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High resolution monitoring of hard rock coastal cliffs: implications to short-, medium- and long-term coastal evolution.

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Results are presented from a detailed study of coastal cliff behaviour on the hard rock cliffs of North Yorkshire, UK. This paper aims to consider the results of intensive direct monitoring of coastal cliff processes and examine these in the context of a historical database of landslide activity for the same coastline. The coast of North Yorkshire is renowned for rapid rates of retreat and has experienced in recent years a number of large failures that have had significant impact on coastal infrastructure and communities. A new high resolution monitoring approach has been developed based on terrestrial laser scanning, digital photogrammetry and 3D modelling. Data derived from this approach allows for the first time high resolution quantification of the nature of cliff rockfalls in addition to developing the understanding of the commonly cited but poorly studied iterative small scale rockfalls from coastal cliffs. Results from over two years of intensive monitoring have been combined with an extensive dataset on forcing factors which influence the cliff behaviour, including wave and tide climate, near-shore bathymetry, weather, micro-seismic wave impact monitoring and cliff groundwater monitoring.

The results present a new understanding of the nature and pattern of controls on cliff erosion, with clear seasonal climatic and geological controls on cliff erosion. The results are considered within the context of the medium- and long-term evolution of the coastline. An extensive desk study has been undertaken into the occurrence of coastal landslides over the last 250 years. Intensive historical mining activity and considerable human modification to the coastline has left a well and perhaps unrivalled documented history. This historical dataset has been used in combination with field mapping of relict landslides to derive the magnitude and frequency of rockfall events. The contemporary monitoring combined with the historical data has generated a data set of statistical significance for rockfall from small ($>$0.00001m^3) to large ($>$1,000,000 m^3) events during the last 250 years. The results are of great value for probabilistic models of coastal evolution and provide interesting recession predictions relative to conventional cliff top retreat measurements.