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# Improved characterization, monitoring and instability assessment of high rock faces by integrating TLS and GB-InSAR

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Rockfall risk analysis require quantifying rockfall onset susceptibility and magnitude scenarios at source areas, and the expected rockfall trajectories and related dynamic quantities. Analysis efforts usually focus on the rockfall runout component, whereas rock mass characterization and block size distribution quantification, monitoring and analysis of unstable rock volumes are usually performed using simplified approaches, due to technological and site-specific issues. Nevertheless, proper quantification of rock slope stability and rockfall magnitude scenarios is key when dealing with high rock walls, where widespread rockfall sources and high variability of release mechanisms and block volumes can result in excessive modelling uncertainties and poorly constrained mitigation measures.
We explored the potential of integrating field, remote sensing, structural analysis and stability modelling techniques to improve hazard assessment at the Gallivaggio sanctuary site, a XVI century heritage located along the State Road 36 in the Spluga Valley (Italian Central Alps). The site is impended by a subvertical cliff up to 600 m high, made of granitic orthogneiss of the Truzzo granitic complex (Tambo Nappe, upper Pennidic domain). The rock mass is cut by NNW and NW-trending slope-scale structural lineaments and by 5-6 fracture sets with variable spatial distribution, spacing and persistence, which bound blocks up to tens of cubic meters and control the 3D slope morphology. The area is characterised by widespread rock slope instability from rockfalls to massive failures. Although a 180 m long embankment was built to protect the site from rockfalls, concerns remain about potential large unstable rock volumes or flyrocks projected by the widely observed impact fragmentation of stiff rock blocks. Thus, the authority in charge started a series of periodical GB-InSAR monitoring surveys using LiSALabTM technology (12 surveys in 2011-2014), which outlined the occurrence of unstable spots spread over the cliff, with cm-scale cumulative displacements in the observation period. To support the interpretation and analysis of these data, we carried out multitemporal TLS surveys (5 sessions between September 2012 and October 2014) using a Riegl VZ-1000 long-range laser scanner. We performed rock mass structural analyses on dense TLS point clouds using two different approaches: 1) manual discontinuity orientation and intensity measurement from digital outcrops; 2) automatic feature extraction and intensity evaluation through the development of an original Matlab tool, suited for multi-scale applications and optimized for parallel computing. Results were validated using field discontinuity measurements and compared to evaluate advantages and limitations of different approaches, and allowed: 1) outlining the precise location, geometry and kinematics of unstable blocks and block clusters corresponding to radar moving spots; 2) performing stability analyses; 3) quantifying rockwall changes over the observation period. Our analysis provided a robust spatial characterization of rockfall sources, block size distribution and onset susceptibility as input for 3D runout modelling and quantitative risk analysis.