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How detectable is climate change in simulations of debris flows and sediment yield at the Illgraben?

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Climate variability and climate change impact sediment yield in Alpine basins by changing the environmental conditions for sediment production in the form of landslides, rockfalls and hillslope erosion, as well as by changing precipitation, runoff, and the sediment transporting capacity of floods and debris flows. Alpine basins are particularly sensitive to air temperature changes, with warming leading to more snowmelt, less snow cover, fewer freeze-thaw cycles, etc. As a result, robust climate change impact predictions in Alpine geomorphic systems can only be achieved if all of the environmental factors affecting sediment production and yield are considered jointly.

In this study we have combined (a) an advanced stochastic weather generator with the state-of-the-art climate change projections from the climate modelling community (CMIP5 Project) to generate ensembles of future climate time series of precipitation and air temperature, with (b) a new hillslope-channel sediment cascade model with hydrological triggering of landslides and sediment export by debris flows (Bennett et al., 2014), to (c) make probabilistic predictions of changes in sediment yield and the number and size of debris flows in a future climate in an active debris flow basin (Illgraben, Switzerland).

The results show that the highly uncertain change in precipitation simulated by GCMs in the Swiss Alps combines with a strongly seasonal and significant rise in air temperature to increase winter runoff and decrease summer runoff, and generate a 30-40% increase in median sediment yield and a slight increase in debris flow frequency in a future climate, with a seasonal signal coming mainly from temperature effects on runoff generation, snow cover dynamics, melt and freeze-thaw processes. However, internal climate variability (stochastic uncertainty) which dominates total uncertainty is responsible for a high predictive uncertainty, and the median predicted change in sediment yield is mostly contained within the natural variability under present-day conditions. Climate change in the Illgraben was shown to have two possible effects: it increases the number of hillslope landslides in a future warmer climate due to less snow cover counteracted by fewer freeze-thaw cycles which contribute to physical weathering of the slopes, and it changes the snowmelt and runoff regime which is responsible for triggering debris flows. The role of transient sediment storage in the geomorphic system is key, modulating the timing and size of debris flows, and utlimately sediment yield.

The long term persistence in sediment storage generated by the accumulation and release of sediment in intermittent bursts of activity has a consequence on the estimates of sediment yield and detectability of change from short records. The mean annual sediment yield from the Illgraben is highly uncertain when estimated from only a few years of data, and can easily lie outside the 50-150% range of the true long-term mean, and this uncertainty is irreducible even for longer sampling durations. This concerns especially inter-annual variability which is significantly biased (unedrestimated) by short sampling. The consequences of short sampling are considerable: they question the reliability of interpretations of landuse and climate change impacts based on the comparison of short and long term erosion rates and have practical implications for assessing the risk associated with sediment-driven natural hazards. Although our results and conclusions presented here pertain only to the Illgraben, the methodology is expected to be valid for most Alpine geomorphic systems where sediment production and transfer are driven by climatic forcing.

Bennett, G., Molnar, P., McArdell, B.W., and Burlando, P., 2014. A probabilistic sediment cascade model of sediment transfer in the Illgraben, Water Resour. Res., 50, doi:10.1002/2013WR013806.