



## Testing the integration of InSAR and optical data for rock glacier detection in a lateral valley of Valtellina (Northern Italy)

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Multi-temporal InSAR techniques allow the detection of millimetric surface displacements, making them particularly suitable for monitoring slow-moving landforms, such as rock glaciers, at a regional scale. Optical data, and in particular Short-Wave Infrared (SWIR) bands, provide complementary information by enhancing the spectral response of bare debris and poorly vegetated surfaces.

This work aims to propose a workflow to recognize the presence of rock glaciers over large areas (approximately 10-100 km<sup>2</sup>) and to distinguish them from other geomorphological units through the integration of optical and interferometric data.

The approach was tested in a restricted study area (3.7 km<sup>2</sup>) in Alpe Visogno, in the municipality of Mello (SO), within a small lateral valley on the Rhaetian side of Valtellina (Northern Italy). This area hosts an atypical rock glacier due to its exposure (south) and relatively low mean altitude (2100 m a.s.l.). Such conditions make the area particularly suitable for investigating peculiar permafrost dynamics in an alpine environment.

Interferometric analysis was conducted using ascending-orbit Sentinel-1 data, covering the period from 10 May 2024 to 24 December 2024, corresponding to the snow-free season. Open-source processing tools were used to derive surface velocity maps for the area of interest. The correction of the Atmospheric Phase Screen (APS) was carried out using the Generic Atmospheric Correction Online Service (GACOS). This choice was based on a comparison of the residuals resulting from different correction approaches. The optical data came from a single Sentinel-2 image acquired during the summer period (08 August 2024) under snow-free conditions for the entire study area, reaching up to 2670 m a.s.l. This image was selected to maximize the radiometric quality and to minimize the effects of clouds and shadows. Subsequently, a specific spectral index (*Debris index*) primarily derived from SWIR bands was defined. These bands are sensitive to the presence of moisture, such as that occurring in pores and fractures, and can be used to discriminate superficial layers with different textural properties. A threshold based on the 75<sup>th</sup> percentile was applied to the *Debris index* to generate polygons representing the deposits. The integration of optical and interferometric data was supported by a statistical analysis, including both boxplots and clustering techniques (k-means and hierarchical Ward's method).

The clustering identified two groups: a fast-moving cluster (average velocity of -24.4 mm yr<sup>-1</sup>)

corresponding to rock glaciers, and a slow-moving cluster corresponding to simple debris deposits (average velocity of  $-11.1 \text{ mm yr}^{-1}$ ). These results are strongly corroborated by field observations, confirming the effectiveness of the workflow in discriminating rock glaciers from other debris accumulations such as talus and colluvial deposits. Future developments will focus on testing the proposed workflow over larger and more heterogeneous areas to assess its robustness and transferability at local, regional, or supra-regional scales.

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