Landslide-GLOF cascade at the expanding Jinwuco in Tibet, 2020: a clear consequence of anthropogenic climate change

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Glacial Lake Outburst Floods (GLOFs) are amongst the most common and high-magnitude natural hydrological disasters in high-mountain regions that have resulted in severe casualties and socioeconomic losses over the last century. Here, we integrate various data and methods to analyse and reconstruct the GLOF process chain involving the moraine-dammed proglacial lake Jinwuco (30.356°N, 93.631°E) in eastern Nyainqentanglha, Tibet, China, which occurred on 26th June 2020. This lake underwent rapid expansion in area from 0.2 km² to 0.56 km² (1965-2020), and subsequently shrank to 0.26 km² after the GLOF. Topographic reconstruction and empirical relationships indicate that the GLOF had a volume of 10 million m³, an average breach time of 0.62 hours, and an average peak discharge of 5,390 m³/s at the dam. Pre- and post-event high-resolution satellite scenes reveal a large progressive debris landslide originating from western lateral moraine. This landslide which occurred 5-17 days before the GLOF was most likely triggered by extremely heavy, south Asian monsoon-associated rainfall in June. The time lag between the landslide and the GLOF suggests that pre-weakening of the dam due to landslide-induced outflow pushed the system towards a tipping point, that was finally exceeded following subsequent rainfall, snowmelt, a secondary landslide, or calving of ice into the lake. We back-calculate a part of the GLOF process chain, using the GIS-based open source numerical simulation tool r.avaflow, considering two scenarios: Scenario A - a debris landslide-induced impact wave with overtopping and resulting retrogressive erosion of the moraine dam; and Scenario B - retrogressive erosion due to pre-weakening of the dam without a major impact wave. Both back-calculated scenarios yield plausible results which are in line with empirically derived ranges of peak discharge and breach time. The breaching process is characterized by a slower onset and a resulting delay in
Scenario B, compared to Scenario A. Our evidence, however, points towards Scenario B. The 2020 Jinwuco GLOF caused severe destruction of infrastructure (e.g. roads and bridges) and property losses in downstream areas (no fatalities were reported).

This study corroborates the clear role of continued glacial retreat in destabilizing the adjacent lateral moraine slopes, and directly enabling the landslide to deposit into the expanding lake body. As such, the GLOF process chain can be robustly attributable to anthropogenic climate change, while downstream consequences have been driven by recent development of infrastructure on exposed flood plains. Such glacial lake related process chains could become more frequent under a warmer and wetter future climate, calling for comprehensive and forward-looking risk reduction planning. We anticipate our findings will provide critical new process understanding on GLOF triggering mechanisms and these new insights will improve GLOF hazard and risk assessment frameworks, highlighting the need to consider both complex instantaneous and gradual process chains.