Glacial moulin formation triggered by rapid lake drainage

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A moulin on the surface of the Greenland Ice Sheet. Moulins are well-like shafts within a glacier or ice sheet through which water travels from the surface to the glacier bed. New research elucidates how moulins form. Credit: Halorache

Scientists are uncovering the mystery of how, where and when important glacial features called moulins form on the Greenland Ice Sheet. Moulins, vertical conduits that penetrate through the half-mile-deep ice, efficiently funnel the majority of summer meltwater from the ice surface to the base of the ice sheet. The lubricating effects of the draining water can lead to faster sliding of the ice sheet. A new study published in *Geophysical Research Letters*, a journal of the American Geophysical Union, finds meltwater lakes that form on the ice surface can drain through moulins in a matter of hours.

"Forming a moulin in Greenland requires a crack on the ice surface, which becomes filled with water that eventually drives the crack through the ice," said Matthew Hoffman, a glaciologist and computer scientist at Los Alamos National Laboratory in Los Alamos, New Mexico and lead author of the new study. "But there's a mystery here: A large fraction of the moulins in Greenland form some distance away from the ice sheet's existing crevasse fields."

In the new study, Hoffman and colleagues compared satellite-image maps of moulins with computer simulations driven by hourly, on-site ice velocity measurements from GPS stations. They found meltwater lakes that form on the ice sheet surface and can catastrophically drain through the ice in a matter of hours.

"The massive ice flow speedup caused by all this water reaching the bed literally pulls the ice at the surface apart over a wide area, temporarily creating pervasive cracks, which seed new moulins where these cracks intersect meltwater flowing on the surface," Hoffman said.

"While these catastrophic lake drainages have been known about for a decade or so, their broader impacts on the ice sheet appeared restricted to a couple of days of localized, faster motion," said Stephen Price, a researcher at Los Alamos and co-author of the new study.

The new results indicate a potentially much broader importance for lake drainage events, because moulins control the locations where the majority of seasonal meltwater enters the ice sheet, accesses the bed, and accelerates the ice flow, according to Price. "These processes, which aren't currently accounted for in computer simulations of ice sheet evolution and sea-level change, may need to be considered more carefully in future models," he said.

This project is the first effort to assimilate hourly scale resolution GPS observations into an inverse ice dynamical modeling framework, according to the researchers. With hourly estimates of the basal conditions of the ice sheet and stresses within the ice, the research reveals important details of the impact of summer meltwater-induced speedup on ice sheet motion.

Lake drainage has a long-lived legacy

The lake drainage events themselves are actually relatively infrequent (at most once per year per lake), but the authors point out that the ability of moulins formed during lake drainage events to persist for multiple years once formed gives each summer drainage event a long-lived legacy. Moulin density and its impact on where and how much water is delivered to the bed are a critical control on subglacial drainage efficiency, evolution and, in turn, the flow of the ice itself.

By triggering moulin formation of moulins, the impact of lake drainage on ice dynamics and Greenland's summer speedup is likely to be more extensive than the direct and short-lived speedup following the drainage itself, according to the authors.

While one might think moulins would form primarily near crevasse fields, where vulnerable cracks provide an easy path for moulin formation, this is not the whole story, Hoffman said. Lakes generally form in uncrevassed regions, and a catastrophic lake drainage event appears capable of triggering new moulin formation—and in some cases additional lake drainages—up to many kilometers away in ice that is otherwise unyielding.

While previous studies identified a distinct possibility of a cascading effect from meltwater reaching the bed and modifying local stresses to cause nearby supraglacial lake drainage, the new results provide direct evidence that this effect is more widespread and can act over distances of many kilometers, Hoffman said. This long-distance triggering mechanism could make new regions of the ice sheet vulnerable to meltwater-induced speedup, including at higher elevations.

More information: Matthew J. Hoffman et al. Widespread Moulin Formation During Supraglacial Lake Drainages in Greenland, *Geophysical Research Letters* (2018). DOI: 10.1002/2017GL075659

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