Geophysical Research Abstracts
Vol. 17, EGU2015-24-2, 2015
EGU General Assembly 2015

The impact of supraglacial debris on the mass balance and dynamics of Khumbu Glacier, Nepalese Himalaya

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Rapid changes in glacier volumes and dynamics have been observed in the monsoon-influenced Himalaya over recent decades, with marked consequences for the hydrological budgets and glacial hazard potential of catchments such as the Dudh Kosi, a tributary of the Ganges River. For many large glaciers such as Khumbu Glacier in eastern Nepal, supraglacial rock debris modifies the thermal properties of the ice surface and mass balance variations in response to climatic change. Ice flow dynamics vary dramatically with supraglacial debris thickness—the debris-covered section of Khumbu Glacier appears stagnant, while the clean-ice section reaches velocities exceeding 50 m per year—resulting in spatial variation in the drivers of mass transfer and loss. However, the relative importance of supraglacial debris in modifying mass balance compared to external forcing by the summer monsoon is poorly understood, and as a result quantifying the sensitivity of this glacier to climatic change is challenging.

To calculate ablation across the glacier we need to incorporate the thermal properties of the debris layer and how these vary with altitude and time into a mass balance calculation. We made field observations describing debris thickness and sub-debris melt rates on Khumbu Glacier. At four different sites, we measured vertical temperature profiles through the supraglacial debris and at the ice surface, debris thickness, and 1 m air temperature through the summer monsoon, and calculated ablation rates following the method of Nicholson and Benn (2006, J. Glacio.). These data were used with local meteorological data to calculate the spatial and temporal variability in the surface energy balance of Khumbu Glacier. To investigate the sensitivity of Khumbu Glacier to climatic change, we developed a numerical model of this glacier from our field data. Our higher-order flow model (Egholm et al., 2011; JGR) reproduces accurately the variations in ice velocity observed using feature tracking, which range from less than 10 m per year on debris-covered sections to over 60 m per year on the clean ice immediately below the icefall. This approach of combining field data with numerical modelling will allow us to explore the changes in ice volume resulting from realistic variations in climate, and make predictions of the future variations in ice volume and hydrological budget.