Title: Optimizing rock glaciers activity classification in South Tyrol (North-East Italy): integrating multisource data with statistical modelling

1) Overall quality and general comments

Rock glaciers are key indicators of permafrost in alpine regions, formed by a seasonally frozen detrital layer overlying supersaturated debris of ice or pure ice, and characterized by gravity flow. Their distribution is influenced by topographic and climatic factors at different scales, and they play a crucial role in high-altitude hydrology by storing ice and water. Traditionally, rock glaciers are classified as active, inactive, or relict based on ice content and movement. However, rising permafrost temperatures have led to an accelerating trend, encouraging an updated classification that considers sediment transport efficiency. In the regional territory of South Tyrol, two rock glaciers activity classifications coexist (Autonomous Province of Bolzano/Bozen and Bertone et al., 2019). By combining geomorphological characteristics, climatic driving factors, and InSAR products, the authors develop a statistical model to refine the classification of rock glaciers.

This study represents an innovative contribution since it integrates multiple variables into a multiclass generalised additive mixing (GAM) model to predict rock glacier activity. Using remote sensing, ground-based data, and digital terrain models, the workflow involves extracting velocity and environmental attributes at a regional scale, calibrating and validating a multiclass predictive GAM, and applying it to classify landforms based on their activity status.

The integration of remote sensing data and statistical modelling significantly advances current methods for assessing rock glacier dynamics. The study is well-structured, with a clear research objective and methodology. The statistical approach, particularly the use of a multiclass GAM model, is effective for the research aims. The discussion is robust, highlighting both its contributions and its limitations. The figures and tables are clear, informative, and support the understanding of the concepts. Finally, this work advances the understanding of rock glacier dynamics by refining their classification system and linking their activity states to a range of predictor variables.

2) Individual scientific questions

3.4.1. Statistical modelling

How did the authors ensure the robustness of the GAM model in terms of the selection and evaluation of predictor variables?

4.1. Exploratory Data Analysis

How did you decide which variables to retain for further analysis, and why were some variables, such as elevation, excluded to avoid redundancy despite their high discriminatory power? Could you clarify the rationale behind this choice?

3) Specific comments on the manuscript

Line 119: How many rock glaciers are present in the analysed dataset?

Line 127: The classification 'n.d.' is unclear. Could you please clarify its meaning and usage in this context?

Line 148: Could you explain in more detail how the variables were extracted and assigned to each individual rock glaciers?

Lines 207-210: "Using this SCD parameter, a potential correlation between the rock glaciers' activity at a regional level was made[...]" Could you explain this statement more clearly? How was the correlation assessed, and what were the main findings regarding the SCD in relation to the rock glaciers' activity?

Figure 4: Does the term "look vector" refer to the Line of Sight (LOS) of the satellites? Could you also better explain if the shadowing and layover effects part is the C index analysis?

Figure 4: Is the vLOS referring to vertical velocity? Additionally, could you adjust the colour scale bar to range between -8 and 8 cm/year to improve the clarity of the data representation?

Lines 244-248: "For each rock glacier polygon, mean values for environmental and climatic variables were assigned based on the values within the polygon boundary. Furthermore, for DInSAR-related variables (i.e., velocity and coherence), additional statistical descriptors [...]". Can you explain how the uncertainty was computed for each rock glacier, based on the SAR data coverage? How did you assess the spatial uncertainty within each polygon?

Line 243: "Starting from the distribution map of the rock glaciers and considering their displacement range, we made two distinctions [...]". Could you clarify the rationale behind the choice of a 100-meter buffer around each mapped landform? How was this distance determined, and how does it affect the classification?

Lines 264-266: "To discern the key factors influencing the distinction between A, R, and T rock glacier classes, we performed an initial Exploratory Data Analysis. This exploration served [...]". Could you provide more details on how this exploratory analysis was performed, and how it helped with the model?

Lines 167-272: "GAM was employed to investigate the associations between the chosen predictor variables derived from both environmental and DInSAR datasets and the response variables. GAM provides [...]". Could you provide more explanation on the use of GAM in this context? A brief discussion of the relevant literature and how GAM has been applied in other studies would strengthen this section.