How can drone imagery and dendrogeomorphology contribute to GLOF hazard assessment in remote areas? A case study from Chilean Patagonia.

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With the substantial glacier mass reduction projected by the end of the century, the formation and rise of periglacial lakes has to be expected. Even though these changes often occur in remote areas, they can nevertheless have catastrophic impacts on populations and infrastructure through processes such as glacial lake outburst floods (GLOF). GLOFs are the result of complex geomorphic changes and subject to various timescales, thus urging the need for a multidimensional approach. The present study combines two approaches to analyze natural hazards in the secluded San Rafael National Park in Chilean Patagonia (North Patagonian Icefield). The Grosse glacier outlet was chosen after interpreting satellite imagery and historical pictures showing a historical emptying of a lateral lake, which was also supported by local testimonies. Dendrogeomorphology was primarily used with an automatic detection approach to identify possible dates of occurrence of past GLOFs at the Grosse outlet. A total of 105 disturbed Nothofagus trees were sampled highlighting 6 event years between 1958 and 2011. The second method aimed at complementing the tree-ring-based findings with UAV imagery acquired during fieldwork and the mapping of geomorphic evidence of past GLOFs. Huge boulders and deposits are one of the signs recognized as remnants of past lake outbursts and were thus used to differentiate small, rainfall-induced floods from high magnitude events. More precisely, through an object-based strategy, we mapped deposits and extrapolated a theoretical flow orientation. Whereas the first method allowed to select dates of potential events, the second facilitated identification and mapping of the spatial extent of past high-energy events. Analysis of imagery also allowed detection of the occurrence of a 200-m wide breach in the frontal moraine as well as the vanishing of a lateral lake estimated to be $1.8 \times 10^6 \text{ m}^2$ in the 1950s, which we date to 1958 using tree-ring records. When used together the two approaches can represent a valuable contribution to historical records and help future assessments of natural hazard at Grosse glacier, but also in other high-mountain environments.