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Rockfall risk mitigation in the Alps

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In the alpine cryosphere, thermo-mechanical stresses due to rock temperature fluctuations, induce crack opening or widening, predisposing rock faces to failure. In the last decades, an increase in rockfalls has been documented and has been attributed to air warming. However, in-situ relationship between air and rock temperature is still little known, while a comprehensive understanding of heat transfer in rocks and their thermophysical properties are crucial to rockfall risk mitigation. This issue is being investigated in the Bessanese high-elevation experimental basin (western Italian Alps) with the following objectives: i) Use of metrologically validated Internet of Things (IoT) devices for continuous, in-situ monitoring of key parameters preconditioning rockfalls; ii) Develop an accurate heat transfer model in rock, to be used for rockfall risk mitigation in the alpine cryosphere; iii) Build a high-elevation monitoring site in rockfall-prone areas to validate the model and monitor rock temperature at different depths (10 cm, 30 cm and 50 cm); iv) Create a web portal to display the monitoring data in near-real time.

The traceability of the rock temperature measurements and the accuracy of the data are essential for the development of reliable heat transfer models in rocks. For this purpose, the six thermometers installed inside the two IoT devices at The Uja of Bessanese at different orientations, elevation and depths were previously calibrated. The calibration was made by comparing the readings of the six thermometers against a reference thermometer, in a thermal bath at different temperatures (-20 °C, -5 °C, 0 °C, 5°C, 20 °C and 40 °C). Since the sensors in the rock are not exposed to wind, direct solar radiation or other quantities of influence, the uncertainty of the instantaneous rock temperature measurements is assumed to be the same as the calibration uncertainty (0.014 °C).

A heat transfer model of rock was developed according to the following steps: i) Theoretical investigation of heat transfer in rocks, survey on simplified and detailed numerical models; ii) Set up of the COMSOL Multiphysics tool with the Heat Transfer Module; iii) Application of numerical heat transfer simulation on the monitoring site; iv) Calibration of numerical heat transfer model, establishing model reliability and accuracy, from experimental data and in-situ measurements; v) Sensitivity analyses to identify the thermal behavior of rocks with varying driving forces; vi) Rock heat transfer scenario analyses.

Main results of this work: i) Enhanced understanding of the relationships between air and rock temperature, and solar radiation at high-elevation sites; ii) Deployment of new-generation, metrologically validated IoT devices, installed in high-elevation rockfall-prone areas; iii) Development of a specific and exportable heat transfer model for metabasites; iv) Implementation of a freely accessible web portal (https://bessanese.lab3841.it). This work was carried out within the project 20223MKEMB_PE10_PRIN2022 - PNRR M4.C2.1.1 Funded by the European Union - Next Generation EU (October 2023 - February 2026).

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