Spatial Extent and Dynamic Impact of Channelised Basal Drainage beneath the Greenland Ice Sheet

Kuba Oniszk[1], Poul Christoffersen[1,2] and Stephen Brough[3]
[1]*Scott Polar Research Institute, University of Cambridge*
[2]*University of Tasmania*
[3]*University of Liverpool*

The Greenland Ice Sheet, as a result of the fossil-fuelled anthropogenic warming, has been undergoing a significant acceleration in ice-mass loss over the recent decades (Bamber et al., 2018). The annual sea-level contribution is currently close to 1 mm and forecast to continue in the next century unless serious climate mitigation strategies are implemented (Otosaka et al., 2023; Aschwanden et al., 2019). The detrimental change to Greenland land ice is thought to progress, in a significant part, through the hydro-dynamic effects of elevated summer ablation (Karlsson et al., 2021). As surface meltwater migrates into the ice-sheet bed via moulins and crevasses, basal lubrication is promoted, inducing a seasonal ice-flow acceleration (Nienow et al., 2017). Continued supply of liquid-water runoff may eventually lead to the development of a channelised hydrological system, allowing for efficient drainage which induces a pronounced late-summer slowdown (Schoof, 2010). This negative feedback between the increasing supply of surface-produced melt and ice flow has been hypothesised to be a long-term self-regulation mechanism of the ice sheet (van de Wal et al., 2015). Consequently, the effect of subglacial hydrology has been largely disregarded in future ice-mass-loss predictions (Davison et al., 2019; Maier et al., 2022). This study investigates whether that assumption is correct by conducting the first-ever large-scale mapping exercise aimed at identifying the inland extents of the efficient subglacial drainage networks at 56 major outlet glaciers in western Greenland during the 2018-2020 period.

For that purpose, over 2300 feature-tracked surface-velocity timeseries based on the ITS_LIVE MEaSUREs project (Lei et al., 2021; Gardner et al., 2023) are generated and analysed, supplemented by the statistical investigation on the likely controls on, and limits to, channel formation. The results demonstrate that melt forcing exerts a substantial influence on the seasonal evolution of basal drainage, explaining the north-south geographical disparity in channel distribution, but factors other than runoff also control the observed variability in hydrodynamics. In particular, this study associates the subdued melt-driven response of land-terminating glaciers with less efficient subglacial systems in comparison to marine-terminating glaciers which, contrary to expectations, display stronger seasonal variability. This finding is explained by marine-terminating glaciers developing a hydrologically well-connected system of relatively large cavities owing to their faster rate of sliding. In contrast, land-terminating glaciers support relatively smaller and therefore more isolated cavities, with the result channels there are less well connected with their surroundings. In addition, glacier hypsometry is found to provide physical constraints to the up-sheet expansion of subglacial channels through three critical thresholds related to surface slope, gradient in hydraulic potential and ice thickness. In that regard, the study suggests that the degree to which subglacial channels can mitigate the ice-sheet dynamical response to climate change has probably been overestimated, thus pointing to a potential and hitherto overlooked ice-sheet instability in southern Greenland.

References

Aschwanden, A., Fahnestock, M. A., Truffer, M., Brinkerhoff, D. J., Hock, R., Khroulev, C., Mottram, R. and Khan, S. A. (2019) ‘Contribution of the Greenland Ice Sheet to Sea Level Over the Next Millennium’, in Science Advances, 5 (6). DOI: 10.1126/sciadv.aav9396.

Bamber, J. L., Westaway, R. M., Marzeion, B., and Wouters, B. (2018) ‘The Land Ice Contribution to Sea Level During the Satellite Era’, in Environmental Research Letters, 13 (6), 063008. DOI: 10.1088/1748-9326/aac2f0.

Davison, B. J., Sole, A. J., Livingstone, S. J., Cowton, T. R. and Nienow, P. W. (2019) ‘The Influence of Hydrology on the Dynamics of Land-Terminating Sectors of the Greenland Ice Sheet’, in Frontiers in Earth Science, 7 (10). DOI: 10.3389/feart.2019.00010.

Gardner, A. S., Fahnestock, M. A. and Scambos, T. A. (2023) Velocity Data Generated Using auto-RIFT and Provided by the NASA MEaSUREs ITS_LIVE Project. URL: https://itslive-dashboard.labs.nsidc.org.

Karlsson, N. B., Solgaard, A. M., Mankoff, K. D., Gillet-Chaulet, F., McGregor, J. A., Box, J. E., Citterio, M., Colgan, W. T., Larsem S. H., Kjeldsen, K. K., Korsgaard, N. J., Benn, D. I., Hewitt, I. J. and Fausto, R. S. (2021) ‘A First Constraint on Basal Melt-water Production of the Greenland Ice Sheet’, in Nature Communications, 12, 3461. DOI: 10.1038/s41467-021-23739-z.

Lei, Y., Gardner, A. S. and Agram, P. (2021) ‘Autonomous Repeat Image Feature Tracking (autoRIFT) and Its Application for Tracking Ice Displacement’, in Remote Sensing, 13 (4), 749. DOI: 10.3390/rs13040749.
Maier, N., Gimbert, F., & Gillet-Chaulet, F. (2022) ‘Threshold Response to Melt Drives Large-scale Bed Weakening in Greenland’, in Nature, 607 (7920), pp. 714–720. DOI: 10.1038/s41586-022-04927-3.
Nienow, P. W., Sole, A. J., Slater, D. A. and Cowton, T. R. (2017) ‘Recent Advances in Our Understanding of the Role of Meltwater in the Greenland Ice Sheet System’, in Current Climate Change Reports, 3, pp. 330-344. DOI: 10.1007/s40641-017-0083-9.
Otosaka, I. N., Shepherd, A., Ivins, E. R., Schlegel, N.-J., Amory, C., van den Broeke, M. R., Horwath, M., Joughin, I., King, M. D., Krinner, G., Nowicki, S., Payne, A. J., Rignot, E., Scambos, T., Simon, K. M., Smith, B. E., Sørensen, L. S., Velicogna, I., Whitehouse, P. L., A, G., Agosta, C., Ahlstrøm, A. P., Blazquez, A., Colgan, W., Engdahl, M. E., Fettweis, X., Forsberg, R., Gallée, H., Gardner, A., Gilbert, L., Gourmelen, N., Groh, A., Gunter, B. C., Harig, C., Helm, V., Khan, S. A., Kittel, C., Konrad, H., Langen, P. L., Lecavalier, B. S., Liang, C.-C., Loomis, B. D., McMillan, M., Melini, D., Mernild, S. H., Mottram, R., Mouginot, J., Nilsson, J., Noël, B. P. Y., Pattle, M. E., Peltier, W. R., Pie, N., Roca, M., Sasgen, I., Save, H. V., Seo, K.-W., Scheuchl, B., Schrama, E. J. O., Schröder, L., Simonsen, S. B., Slater, T., Spada, G., Sutterley, T. C., Vishwakarma, B. D., van Wessem, J. M., Wiese, D., van de Wal, W. and Wouters, B. (2023) ‘Mass Balance of the Greenland and Antarctic Ice Sheets from 1992 to 2020’, in Earth System Science Data, 15, pp. 1597–1616. DOI: 10.5194/essd-15-1597-2023.Schoof, C. (2010) ‘Ice-sheet Acceleration Driven by Melt Supply Variability’, in Nature, 468, pp. 803-806. DOI: 10.1038/nature09618.
van de Wal, R. S. W., Smeets, C. J. P. P., Boot, W., Stoffelen, M., van Kampen, R., Doyle, S. H., Wilhelms, F., van den Broeke, M. R., Reijmer, C. H., Oerlemans, J. and Hubbard, A. (2015) ‘Self-regulation of Ice Flow Varies across the Ablation Area in South-west Greenland’, in The Cryosphere, 9, pp. 603-611. DOI: 10.5194/tc-9-603-2015.