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Cold basal conditions during surges control flow of fringing Arctic ice caps in Greenland

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Fringing ice caps separated from larger ice sheets are rarely studied, yet they are an important part of earth's cryosphere, which has become the largest source of global sea-level rise. Understanding marginal ice caps is crucial for being able to predict sea-level change as they are responsible for up to 20% of Greenland's mass loss for 2003-2008. Studies of fringing ice caps can furthermore provide useful insights into processes operating on glaciers that surge. Surging has been the focus of much recent glaciological work, especially with reference to thermal evolution of polythermal glaciers in High Mountain Asia and the High Arctic. This has shown that the classic divide between hydrologically-controlled surges ('hard-bed') in Alaska and thermally-regulated ('soft-bed') surges elsewhere is less stark than previously assumed. Studying marginal ice caps can therefore be valuable in several ways.

The largest fringing ice cap in Greenland is Flade Isblink. Previous work has established that this ice cap is showing a range of dynamic behaviour, including subglacial lake drainage and varied patterns of mass-balance change. In particular, a substantial surge, assumed to be caused by a version of the thermally-regulated mechanism, occurred between 1996 and 2000, making the ice cap a useful case study for investigating this process.

Here we investigate the surge on Flade Isblink using the open-source, Full-Stokes model Elmer/Ice to invert for basal conditions and englacial temperatures using the adjoint method. We specifically study steady-state conditions representative of the active surge phase in 2000, and the subsequent quiescent phase, using patterns of surface velocity observed in 2000, 2005, 2008 and 2015. Under constant geometry, temperature and geothermal heat, it is shown that surging increases basal freezing rates by over 60% across an area that is twice as large as the area over which the bed freezes in the quiescent phase. The process responsible for this is the conductive heat loss, which increases faster than frictional heat is produced. When the bed becomes weaker, basal conditions become colder despite faster basal sliding, resulting in steep basal ice temperature gradients, which transfer heat effectively from the bed into the ice. In contrast, we find the increase in frictional heat to be insufficient, because weaker basal conditions offset the effect of faster basal sliding. Hence, frictional heat cannot provide enough extra melting to maintain surge conditions. We hypothesise that this heat transfer mechanism terminates surges on Flade Isblink, irrespective of any thinning that would also occur. The latter is not included in our model, but is required in the classic soft-bed surge model. In the quiescent phase, lower temperature gradients reduce the conductive heat loss, while a stronger bed produces more frictional heat, favouring basal melting and a warm bed, which ultimately create the weak basal conditions that result in yet another surge, regardless of any change in ice thickness. Our results indicate that soft-bed surges may occur even if the surge-related change in glacier geometry is modest, making surging glaciers of this type similar to ice streams that stagnate and reactivate periodically.