Geophysical Research Abstracts,
Vol. 10, EGU2008-A-01898, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-01898
EGU General Assembly 2008

Englacial and supraglacial hydrology of Himalayan glaciers, and their role in GLOF hazard evolution

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Climatic warming in recent decades has resulted in increased temporary storage of water in Himalayan glaciers, and associated risk of glacier lake outburst floods (GLOFs). For the last decade, we have conducted detailed studies of glaciers in the Everest region of Nepal, focusing on patterns of surface elevation change, processes of lake evolution, and direct exploration of englacial conduits using speleological techniques. This work allows GLOF hazards to be understood as outcomes of a cascade of processes resulting from an initial climatic trigger.

During periods of climatic warming, debris cover profoundly affects patterns of downwasting, lowering the glacier surface gradient and reducing the efficiency of drainage systems. On Himalayan glaciers, terminal moraines form effectively impermeable barriers to water flow, so that the lowest points on their crests act as base level for the entire drainage system of the glacier. Supraglacial lakes forming at this elevation (*base-level lakes)* will not drain unless base level is lowered by erosion or failure of the moraine dam, and thus have the potential to evolve into large, potentially hazardous lakes. *Perched lakes* form on glacier surfaces above base level, and are intrinsically ephemeral. They can exist only insofar as they are floored by impermeable glacier ice, and are prone to partial or complete drainage if breakthrough is made via an englacial conduit. Analysis of Aster imagery shows that such lakes generally persist for 3 – 5 years before drainage occurs.

Melting and calving processes around lake margins are very rapid, with ablation rates 3-4 orders of magnitude greater than those for debris-covered ice. Thus, ice wastage rates are largely controlled by the spatial and temporal frequency of perched lakes, which eat away at the glacier surface, progressively reducing its elevation. When the downwasting surface reaches the level of the terminal moraine, growth of base level lakes can continue unchecked until the moraine dam is incised or fails.

The inception and drainage of perched lakes are both strongly influenced by subsurface processes. Collapses of englacial conduits cause surface subsidence, exposing bare ice and providing nuclei for new lakes, while the formation of new conduits or the enlargement of old ones can trigger lake drainage, switching off rapid ablation processes around the lake periphery. Englacial conduits form by three distinct mechanisms: (1) incision and closure of surface streams; (2) exploitation of permeable debris layers by water forced along high hydraulic gradients; and (3) hydrologically-driven fracturing of stressed ice. By locally elevating hydraulic head, supraglacial lakes encourage mechanisms (2) and (3) and hence actively promote their own destruction. The mass balance, hydrology and GLOF potential of Himalayan glaciers thus form an intimately linked system, which exhibits strongly non-linear threshold behaviour.