Supplementary Information

1. *Two-stage model description*

The model of marine-terminating glacier evolution used in this study is described in detail in Robel et al. (2018). Here, we given an abbreviated description of the model, and the choices made for various model components which are specific to this study.

The model consists of two coupled ordinary differential equations, which describe the evolution of spatially averaged ice thickness in the glacier interior (*h*) and grounding line position (*L*)

$$\frac{dH}{dt} = P - \frac{Q_g}{L} - \frac{H}{h_g L}\left(Q - Q_g\right) \qquad (1)$$

$$\frac{dL}{dt} = \frac{1}{h_g}\left(Q - Q_g\right) \qquad (2)$$

Where P is the spatially averaged surface mass balance, Q_g is the ice flux through the grounding line (see more below), Q is the ice flux in the glacier interior (also see below), and h_g is the ice thickness at the grounding line. The first equation tracks the mass flow through the marine-terminating glacier interior and the corresponding evolution of the glacier thickness. The second equation tracks the moving boundary (the grounding line) that controls the magnitude of ice flux out of the glacier.

The grounding line is the location where ice is sufficiently thin to float in seawater, and so the grounding-line ice thickness is exactly at hydrostatic equilibrium with the local water depth

$$\mathrm{h_g} = -\lambda \mathrm{b(L)} \qquad (3)$$

where $\lambda = \rho_w/\rho_i$ is the ratio between the densities of seawater and glacial ice, and $b(L)$ is the depth of the bed below sea level at the grounding line.

When, in the glacier interior, there is a leading-order balance between gravitational driving stress and basal shear stress set by a Weertman-style friction law ($Cu^{\frac{1}{n}}$), the ice flux is given by

$$Q = \left(\frac{\rho_i g}{C}\right)^n \frac{H^{2n+1}}{L^n} \qquad (4)$$

where g is the acceleration due to gravity, C is the basal friction coefficient, and n is the flow law exponent for ice.

Ice flux through the grounding line or terminus (Q_g) is generally thought to be a function of the local ice thickness (h_g)

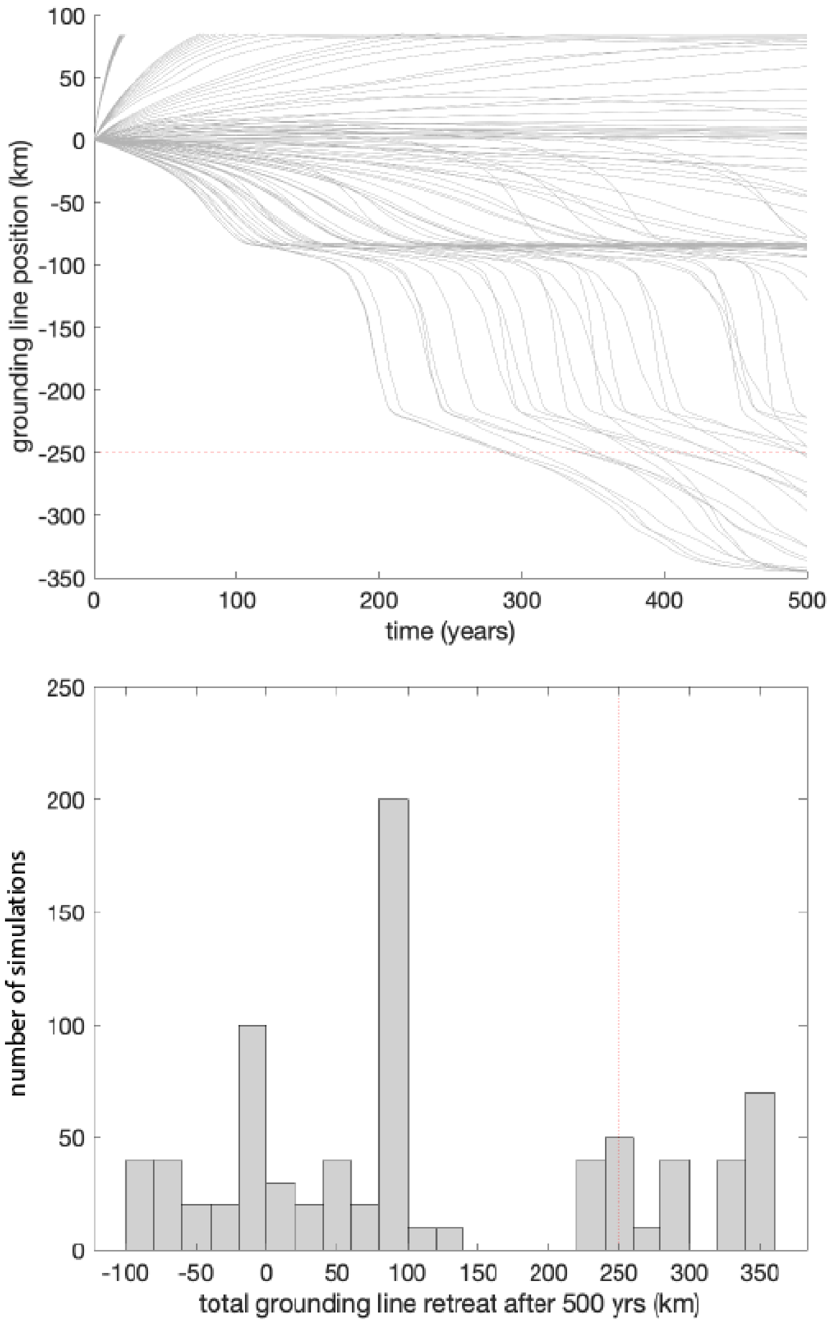
$$Q_g = \Omega h_g^{\beta} \qquad (5)$$

where β is an exponent that can be derived from various mathematical approaches (Lingle 1984, Schoof 2007, Hindmarsh 2012, Tsai et al. 2015, Schoof et al. 2017, Haseloff et al. 2018), or estimated empirically for tidewater glacier termini (Pelto & Warren 1991). Ω is a scalar parameter which incorporates the various factors (besides ice thickness) that can influence ice flux in the grounding zone or near the terminus. In this study, we pick Ω and β given by the asymptotic analysis of Schoof 2007, where

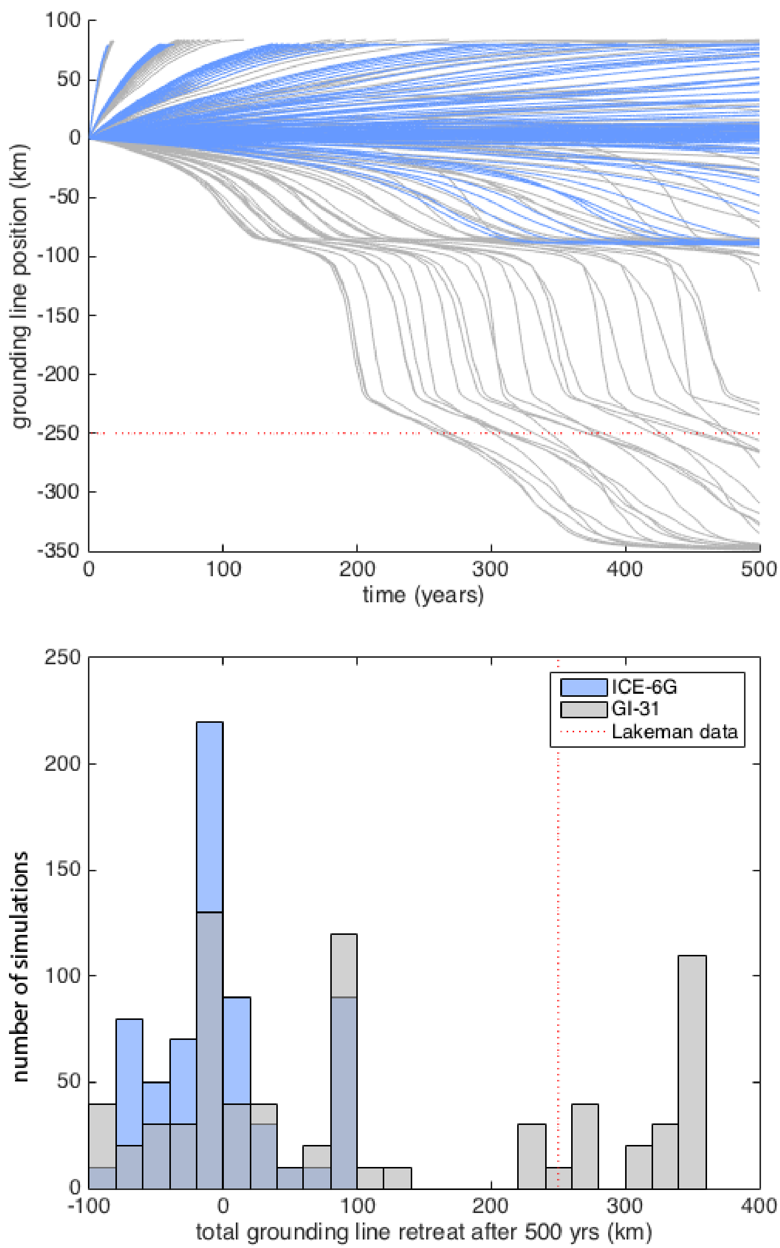
$$\beta = \frac{n^2+3n+1}{n+1} \qquad (6)$$

$$\Omega = \left[A_g(\rho_i g)^{n+1}\left(\theta(1-\lambda^{-1})\right)^n (4^n C)^{-1}\right]^{\frac{n}{n+1}} \qquad (7)$$

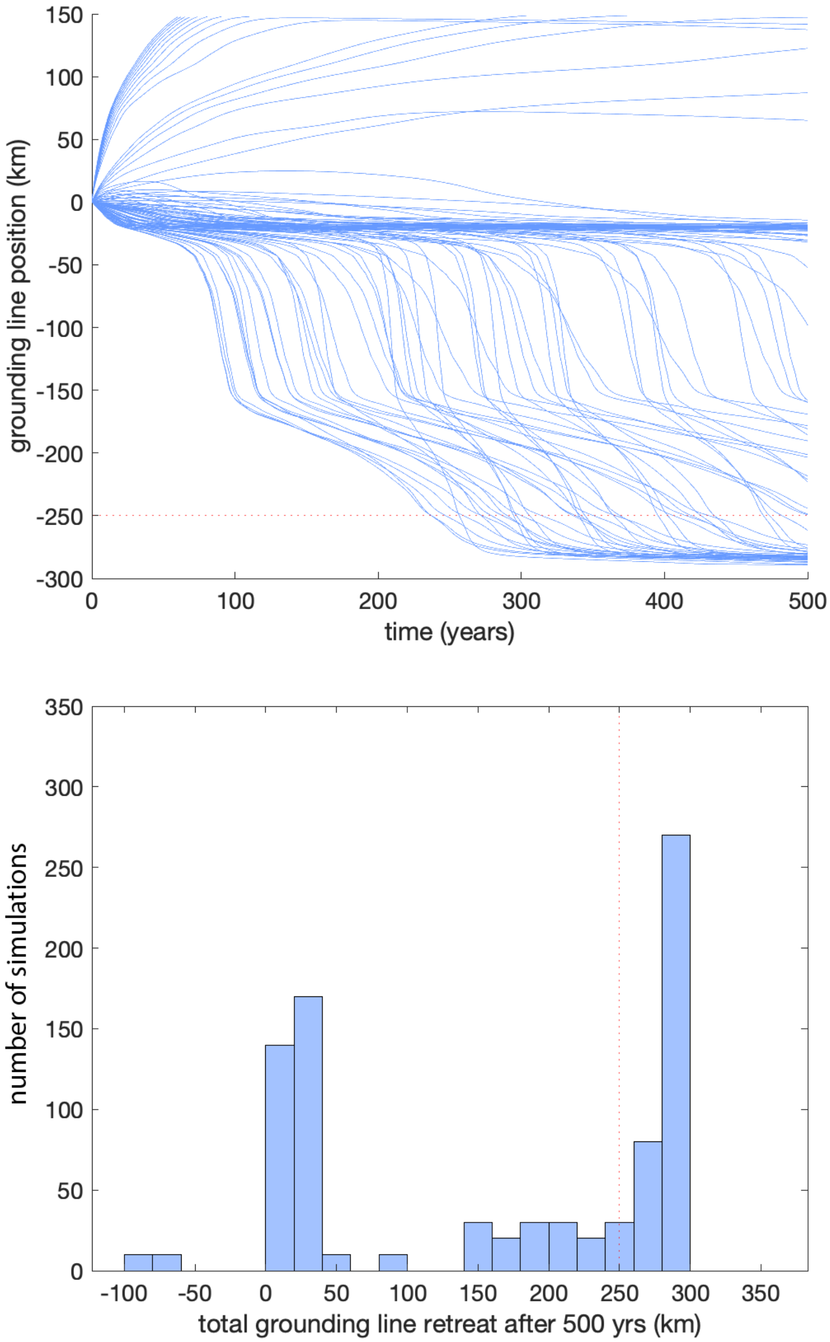
and θ is a buttressing parameter which parameterizes the effect of ice shelf buttressing, where $\theta = 0$ indicates full buttressing and $\theta = 1$ indicates no buttressing. Robel et al. (2018) demonstrates how this model reproduces the most important aspects of spatially-extended models of marine-terminating glacier evolution.



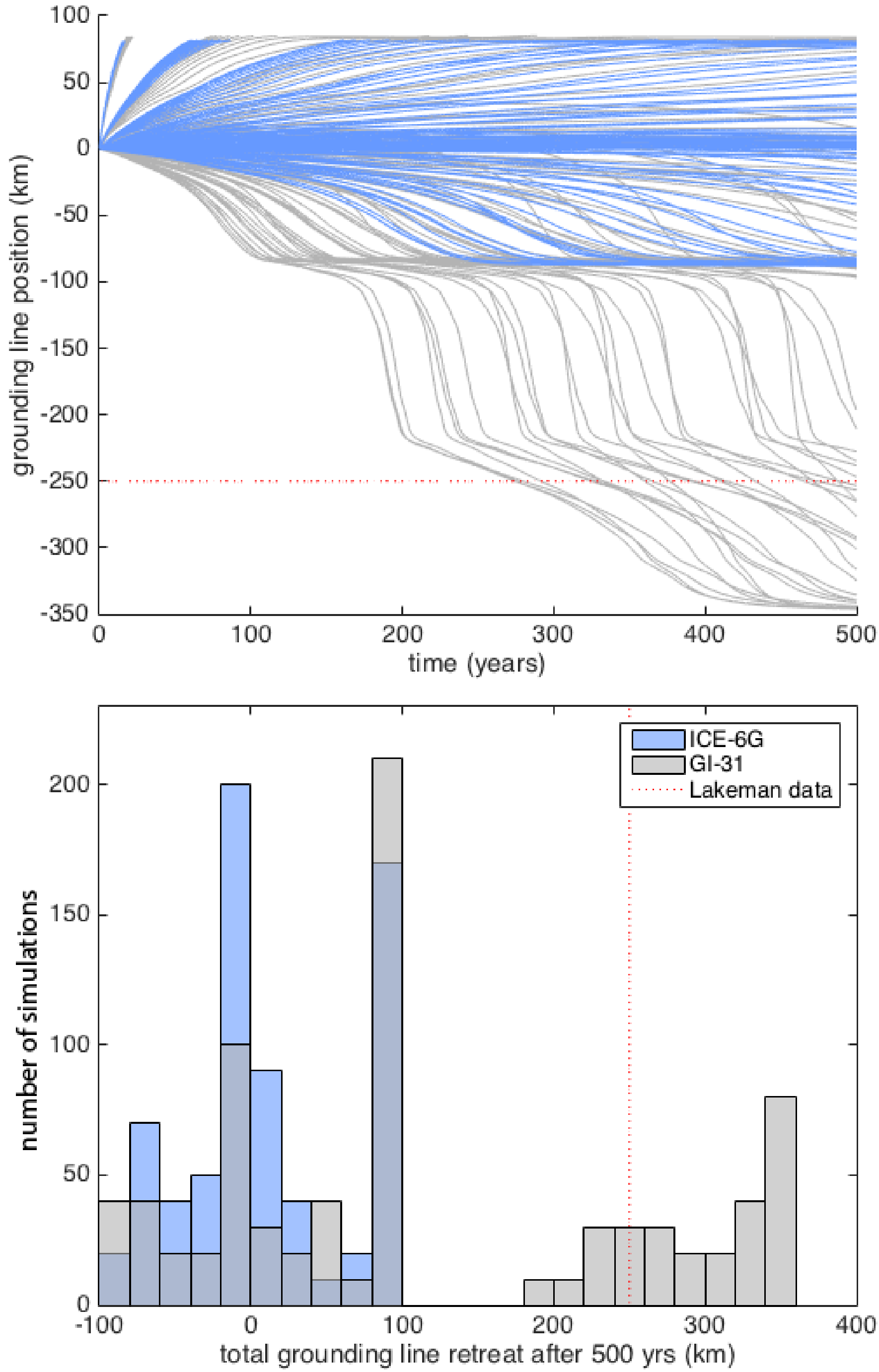
Appendix Figure 1 |Simulations that repeat the analysis shown in the main text (Figure 4) using paleotopography associated with GI-31 at 12.5 ka (see text for details). Grounding line position (relative to the initial position) is calculated from the marine-terminating glacier model using the GI-31 (gray) paleotopography. The dotted red line is the total grounding line retreat of the Amundsen Ice Stream reported by Lakeman et al. (2018). In these simulations 190/1000 produced over 250 km of grounding line retreat within 500 years



Appendix Figure 2| Simulations that repeat those shown in the main text (Figures 4, 5) using an alternate Earth model alternate Earth model characterized by a lithospheric thickness of 48 km, and an upper and lower mantle viscosities of 5 x10^{20} Pa s and 5 x10^{21} Pa s, respectively.



Appendix Figure 3 | Simulations that repeat those shown in the main text (Figures 4, 5) using an ice profile and paleotopography associated with the ICE-6G ice history at 14.5 ka, during MWP-1a (see text for details).



Appendix Figure 4 | Grounding line position (relative to the initial position) calculated from the marine-terminating glacier model using the GI-31 ice thickness and either the GI-31 (gray) or ICE-6G (blue) paleotopographies at 13 ka. The dotted red line is the total grounding line retreat of the Amundsen Ice Stream reported by Lakeman et al. (2018).