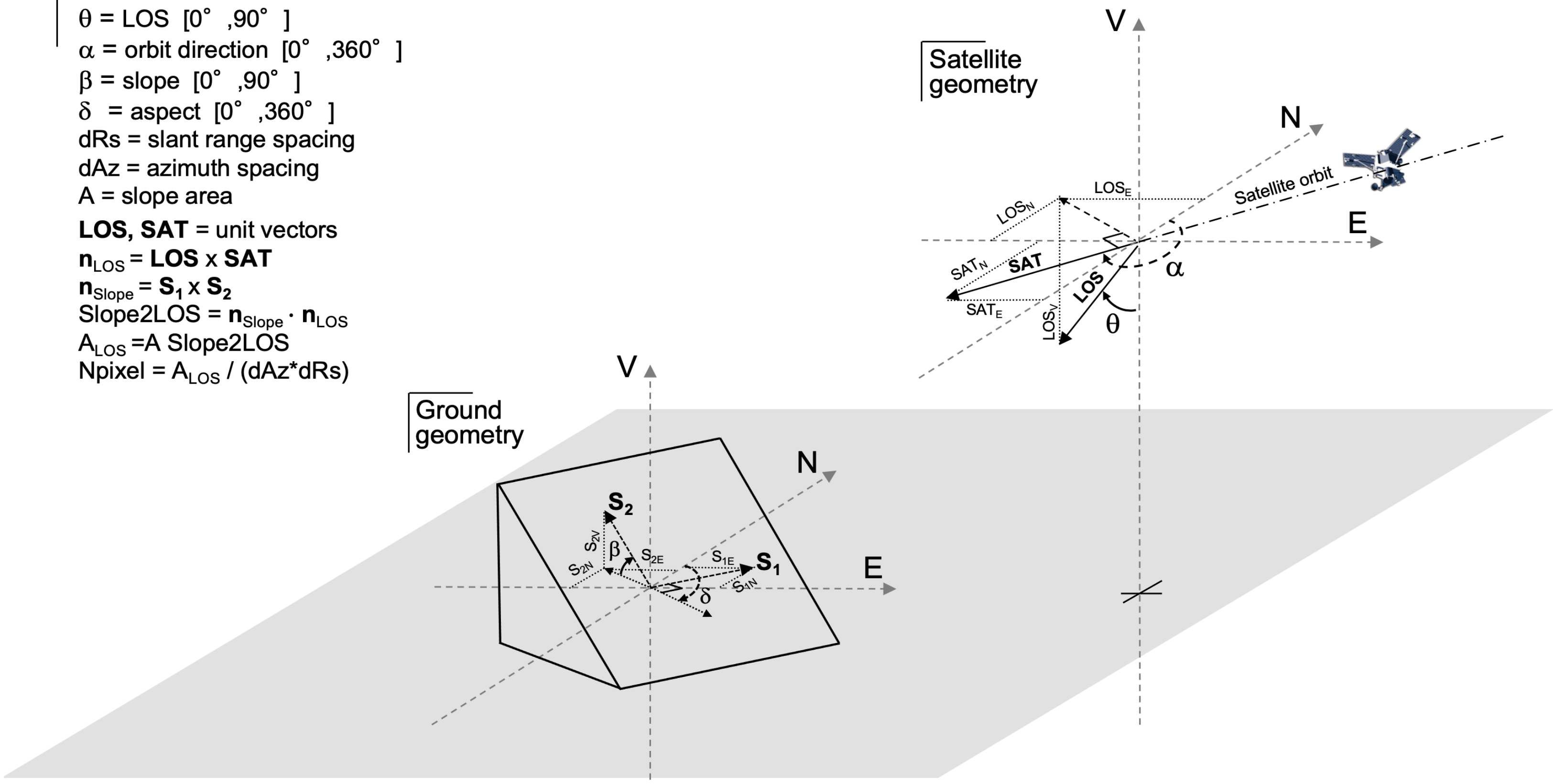
✓ The algorithm has been run by selecting spring-summer acquisitions, and forced to search for solutions corresponding to phase changes behind the aliasing limit (the set of solutions explored by the displacement estimator is not centered around zero but shifted at higher values).



MTInSAR-based Rock Galcier Classification

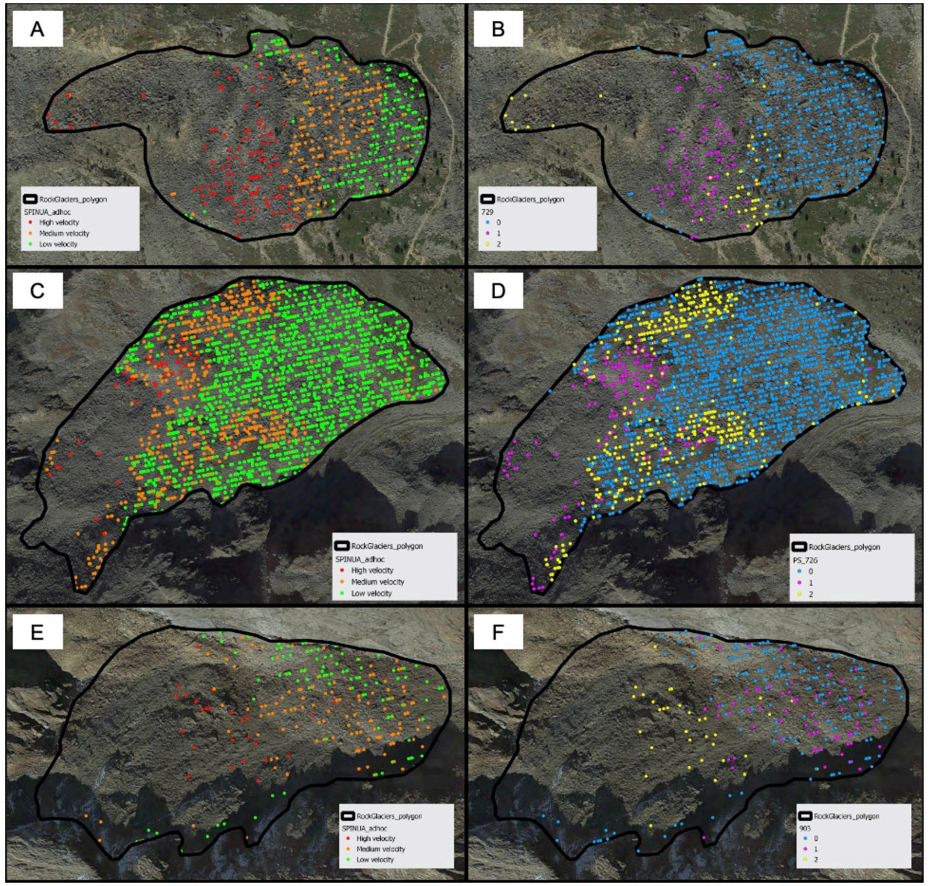
- ✓ The reliability and the weight of the information coming from the MTInSAR products, depends also on the spatial coverage of the rock glacier provided by the coherent targets.
- ✓ This information has been included into the classification process by computing the percentage of rock glacier surface covered by the MTInSAR targets.

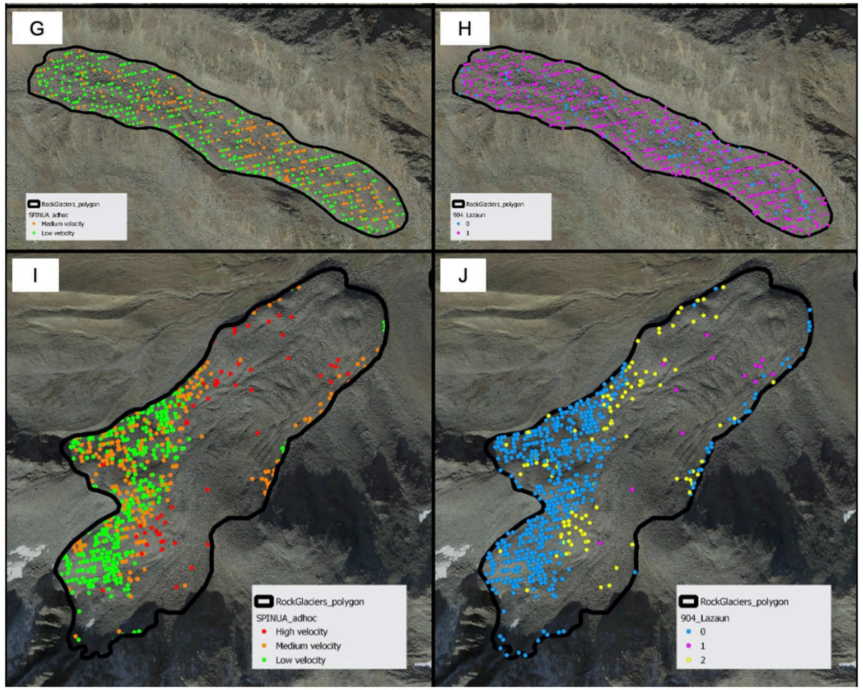
θ = LOS [0°, 90°]
α = orbit direction [0°, 360°]
β = slope [0°, 90°]
δ = aspect [0°, 360°]
dRs = slant range spacing
dAz = azimuth spacing
A = slope area
LOS, SAT = unit vectors
$\mathbf{n}_{LOS} = \mathbf{LOS} \times \mathbf{SAT}$
$\mathbf{n}_{Slope} = \mathbf{S_1} \times \mathbf{S_2}$
$Slope2LOS = \mathbf{n}_{Slope} \cdot \mathbf{n}_{LOS}$
$A_{LOS} = A \; Slope2LOS$
$Npixel = A_{LOS} / (dAz*dRs)$



MTInSAR-based Rock Galcier Classification

- ✓ The spatial clustering of target velocities has been investigated by using the K-Means algorithm. This analysis confirms the presence of spatial clusters of displacement velocities, with velocity values increasing by moving from the borders to the inner part of the rock glaciers.
- ✓ The presence of a spatial clustering has been used to refine the classification of the rock glacier activity.





MTInSAR-based Rock Galcier Classification

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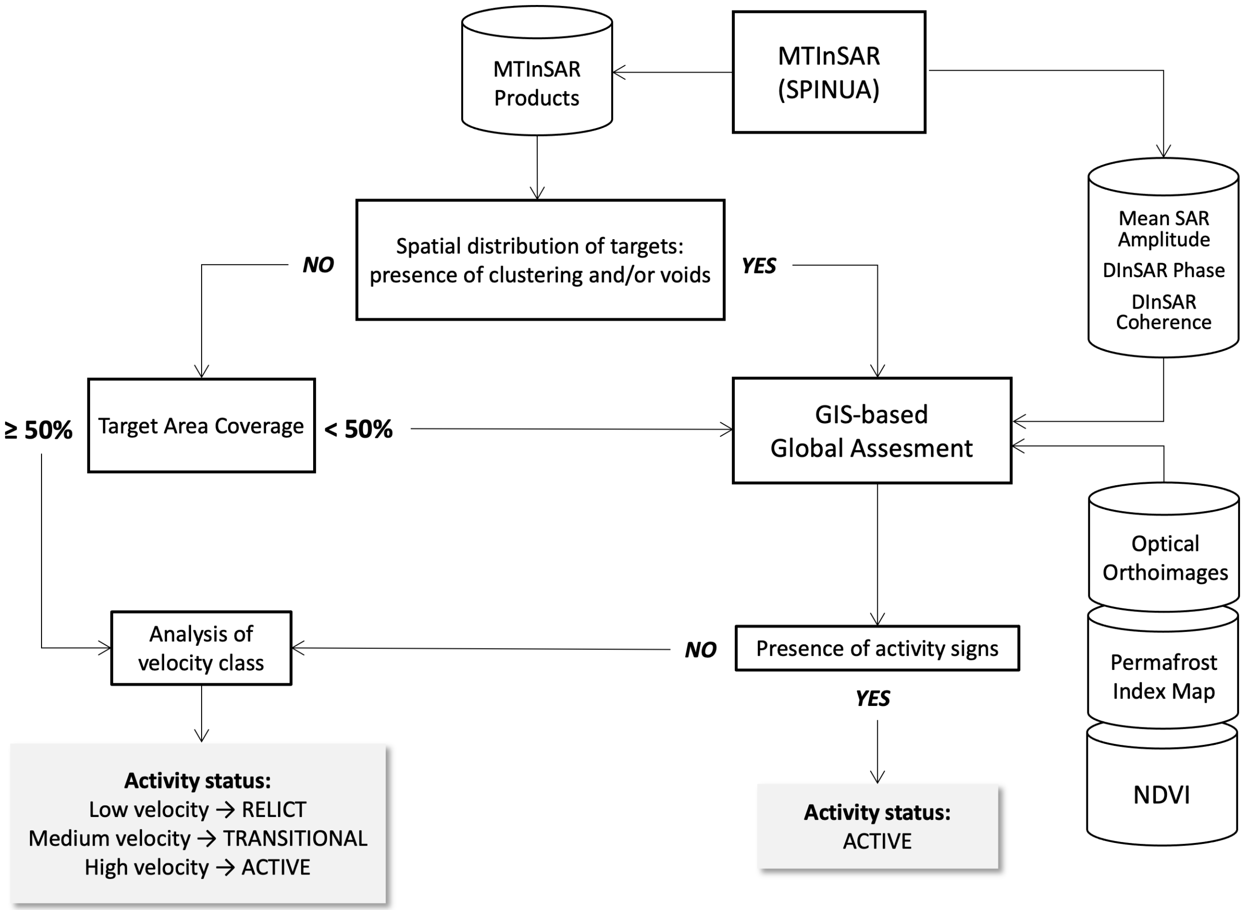
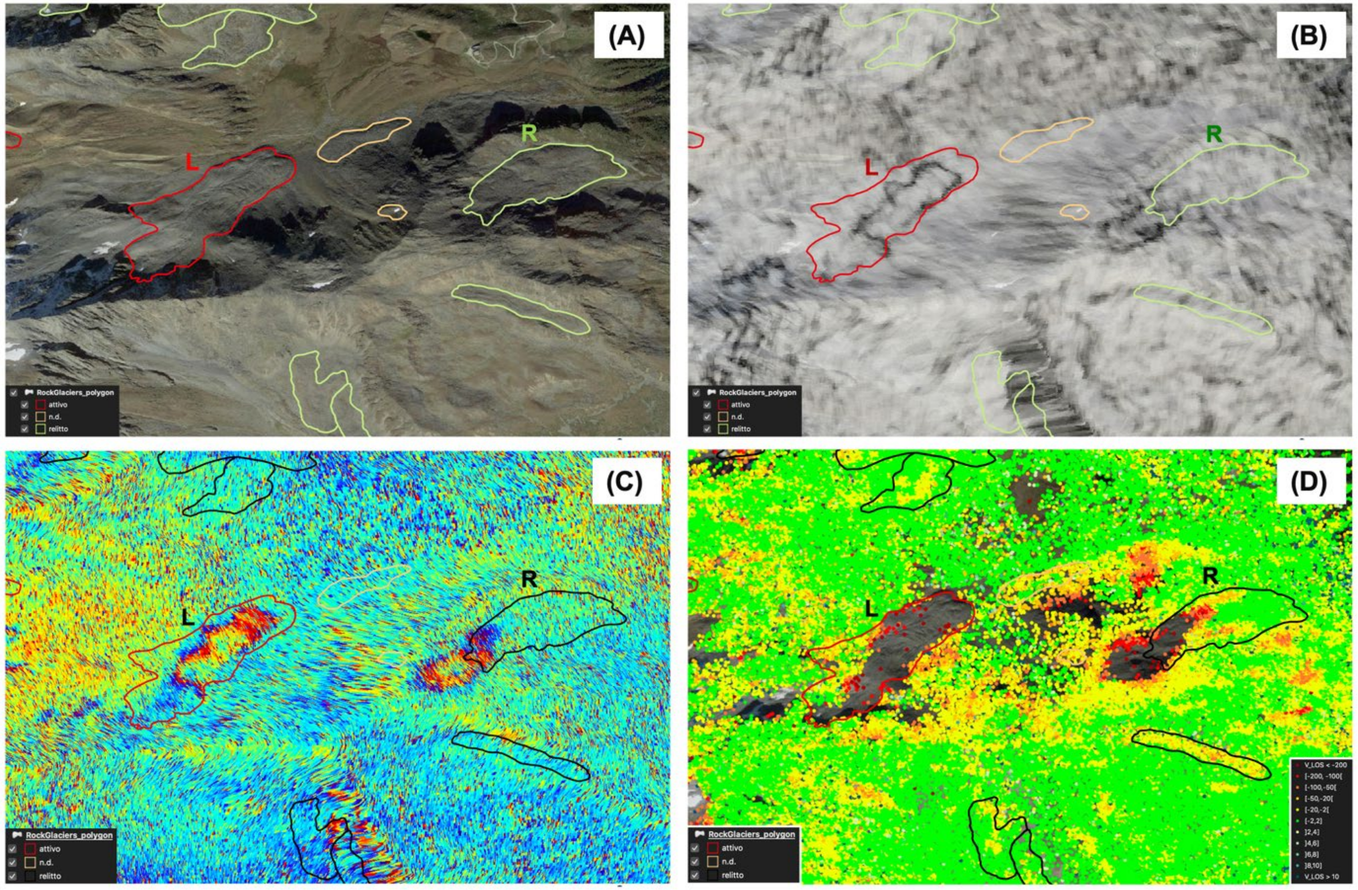
- ✓ We developed a classification procedure, which combines in a GIS environment several inputs (optical orthophotos, permafrost probability index, NDVI, MInSAR products, DInSAR Phase and Coherence)

Mean Velocity [m/a]	Velocity class
$V_{LOS} < -0.1$	Active
$-0.1 \le V_{LOS} \le -0.01$	Transitional
$V_{LOS} > -0.01$	Relict



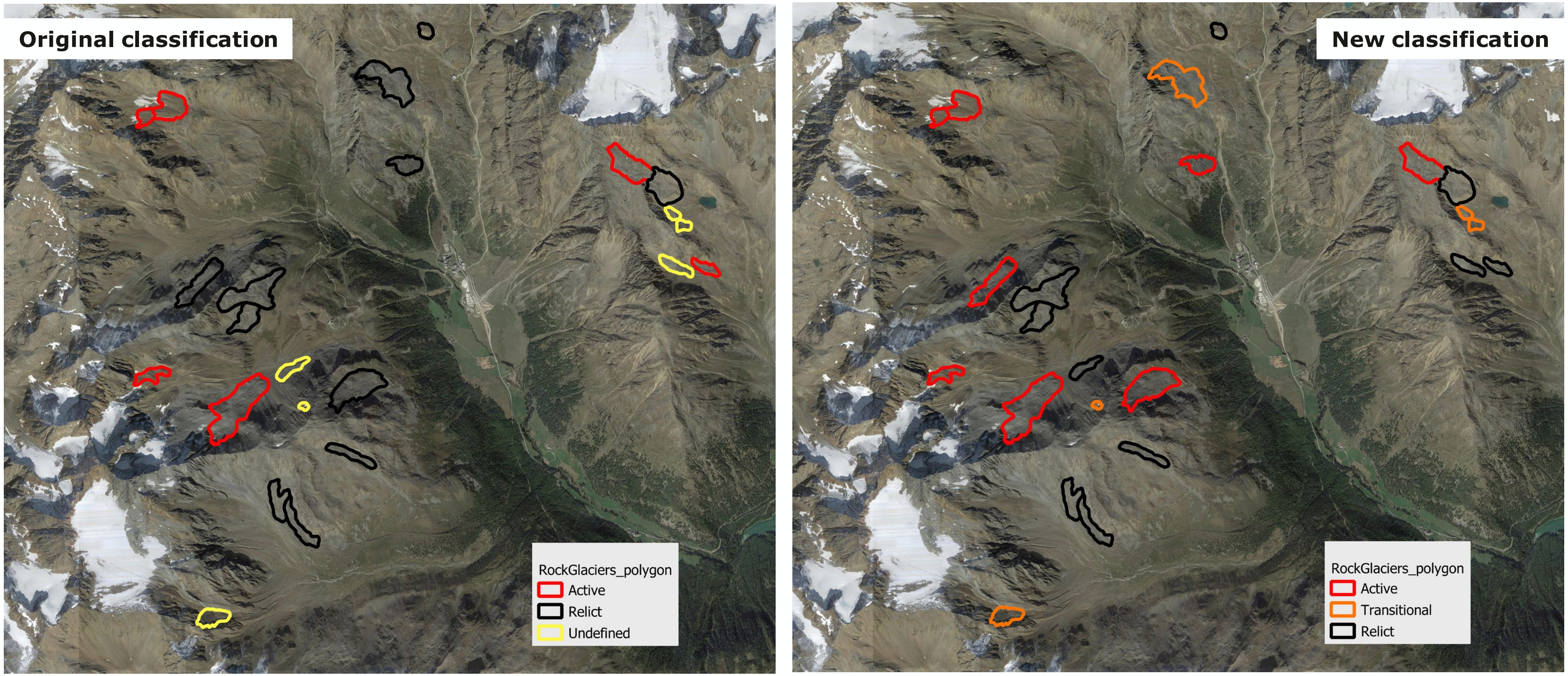
MTInSAR-based Rock Galcier Classification

- ✓ The more complex cases for the classification procedure occur where MTInSAR targets are lacking just within the rock glacier borders (potentially related to the presence of very high displacement rates): optical orthoimages, DInSAR phase, and coherence maps are very useful in this case for assessing the rock glacier activity.



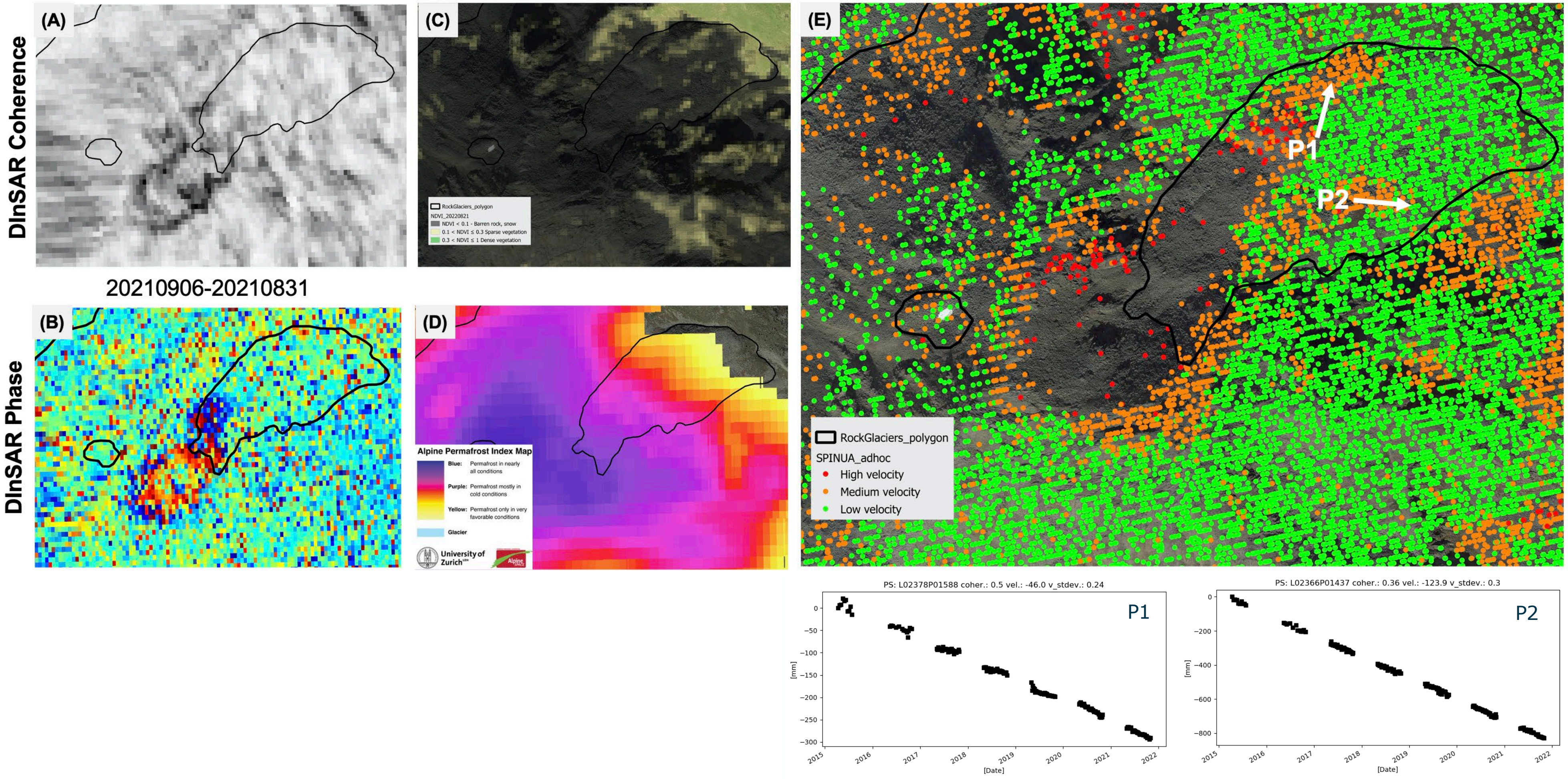
MTInSAR-based Rock Galcier Classification

- ✓ This new classification was compared to that derived according to (Bollmann et al. 2012) showing several differences. For instance, 3 out of the 6 rock glaciers classified as undefined were reclassified as relict or translational, 6 out of the 11 rock glaciers classified as relict were reclassified as transitional, and conversely, one rock glacier classified as active was reclassified as relict.



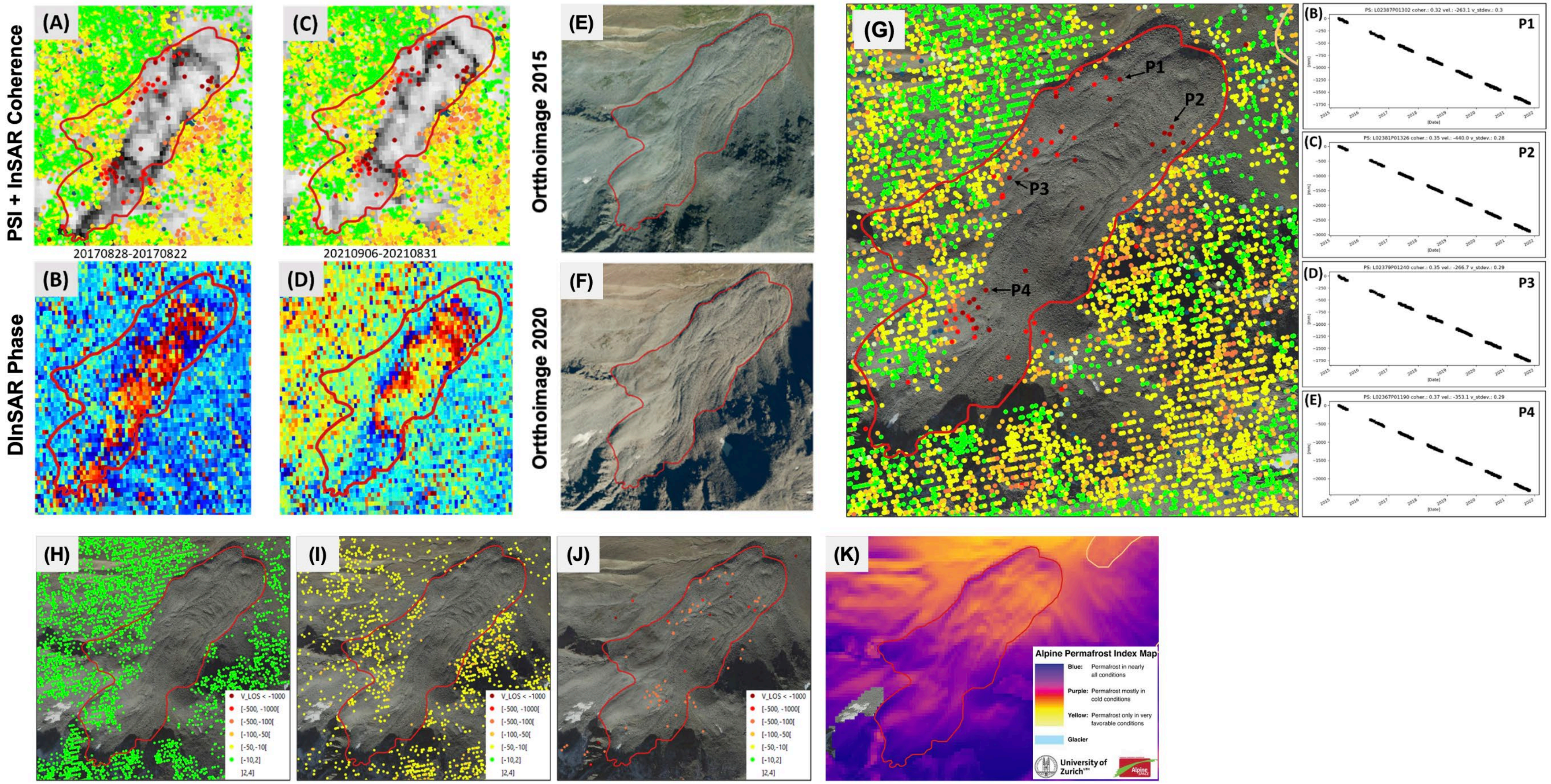
Rock Galcier Detailed Analysis

✓ Example of rock glacier, which was relict in the original classification, and according to our MTInSAR-based procedure has been reclassified as active with borders to be redefined.



Rock Galcier Detailed Analysis

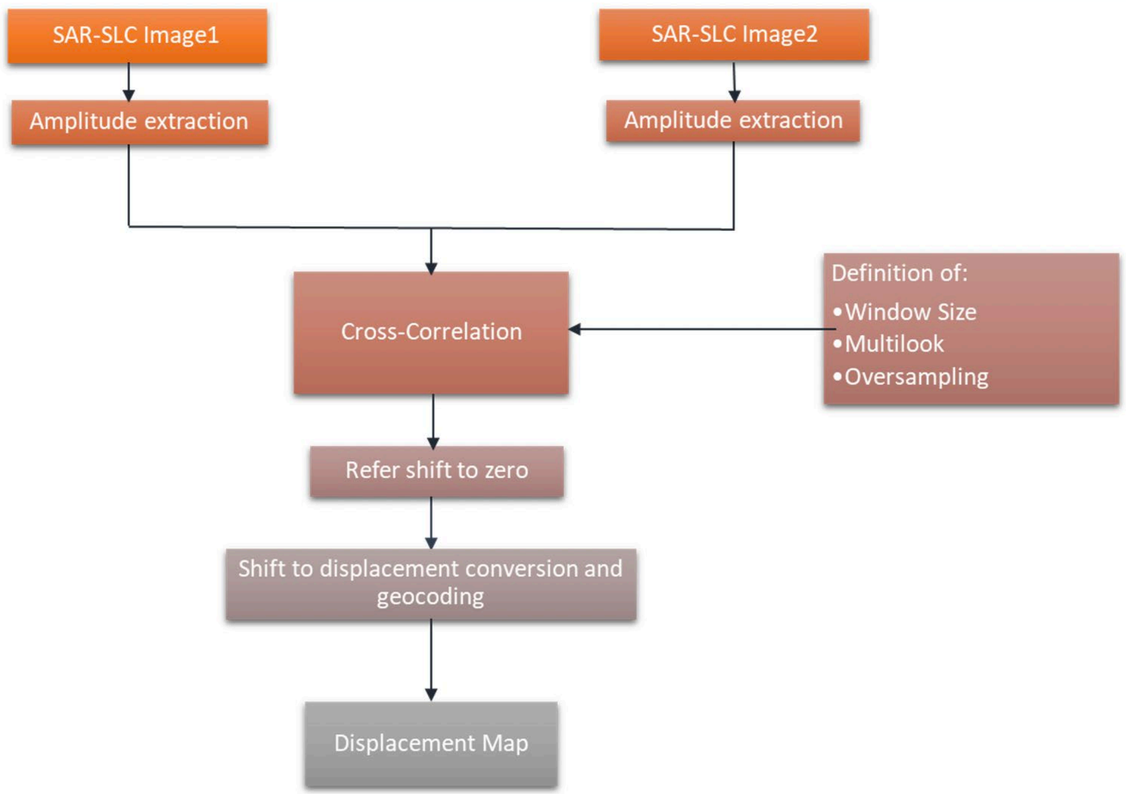
✓ The Lazaun rock glacier is a tongue-shaped, 660 m long and 200 m wide, active rock glacier located in Senales Valley (Italy) at about 2600 m asl. Interannual and seasonal displacement rates up to few mm/day are reported by previous studies, which used different techniques including GNSS, inclinometers, and both ground based and spaceborne SAR systems.



Intensity Tracking of X-banda Data

- ✓ Offset tracking techniques exploit SAR amplitude instead of phase, overcoming the DInSAR limitations related to high deformation rates.
- ✓ To investigate displacements on Lazaun, intensity tracking has been adopted instead of coherence tracking, which is unfeasible due to the low coherence.
- ✓ Pairs from TSX Spotlight, CSG Spotlight, and CSK Stripmap have been processed to derive displacements along Azimuth, LOS and Slope projected.
- ✓ For CSK Stripmap data a 5x5 Lee filter has been applied before the procedure for the maximization of the normalized cross-correlation between pairs of images.

Platform	Acquisition Mode	Dates	Analysis
TSX	Staring SPOTLIGHT ASCENDING 028R	16/08/2016-18/08/2017 14/07/2017-16/08/2017 14/07/2017-27/09/2018	Seasonal/Interannual
CSG	SPOTLIGHT-2C ASCENDING 035	18/06/2022-21/08/2022 18/06/2022-30/09/2022 21/08/2022-30/09/2022 21/08/2022-16/10/2022	Seasonal
CSK	STRIPMAP(HIMAGE)	Between 2016 and 2022 Time Interval between image pairs from 1-6 years	Interannual



Intensity Tracking of X-banda Data

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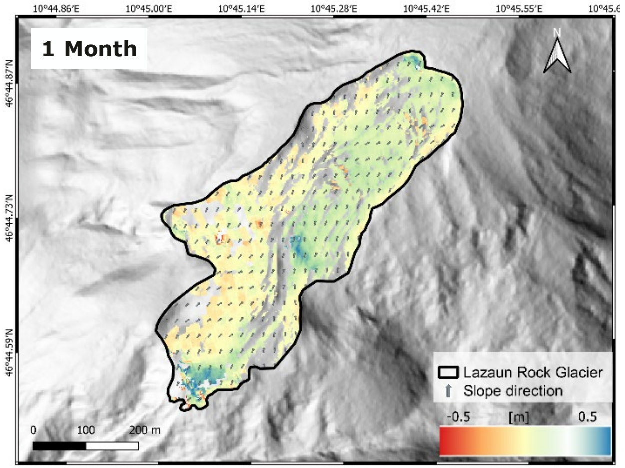
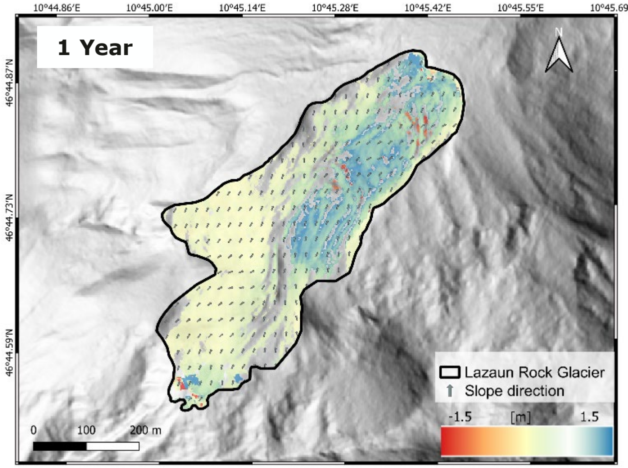
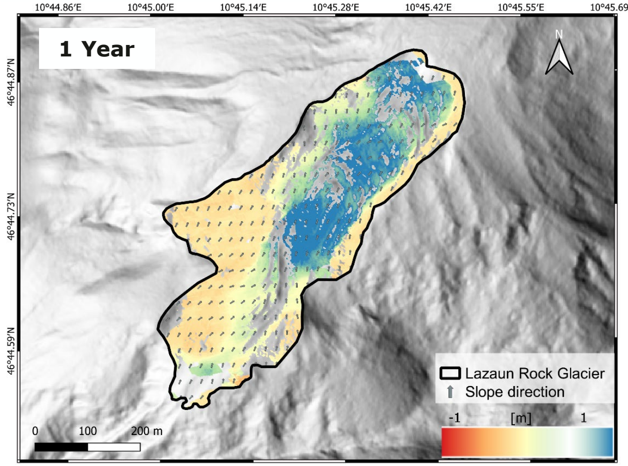
CSG SPOT: June 2022 – Aug. 2022

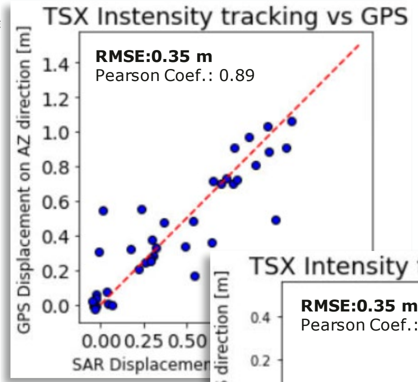


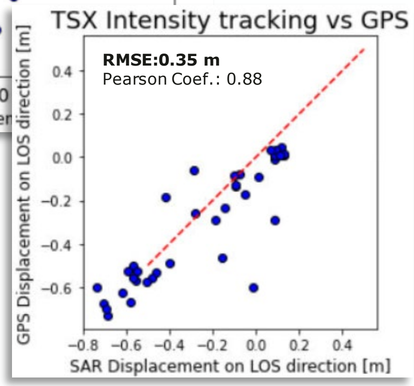
CSG SPOT: Aug. 2022 - July 2023



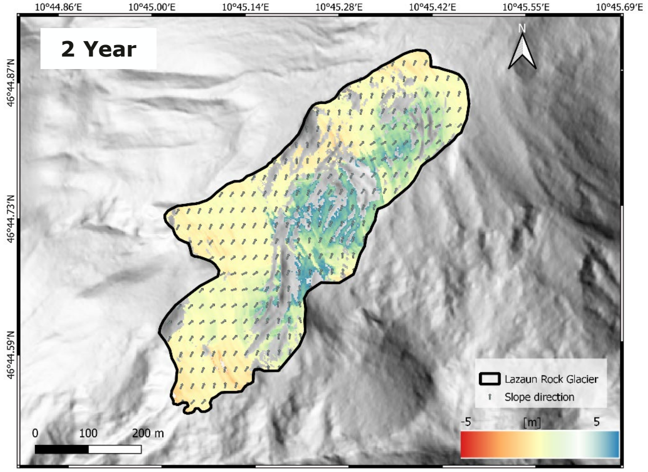
TSX SPOT Aug. 2016 – Ago.2017



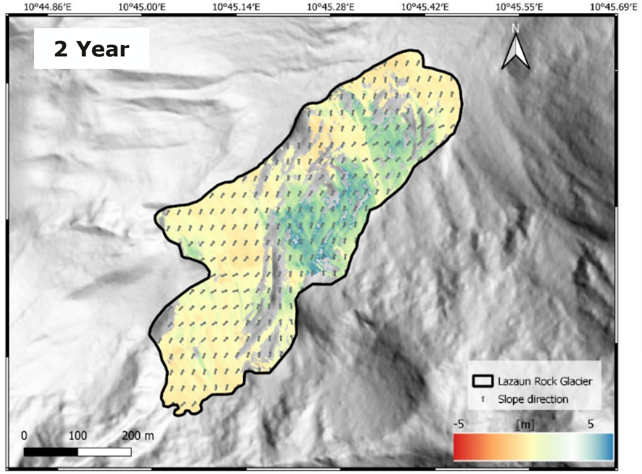


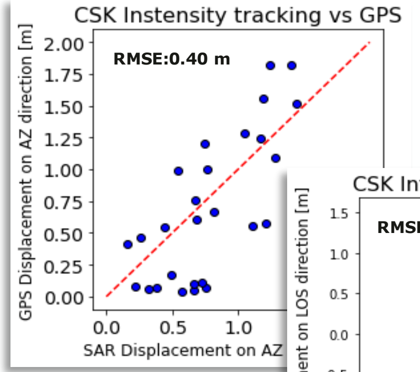


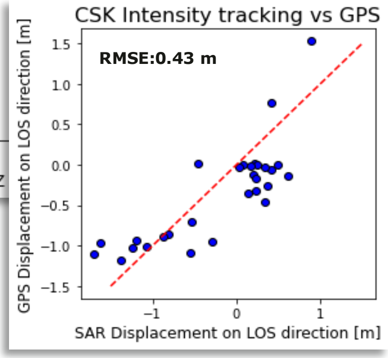
CSK STRIP Aug. 2018 - Sept. 2020



CSK STRIP Sept. 2020 - Aug. 2022

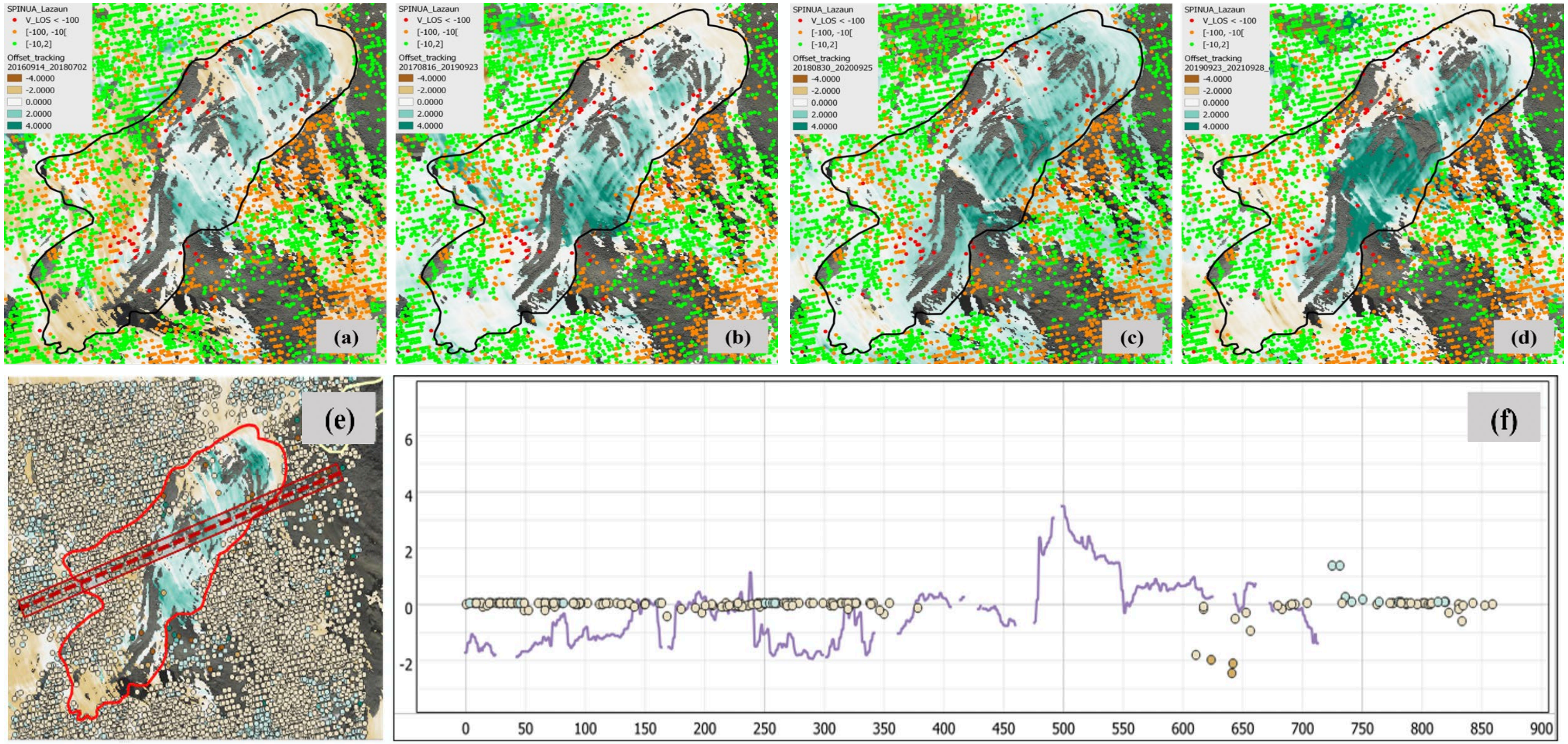






Detailed Analysis of Lazaun Rock Glacier

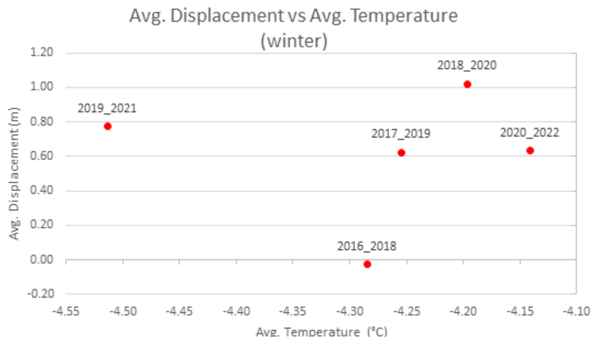
- ✓ MTInSAR LOS displacement rates (mm/y) have been compared with the displacement patterns along the slope derived through offset-tracking technique and COSMO-SkyMed data (m). The MTInSAR targets are distributed where the displacements derived through offset-tracking are lowest, while the area lacking of coherent targets show the highest displacement values.

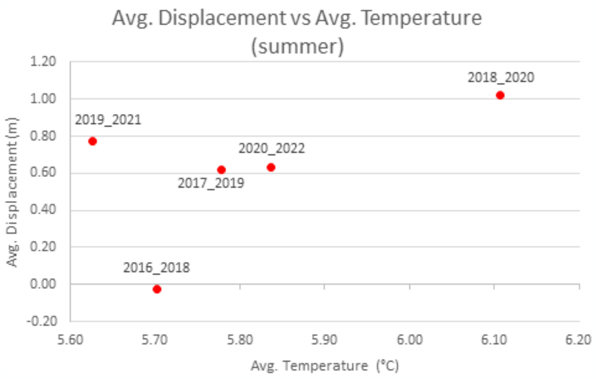


Detailed Analysis of Lazaun Rock Glacier

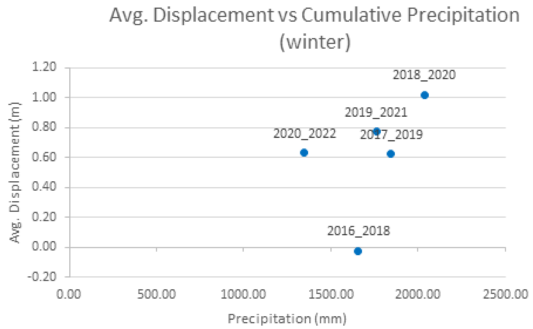
- ✓ Intensity tracking - The summer temperatures appear to produce larger shifts due to higher thawing rate of permafrost. Winter temperatures does not seem to influence the movements because snow insulates the rock glacier, which is thus unaffected by temperature changes.
- ✓ Intensity tracking - The precipitation during winter can produce higher displacement due to heavier weight of the snow and more water during the snowmelt season. Summer precipitations do not appear to correlate with displacement.
- ✓ MTInSAR - The preliminary analysis does not show any correspondence between deformations, changes in temperature and rainfall events.

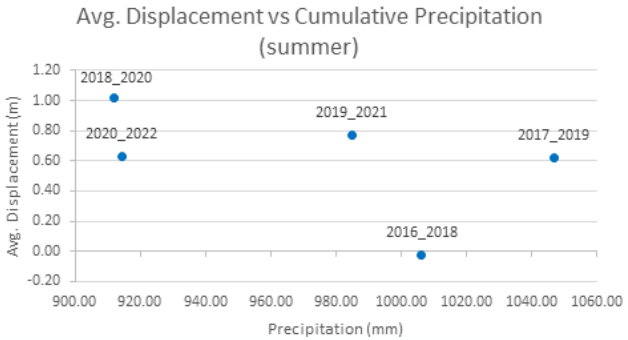
Intensity tracking vs Temperature



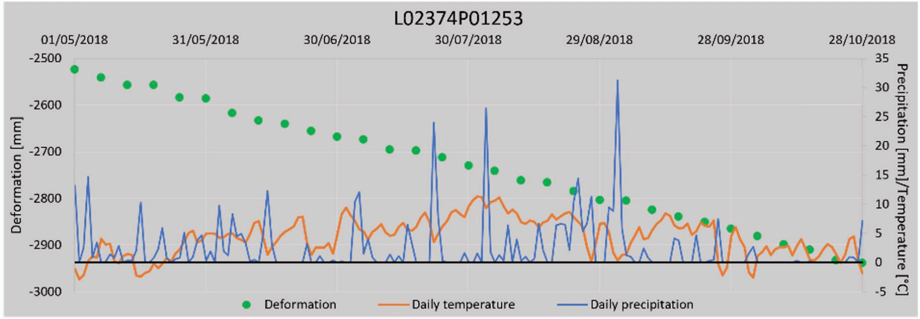


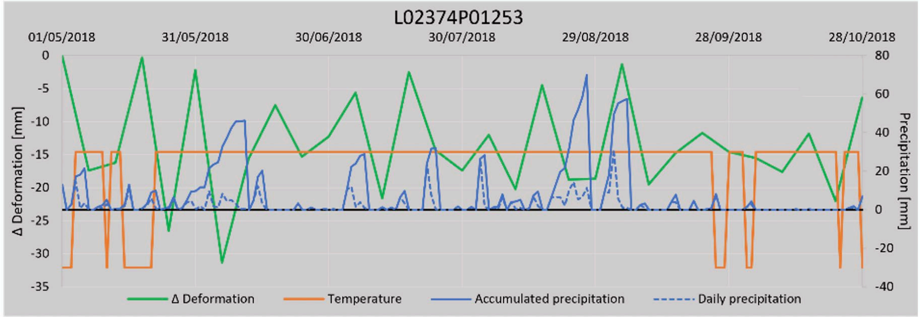
Intensity tracking vs Cumulative precipitations





MTInSAR vs Cumulative precipitations & Temperatures





Final Comments

- ✓ Investigation of rock glacier stability poses several challenges related the phase noise (due to both scattering properties and atmospheric artifacts), and phase aliasing, which limits the maximum measurable displacements.
- ✓ To derive reliable and useful displacement information over rock glaciers, an ad hoc MTInSAR processing strategy has been needed.
- ✓ A procedure has been developed, which leverages these MTInSAR products to improve the classification of rock glacier activity.
- ✓ To overcome the limits of MTInSAR technique, the intensity of high resolution X-band data has been also exploited.
- ✓ Intensity tracking provides results complementary to MTInSAR, by allowing the displacement estimation over areas and time periods not covered by MTInSAR.
- ✓ Future works: i) introducing automatic procedures for spatial and temporal analysis of displacement maps; ii) developing procedure for reliably fusing MTInSAR and intensity tracking products; iii) refining the classification procedure by including products from intensity tracking and L-band DinSAR.

Acknowledgments

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Thanks!

Questions?

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