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Using seismic arrays to quantify the physics of a glacial outburst flood and its legacy on upland river dynamics

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In the Himalayas fluvial erosion is thought to be controlled by the intense annual Indian Summer Monsoon precipitation. However, this region is also exposed to catastrophic floods generated by the sudden failure of landslides or moraine dams. These floods are rare and particularly devastating. Thus they have a strong impact on rivers and adjacent hillslopes, and they represent a hazard for local populations. Due to the difficulties to observe these floods and quantify their physics using traditional methods, their importance for the long-term evolution of Himalayan Rivers remains largely unknown, and no consistent early warning system exists to anticipate these events, especially in trans-boundary regions.

Here we show that seismic arrays can be used to (i) reliably anticipate outburst floods and to (ii) quantify multiple and key fluvial processes associated with their propagation and their lasting impacts on upland river dynamics. We report unique seismic observations of a glacial lake outburst flood event that occurred the 5th of July 2016 in the Bhote Koshi River (Central Nepal). Precursory seismic signals are identified from the onset of the lake drainage event such that an early warning alarm may be turned on about an hour before the outburst flood wave reaches areas with an exposed population. Using our network of stations we observe for the first time that the outburst flood wave is in fact made of two distinct waves, namely a water flow wave and a bedload sediment wave. As expected these two waves travel at different speeds. We find that the ratio between the two wave speeds matches with that previously found at much smaller scales in flume laboratory experiments. Based on the physical modelling of both water-flow- and bedload- induced seismic noise we provide estimates of flow depth and bedload transport characteristics (flux, moving grains sizes) prior, during and after the flood. In particular we show that bedload sediment flux is enhanced by up to a factor 30 right after the flood before it goes back to normal about 2 weeks later. This behavior is not only observed for bedload using seismic observations but also for the suspended load from direct sampling measurements. We suggest that this enhanced sediment transport phenomenon reflects the profound and lasting impact of the outburst flood event on the destabilization of river beds and banks. We estimate that the total bedload sediment mass evacuated only due to the destabilization of the river bed and banks by the floods is of similar order of magnitude or larger than that due to the entire monsoon precipitation. Thus the outburst flood definitely has an impact on sediment budget that is at least as large as that due to the Indian Summer Monsoon. This finding underlines the necessity to explicitly account for outburst floods and their impacts on landscapes in landscape evolution models.