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Climatic and topographic controls on the development of glacial lakes and outburst floods: the insights from the Cordillera Blanca, Peru

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Research on the evolution of glacial lakes and glacial lake outburst floods (GLOFs) in glacierized mountains has attracted the attention of scientists all over the world. Despite a rapidly increasing amount of research activities, crucial questions remain unanswered with regard to spatio-temporal occurrence of GLOFs, attribution to climate change, and future risks. Here we provide a comprehensive view of 70 years of evolution (1948-2017) of the glacial lakes of the Cordillera Blanca (Peru) and test recent models of the occurrence of GLOFs in rapidly deglaciating mountains. Regional scale assessment of GLOF occurrence in the post-Little Ice Age context (lag time concept) is linked with the scale of individual lakes (limnological response time (LRT) and GLOF response time (GRT)). Building on a regional GLOF inventory, the peak frequency of GLOF events is observed from the late 1930s to early 1950s. While GLOF-producing lakes show LRTs typically <70 years, GRTs typically vary between 5 and 30 years. Differences between individual lake dam types, however, exist. GLOFs from moraine-dammed lakes were observed in earlier stages of post-LIA glacier recession (the first peak; with a lag time 60-80 years) whereas GLOFs from bedrock-dammed lakes were observed later on (lag time 125-135 years), corresponding with dominantly forming lake dam types. Based on this novel evidence we introduce a new conceptual model that suggests a possible secondary peak frequency of GLOFs from bedrock-dammed lakes yet to come, but likely with lower magnitudes.

It is further shown that disturbances such as El Niño forcing and earthquakes are able to trigger GLOFs and influence the observed frequency of GLOFs at regional scales without any causal relation to post-LIA climate warming and glacier recession (e.g., the 1970 earthquake). This leads us to the conclusion that long-term climate, glacier and lake evolution sets the preconditions for GLOFs at regional scale (e.g., the increased share of lakes in GLOF-susceptible proglacial stage), whereas specific events trigger them at the scale of individual lakes, highlighting the need for complex and multi-scale monitoring and assessment. This pattern is further complicated by the fact that several peak frequencies of GLOFs might be observed in high mountainous terrain with multiple generations of topographic overdeepenings associated with previous phases of glacial erosion.