Constraining the role of weather conditions in driving damage accumulation leading to rockfall

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1. Abstract

Long-term climate and short-term weather conditions, notably rainfall and temperature, are cited as fundamental controls on rockfall initiation (Delonca et al. 2014; Strunden et al. 2015; Collins & Stock, 2016). The intricacies of how climate and weather climate drive rock-mass damage accumulation and, ultimately failure (as rockfall), are poorly constrained. This partially stems from the limited availability of monitoring data at an appropriate resolution that captures variations in environmental conditions that drive progressive failure of rock masses (Williams 2017; Williams et al., 2018 2020). Given projected climate change (Gariano & Guzzetti, 2016; Raible et al., 2021) understanding the interplay between weather, damage accumulation and rock-slope failure is crucial in constraining if and how future rockfall hazard and rock-slope erosion will change.

To address this, we aim to monitor rock-slope deformation and rockfall activity over a 1-year period using ±0.05 m resolution hourly terrestrial-laser-scanning (TLS) and thermal imaging along an actively failing rock slope in the UK. This rock slope has previously displayed deformation that is indicative of progressive failure mechanisms (Rosser et al. 2007, 2013; Williams, 2017). We supplement cliff-face monitoring with cliff-top sandstone slabs (pseudo-rock-faces), monitored for microcrack-generated acoustic emissions. Monitoring of cliff-top weather conditions will provide a minute-by-minute resolution catalogue of localized conditions. This research is currently ongoing and in the data collection phase; as such, we cover here the rationale and conceptual framework which underpins this work, alongside an overview of the methods used to address the research objectives.

2. Rationale

How weather and climate link to the intricacies of rockfall generation is ultimately poorly captured and described. Previous work has focused heavily upon cause-effect relationships between weather and rockfall occurrence, inherently oversimplifying internal rock-mass processes such as subcritical crack growth, damage accumulation and progressive failure mechanisms (Petley et al., 2005; Strunden et al., 2015; Williams, 2017). The timing of rockfall failure may not be known to less than sub-daily or an even coarser temporal resolution, which makes it increasingly difficult to precisely assess weather conditions leading up to, and coincident with, time of failure.

Rockfall sequences indicative of progressive failure have been observed using TLS monitoring, where precursory patterns of surface deformation and smaller rockfall precede larger events (Rosser et al., 2007; 2013). Once a critical internal rock-slope threshold is exceeded, crack propagation has been hypothesised to operate independently of ambient environmental conditions (Rosser et al., 2007, 2013). This illustrates the need for caution when attempting to link environmental conditions to rockfall occurrence using cause-effect approaches in the absence of direct surface monitoring at appropriate resolution.

Storm systems are projected to become increasingly intense and more frequent under future climate change (Gariano & Guzzetti, 2016). Previous work has often been forced to draw upon weather data sourced from weather stations located considerable distance (~kms) from the location of rockfall activity, leading to inaccurate assessment of weather conditions both leading up to and around the time of rockfall occurrence.

This lack of rockfall and weather data in appropriate locations at an appropriate scale and spatial and temporal resolution, limits our understanding of the link between weather conditions and rockfall occurrence. Given anticipated climate change, constraining and quantifying the relationship between weather and rockfall generation is increasingly important if we are to accurately forecast how rock-slopes will respond in the future.

The idea of geomorphic legacy and 'enduring landscape damage', in which the critical rainfall conditions required to instigate mass movements change following major storm events, has been explored chiefly for landslides (Hung et al., 2019; Chen et al., 2020). Whether this holds true for rock-slopes and at smaller scales (10^1 – 10^2 m) has previously received little attention, which may be an artefact of a lack of long-term rock-slope monitoring projects and thus data availability. Given projections that storms may become both more intense and occur with higher frequencies under climate change (Gariano & Guzzetti, 2016; Raible et al., 2021), the possibilities of extreme storm event legacy on rockfall activity warrant attention accordingly.

3. Methods

The overall aim of this work is to monitor rock-slope response to changes in weather conditions. Figure 1 details an overview of how this project will address this challenge. We are currently monitoring rock-slope deformation and rockfall activity over a 1-year period using ±0.05 m resolution hourly terrestrial-laser-scanning (TLS) and thermal imaging along an actively failing hard rock coastal rock face at Whitby, North Yorkshire, UK. This, alongside weather data from a cliff-top station, will allow us to directly monitor rock-face response to variations in weather conditions and changing rock surface moisture and thermal signatures. Rock-slope response during and after notable storm events will form a focus, with the aim of examining evidence for storm-associated geomorphic legacy in rock slopes.

Past work has focused on smaller scale (~boulder-size) monitoring of environmental driven sub-critical crack growth (Eppes et al. 2016, 2020); our work builds on this, but upscales to a 300 m section of ~60 m high hard rock cliff. Our research therefore has a spatial component which allows for examination of how rockfall evolve and occur spatially, and how this may change under climate change.

As part of our field monitoring campaign, we have set up a series of sandstone slabs which are monitored for subcritical cracking induced acoustic emissions (AE) activity. AE can serve as the unifying link between monitored environmental forcings (i.e., rainfall, temperature fluctuations etc.) and rockfall generation (crack growth), in contrast to some previous work which draws on cause-effect presumptions. In combination, these field-monitoring approaches aim to provide insight into diurnal, seasonal and episodic rock-damage accumulation driven by weather conditions.

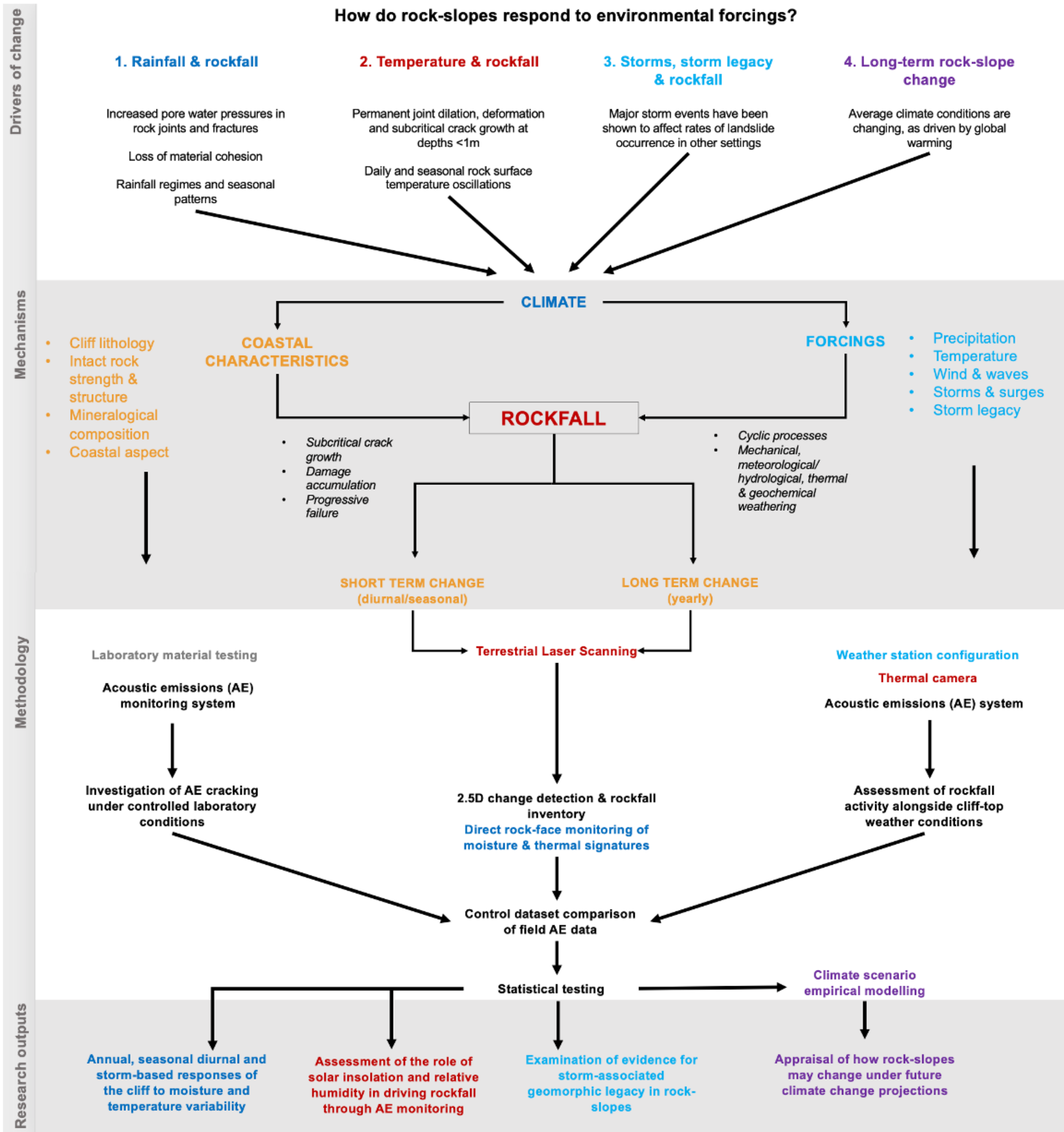

Figure 1: How do rock-slopes respond to environmental forcing? Summary of research project justification, aims, methods & output

4. Acknowledgements

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