A Stochastic Case Study: Monte Carlo ice flow modeling projects a new stable configuration for Columbia Glacier, Alaska, by c. 2020

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LIWG Workshop
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Online in *The Cryosphere Discussions* (tc-2012-15)

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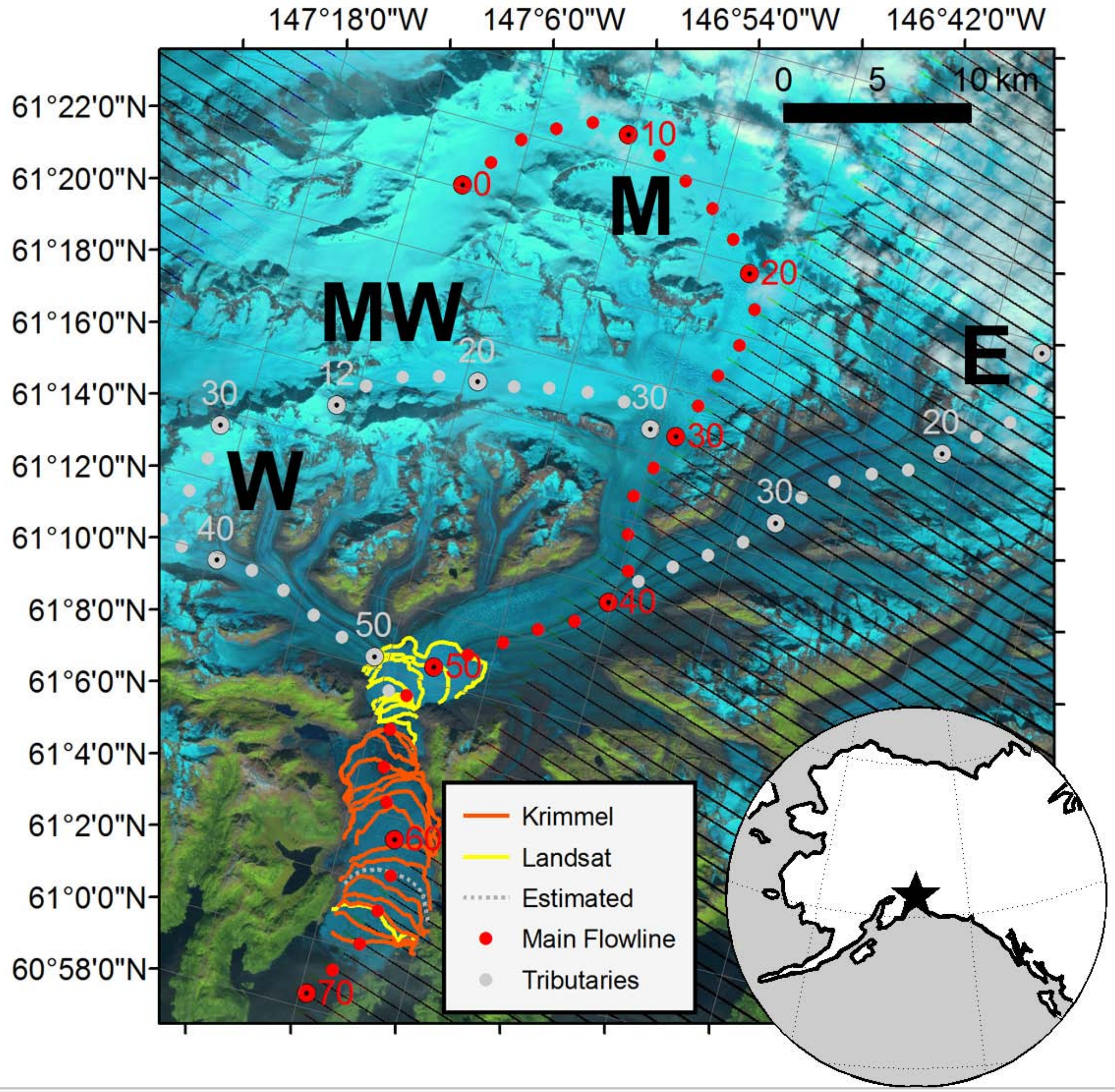
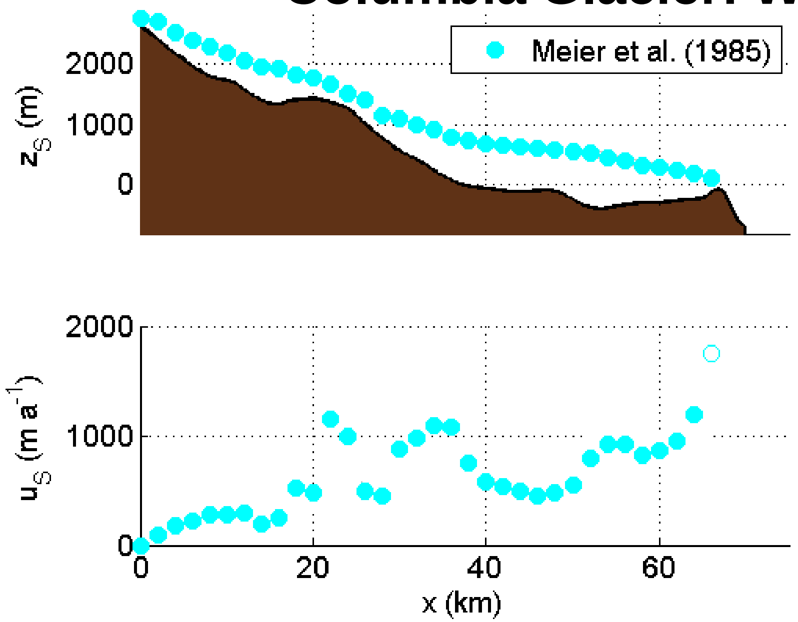
Columbia Glacier: Highly transient modeling target

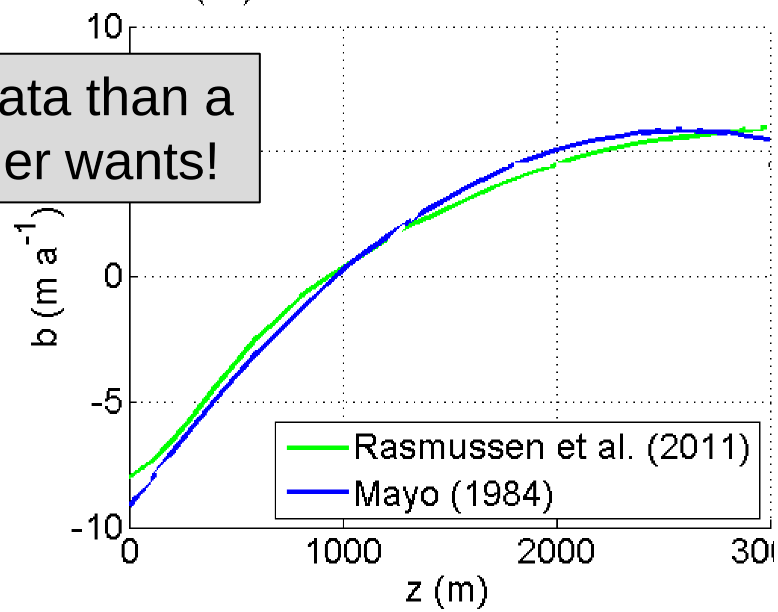
Projecting uncertainty benefits from models being executed many times (n > 1000) under slightly different conditions.

- ~ 18 km of retreat and ~ 100 km^2 loss of ice covered area since 1983.
- ~ 0.6 % of global sea level rise over the 2003-2007 period.

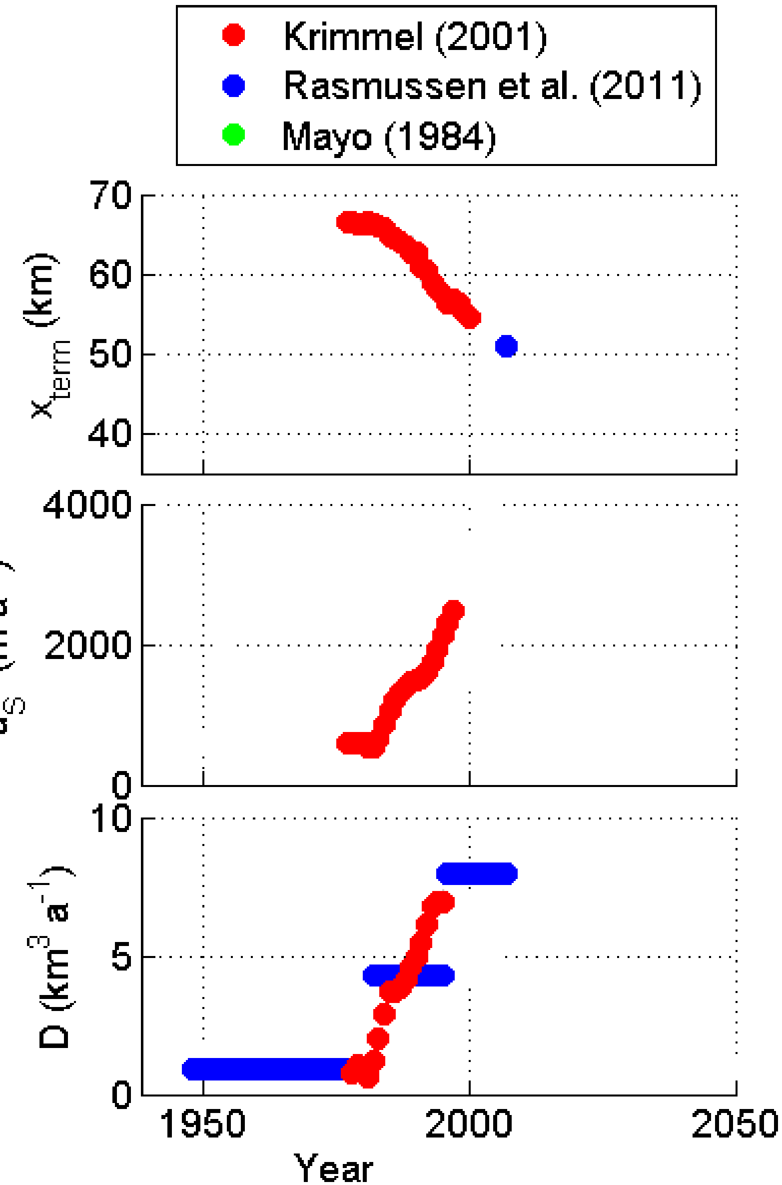


Columbia Glacier: Well-documented modeling target





More data than a modeller wants!



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“Typical” 1D (depth-integrated) ice flow model

$$\frac{\partial H}{\partial t} = b - \frac{1}{w}\frac{\partial Q}{\partial x}$$

$$Q = Fw\left(u_b H + \frac{2A}{(n+2)}\left(\rho g \left|\frac{\partial z_s}{\partial x}\right|\right)^{(n-1)} \tau H^{(n+1)}\right)$$

$$\tau = -\rho g H \frac{\partial z_s}{\partial x} + \ 2\frac{\partial}{\partial x}\left(H\bar{\tau}'_{xx}\right)$$

$$0 = \bar{\tau}'_{xx}{}^{3}\left\{2\frac{\partial z_s}{\partial x}\left(\frac{\partial H}{\partial x} - \frac{\partial z_s}{\partial x}\right) + H\frac{\partial^2 z_s}{\partial x^2} - \frac{1}{2}\right\} + \bar{\tau}'_{xx}{}^{2}\left\{\tau\left(\frac{2}{3}\frac{\partial H}{\partial x} - \frac{3}{2}\frac{\partial z_s}{\partial x}\right)\right\} + \ldots$$

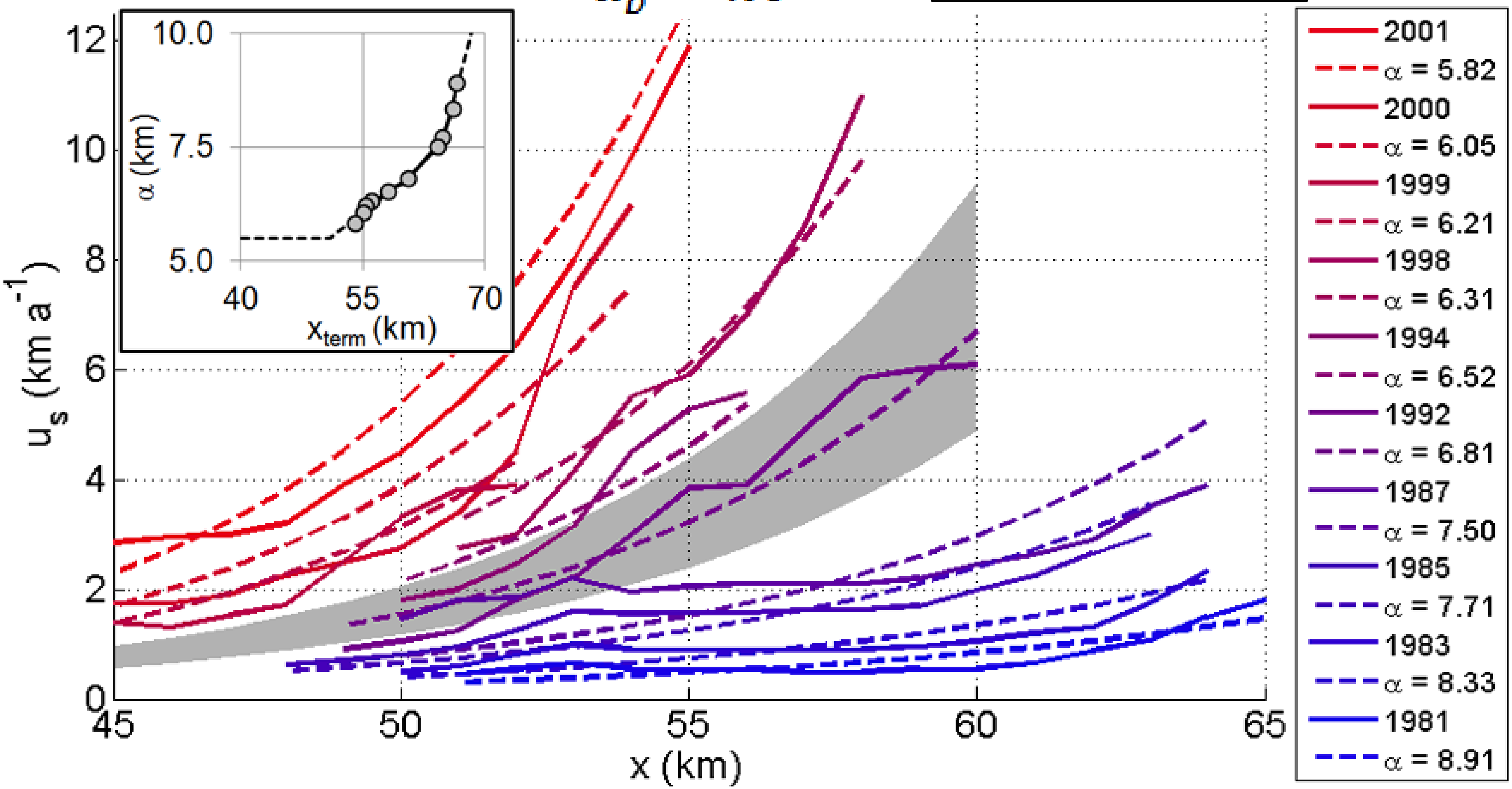
$$\bar{\tau}'_{xx}\left\{\tau^2\left(3\frac{\partial z_s}{\partial x}\frac{\partial H}{\partial x} + \frac{3}{2}H\frac{\partial^2 z_s}{\partial x^2} - 2\left(\frac{\partial z_s}{\partial x}\right)^2 - \frac{1}{6}\right)\right\} + \tau^3\left(\frac{2}{5}\frac{\partial H}{\partial x} - \frac{1}{4}\frac{\partial z_s}{\partial x}\right) + \frac{1}{2A}\frac{\partial u_b}{\partial x}$$

Upstream BC: Type 2 (specified flux) Q = 0 at flow divide
Downstream BC: Type 1 (specified head) of observed ice cliff height
Top BC: Statistical param. of surface mass balance (wide param. space)
Bottom BC: Statistical param. of basal sliding velocity (wide param. space)

Statistical Parameterization: Basal sliding velocity

$$u_b = ke^{(x/\alpha)}$$

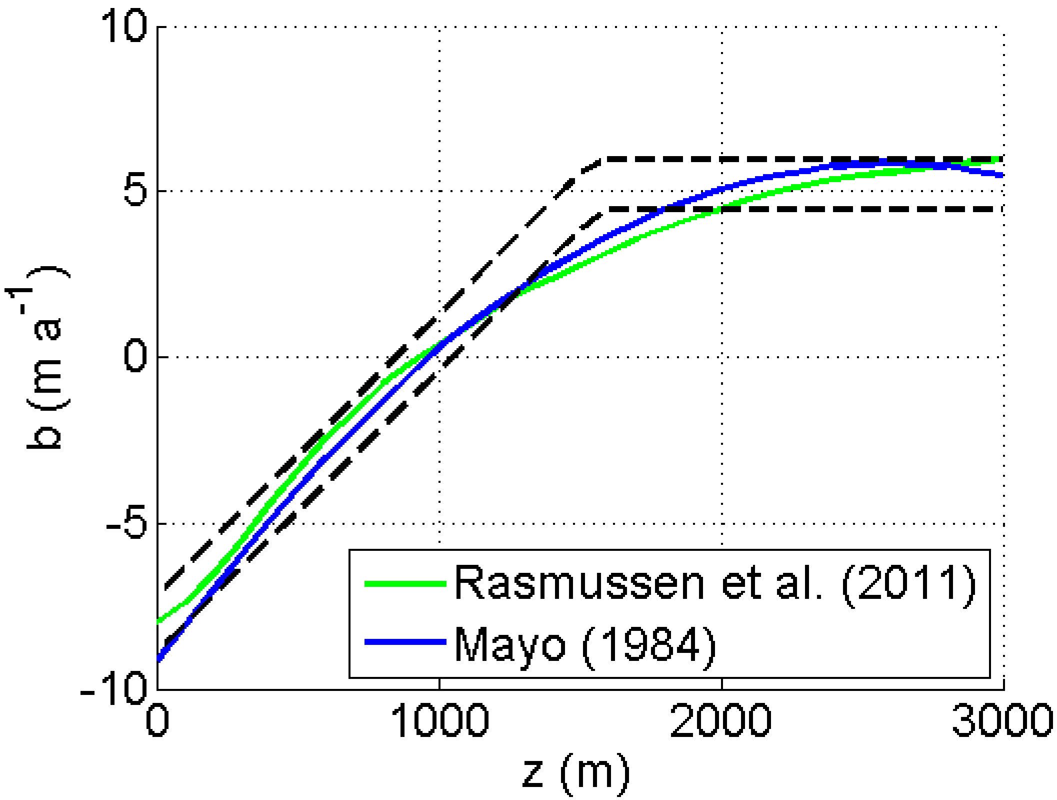
No physics: f(x)



Length scale alpha varies within this range each simulation

Statistical Parameterization: Surface mass balance

$$b = \begin{cases} \gamma(z_s - z_{ela}) & \text{if } b < b_{max} \\ b_{max} & \text{if } b \geq b_{max} \end{cases}$$

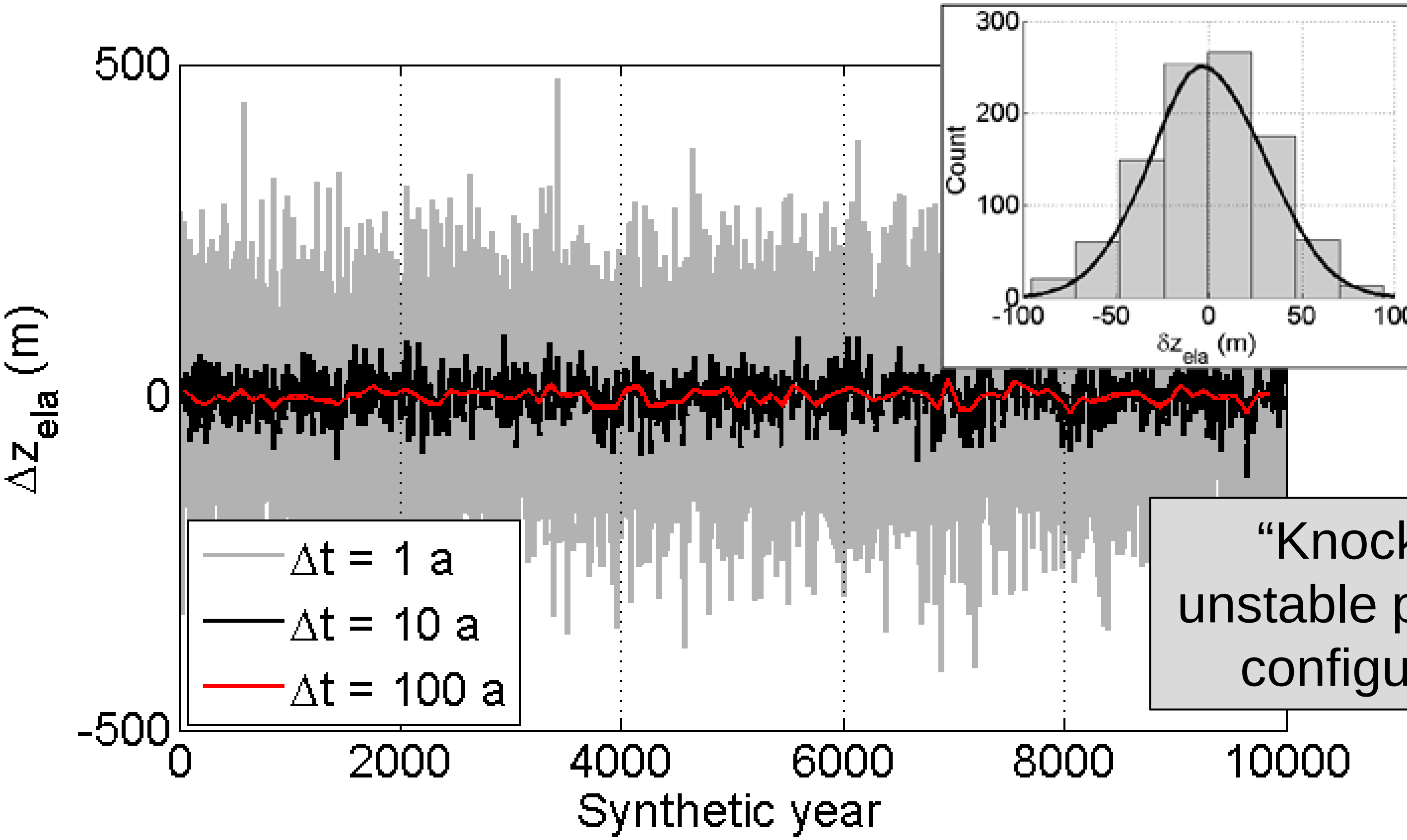


...also no physics: f(z)

Surface mass balance varies within this range each simulation

Statistical Parameterization: Climatic variability

$$\frac{\Delta z_{ela}}{\Delta t} = \left(\frac{\Delta T}{\Delta t}\right)\left(\frac{\Delta T}{\Delta z}\right)^{-1}$$



"Knocks out" unstable parameter configurations

Randomly perturb ELA every decade

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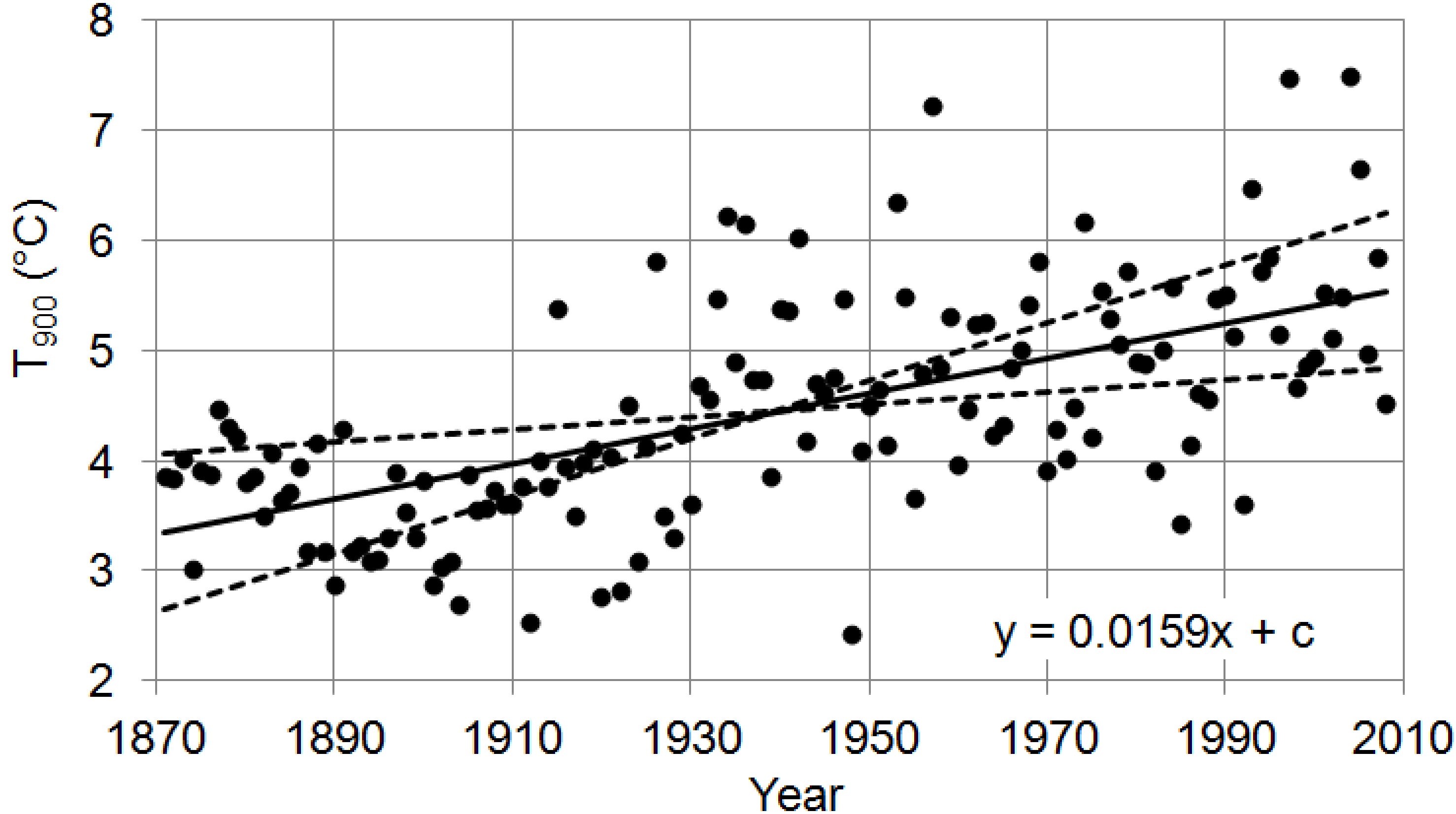
Statistical Parameterization: Climate forcing

$$\frac{\Delta z_{ela}}{\Delta t} = \left(\frac{\Delta T}{\Delta t}\right)\left(\frac{\Delta T}{\Delta z}\right)^{-1}$$



Randomly prescribe forcing from this range of 900mb air temperature increase

Ensemble selection: A diverse population of Columbia Glaciers

5000 simulations

↓

Is pre-retreat ice geometry (i.e. $\overline{H}_{40\text{-}60km}$ and x_{term}) reproduced?

→ 3118 (62%) **“A”**

↓

1882 (38%) **“B”**

↓

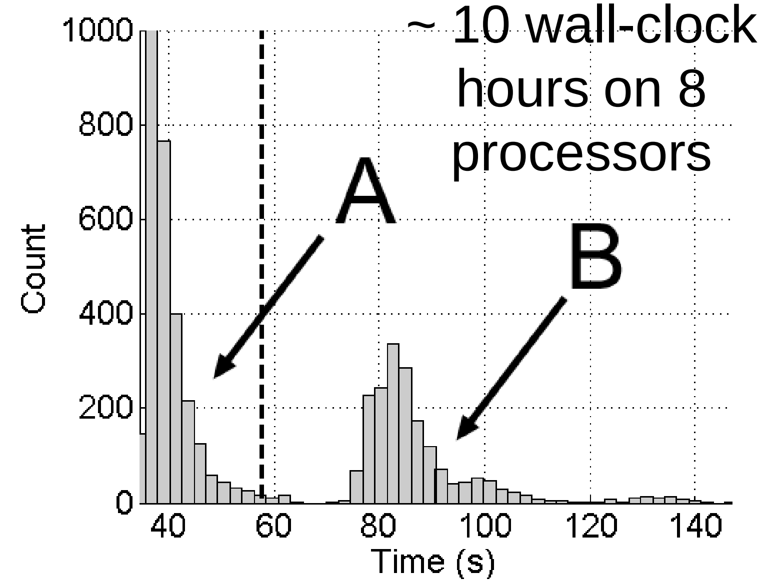
Retreat (i.e. x_{term}) within 100 years of forcing?

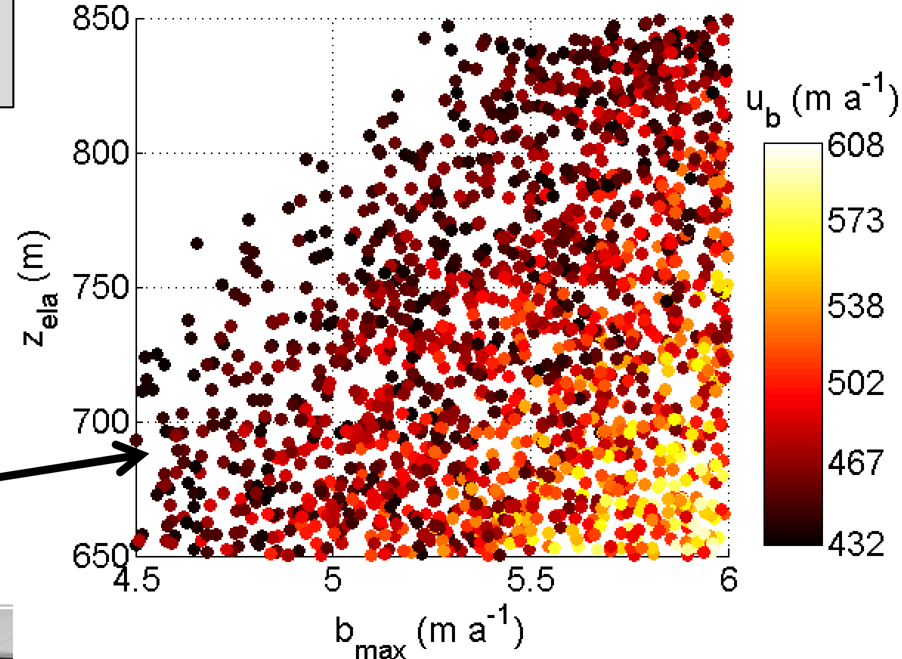
→ 175 (4%)

↓

1707 (34%)

Forward model selection





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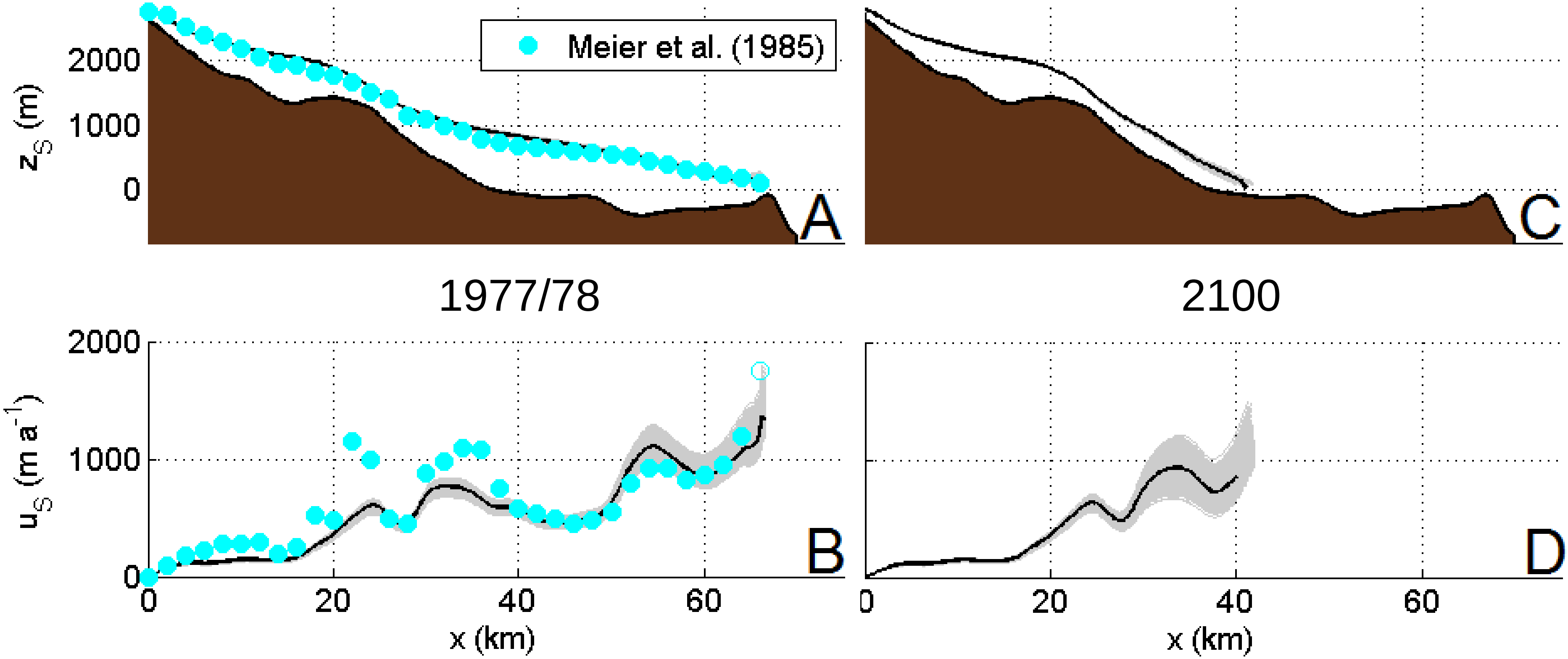
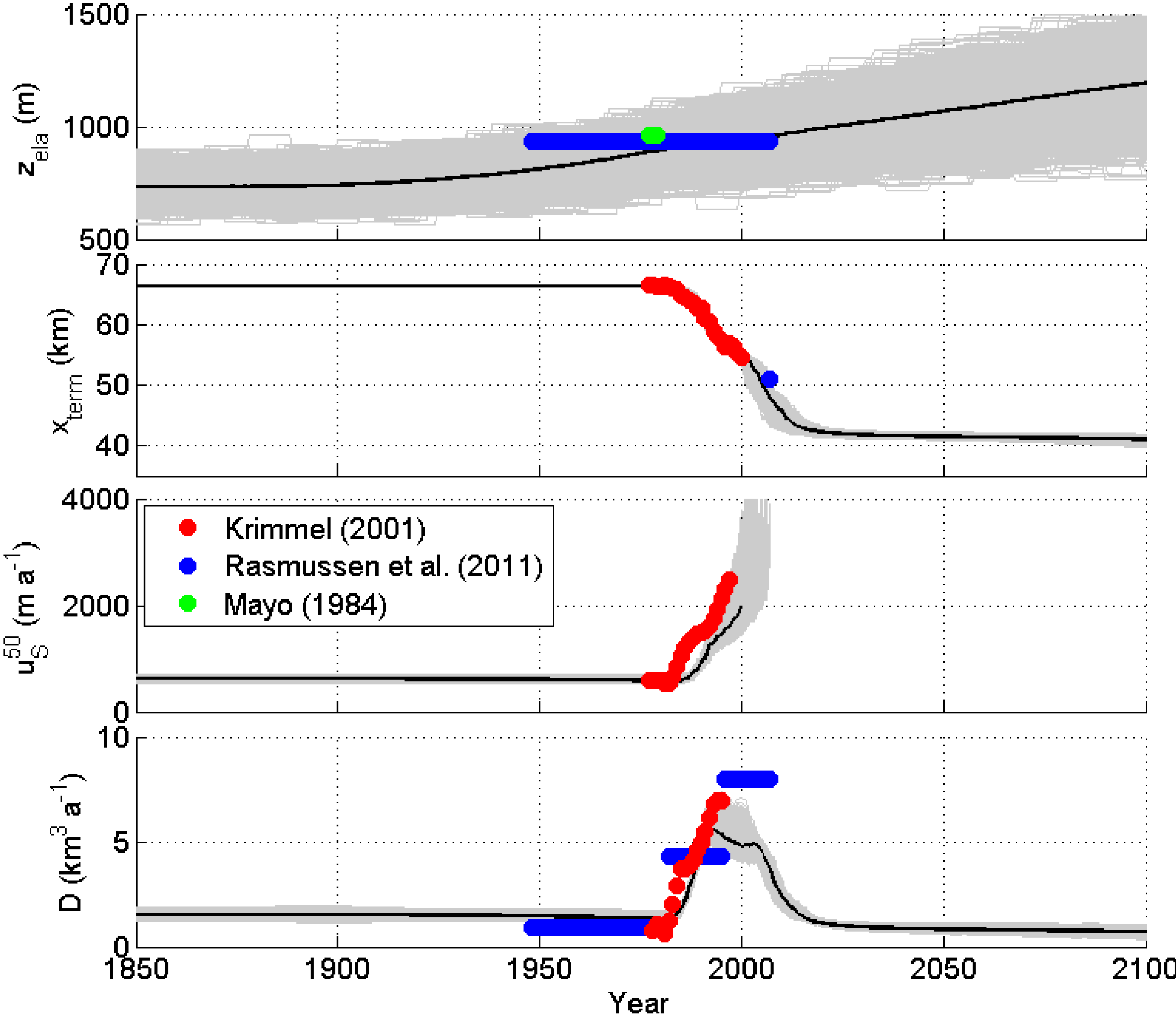
Results: Selected ensemble



The momentum approx. fails in some spots, but overall good fit…

…confidence in future ice geometry: 83 % of ice loss occurred by 2007

Results: Selected ensemble



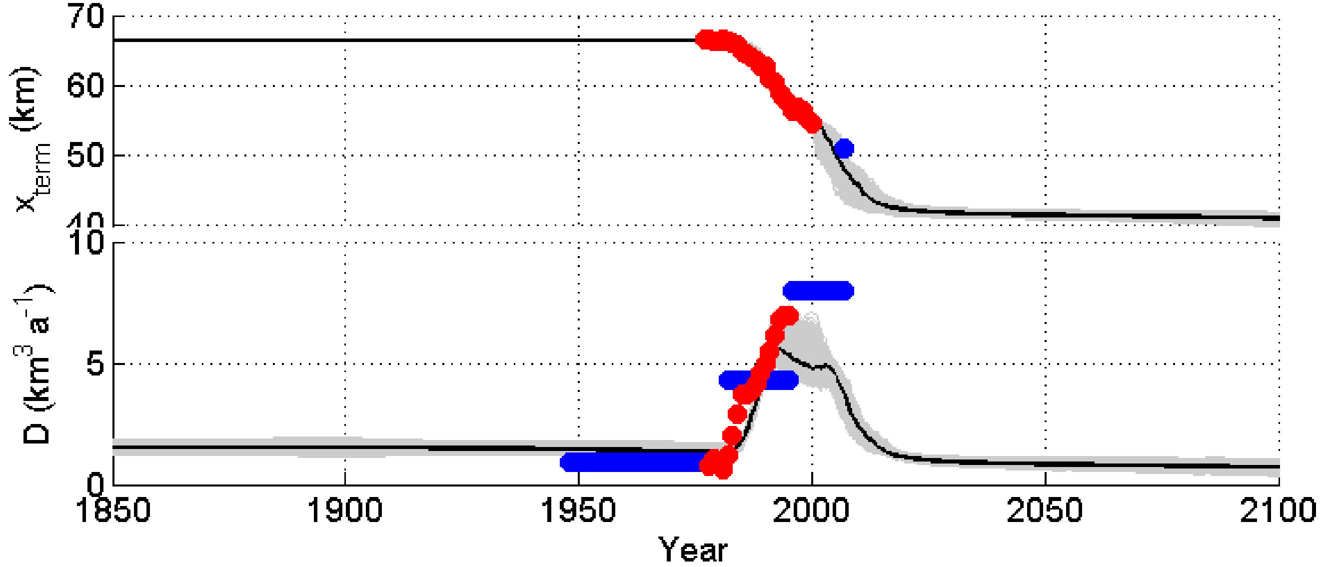
Reasonable SMB and climate variability

New stable geometry c. 2020

Not bad for blunt statistical parameterization

Return to dynamic equilibrium iceberg calving c. 2020

Discussion points: Applicability beyond Columbia Glacier



High likelihood of spatially (*Venteris*, 1997) temporally (*Meier et al*., 1994) transient ice density at Columbia Glacier:

Is “swelling” of remaining ice suppressing the apparent retreat rate?
How can the momentum balance be modified to accommodate this?

Highly transient iceberg calving can “turn off” just as quickly as it “turned on”:
Can we use rapid response time (i.e. ~ 40 a) to model future ice volume in steady-state with future climate?

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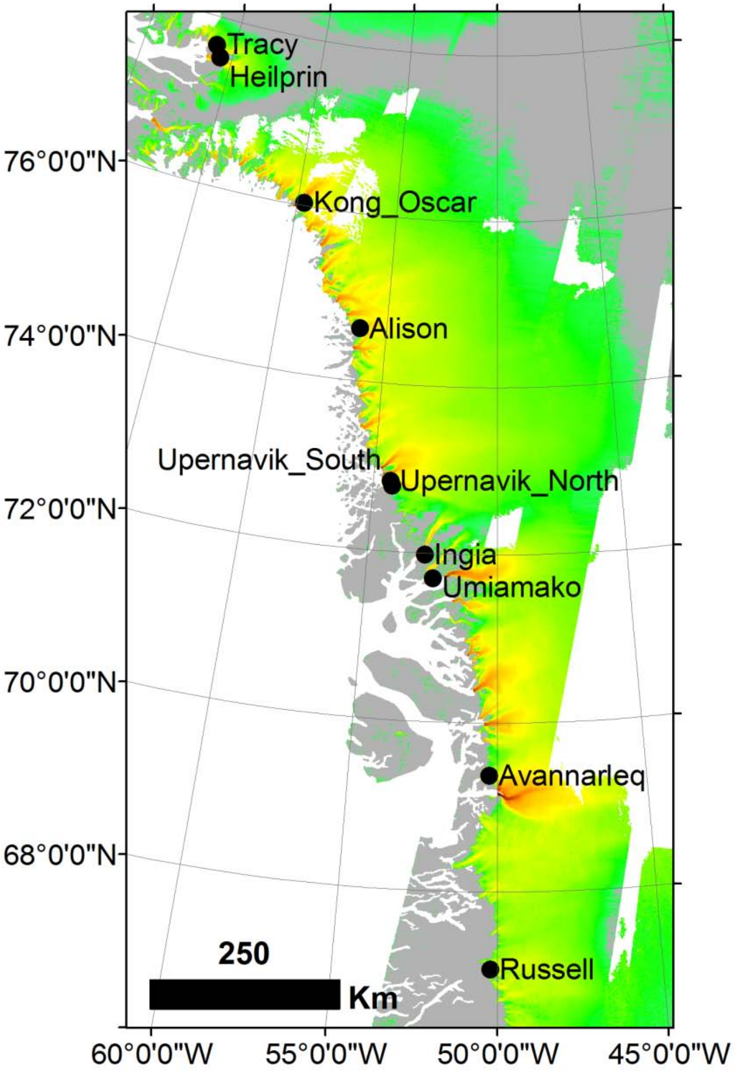
Future work: West Greenland outlet glaciers

NASA ROSES

"Integrating IceBridge and ICESat data with a Monte-Carlo modeling framework to constrain the mechanisms of recent acceleration in West Greenland outlet glaciers."

H. Rajaram, T. Phillips and W. Colgan

- 2D (cross-sectional) thermo-mechanical
- More selection filters (velocity, dH/dt…)
- Five acceleration mechanisms:
  (i) Meltwater-enhanced basal sliding
  (ii) Loss of terminus back-stress
  (iii) Adjustment to surface ablation
  (iv) Decreased effective basal pressure
  (v) Cryo-hyrdologic warming



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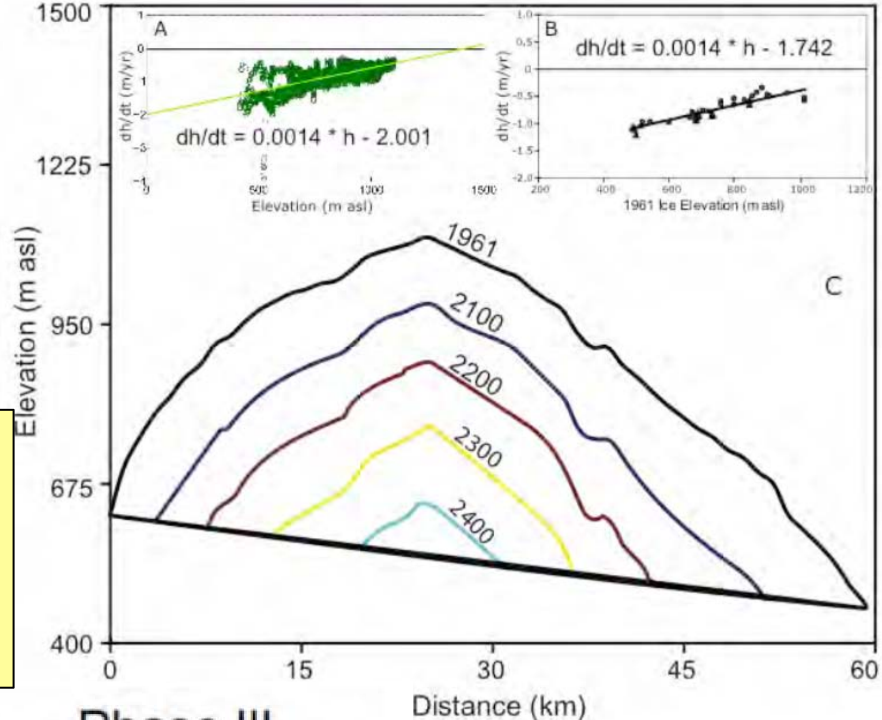
Future work: Barnes Ice Cap

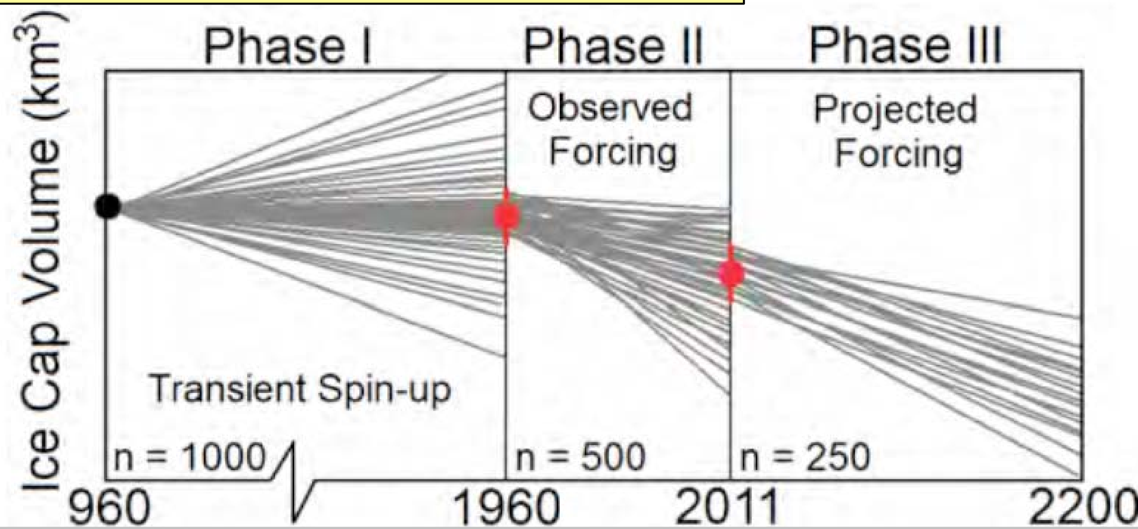
NSF OPP (Pending)

“The End of the Ice Age: Modeling the Disappearance of the Barnes Ice Cap”

G. Miller and W. Colgan

- 3D thermo-mechanical model (Elmer?)
  - Inverse approach to Wisconsin Ice
- Radiocarbon dates: disappearance will be a once in ~ 2.5 Ma event?





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