Supporting Information for

Controls on the transport of oceanic heat to Kangerdlugssuaq Glacier, east Greenland

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Sensitivity to model parameters

In this section, we test the sensitivity of our findings to key model parameters. We find that our results (with respect to Q_{up} and T_E) are insensitive to the choice of vertical viscosity, A_z, and diffusivity, K_z, with an order of magnitude increase or decrease in these parameters resulting in a < 5 % change in Q_{up}, V_{total} or T_E (Table S1). We therefore focus this sensitivity analysis on the horizontal viscosities, as controlled by the Smagorinsky coefficient, C_s. Appropriate values of C_s may lie in the range 0.1-4 (Griffies and Hallberg, 2000). For the experiments described in the main paper, we use C_s = 2.2, which gives a good agreement to observed velocities in KF and SF whilst maintaining numerical stability. Here we test the implications of this selection by running experiments using C_s values from 0.4 (below which results suffer from excessive numerical noise) to 4.0. We conduct these tests mainly on two reference scenarios: for intermediary circulation, we use the standard shelf forcing with p = 10 days, while for the buoyancy-driven circulation, we use on the summer runoff forcing.

The results of these experiments are shown in Figures S1 and S2. Increasing C_s increases the viscosity and hence results in a less vigorous circulation. For the intermediary circulation reference scenario, this results in a decrease in V_{total} and increase in T_E as C_s is increased (Figure S1a-b). For the minimum C_s value (0.4) V_{total} is 17 % higher, and T_E is 23 % shorter, relative to using C_s = 2.2 (Table S1). For the buoyancy-driven circulation reference scenario, we also observe a decrease in Q_{up} as C_s is increased (Figure S1a), with Q_{up} 42 % greater for the lowest viscosity scenario (C_s = 0.4) compared to the values presented in the main paper (Table S1). Nevertheless, the form of the relationship between runoff and volume transport remains very similar to that shown in Figure 9, with $Q_{up} = 2447 \times Q_r^{0.45}$ (Figure S2b). The relationship between C_s and T_E for the buoyancy-driven circulation scenario is somewhat more complex, with an increase in C_s decreasing flow speeds but increasing the rate of mixing within the fjord. At lower viscosities, T_E increases with C_s at a rate similar to that observed for the intermediary circulation reference scenario, but this sensitivity decreases in the upper part of the C_s range, with little change in T_E for values of C_s greater than ~1.6 (Figure S1b).

There are two main conclusions from this sensitivity analysis. Firstly, the absolute values of Q_{up} and T_E vary depending on the choice of C_s. The minimum value of C_s = 0.4 results in an increase in Q_{up} of 17 % (42 %) and decrease in T_E of 23 % (34 %) for the intermediary (buoyancy-driven) circulation reference scenarios relative to the value of C_s = 2.2 as used in the main experiments (Table S1; Figure S1a,b). Without a better observational record, it is not possible to further tune this parameter to optimise the agreement between model output and observations and thus to reduce the uncertainties in Q_{up} and T_E. The second conclusion is that, despite these uncertainties, the key findings of the paper remain robust to the selection of C_s. The volume transport associated with the intermediary circulation scales with Δh_i (Section 5.1), while for the buoyancy-driven circulation it remains proportional to runoff to the power of ~1/2 (Section 5.2), even at the minimum value of C_s. For values of C_s between ~1.0-1.6, T_E is ~ 10 % lower for the intermediary circulation reference scenario than for the buoyancy-driven circulation reference scenario (Figure S1b); more importantly however with respect to the conclusions of the paper, the transport of shelf water to the fjord head (Figure S1c) remains far more rapid for the buoyancy-driven circulation reference scenario compared to the intermediary-circulation reference scenario for all values of C_s, supporting our conclusion that the buoyancy-driven circulation plays a key role in transporting oceanic heat towards Kangerdlugssuaq Glacier during the melt season.

References

Griffies, S. M., and R. W. Hallberg, 2000, Biharmonic friction with a Smagorinsky-like viscosity for use in large-scale eddy-permitting ocean models: Monthly Weather Review, v. 128, p. 2935-2946.

Figures

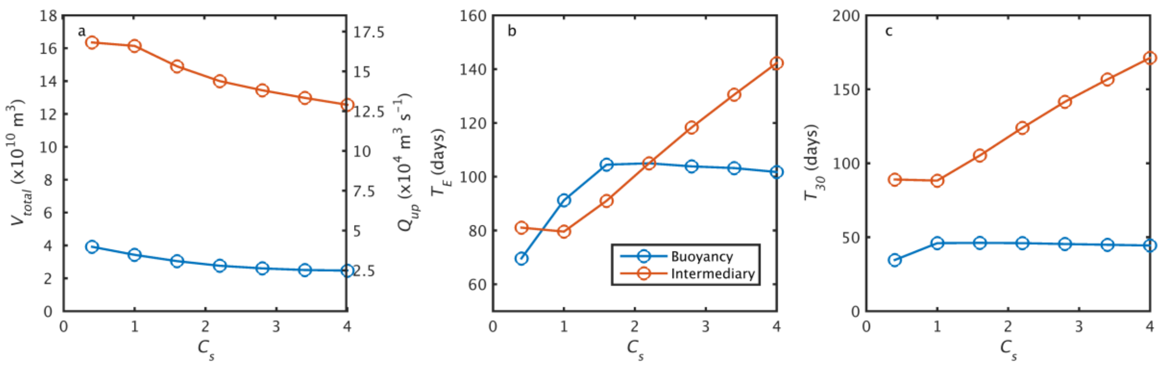

Figure S1. Sensitivity of key model outputs with respect to C_s, for the intermediary circulation reference scenario (standard shelf forcing with p = 10 days, red) and buoyancy-driven circulation reference scenario (summer runoff forcing, blue). (a) Up-fjord volume transport across the fjord mouth, expressed as V_{total} for the intermediary circulation and Q_{up} for the buoyancy-driven circulation. The two vertical axes are aligned such that for a given V_{total} (m^3) over a 10 day forcing cycle, the equivalent mean Q_{up} (m^3 s^{-1}) can be read off the right hand axis. (b) Turnover time for the whole fjord. (c) Turnover time for the 13 km of the fjord closest to Kangerdlugssuaq Glacier (note that this turnover time, T_{30}, is defined as the time taken for 30 % of the volume of this section of the fjord to be replaced by shelf waters, as in some experiments shelf water concentration in this zone did not reach the 63 % required for T_E within the 300 day run time).

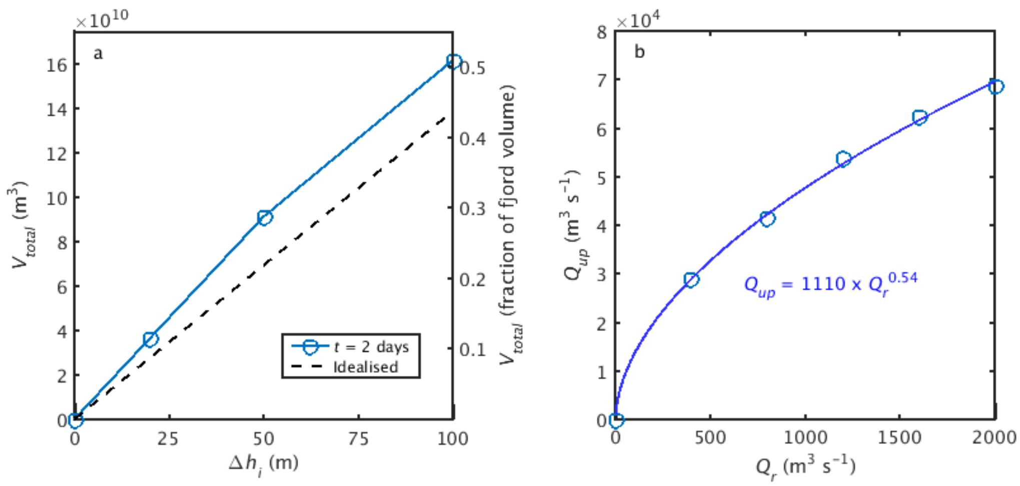

Figure S2. (a) Volume of water exchanged between the shelf and fjord during intermediary circulation scenarios with C_s = 0.4 (over a 10 day window), shown as a function of Δh_i and *t* (i.e. as for Figure 6a, except with C_s = 0.4). The dashed 'idealised' line shows $2\Delta h_i\ A$ (Section 4.1). (b) Up-fjord volume transport across the fjord mouth with C_s = 0.4 as a function of runoff input (i.e. as for Figure 6b, except with C_s = 0.4).

Circulation scenario	**Parameter(s)**	**Default**	**Low**	**High**	**Output**	**Change in output relative to default (%)**	
						Low	**High**
Intermediary	A_z, K_z	1.0x10^{-5} m^2 s^{-1}	1.0x10^{-6} m^2 s^{-1}	1.0x10^{-4} m^2 s^{-1}	V_{total}	+ 0.1	-0.4
					T_E	+ 0.4	-2.2
Intermediary	C_s	2.2	0.4	4.0	V_{total}	+ 16.8	-10.3
					T_E	- 22.8	+35.5
Buoyancy-driven	A_z, K_z	1.0x10^{-5} m^2 s^{-1}	1.0x10^{-6} m^2 s^{-1}	1.0x10^{-4} m^2 s^{-1}	Q_{up}	+ 1.1	-3.3
					T_E	- 0.3	-3.5
Buoyancy-driven	C_s	2.2	0.4	4.0	Q_{up}	+ 41.7	-10.7
					T_E	- 33.7	-3.1

Table S1. Sensitivity to key model parameters: vertical Laplacian diffusivity A_z, vertical eddy viscosity K_z, and the Smagorinsky coefficient (C_s) used in the parameterisation of horizontal viscosity. Sensitivity experiments were undertaken for intermediary circulation and buoyancy-driven circulation reference scenarios. For each parameter, the change in up-fjord volume transport at the fjord mouth (Q_{up}) and turnover time (T_E) are shown for a low and high parameter value relative to the default value used in the main experiments.