When Buttressing Matters: a sensitivity study

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MOTIVATION

- Ice shelves can buttress their ice streams
- Weaker ice shelves will buttress less
- Thinning and upstream migration of the grounding line *may* result

GOAL & APPROACH

Goal : Assess the sensitivity of stream/shelf systems to a change in buttressing

Approach : Use a simple model to examine how an initially steady-state system responds to a loss of buttressing

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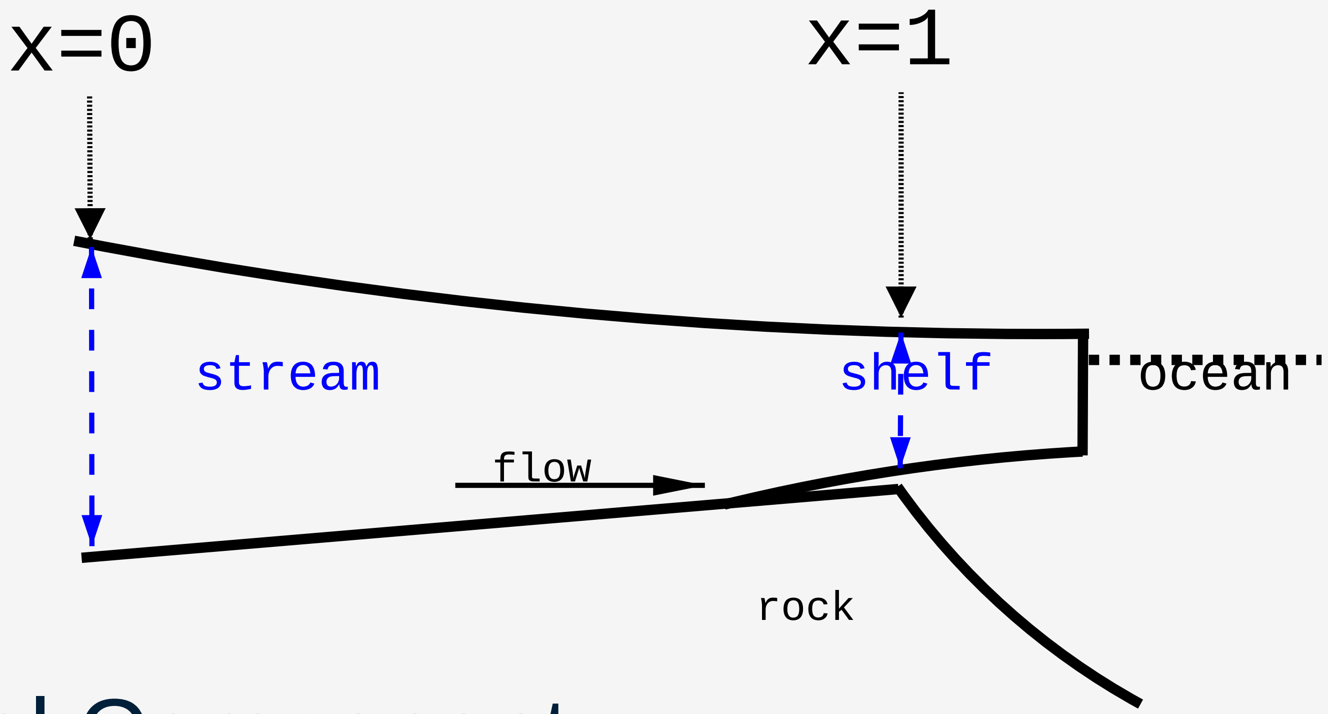
SNEAK PREVIEW

- Ice shelves do matter, at least for "PIG-like" systems
- We have a nice tool ideal for reconnassance style studies

MODEL OVERVIEW



Model Components

- diagnostic momentum balance
- prognostic mass balance

MOMENTUM BALANCE

- 1-d flowline, nondimensionalized, FEM treatment
- derived similarly to the plan-view eqn's of MacAyeal (1989)
- treats basal drag and lateral drag as boundary layer phenom.
- includes long. dev. stress
- appropriate for thin, channelized, free-surface, 'plug' flow
- buttressing applied as a boundary condition

MOMENTUM BALANCE cont'd

$$\frac{\partial}{\partial x}\left(2h\nu\frac{\partial u}{\partial x} - \frac{A}{2}h^2\right) = G_s h u^{\frac{1}{n}} + \begin{cases} A\beta h + G_b u^{\frac{1}{m}} & h > h_f \\ -\frac{A}{2}\frac{1}{r_{sw}}\partial_x h^2 & h \le h_f \end{cases}$$

$$\text{stretching} - \text{press. grad.} = \text{side drag} + \begin{cases} \text{basal drag} & \text{grounded} \\ \text{ocean press.} & \text{floating} \end{cases}$$

where x is the along-flow coordinate, h is thickness, u is velocity, n and m are the ice and basal flow-law exponents, $r_{sw} = \rho_{sw}/\rho_i$ is nondim. density of seawater, β is the bed slope, and $\nu \equiv \left|\frac{\partial u}{\partial x}\right|^{\frac{1-n}{n}}$ is the strain-rate dependent viscosity.

- A is a measure of the importance of ice thickness gradients
- G_b measures the importance of basal drag
- G_s measures the importance of side drag

MOMENTUM BALANCE cont'd

Boundary conditions:

- Upstream ($x = 0$) boundary condition $u(0, t) = u_0$
- Downstream, or terminal, ($x = 1$) boundary condition

$$\left[2h\nu\frac{\partial u}{\partial x} - \frac{A}{2}h^2\right]_{x=1} = -f\,\frac{A}{2}h(1)^2 - (1 - f)\,r_{sw}\,\frac{A}{2}z_b(1)^2$$

f is the **buttressing parameter**, such that

⋆ $f = 1 \rightsquigarrow$ fully buttressed condition

⋆ $f = 0 \rightsquigarrow$ freely-spreading condition = unbuttressed

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MASS BALANCE

- 1-d, time-dependent, non-dimensional
- derived from depth-integrated continuity
- neglects accumulation & lateral variations in thickness

$$\begin{aligned} \frac{\partial h}{\partial t} &= -\frac{\partial}{\partial x}(uh) \\ \text{thickening rate} &= \text{flux convergence} \end{aligned}$$

Boundary condition:

- fixed upstream thickness, $h(0,t) = h_0$ ⚠

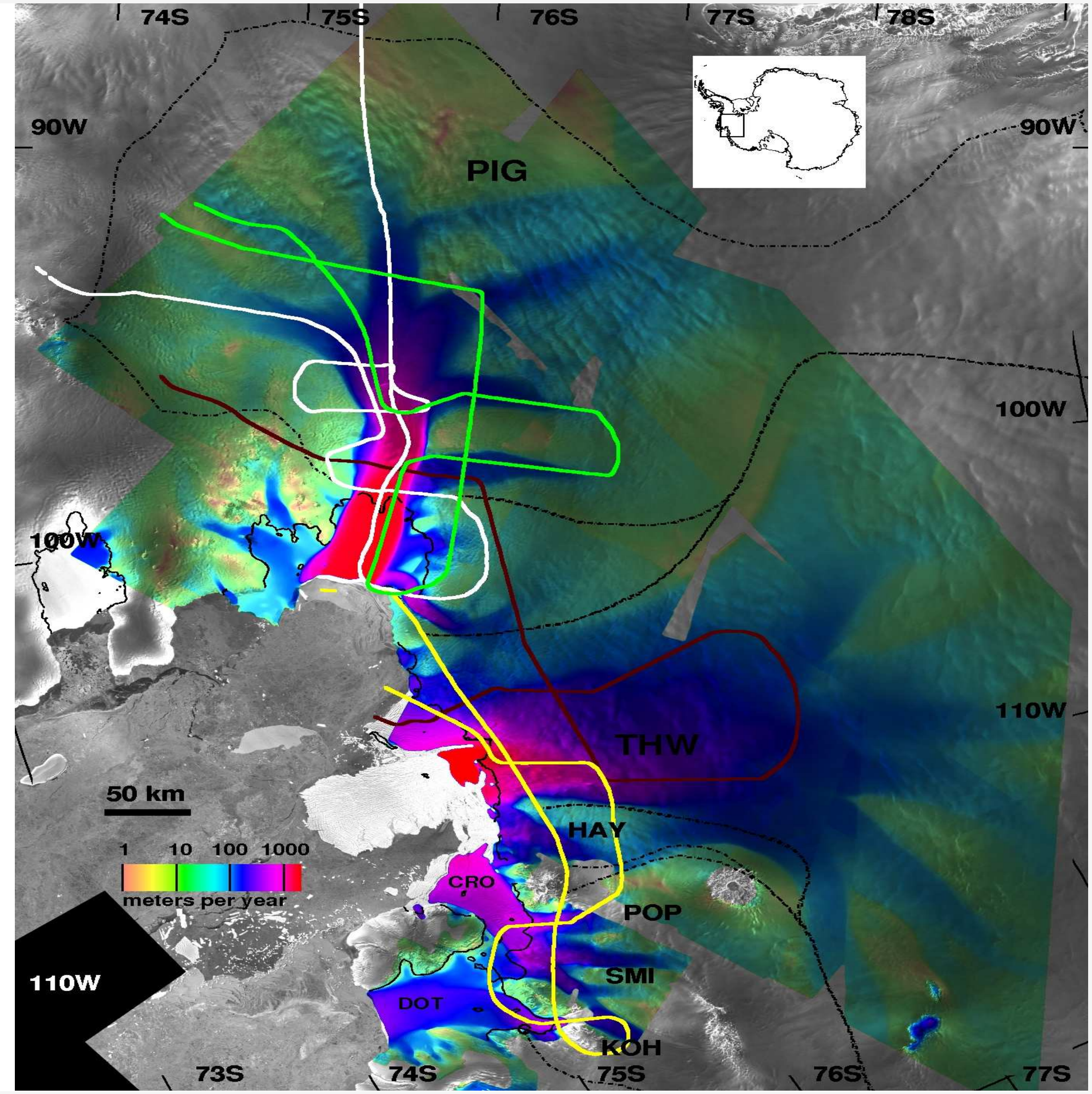
EXPERIMENTAL APPROACH

- Start with a system which is at steady-state with 50% buttressing (f=0.5)
- Remove buttressing (f=0) and watch the system adjust

EXPERIMENTS

- Performed a reference experiment using "PIG-like" numbers
- Many sensitivity experiments were conducted (e.g., 20% incr. in G_s, or 20% decr. A)

PIG GEOMETRY



From Rignot et al., *Ann. Glaciol.*, 39, in press

PIG-LIKE SCALES

Scale, constant or parameter	Value
H	1 km
L_x	100 km
L_y	20 km
U	7.6×10^{-5} ms^{-1} ≈ 2.4 km/year
B_i	2×10^{8} Pa s$^{1/3}$
τ_b	0.73 bar
τ_y	5.5 bar
$T = L_x/U$	1.3×10^{9} s ≈ 41 years

$$A \equiv \frac{\rho_i g H}{B_i \left(\frac{U}{L_x}\right)^{\frac{1}{n}}} = 50 \qquad G_b \equiv \frac{\tau_b L_x}{H B_i \left(\frac{U}{L_x}\right)^{\frac{1}{n}}} = 40 \qquad G_s \equiv \frac{\tau_y L_x}{L_y B_i \left(\frac{U}{L_x}\right)^{\frac{1}{n}}} = 15$$

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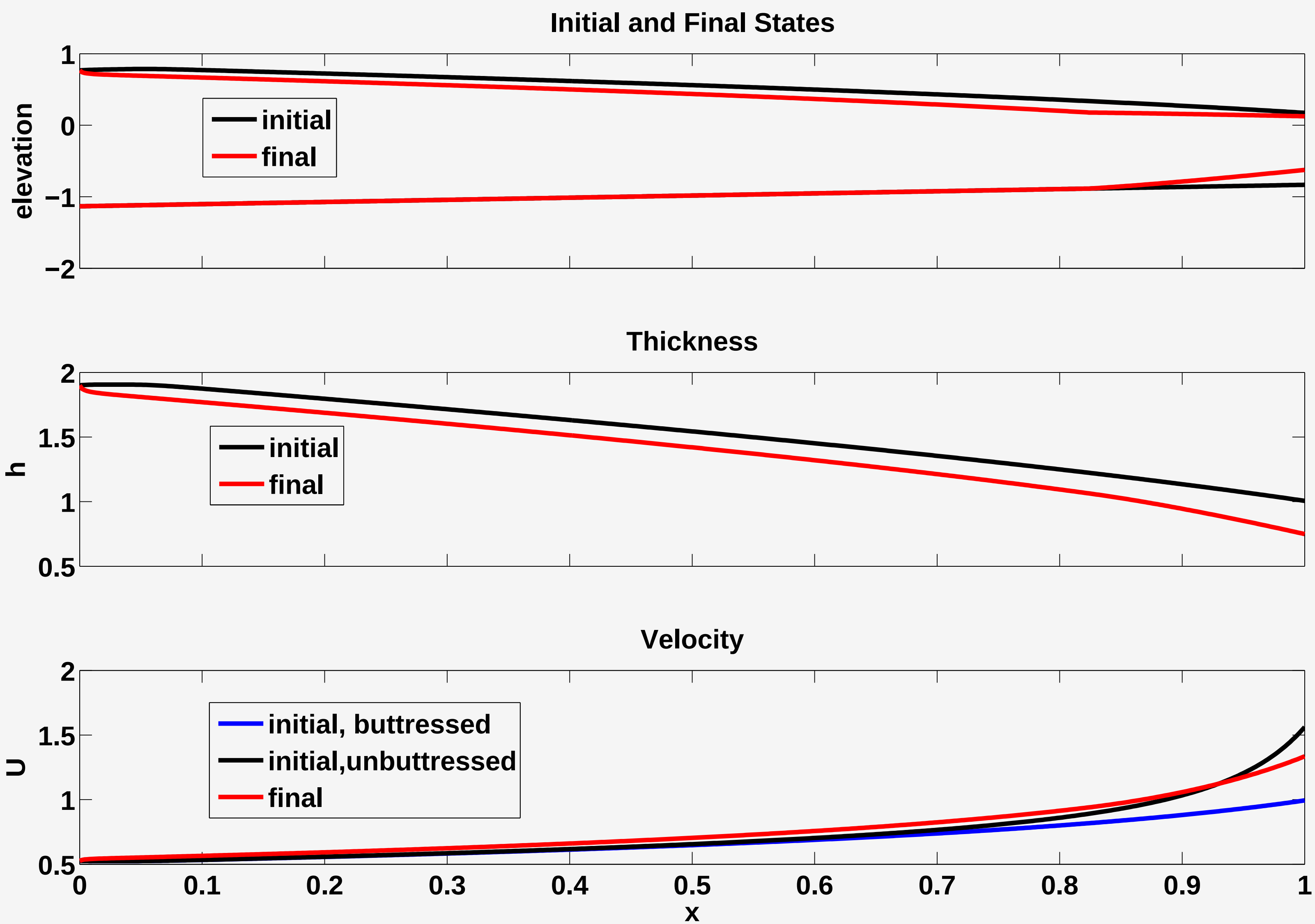
EXPERIMENTS

experiment	G_s	β	G_b	A	h_0	u_0
reference	15	0.3	40	50	1.9	0.53
+G_s	18					
-β		0.24				
+G_b			48			
+A				60		
-A				40		
+h_0					2.3	
+u_0						0.63

RESULTS: reference



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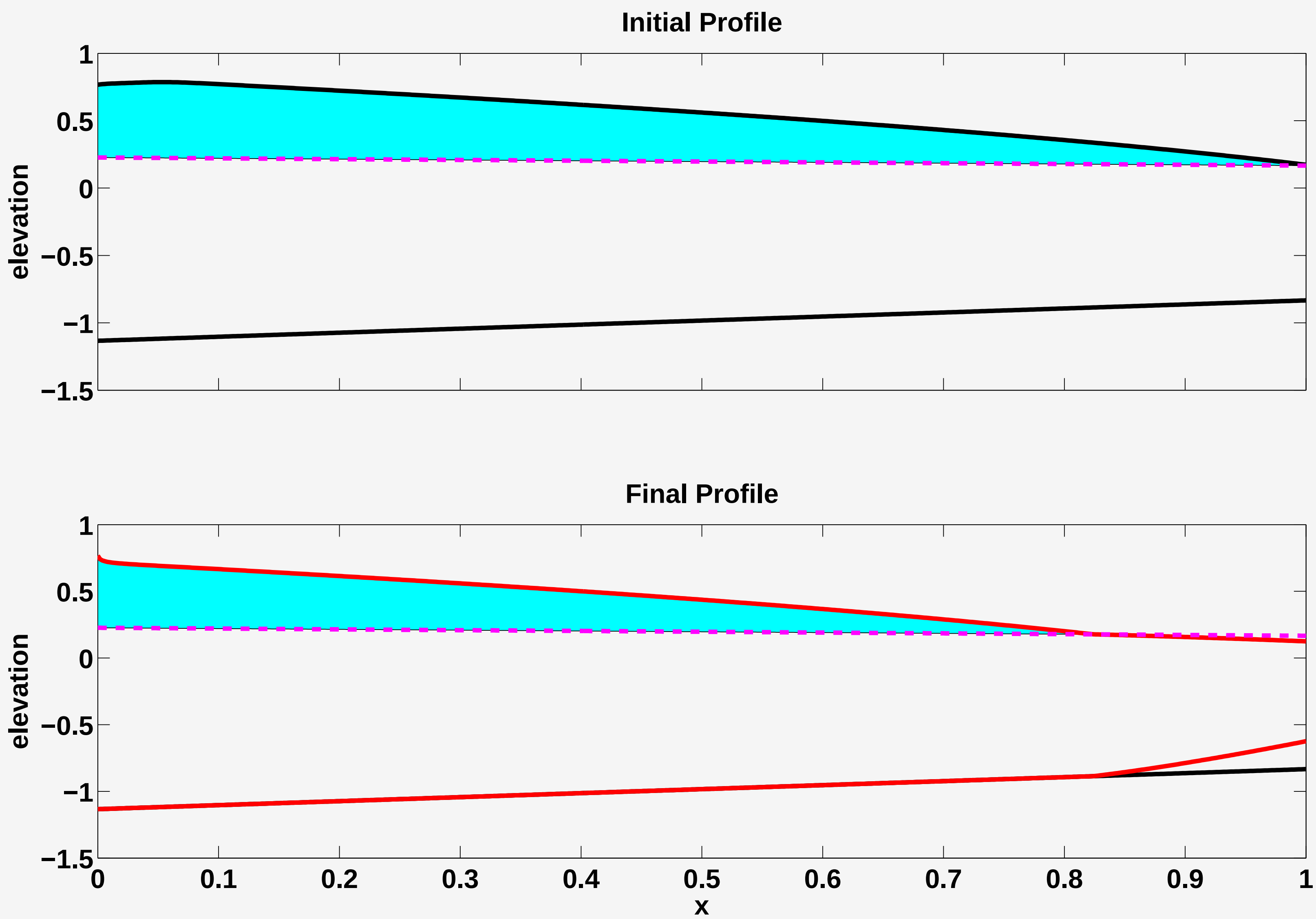
RESULTS: reference, cont'd



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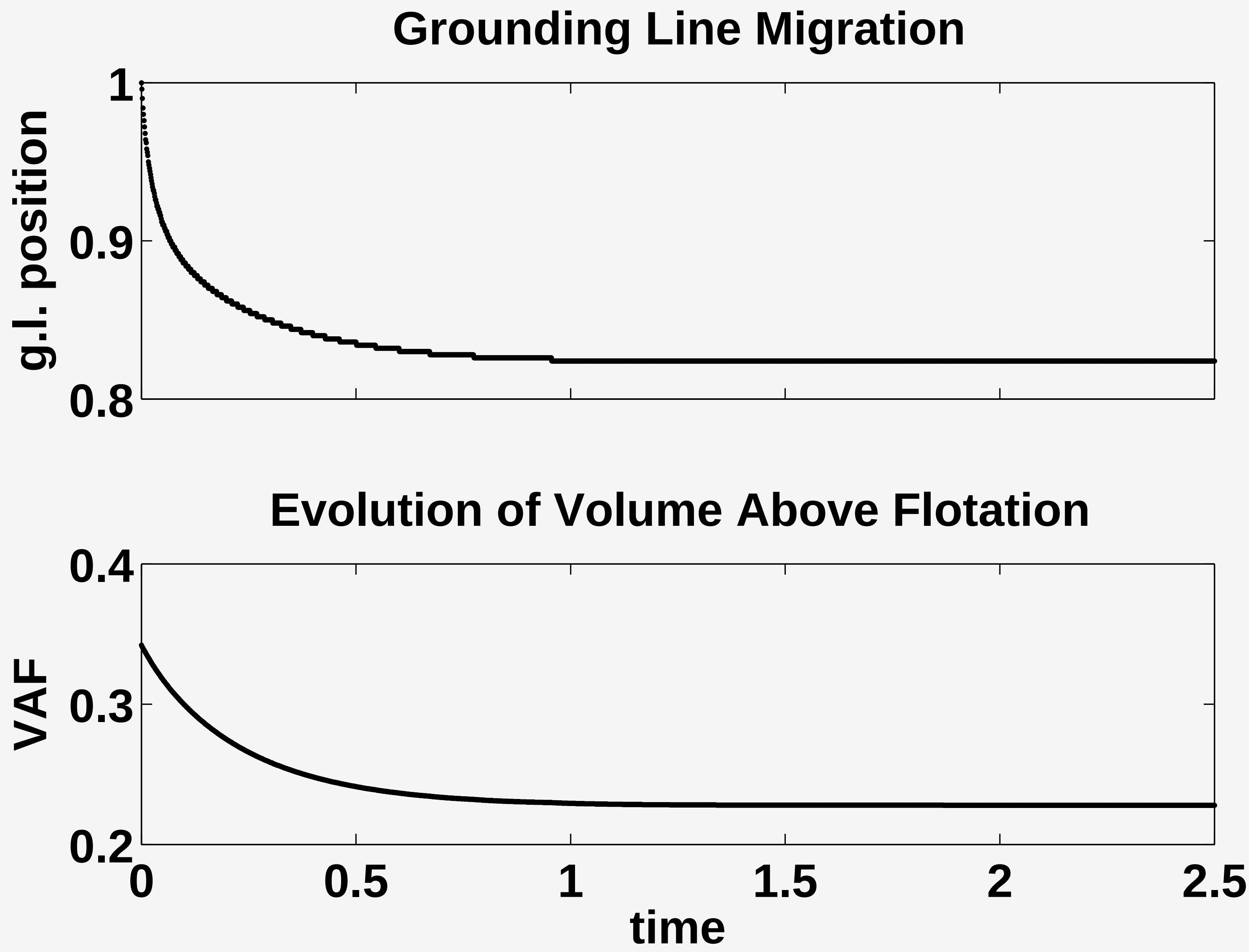
RESULTS: reference, cont'd



SENSITIVITY RESULTS

experiment	g.l. retreat	init'l VAF	final VAF	VAF loss (% of init'l)
reference	0.18	0.34	0.23	0.11 (33%)
+20% in G_s	0.14	0.37	0.27	0.10 (27%)
-20% in β	0.17	0.35	0.24	0.11 (32%)
+20% in G_b	0.17	0.38	0.26	0.12 (32%)
+20% in A	0.22	0.21	0.14	0.11 (43%)
-20% in A	0.08	0.43	0.35	0.09 (20%)
+20% in h_0	0.18	0.34	0.23	0.12 (34%)
+20% in u_0	0.14	0.39	0.28	0.11 (28%)

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CONCLUSIONS

- Loss of buttressing results in notable g.l. retreat and VAF loss (18 km & $\sim$300 km^3, respectively, using PIG scales)

- Thinning extends far upstream

- $\uparrow$ buttressing sensitivity for $\downarrow$ side drag and $\uparrow$ driving stress ($\uparrow$ basal drag)

- Siple Coast ice streams may be vulnerable
- Results are likely conservative
  - $\star$ fixed upstream thickness
  - $\star$ no sub-ice-shelf melting

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FUTURE WORK

- Adaptive meshing $\longrightarrow$ better efficiency
- Include dynamic accumulation/melting
- Free the upstream boundary
- Perform new, "improved", PIG-like experiments
- Perform Siple experiments