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Dynamic interactions between glacier and glacial lake in the Bhutan Himalaya

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A number of supraglacial lakes formed on the termini of debris-covered glaciers in the Bhutan Himalaya as a result of glacier retreat due to climate change. The terminal part of the lake-terminating glaciers flow faster than that of the land-terminating glaciers because the basal ice motion is enhanced by high subglacial water pressure generated by lake water. Increased ice flux caused by the accelerated glacier flow could be dissipated through the calving process which reduced the glacier thickness. It is important to understand the interaction between lake formation and glacier dynamics. Although glacier flow velocity has been measured by remote-sensing analysis in several regions of the Himalayas, glacier thinning rates have not been observed by neither in-situ nor remote-sensing approaches. The lack of field data raises limitation to interpretations for glacier dynamics. We investigate the influence of the presence/absence of glacial lakes on glacier dynamics and changes in surface elevation.

We study two debris-covered glaciers in the Lunana region, the Bhutan Himalaya. Thorthormi Glacier is a land-terminating glacier with some supraglacial lakes while Lugge Glacier is a lake-terminating glaciers. We surveyed the surface elevation of debris-covered areas of the two glaciers in 2004 and 2011 by a differential GPS.

Change in surface elevation of the lake-terminating Lugge Glacier (-5.4–-2.4 m yr^{-1}) was much more negative than that of the land-terminating Thorthormi Glacier (-3.3–0.6 m yr^{-1}). Surface flow speed of the Thorthormi Glacier measured during 2002–2004 was faster in the upper reaches ($\sim$90 m yr^{-1}) and reduced toward the downstream (40 m yr^{-1}). In contrast, the surface flow speed at the Lugge Glacier measured in the same periods was 40–55 m yr^{-1} and the greatest at the lower most part.

Observed spatial distribution of surface flow velocity at both glaciers were evaluated by a two-dimensional numerical flow model. Calculated emergence velocities are 1.9–18.8 m yr^{-1} at the Thorthormi Glacier while -12.0–2.7 m yr^{-1} at the Lugge Glacier. This result suggests that decreasing in flow velocity towards the terminus in the Thorthormi Glacier causes compressive flow. It suggests that the compressive flow of the Thorthormi Glacier counterbalanced surface melting, resulting in inhibition of the surface lowering. In contrast, the extensional flow of the Lugge Glacier accelerated the surface lowering. Speed up of glacier terminus induced extensional flow regime causes the thinning of ice and increase in basal motion, which will lead to further flow acceleration. Such positive feedbacks have been found over the ice streams in the polar ice sheets. In this study we showed the observational evidences, in which the similar feedbacks make contrast the terminus behaviors of glaciers in the Bhutan Himalaya. If the supraglacial lake on Thorthormi Glacier expanded, the surface lowering may be accelerated in the future.