Implementing Damage Mechanics in the Community Ice Sheet Model

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ENGINEERING CLASP

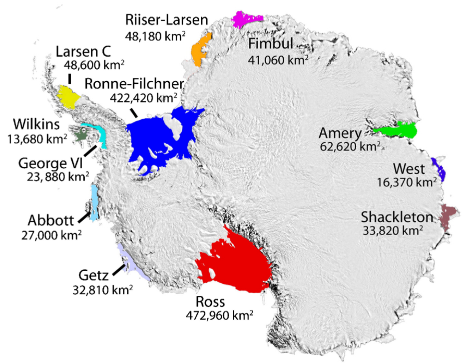
What Is Calving, and Why Do We Care?

- Responsible for $\sim$ 50% of ice mass loss from both ice sheets

Columbia Glacier, AK. **Source:** NASA and U.S. Army Engineer Research & Development Center

Existing Calving Schemes and Ice Shelves

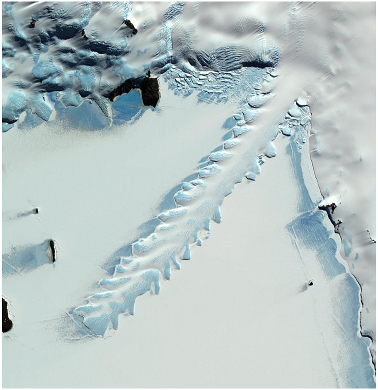
- Two possible criteria:
  1. Flotation, determined directly or by analyzing water depth
  2. Thickness
- Useful for tidewater glaciers - not so useful for ice shelves
- We want to describe how crevasses propagate and change through the ice



Source: National Snow & Ice Data Center

Ice Shelf Geometries - Satellite Images

Larsen Ice Shelf, Antarctica. **Source:** NASA



Erebus Ice Tongue, Antarctica. **Source:** ASTER, Jet Propulsion Laboratory, Caltech

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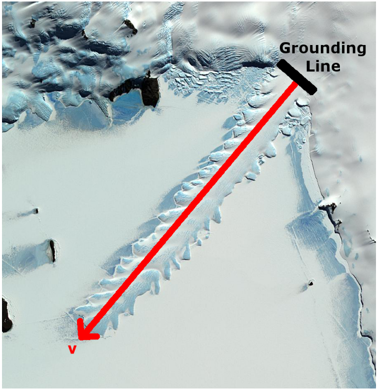
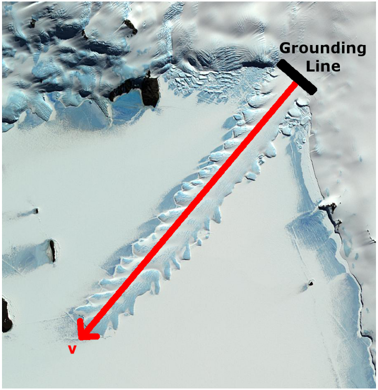


Erebus Ice Tongue, Antarctica. **Source:** ASTER, Jet Propulsion Laboratory, Caltech

Test Case: 1D Ice Tongue

- Simple geometry
- Exact analytic solutions for thickness H, velocity $\mathbf{v}$, and deviatoric stress τ_{yy}



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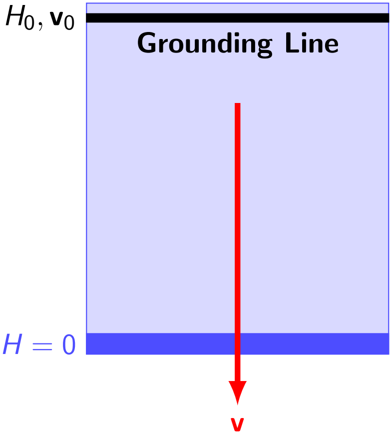

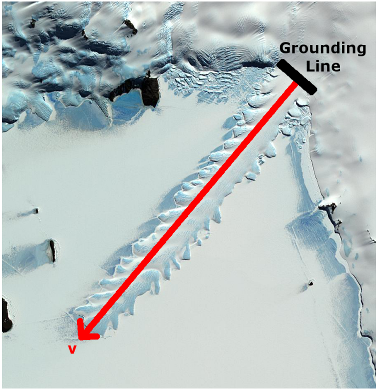

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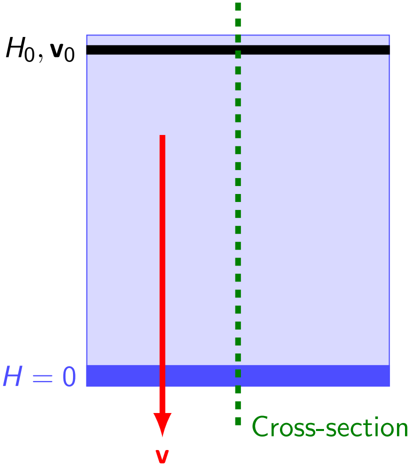

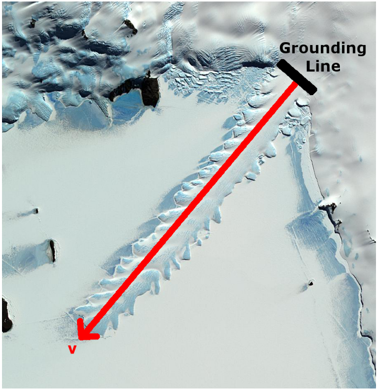

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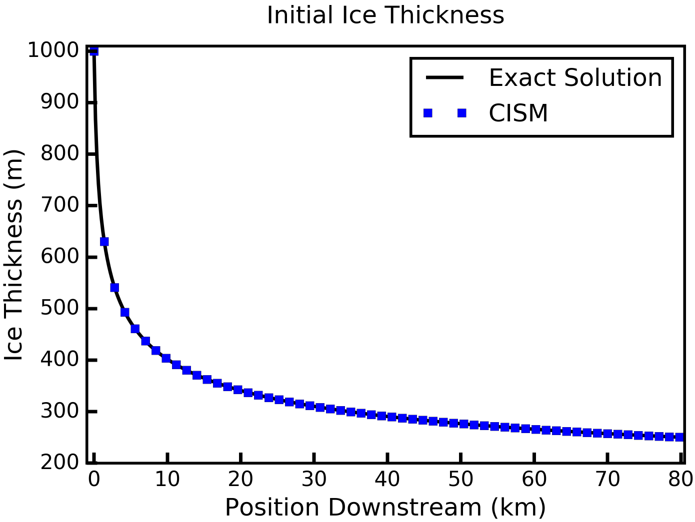
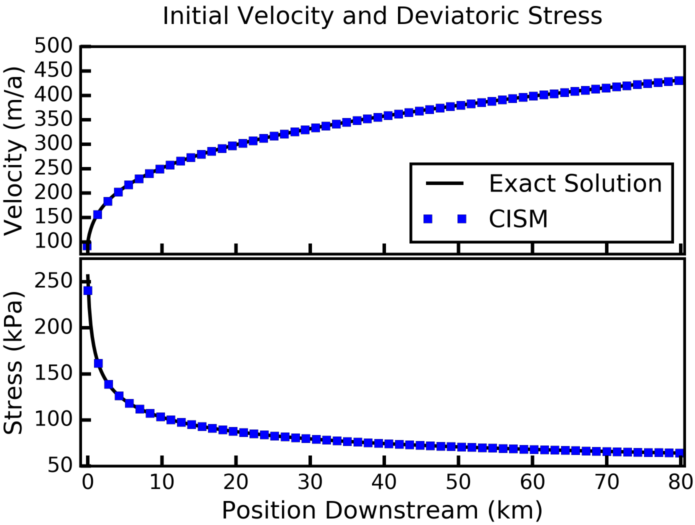
Initial Thickness Profile - Analytic Solution



Initial Velocity and Stress Profiles



Damage Mechanics

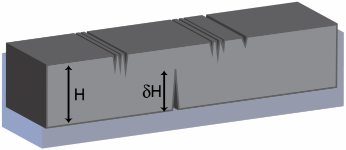
- Define damage as

$$r \equiv \frac{\delta H}{H}$$

- Initialization: everywhere on our geometry,

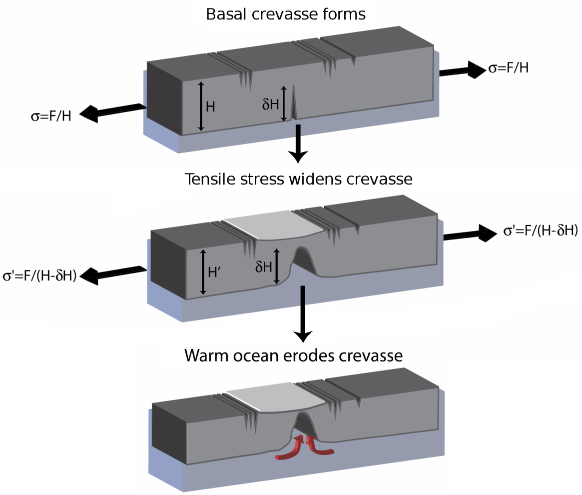
$$r_0 = \text{constant}$$

- Time evolution: what governs changes in damage?



Source: Bassis & Ma. *Earth Planet. Sci. Lett.*, 2015

Damage Mechanics



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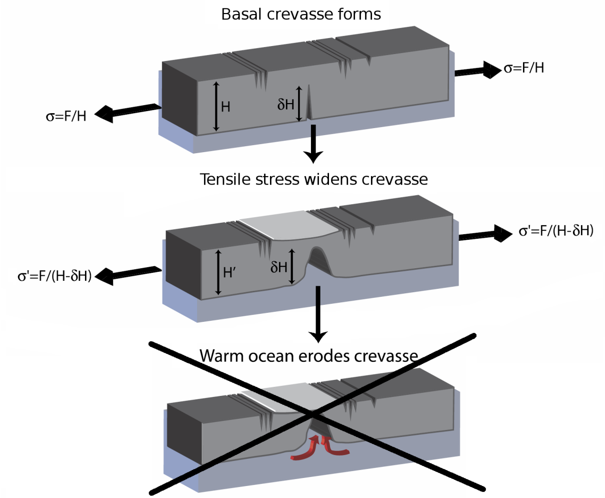
$$\frac{\partial r}{\partial t} + v\frac{\partial r}{\partial y}$$

$$\left[-3\left(S_0 - 1\right)\dot{\epsilon}_{yy}\right] r$$

$$\left[\frac{\dot{m}}{H}\right] r$$

Damage Mechanics



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Damage Mechanics

- Time evolution: how can we verify that it works?

$$\frac{\partial r}{\partial t} + v\frac{\partial r}{\partial y} = \left[-3\left(S_0 - 1\right)\dot{\epsilon}_{yy}\right] r$$

Damage Mechanics

- Time evolution: how can we verify that it works?

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where $S_0 = \frac{\text{pressure}}{\text{stress}}$ (dimensionless)

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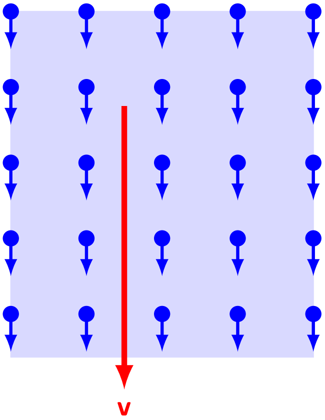
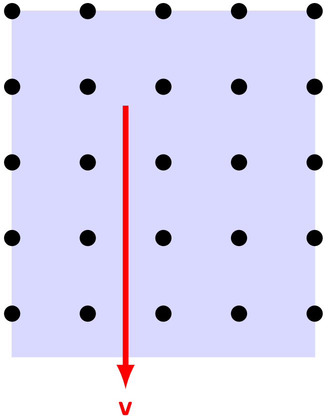
Simple Damage Solution - No Advection



Advection: damage moves with the ice



No advection: damage fixed to grid points

Damage Mechanics

- Time evolution: how can we verify that it works?

$$\frac{\partial r}{\partial t} + \cancel{v\frac{\partial r}{\partial y}} = \left[-3\left(S_0 - 1\right)\dot{\epsilon}_{yy}\right] r$$

$$\text{where } S_0 = \frac{\text{pressure}}{\text{stress}}\,(\text{dimensionless}) \approx 2$$

Damage Mechanics

- Time evolution: how can we verify that it works?

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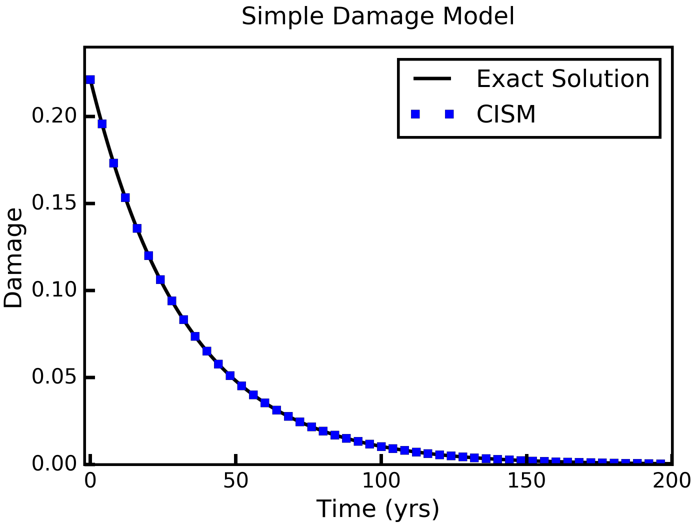
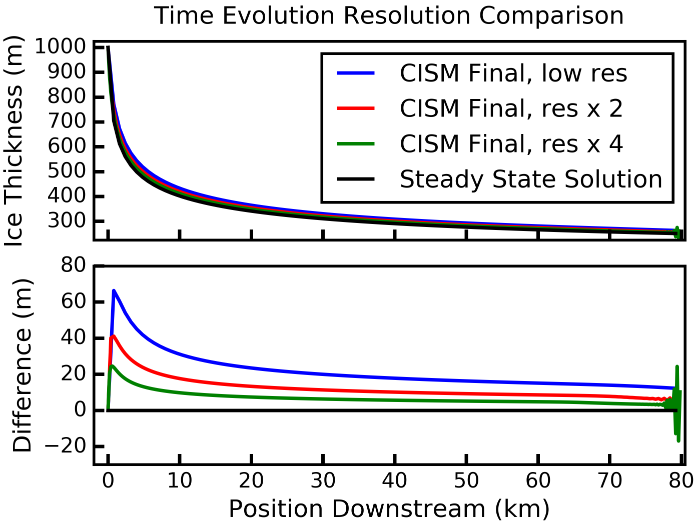
$$\text{where } S_0 = \frac{\text{pressure}}{\text{stress}}\,(\text{dimensionless}) \approx 2$$

$$\frac{\partial r_s}{\partial t} = -3\left(S_0 - 1\right)\dot{\epsilon}_{yy} r_s \longrightarrow \boxed{r_s\left(t\right) = r_0 \exp\left[-3\left(S_0 - 1\right)\dot{\epsilon}_{yy} t\right]}$$

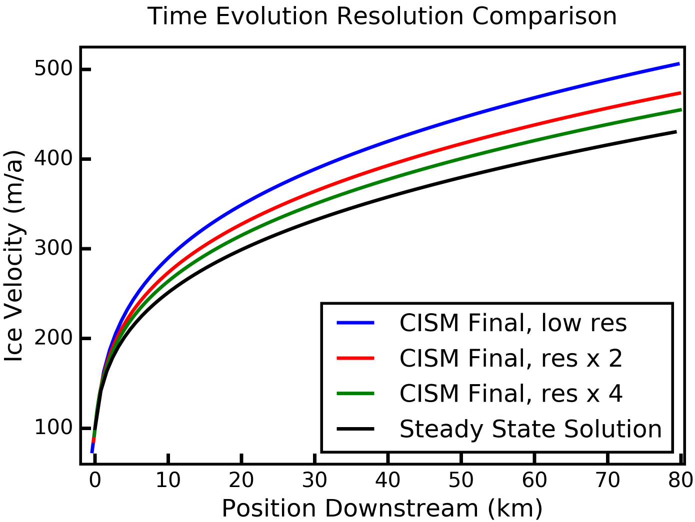
Damage Results - Time Evolution, No Advection



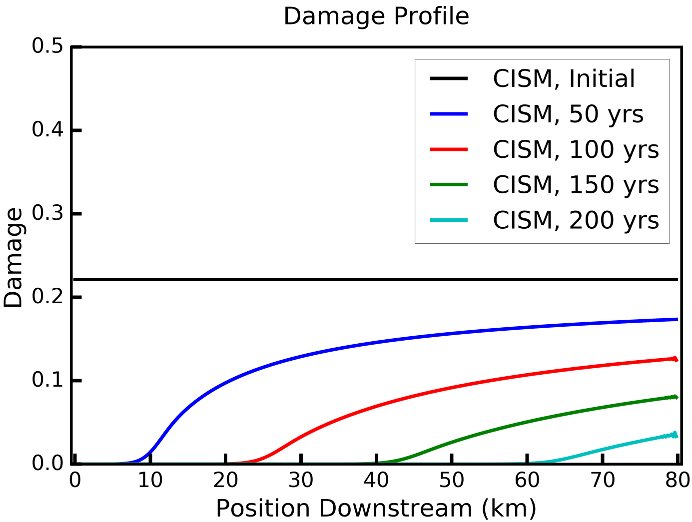
Thickness Profile - Time Evolution



Velocity Profile - Time Evolution



Damage Results - Time Evolution, Advection



Roadmap

1. Allow temperature to vary:

$$\frac{\partial r}{\partial t} + v\frac{\partial r}{\partial y} = -\left[3\left(S_0 - 1\right)\dot{\epsilon}_{yy}\right] r, \quad S_0 \sim \frac{\text{pressure}}{\text{stress}}$$

2. Implement a calving criterion
   - Calving occurs with $\delta H < H$, so $r = 1$ is not quite right

3. Test realistic ice shelf geometries

Thank You!

Acknowledgements

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