Text S1

1. Model Equations

We consider a gravity-driven flow of isothermal, incompressible and non-linearly viscous ice. The geometry is restricted to a two-dimensional plane flow (x, z) with ice flowing along the $x-$direction. The $z-$axis is the vertical upward pointing axis. The ice-sheet flows over a rigid bedrock $z = b(x)$ and further extends as an ice-shelf over the ocean. For the grounded part, we assume a non-linear friction law. The upper and lower surfaces of the ice are given by $z_s(x, t)$ and $z_b(x, t)$, respectively, with the condition $z_s > z_b \geq b$. All the values of the various parameters entering the following equations are given in Table S1.

The constitutive relation for ice is assumed to be a viscous power law (called Glen's flow law in glaciology)

$$\tau_{ij} = 2\eta\dot{\varepsilon}_{ij} \, , \tag{S1}$$

where $\boldsymbol{\tau}$ is the deviatoric stress tensor, $\dot{\varepsilon}_{ij} = (u_{i,j} + u_{j,i})/2$ are the components of the strain-rate tensor, and $\boldsymbol{u}$ the velocity vector. The effective viscosity η can be expressed as:

$$\eta = \frac{1}{2} A^{-1/n} \dot{\varepsilon}_e^{(1-n)/n} \,, \tag{S2}$$

where $\dot{\varepsilon}_e = \sqrt{\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}/2}$ is the second invariant of the strain-rate tensor.

The ice flow is computed by solving the Stokes problem with non-linear rheology, coupled with the evolution of the upper and lower free surfaces, summarized by the following field equations and boundary conditions:

$$\operatorname{div} \boldsymbol{u} = 0 \,, \qquad z_b \le z \le z_s \,, \tag{S3}$$

$$\operatorname{div} \boldsymbol{\sigma} + \rho_i \boldsymbol{g} = 0 \,, \qquad z_b \le z \le z_s \,, \tag{S4}$$

$$\partial_t z_s + u \partial_x z_s = w + a_s \,, \qquad z = z_s \,, \tag{S5}$$

$$\partial_t z_b + u \partial_x z_b = w \,, \qquad z = z_b \,, \tag{S6}$$

$$\boldsymbol{\sigma} \cdot \boldsymbol{n} = \boldsymbol{0} \,, \qquad z = z_s \,, \tag{S7}$$

$$\left.\begin{array}{r} \sigma_{nt} = C u_t^m \\ \boldsymbol{u} \cdot \boldsymbol{n} = 0 \end{array}\right\} , \qquad z = z_b \,;\, x \le x_G \,, \tag{S8}$$

$$\left.\begin{array}{r} \sigma_{nt} = 0 \\ \sigma_{nn} = -\rho_w g (l_w - z_b) \end{array}\right\} , \qquad z = z_b \,;\, x > x_G \,, \tag{S9}$$

$$u = 0 \,, \qquad x = 0 \,, \tag{S10}$$

$$\sigma_{nt} = 0 \,, \qquad x = 0 \,, \tag{S11}$$

$$\sigma_{nn} = -\max(\rho_w g (l_w - z_b), 0) \,, \qquad x = x_G + L_{\text{shelf}} \tag{S12}$$

Equation (S3) expresses the conservation of mass, Equation (S4) the conservation of momentum, and Equations (S5) and (S6) the evolution of the upper and lower free surfaces respectively. We note $\partial_i z$ the partial derivative of the function z with respect to the variable i. Here $\boldsymbol{u} = (u, 0, w)$ is the velocity vector, $\boldsymbol{\sigma} = \boldsymbol{\tau} - p\boldsymbol{I}$ is the Cauchy stress tensor and p the isotropic pressure. $\boldsymbol{n}$ and $\boldsymbol{t}$ are the normal and tangential unit vectors to the considered boundary and therefore, $\sigma_{nn} = \boldsymbol{n} \cdot (\boldsymbol{\sigma} \cdot \boldsymbol{n})$, $\sigma_{nt} = \boldsymbol{t} \cdot (\boldsymbol{\sigma} \cdot \boldsymbol{n})$ and $= \boldsymbol{u} \cdot \boldsymbol{t}$ are respectively the normal stress, tangential stress and tangential velocity. ρ_i and ρ_w are the density of ice and sea water respectively, l_w the sea level, and $\boldsymbol{g} = (0, 0, -g)$ the gravity vector.

The most downstream grounded point defining the grounding line is denoted x_G and is identified as the last point for which $z_b = b$ and $-\sigma_{nn} > \rho_w g(l_w - z_b)$. The grounding line position $x_G(t)$ is fully determined by solving this contact problem and is then part of the solution.

The upper surface is a stress-free surface (Eq. S7) with a prescribed accumulation a_s. For the lower surface (Eq. S8), the dynamic boundary condition depends on whether the ice is grounded or rests over the sea. If the ice is grounded, the normal velocity is null and a Weertman type friction law applies (Eq. S8), whereas for those parts of the ice in contact with water, the normal stress is equal to the sea water buoyancy pressure and the tangential friction is null (Eq. S9).

The left boundary condition (Eq. S10 and S11) expresses a symmetry axis, whereas the right boundary condition (Eq. S10) is the end of the ice-shelf front, assumed to have a constant length L_{shelf}. This artificial truncation of the ice-shelf can be seen as the point where icebergs are calved.

All the equations presented above are solved using the finite element code Elmer/Ice. For these new simulations, we used the mesh refinement methods presented by *Durand et al.* [2009]. The horizontal size of the mesh in the vicinity of the grounding line was reduced to 50 m. The values of the parameters prescribed in this study are presented in Table S1. More details on the numerics are given by *Durand et al.* [2009].

References

Durand, G., O. Gagliardini, B. de Fleurian, T. Zwinger, and E. Le Meur (2009), Marine ice sheet dynamics: Hysteresis and neutral equilibrium, *J. Geophys. Res.*, *114*, F03009, doi:10.1029/2008JF001170.

Table S1. Values of the parameters used in this study

Parameter	Value	Unit
a_s	0.3	m a^{-1}
A	5.49×10^{-17}	Pa^{-3} a^{-1}
C	3.0×10^{4}	Pa m$^{-1/3}$a$^{1/3}$
g	9.8	m s^{-2}
L_{shelf}	100	km
m	1/3	
n	3	
ρ_w	1000	kg m^{-3}
ρ_i	900	kg m^{-3}