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Increased glacier runoff enhances the penetration of warm Atlantic Water into a large Greenland fjord

Andrew Sole (1), Anthony Payne (2), Peter Nienow (3), Poul Christoffersen (4), Finlo Cottier (5), and Mark Inall (5)

(1) Department of Geography, University of Sheffield, Sheffield, UK (a.sole@sheffield.ac.uk), (2) Bristol Glaciology Centre, University of Bristol, Bristol, UK (A.J.Payne@bristol.ac.uk), (3) School of Geosciences, University of Edinburgh, Edinburgh, UK (peter.nienow@ed.ac.uk), (4) Scott Polar Research Institute, University of Cambridge, Cambridge, UK (pc350@cam.ac.uk), (5) Scottish Association for Marine Science, Scottish Marine Institute, Oban, UK (finlo.cottier@sams.ac.uk, mark.inall@sams.ac.uk)

The retreat and acceleration of Greenland's marine-terminating outlet glaciers have been linked to ocean warming. However the mechanisms which control the transmission of this warming along fjords towards the glacier termini remain poorly understood. Here we aim to elucidate observed changes in water properties in Kangerdlugssuaq Fjord (KF), east Greenland, between 1993 and 2004 using the Bergen Ocean Model (BOM). Model outputs are compared with observed potential temperature, salinity and velocity data to determine the principal controls on heat transport within KF. The BOM includes wind, tidal and glacier runoff forcing and is able to replicate observed temperature and salinity profiles. Model results describe a robust four-layer estuarine flow, consisting of two distinct circulations. The shallow circulation (0 - $\sim$60 m) is forced by surface wind stress and to a lesser extent supraglacial runoff, while the intermediate circulation ($\sim$60 - 500 m) is driven by runoff discharged into the fjord subglacially. AtlanticWater (AW) and warm Polar Surface Water (PSWw) are drawn into the fjord by the intermediate and shallow circulation cells respectively, in a pattern consistent with observations, and AW reaches Kangerdlugssuaq Glacier (at the fjord head) over a single summer. Along-fjord heat transport towards KG increases significantly with both glacier runoff and coastal water temperature. A doubling of glacier runoff produces a 29 % (48 %) amplification of mean annual (summer) heat transport towards the KG terminus. Our model shows, in agreement with observations, that maximum submarine melt rates occur when AW and PSWw are present at the fjord mouth and, crucially, glacier runoff is also high. Rising ice sheet runoff therefore increases the sensitivity of KG (and other Greenland marine-terminating glaciers) to ocean warming.