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Using the glacial geomorphology of palaeo-ice streams to understand mechanisms of ice sheet collapse

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Processes which bring about ice sheet deglaciation are critical to our understanding of glacial-interglacial cycles and ice sheet sensitivity to climate change. The precise mechanisms of deglaciation are also relevant to our understanding of modern-day ice sheet stability and concerns over global sea level rise. Mass loss from ice sheets can be broadly partitioned between melting and a 'dynamic' component whereby rapidly-flowing ice streams/outlet glaciers transfer ice from the interior to the oceans. Surface and basal melting (e.g. of ice shelves) are closely linked to atmospheric and oceanic conditions, but the mechanisms that drive dynamic changes in ice stream discharge are more complex, which generates much larger uncertainties about their future contribution to ice sheet mass loss and sea level rise. A major problem is that observations of modern-day ice streams typically span just a few decades and, at the ice-sheet scale, it is unclear how the entire drainage network of ice streams evolves during deglaciation. A key question is whether ice streams might increase and sustain rates of mass loss over centuries or millennia, beyond those expected for a given ocean-climate forcing. To address this issue, numerous workers have sought to understand ice stream dynamics over longer time-scales using their glacial geomorphology in the palaeo-record. Indeed, 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. Building on this body of work, this paper uses the glacial geomorphology of 117 ice streams in the North American Laurentide Ice Sheet to reconstruct their activity during its deglaciation (∼22,000 to ∼7,000 years ago). Ice stream activity was characterised by high variability in both time and space, with ice streams switching on and off in different locations. During deglaciation, we find that their overall number decreased, they occupied a progressively smaller percentage of the ice sheet perimeter, and their total discharge decreased. Underlying geology and topography clearly influenced ice stream activity, but - at the ice sheet scale - their drainage network adjusted and was strongly linked to changes in ice sheet volume. It is unclear whether these findings are directly translatable to modern ice sheets but, contrary to the view that sees ice streams as unstable entities that can draw-down large sectors of an ice sheet and accelerate its demise, we conclude that they reduced in effectiveness during deglaciation of the Laurentide Ice Sheet, with final deglaciation accomplished most effectively by surface melting. This raises some interesting questions about the source and nature of major meltwater pulses and iceberg discharge events in the sea-level record.