# Supporting Information for "Nonlinear Response of Iceberg Side Melting to Ocean Currents"

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## S1 Additional Experimental Details

### 0.1. Experimental Configuration

**The experimental configuration used in this study addresses the effect of ambient velocity on the side melt of icebergs in isolation of other factors (e.g.**

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stratification, ice roll-over). The ice was frozen with a slim wooden stick running down its center. This wooden stick was clamped to a bar above the tank to prevent the ice block from rolling. We hypothesize that if an iceberg rolls, its shape is changed, but the proposed side melt parameterization should still hold for the new iceberg geometry.

For simplicity, we performed our experiments, investigating the response of side melting to a background velocity, in an unstratified room temperature flow. We expect the occurrence of attached/detached plumes to persist at lower water temperatures. However, the melt plume velocity will be smaller at lower temperatures, due to the smaller buoyancy flux, and the transition between the attached and detached regimes is expected to occur at a lower background velocity in dimensional units (this is accounted for in the updated parameterization by non-dimensionalizing the regime transition with the plume speed). However, we still expect to observe a nonlinear dependence of side melt on the relative flow speed, even if the experiments were carried out with lower water temperatures.

The temperature of the ice was measured by inserting HOBO temperature probes near the center of the ice block. The temperature of the ice block when the experiment starts is $\sim -20°$C, and it warms from this value to $-5°$C over the course of the experiment, maintaining an average temperature between -10 and -15°C. With this average ice temperature the updated melt parameterization accurately describes the side melt rate measured in the laboratory

**experiments (Figure 3 of the main text). We performed 4 experiments, covering a range of flow speeds, in which the ice block mass difference was measured every 3 minutes throughout the 15 minute experiment. From the mass difference, the melt rate was calculated at 3-minute intervals using equation 1 below. The melt rate exhibited a slight decrease over time, however the magnitude of this decrease was within the experimental error.**

### 0.2. Calculation of SMR

The SMR was calculated using the formula

$$\mathrm{SMR} = \frac{\mathrm{d}W}{\rho_i A_{\mathrm{ave}} \mathrm{d}T,} \tag{1}$$

where $\mathrm{d}W$ is the ice block mass difference over the course of an experiment of length $\mathrm{d}T$, $\rho_i \equiv 0.92$ kg m$^{-3}$ is the density of the ice, and $A_{\mathrm{ave}}$ is the average surface area of the block over the course of the experiment.

In developing an updated parameterization of iceberg side melt, we assume that the measured mass loss in the present laboratory experiments is predominantly due to side melt. This is justified by the aspect ratio of the ice blocks used in our experiments, as the basal area of 150 cm$^2$ is less than one third of the side area of 500 cm$^2$. Despite the smaller basal area however, this assumption would not hold if the basal melt rate was large compared to the side melt rate. To assess this, we analyzed videos of the ice block melting to separate the total SMR into its side and basal components by tracking the edge of the ice block in each of these regions over the course of the experiments. The results of this analysis are illustrated in Figure S1, which shows that the basal SMR is marginally less than the side SMR, and that the nonlinear behaviour discussed in this work is still present in the side SMR. Note that the video-derived SMRs have a larger error than the measured SMRs as the video only shows a two-dimensional side view of the ice block, and edge-tracking loses accuracy when the ice block melts such that there is curvature in the plane perpendicular to the plane of view of the camera. The right panel of Figure S1 shows that the small basal melt rate acting on a small area leads to an average contribution of basal melt of just 19% to the total melt volume. This is only approximately twice the average experimental error in this study of 9%.

**S2 Details of SMR Parameterization**

**Current parameterizations of iceberg side melt $M_s$ separate melting into a forced convection term $M_b$, due to heat exchange driven by flow past the iceberg, and a buoyant convection term $M_v$. From the theory of heat exchange for flow past a body of length $L$,**

$$M_b = \frac{k\mathrm{Nu}(T_o - T_i)}{\rho_i \Gamma L}, \tag{2}$$

**for thermal conductivity $k$, water temperature $T_o$, ice temperature $T_i$, ice density $\rho_i$, and latent heat of ice $\Gamma$ [*Weeks and Campbell*, 1973]. The Nusselt number Nu may be approximated as Nu $= C\mathrm{Re}^m\mathrm{Pr}^{1/3}$, where $C$ and $m$ are functions of the Reynolds number Re and the shape of the body, and Pr is the Prandtl number. Thus substituting for Re$= |\vec{u_i} - \vec{u_o}|L/\nu$ (with$|\vec{u_i} - \vec{u_o}|$ the relative speed between the iceberg and the water, and $\nu$ the kinematic viscosity), $M_s$ in units of m d$^{-1}$ is**

$$M_s = M_v + K\ |\vec{u_i} - \vec{u_o}|^m\ \frac{T_o - T_i}{L^{1-m}}, \tag{3}$$

**where** $M_v = aT_o + bT_o^2$ **for** $a = 7.62 \times 10^{-3}$, $b = 1.29 \times 10^{-3}$ [***Neshyba and Josberger***, **1980**] **and**

$$K = \frac{86400k\mathrm{Pr}^{1/3}C}{\rho_i \Gamma \nu^m}. \tag{4}$$

**For flow past a flat plate,** $C = 0.037$ **and** $m = 0.8$ [***Weeks and Campbell***, **1973**]. **So for ocean waters at approximately** $T_o \sim 0°$**C,** $k = 0.563$, **Pr**$= 13.1$ **and** $\nu = 1.826 \times 10^{-6}$ **giving** $K = 0.58$. **In the laboratory setting (**$T_o = 20°$**C),** $k = 0.6$, **Pr=7.01, and** $\nu = 1.004 \times 10^{-6}$ **giving** $K = 0.75$.

**The updated parameterization for submarine melting along the iceberg sides** $M_s(u, T_a)$ **described in the main text is given by**

$$M_s = \begin{cases} \dfrac{K|w|^m(T_p - T_i)}{D^{1-m}} & |u_o - u_i| \leq |w| \\ \dfrac{K|u_o - u_i|^m(T_a - T_i)}{L^{1-m}} & |u_o - u_i| > |w|, \end{cases} \tag{5}$$

**where** $T_p = \alpha_0\sqrt{u^2 + w^2}T_a$. **The constant** $\alpha_0$ **may be chosen to ensure continuity in the case** $D = L$ **by taking** $\alpha_0 = 1/\sqrt{2}w$. **In the laboratory experiments we use** $|w| = 0.024$ **m s**$^{-1}$**, based on the observed velocity at which the regime transition is observed in the data (Figure 3 of the main text), and** $T_a = 20°$**C.**

## References

Neshyba, S., and Josberger., E. G. (1980), On the estimation of Antarctic iceberg melt rate., *Journal of Physical Oceanography*, *10*(10), 1681-1685.

Weeks, W. F., and Campbell, W. J. (1973), Icebergs as a fresh-water source: an appraisal., *Journal of Glaciology*, *12*(65), 207-233.

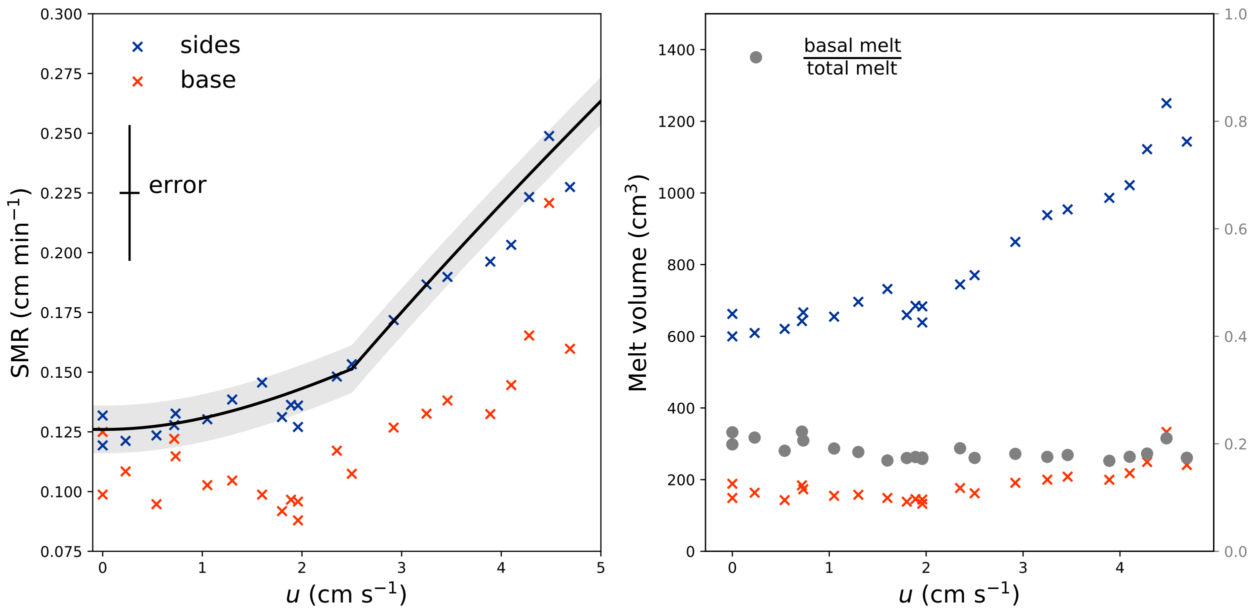


**Figure S1.** Left: Side (blue crosses) and basal (red crosses) SMRs as a function of ambient flow speed, calculated from tracking the ice edge in each of these regions in the experiment videos. The updated side melt parameterization (solid line) and error (gray shading) of the SMRs calculated from the mass loss over the course of the experiments, as seen in Figure 3 of the main text, are shown for reference. Right: Total side and basal melt volumes as a function of ambient flow speed, calculated by scaling the SMR by the experiment length and the basal/side area, respectively. The proportion of the basal melt to the total melt is shown by the gray circles.