Nature news and views article

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Title: Climate change and geohazards

Strapline: Geology and environment

Standfirst: Long term monitoring is required to determine whether climate change is having an impact on shallow geohazard frequency and magnitude, however these records rarely exist. An innovative approach, using tree damage as evidence, suggests climate change has shifted the seasonality of alpine rockfalls as well as increasing their frequency and volume.

There is evidence that landslides such as the 2023 Brienz (Switzerland) rockfall that encroached to within metres of the village school [(1)] and the 2017 landslide near Bondo which killed 8 hikers [(2)] are increasing in frequency in high mountain areas, linked to warmer temperatures [(3)]. To fully understand relationships between climate change and rockfall hazard decades of event monitoring would be necessary. However, as rockfalls in high mountain regions often go unnoticed, monitoring changes over time is a real challenge. Now, writing In Nature Geoscience, Markus Stoffel et al. [(4)], employed an innovative approach to understand the climatic drivers of landslides, using trees as recorders of historic rockfalls over the last century. Their research indicates rockfalls are becoming more frequent, and potentially larger, due to increasingly warmer summers.

Many mountainous communities are vulnerable to landslide activity due to the steep topography, climatic conditions, and high levels of weathering and fracturing of the rocks on which they are located. Permafrost, ground that remains frozen throughout the year, fills cracks and acts like a frozen 'glue' stabilising rock faces. This permafrost sits beneath an active layer that experiences the annual freeze-thaw cycle. When temperatures get warmer, the melting deepens, the permafrost 'glue' thaws, and ground cohesion is reduced, alongside other physical processes impacting slope stability. There is clear potential for climate change to lead to increased rockfall hazard with serious implications for greater loss of life, injury, and property damage. Impacts can also be indirect, due to the communities' reliance on a small number of roads and the harsh geomorphology. The blockage of a single road may have huge implications for transport links, infrastructure, tourism, and trade.

It is important to understand this increasing risk and, in their study, Stoffel et al [(4)] have compiled a continuous time series of periglacial rockfall activity, using growth rings and tree damage in the Swiss Alps. The authors found a gradual shift from 1920, when the majority of rockfalls occurred in the tree's dormant season (October to May), to 2020, when most now occur in the warmer summer – fall season (May to September). They suggest that this is driven by warming summers, with enhanced permafrost melting and resultant destabilisation. A detailed statistical analysis confirms a significant correlation between rockfall frequency and air temperature, with a shift over time of the influential season(s). Prior to the 1970s, the Springtime thawing of the near surface triggered slope instability; since the 1970s, thawing of the deeper permafrost in summer months has resulted in more and larger rockfalls.

The authors' observations are supported by ongoing research. Field laboratories have provided exceptionally detailed observations and measurements over the last few decades [(5,6)]. However, much more data will be required to build robust models predicting climate-driven changes in rockfall susceptibility. Looking to the future, analysis of the EURO-CORDEX regional climate model ensemble, reveals that the entire Alpine region will face a warmer climate in the coming century, with the strongest warming projected for the summer season [7], highlighting the importance of Stoffel and colleagues' research.

The impacts of climate change on geohazards are global, and not restricted to high altitude areas or permafrost environments [8]. Building a robust understanding of the climatic drivers, and processes that impact geohazards, such as landslides, subsidence, and coastal change, is a key area of research at the British Geological Survey (BGS) [9, 10]. The BGS have identified a strong positive correlation between rainfall and landslides (Fig 1), and UK Climate projections suggest warmer, wetter winters, and hotter, drier summers [11]. This underscores the need to understand how climate influences geohazard occurrence, especially in densely populated regions with diverse geology like the UK.

Further scientific research will focus on expanding understanding of the climate drivers for different geohazard types. By building detailed catalogues of long-term time series datasets, such as that demonstrated by Stoffel et al. [4], which can be correlated with historic climate records, it is possible to develop quality models to enable forecasting of future geohazard susceptibility. Understanding the risk and impact of future geohazards is vital for informing future adaptation, mitigation, and planning practises.

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Competing interests

The authors declare no competing interests.

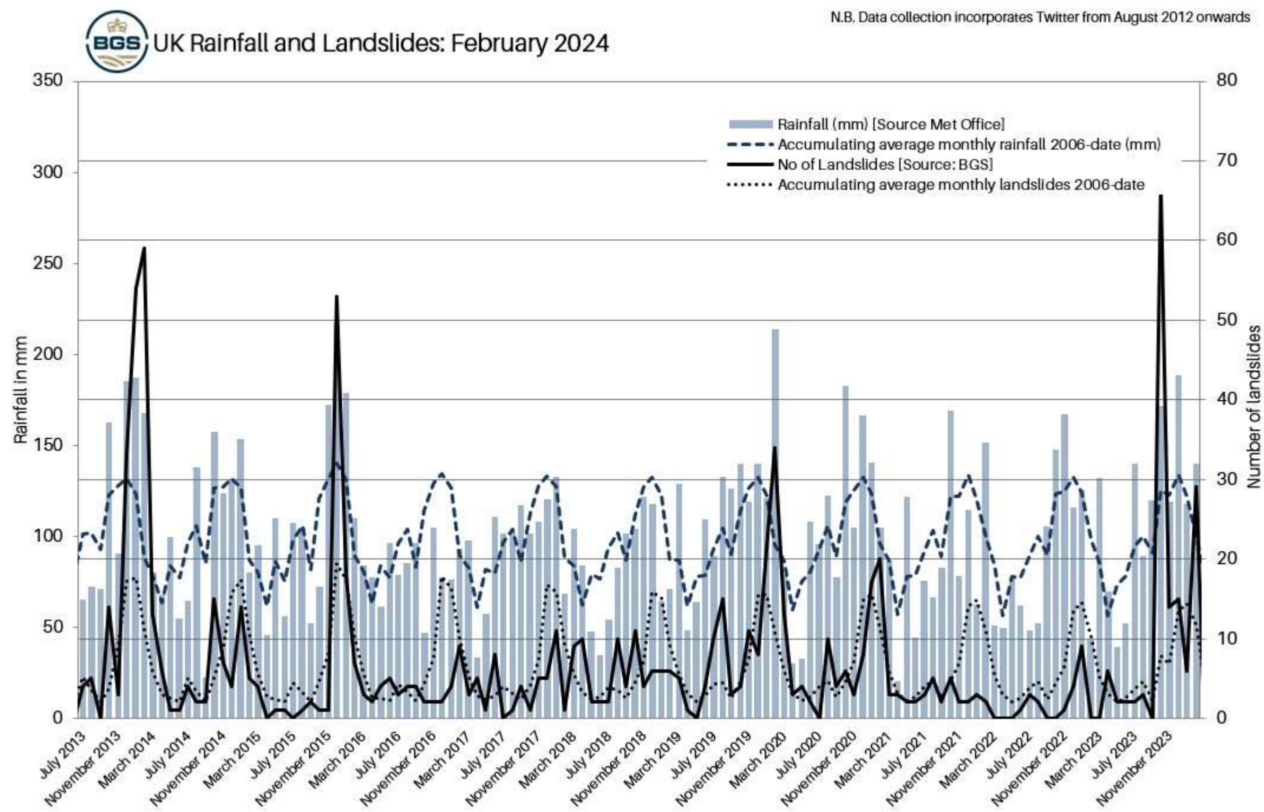

Figure 1: **British Geological Survey UK Rainfall and Landslides**. UK rainfall (source: MetOffice) and landslides (source: BGS) in the UK. BGS © UKRI from https://www.bgs.ac.uk/geology-projects/landslides/landslides-and-rainfall/ [12]