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Geomorphology of ice stream beds: recent progress and future challenges

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Ice sheets lose mass primarily by melting and discharge via rapidly-flowing ice streams. Surface and basal melting (e.g. of ice shelves) are closely linked to atmospheric and oceanic conditions, but the mechanisms that drive changes in ice stream discharge are more complex; and are influenced by conditions at their bed which can sustain, enhance or inhibit their motion. Although explicit comparisons are rare, the ice-bed interface is similar to the 'boundary layer' in fluvial and aeolian environments, where shear stresses (both basal and lateral in the case of ice streams) oppose the flow of the overlying medium. The analogy extends further because processes within the boundary layer create a distinctive geomorphology (and roughness) that is characterised by subglacial bedforms that resemble features in fluvial and aeolian environments. Their creation results from erosion, transport and deposition of sediment which is poorly constrained, but which is intimately linked to the mechanisms through which ice streams are able to flow rapidly. The study of ice stream geomorphology is, therefore, critical to our understanding of their dynamics. Despite difficulty in observing the subglacial environment of active ice streams, our understanding of their geomorphology has grown rapidly in the last three decades, from almost complete ignorance to a detailed knowledge of their geomorphological products. This has been brought about by two main approaches: (i) geophysical investigation of modern (active) ice streams, and (ii) sedimentological and geomorphological investigation of palaeo-ice stream beds. The aim of this paper is to review progress in these two areas, highlight the key questions that remain, and discuss the opportunities that are likely to arise that will enable them to be addressed. It is clear that whilst these two main approaches have led to important advances, they have often been viewed as separate sub-disciplines, with minimal cross-pollination of ideas and concepts, particularly with respect to how landforms can be securely linked to subglacial processes and ice dynamics. However, recent developments in numerical modelling of the subglacial environment are beginning to offer new opportunities to tackle this issue and observations from both modern and palaeo-ice streams will be critical to constrain and validate such modelling.