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Climatic extreme events combine with impacts of gradual climate change: recent evidence from the Andes and the Alps

Christian Huggel (1), Claudia Giráldez (1), Wilfried Haeberli (1), Demian Schneider (1), Holger Frey (1), Yvonne Schaub (1), Alejo Cochachin (2), Cesar Portocarrero (3), Javier García (4,5), Sebastián Guillén Ludeña (5), Mario Rohrer (6), and Brian McArdell (7)

(1) University of Zurich, Dep. of Geography, Zurich, Switzerland (christian.huggel@geo.uzh.ch, +41 1 6356841), (2) Unidad de Glaciología y Recursos Hídricos, Autoridad Nacional de Agua, Huaraz, Peru, (3) Huaraz, Peru, (4) CREALP, Sion, Switzerland, (5) Ecole Polytechnique Fédérale de Lausanne, Switzerland, (6) Meteodat, Zurich, Switzerland, (7) Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland

In high-mountain areas climatic extreme events can combine with effects of gradual climate change to form cascading processes, occasionally resulting in major disasters. Heavy precipitation events thereby evolve into mass movement processes such as landslides, avalanches and debris flows that can devastate urban areas at the foot of mountains.
The transformation and interaction of processes are complex and often not sufficiently understood or difficult to predict, and thus more research is needed. Of particular concern are landslide impacts into existing or new glacier lakes from destabilized mountain flanks in relation with glacier retreat and permafrost degradation.
Here we analyze a number of recent events in the Andes of Peru and compare them with observations in the Alps in Europe. In southern Peru debris flow events that were among the largest recent ones worldwide remained largely unstudied although they destroyed entire towns and important traffic and energy infrastructure. We used a combination of field work, satellite images, satellite rainfall data and available meteorological stations as well as numerical modeling to reconstruct origin, type and effect of these events. Large sediment deposits resulting from deglaciation processes represent a key factor, and were mobilized by heavy rainfall events. Tens of millions of m3 sediment were transported downstream in single events, with compound effects on downstream river systems causing destruction and inundation.
Other recent events in Peru underline the importance of a cascade of process interaction, with ice avalanches impacting glacier lakes, triggering flood waves and debris flows that travel downstream and eventually impact urban areas.
In the Alps recent observations indicate an increase of occurrence of complex compound processes with short-term climatic events overprinting on longer-term effects of gradual climate change (e.g. from glacier retreat and permafrost degradation). Especially important are threshold effects that can tip climatic-geomorphological systems in a way that results in hazards and risks of no historical precedence. We show here methods how to analyze such events in data-scarce mountain areas, and how to numerically model process interactions to support hazard and risk assessments.