Grounding lines: a Boundary to ice sheet modeling

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Grounding Lines

- Grounding lines are the boundary between grounded and floating ice
- They are also the boundary between very different types of ice flow
- They are the "medium" through which ocean processes can affect land ice

Pine Island

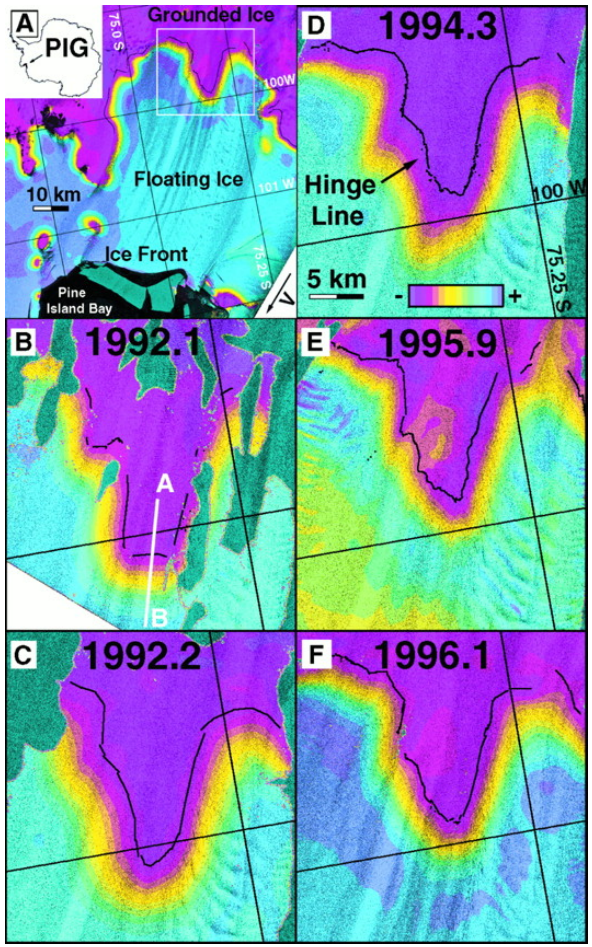

Figure: *Rignot* (1998)

- E Rignot (1998) inferred location of PIG grounding line by tidal flexure
- Retreat of 1.2±0.3 km/yr from 1992-1996
- Concurrent with observed thinning of both shelf and stream (Shepherd et al, 2004)

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- Large speed increase after dramatic retreat of glacier's ice tongue in late 1990s
- Now glacier appears to be thinning and accelerating, but with pronounced seasonal pattern that corresponds to advance and retreat of calving front (Joughin et al, 2008)
- Calving cycle may be related to contents of Disko bay (i.e. ice chunks, sea ice)

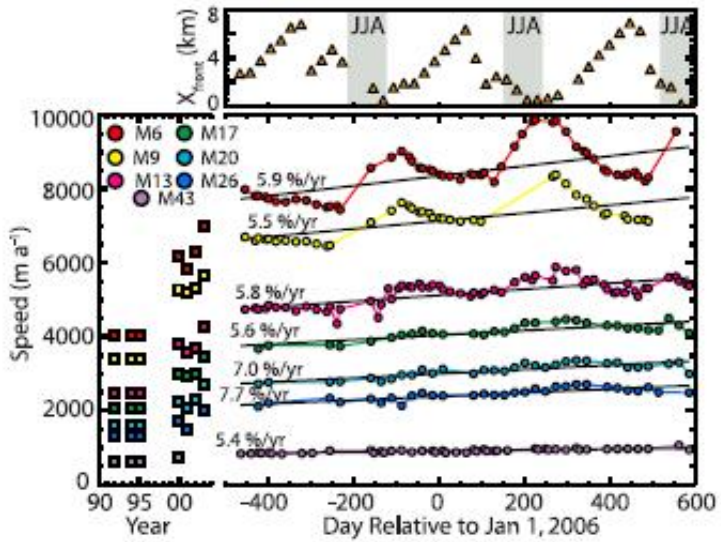
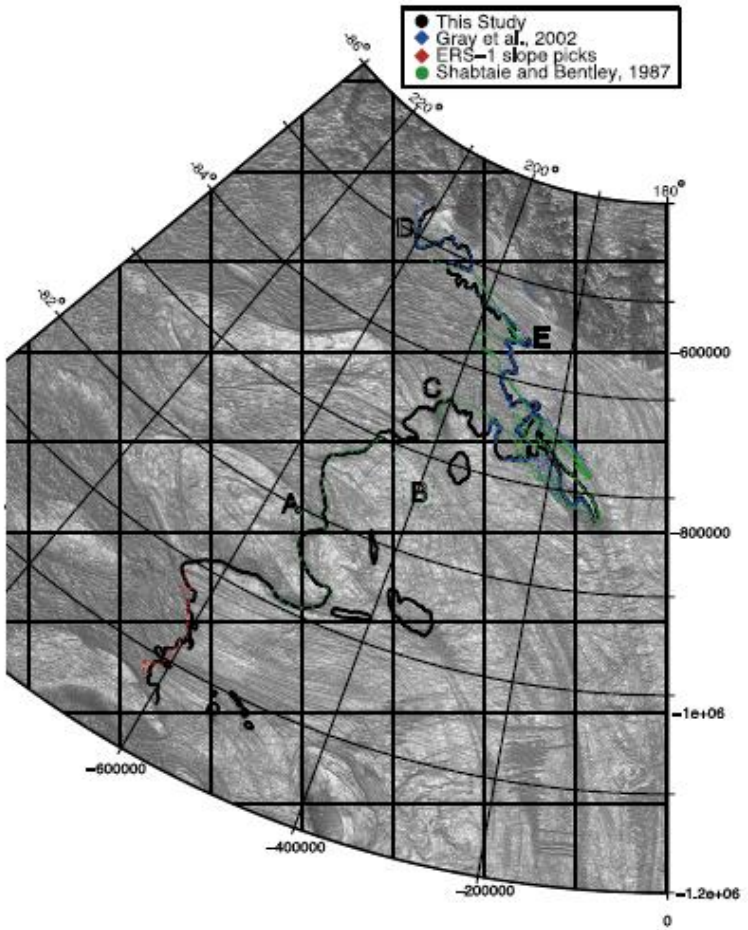


Figure: *Joughin et al* (2008)

Siple Coast



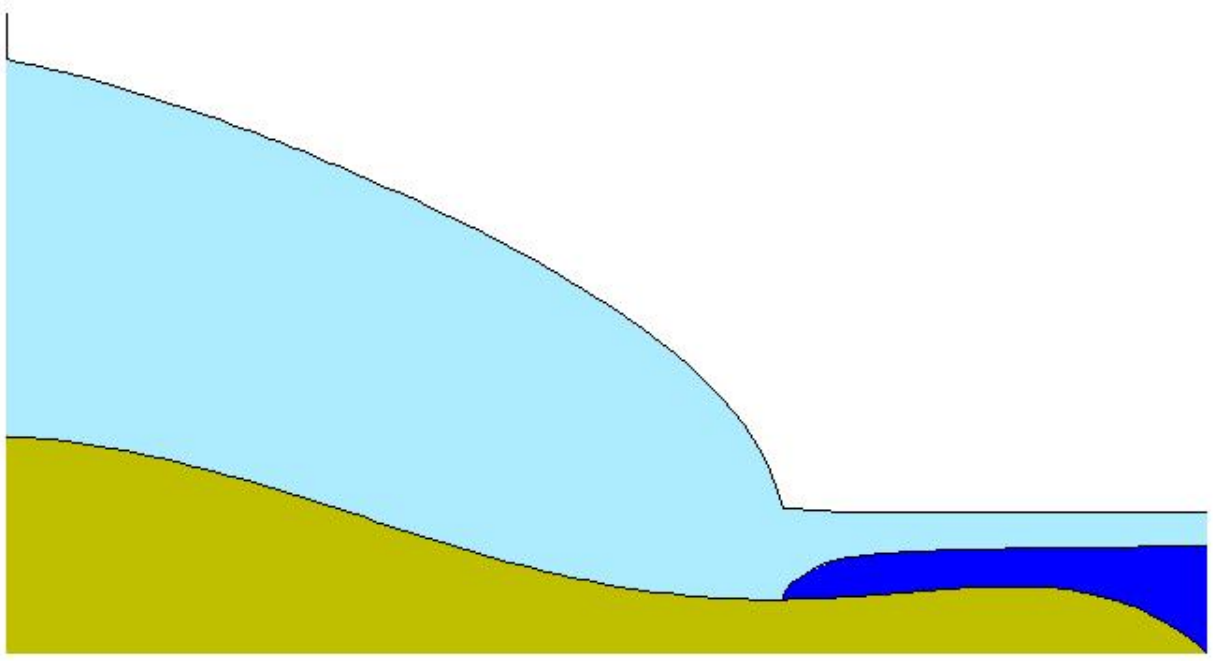
- Horgan and Anandakrishnan use different methodology to find grounding line based on "slope ramp" location
- They find that while Siple Coast streams have undergone changes in last one to three decades, grounding line has not

Figure: *Horgan and Anandakrishnan* (2006)

That is how remote sensors (sp?) and observationalists (?) see the grounding line, now here is how modelers see it...

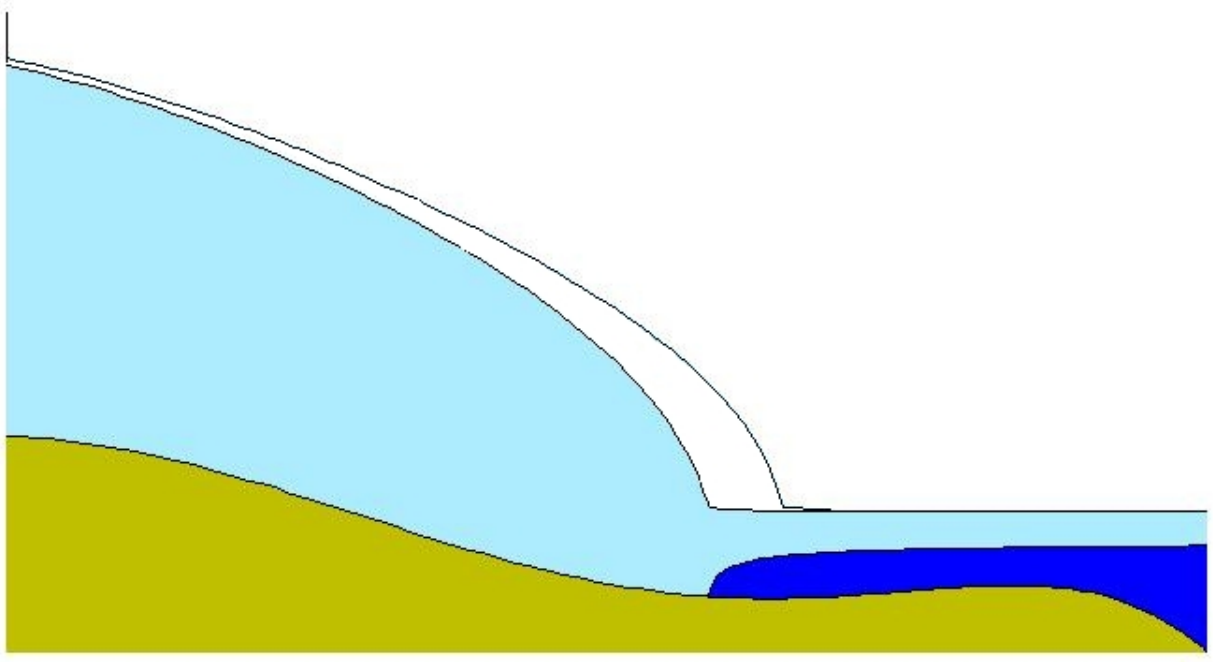
How does the grounding line move?

- Under the **Glaciostatic approximation**, grounding line is **just** at floatation (and pretty close regardless)



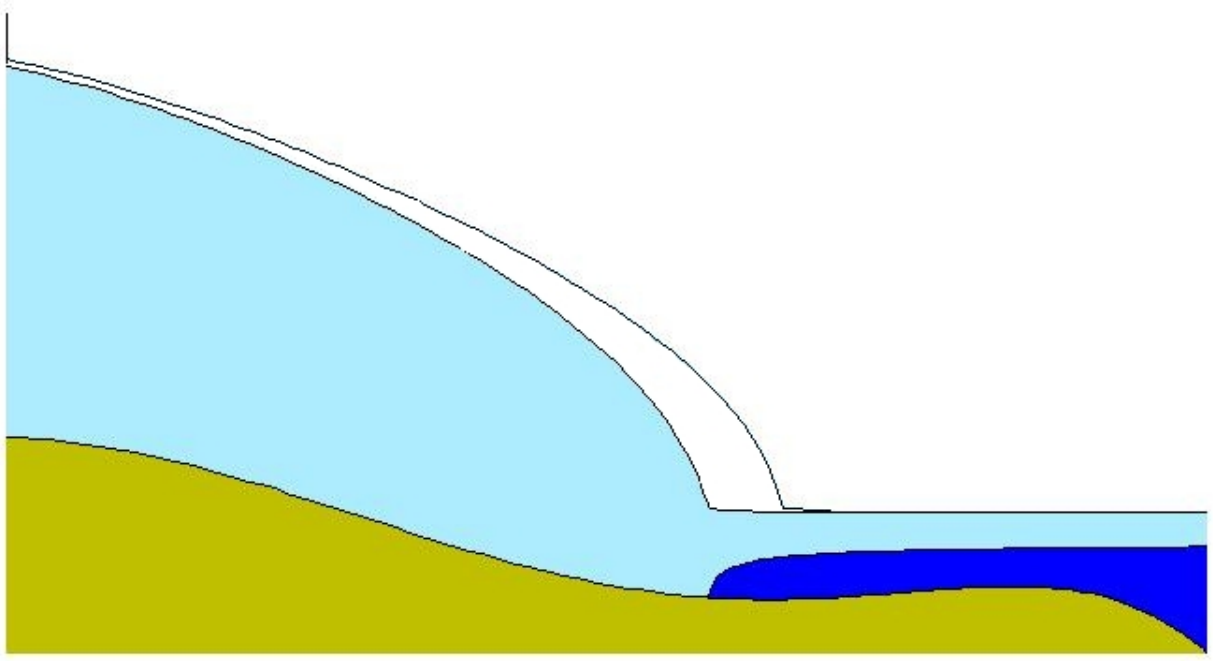
How does the grounding line move?

- A change in surface elevation (thickness) there will affect the grounding line



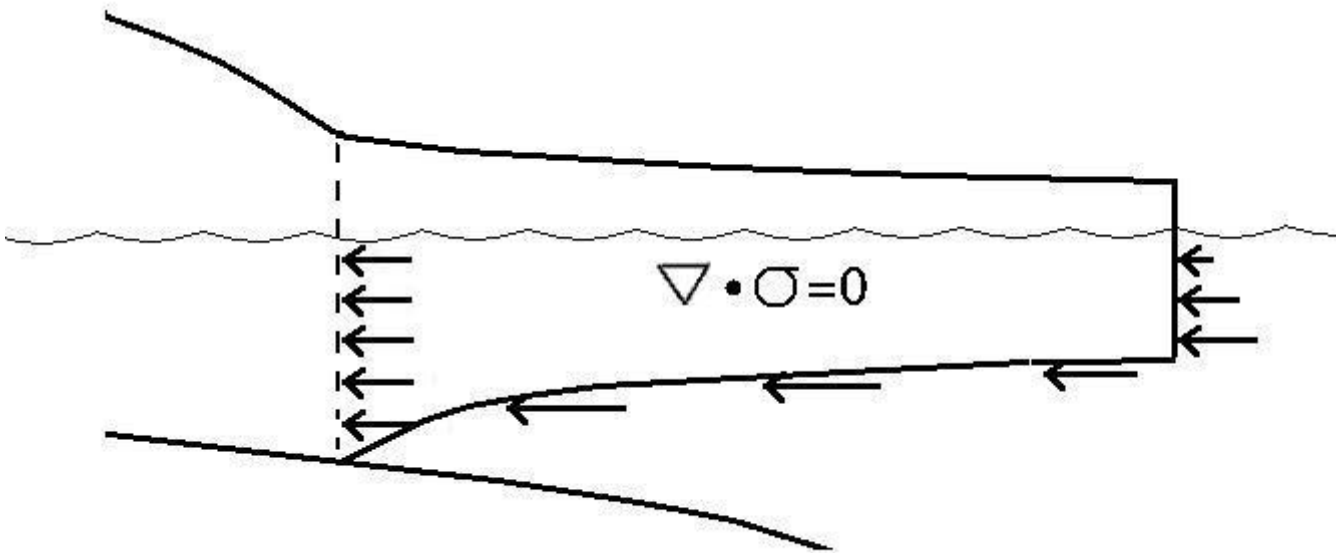
How does the grounding line move?

- Thickness evolves due to velocity gradients (shallow-water mass equation), which are influenced by forces in the shelf...



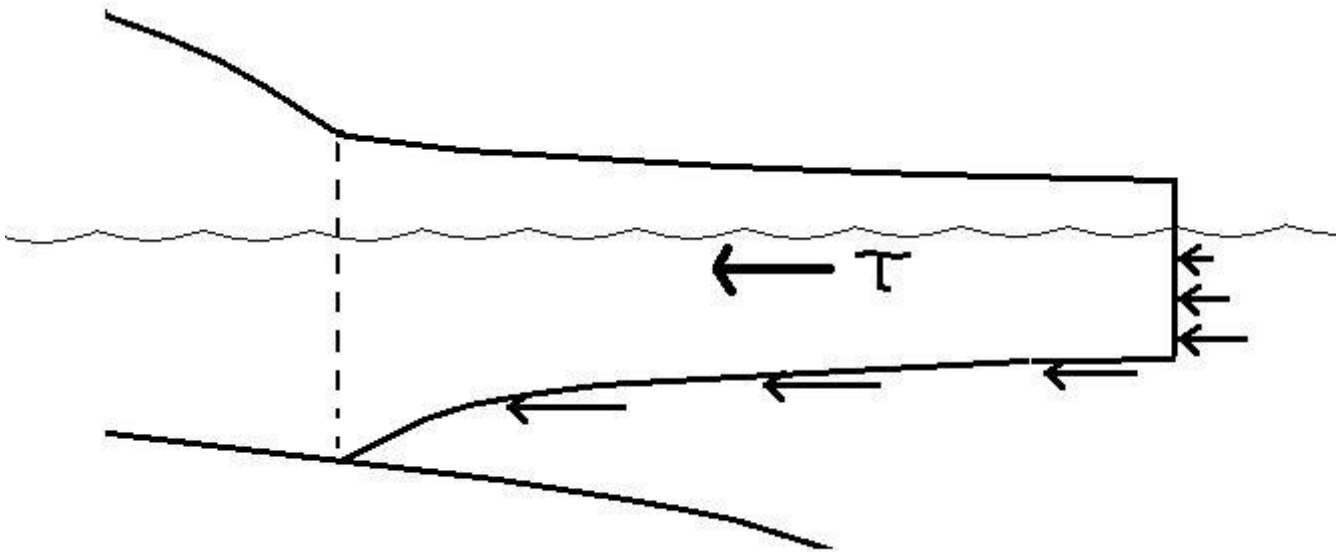
Ice shelf backstress

With no tangential stresses, grounding line feels depth-integrated ocean pressure



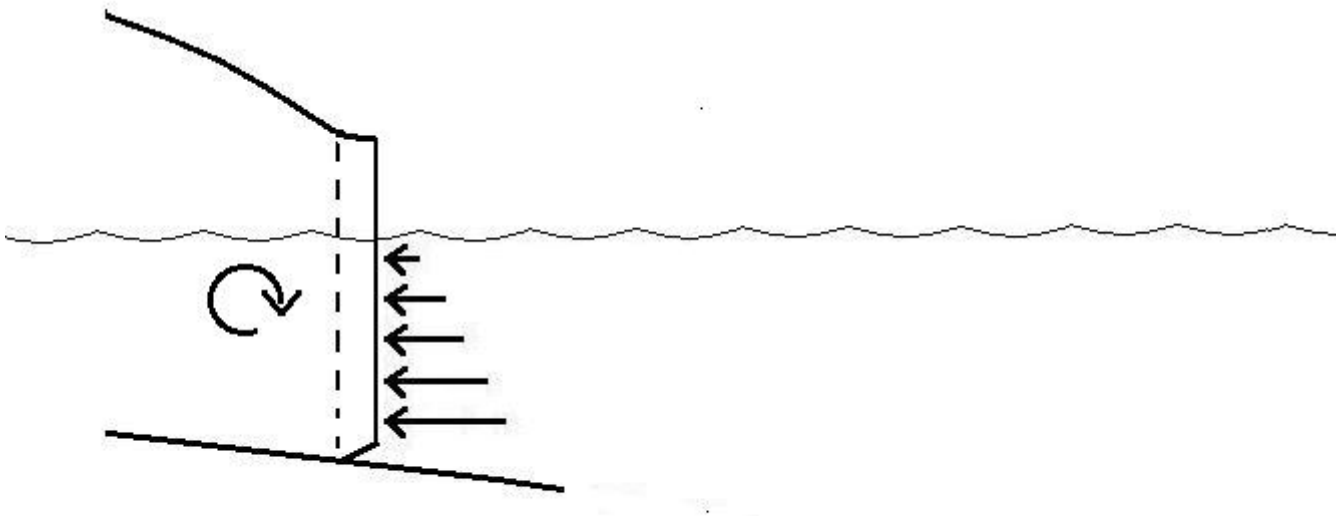
Ice shelf backstress

But with forces acting along side of shelf this is no longer true



Ice shelf backstress

And if shelf is very small, moment is felt due to ocean pressure at depth

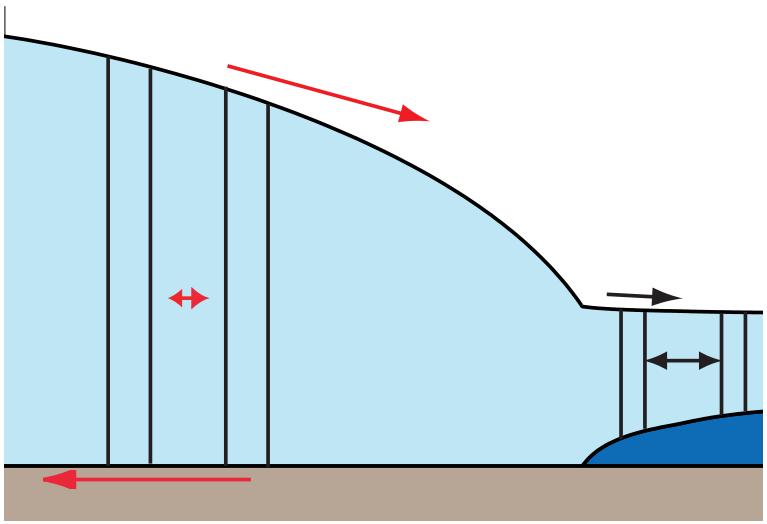


Grounding line dynamics

Key point is that flow and thickness in the shelf (in general) influence grounding line dynamics, but flux through grounding line influences flow in the shelf, so grounded and floating ice must be modeled *together*

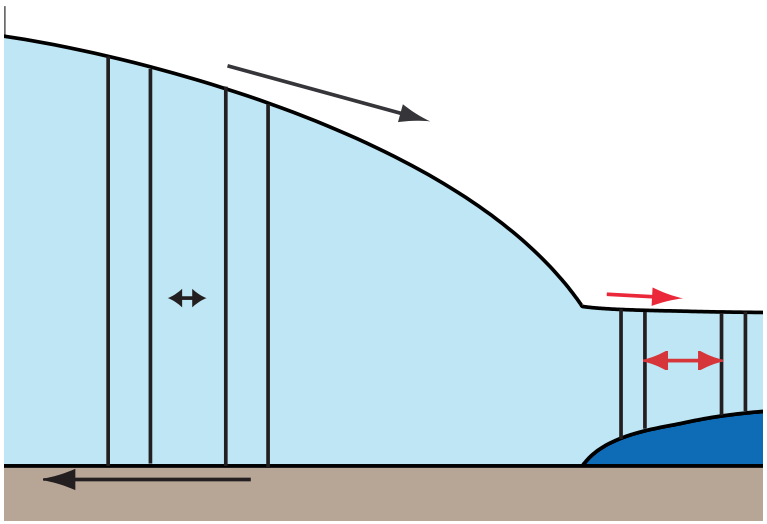
Why is this difficult?

In grounded ice, pressure gradient due to surface slope mostly balanced by stress at base



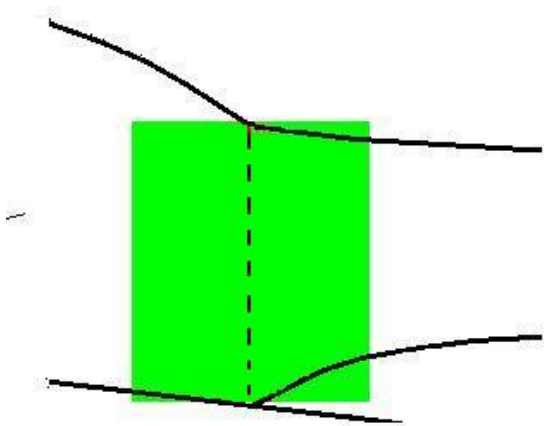
Why is this difficult?

While in floating ice, pressure gradient balanced by lateral stretching and shearing; and so there is a boundary layer near the grounding line in stress (and surface slope)



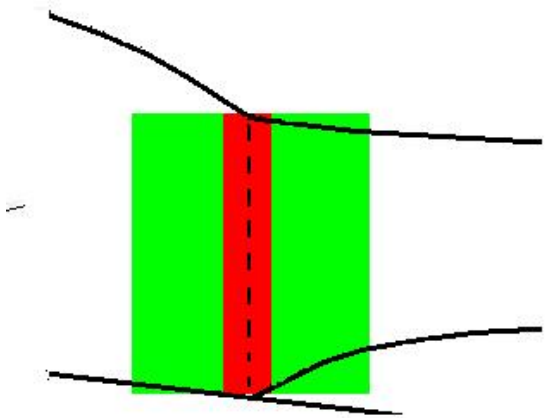
Are these boundary layers important?

- There is a "Glaciostatic transition region" over which lateral internal stresses become important in grounded ice
- While some have argued this is *passive*, Schoof (2007) and others have shown that it is *active*, i.e. its bulk properties (stress, flux) affect the large scale



Are these boundary layers important?

- There may be an "inner" transition region where non-glaciostatic forces become important (Wilchinsky and Chugunov, 1996), especially if there is little or no basal sliding
- But it is not clear whether this "inner" boundary layer is an *active* one



Modeling of grounding line dynamics

- Most has been in flowline (x-z) models
  - Grounding line is simply a point
- Most have used Glaciostatic (or further) approximations
  - Complicated contact problem for grounding line location is avoided, simple floatation condition can be used

Marine instability

- Using a flowline model, Weertman (1973) argued that flux increases with ice thickness at the grounding line.
- This leads to the argument of unstable steady states when the ice sheet rests on a foredeepened bed

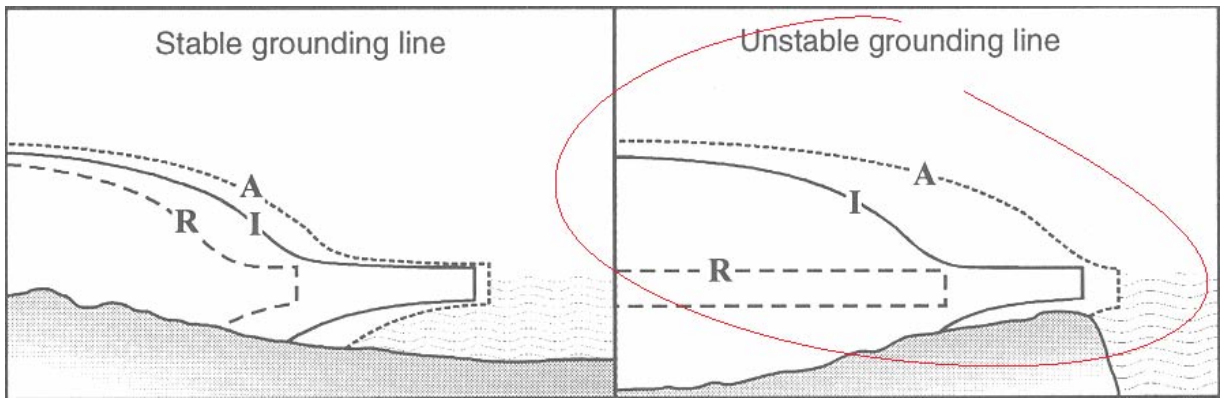


Figure: Van der Veen, Fundamental of Glacier Dynamics

- However, Dupont and Alley (2005) showed that buttressing can reverse the instability

Modeling of grounding line dynamics

Vieli and Payne (2005) examined grounding line migration in flowline models and found disagreement with Weertman and with "common sense"

- Continuum of equilibrium configurations for a given forcing (inconsistent with other results)
- Extreme sensitivity of model to numerical resolution

Modeling of grounding line dynamics

Schoof (2007) - matched asymptotic treatment of transition zone in a depth-integrated flowline model with unbuttressed shelf

- Suggests that Vieli and Payne were underresolved or did not treat lateral stresses correctly
- Provides parameterization in form of functional dependence of flux on thickness at grounding line

2D grounding line

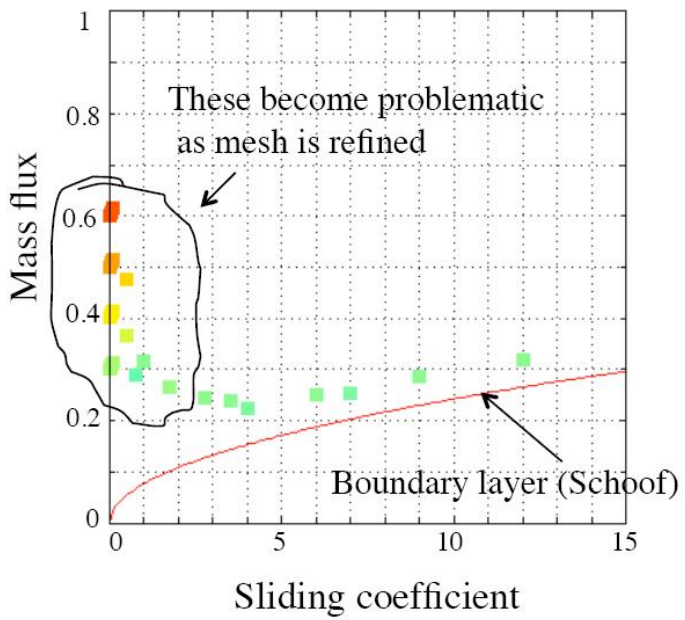
Grounding line activity in two horizontal dimensions

- Goldberg, Holland and Schoof (2007) made use of adaptive meshing to resolve stress and thickness gradients near grounding line
- Pollard and DeConto (2009) adopt an extension of Schoof's parameterization to assess grounding line flux
- Both glaciostatic, depth-integrated models

Full Stokes

Grounding line activity in non-Glaciostatic models

- Durand et al (2009) used a Full Stokes flowline model and obtained results similar to that of Schoof (2007)
- Nowicki and Wingham (2008) - results suggest that at reasonable sliding velocities flux has one-to-one relationship with thickness



Verification

How can we know whether these (idealized) simulations are solving the equations correctly?

- Intercomparison tests (MISMIP)
- Quasi-analytic solutions (i.e. Schoof, 2007)
- Numerical convergence (barring numerical artifacts)
  - Goldberg, Schoof, Holland, unpublished: depth-integrated flowline model has a unique time-dependent solution to which numerical model is guaranteed to converge

What is important for grounding lines?

Jakobshavn Isbrae

- Controls on seasonal calving of ice tongue is large part of the equation
- Differs from West Antarctic ice streams in that it cannot be described by a depth-integrated model (Truffer and Echelmeyer, 2003)

What is important for grounding lines?

Siple Coast

- Small surface slopes, small basal stress (<10) except for "sticky spots"
- With recent activity in streams and relative stagnancy of grounding line, the question of g.l. migration might not be the most relevant (IMHO)

What is important for grounding lines?

Pine Island

- Strong evidence that g.l. is moving (Rignot, 1998) and that melting is related to inland thinning (Shepherd et al, 2004)
- Models suggest that changes in shelf and grounding line can have strong impact on grounded ice (Schmeltz et al, 2002, Payne et al, 2004)