Impacts of initialisation of coupled ice sheet-ocean models forecasting

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EGU display, 5 May 2020

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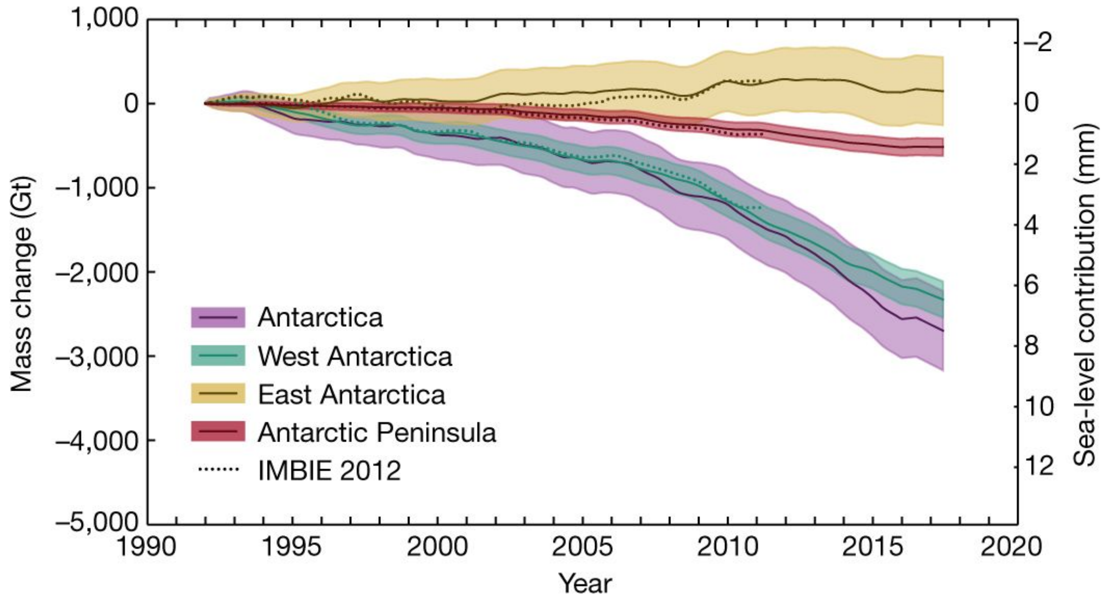
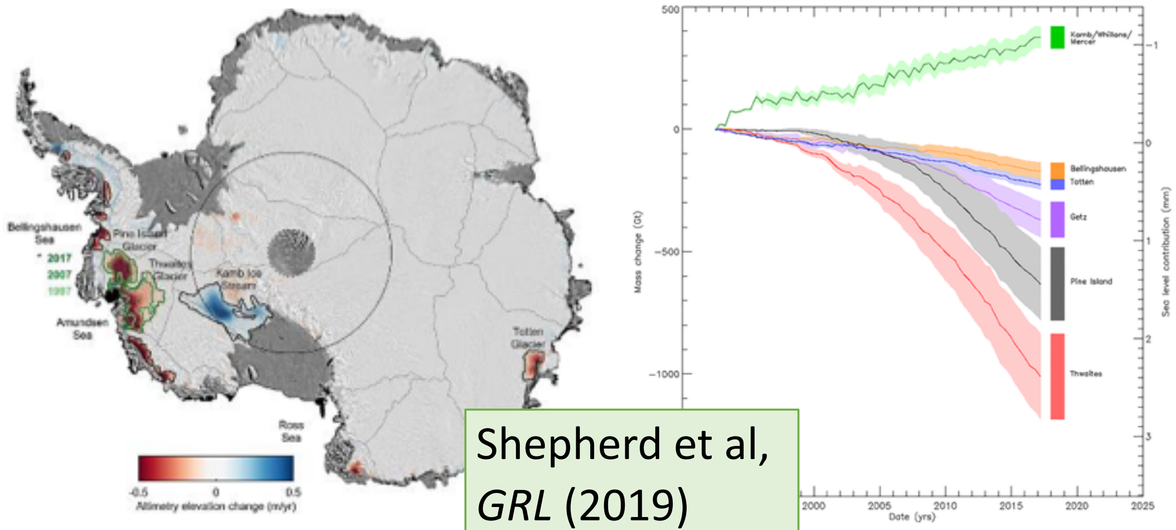
Mass balance trends and Sea Level Contribution



The IMBIE team, *Nature* (2019)



Shepherd et al, *GRL* (2019)

Focussed thinning in West Antarctica

- Amundsen Embayment in particular
- Resulting Sea Level impacts greatest in Northern Hemisphere (*Tamisiea et al, 2012*)

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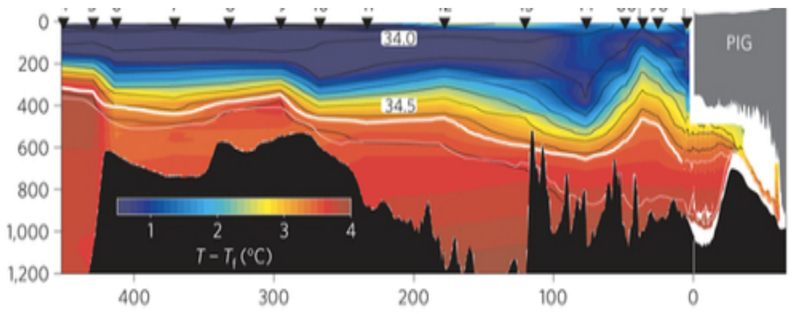
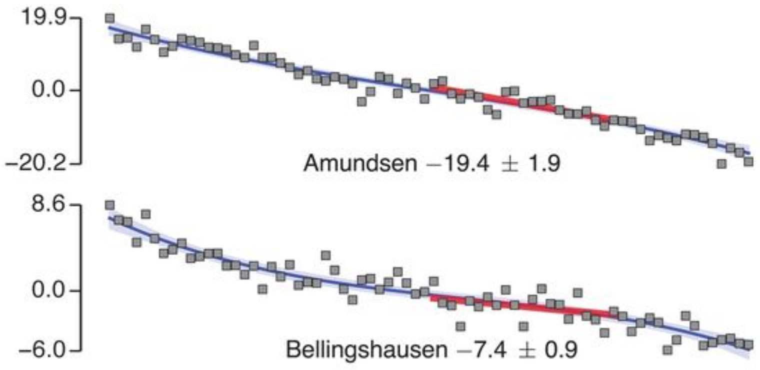
Drivers of loss/retreat

Why is loss so extensive in Amundsen?

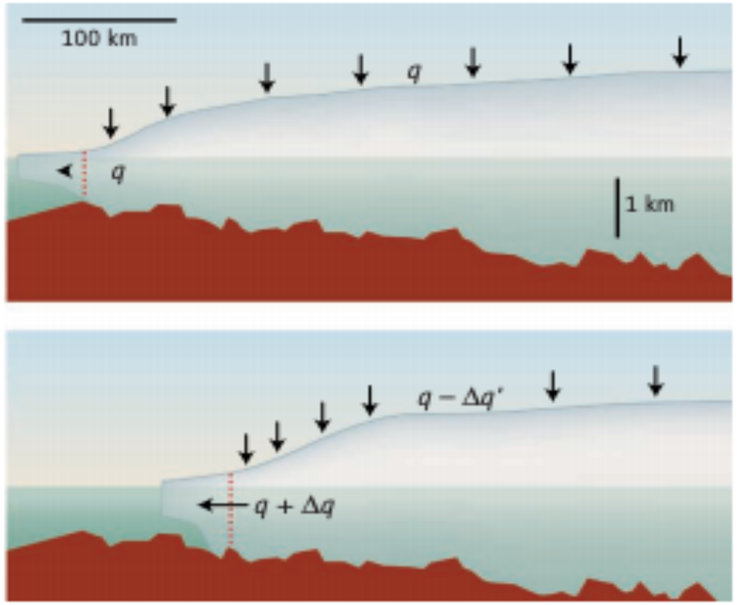
- Access of Warm Circumpolar Deep Water (CDW) to ice-shelf cavities
- High melt rates triggers loss of ice-shelf buttressing and dynamic thinning
- Embayments deepen (and widen) inland, allowing Marine Ice Sheet Instability



Ocean temperatures on Amundsen shelf (Dutrieux et al, 2014)



Ice shelf mean thickness change in meters (Paolo et al, 2015)



Vaughan and Arthern, 2007

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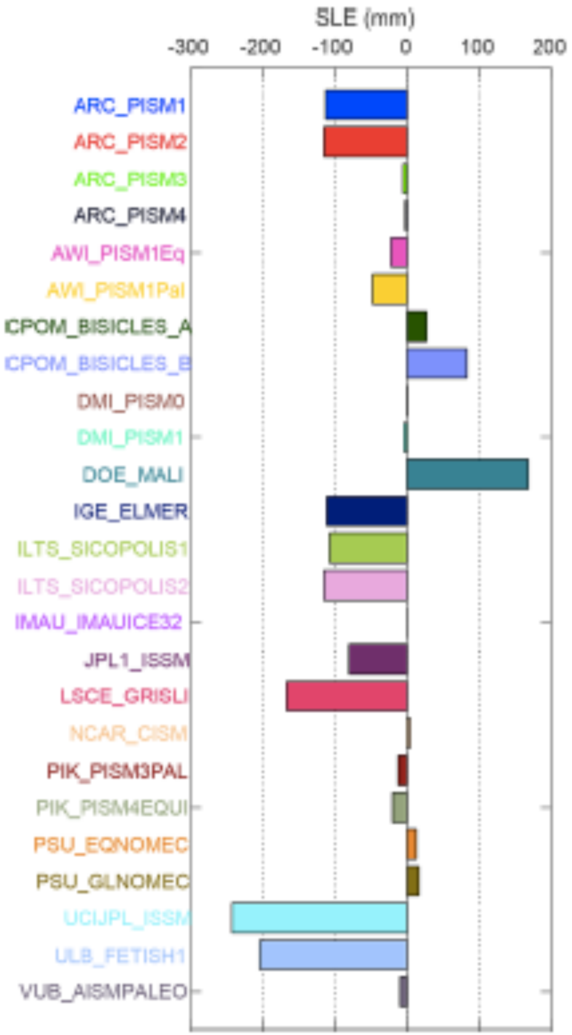
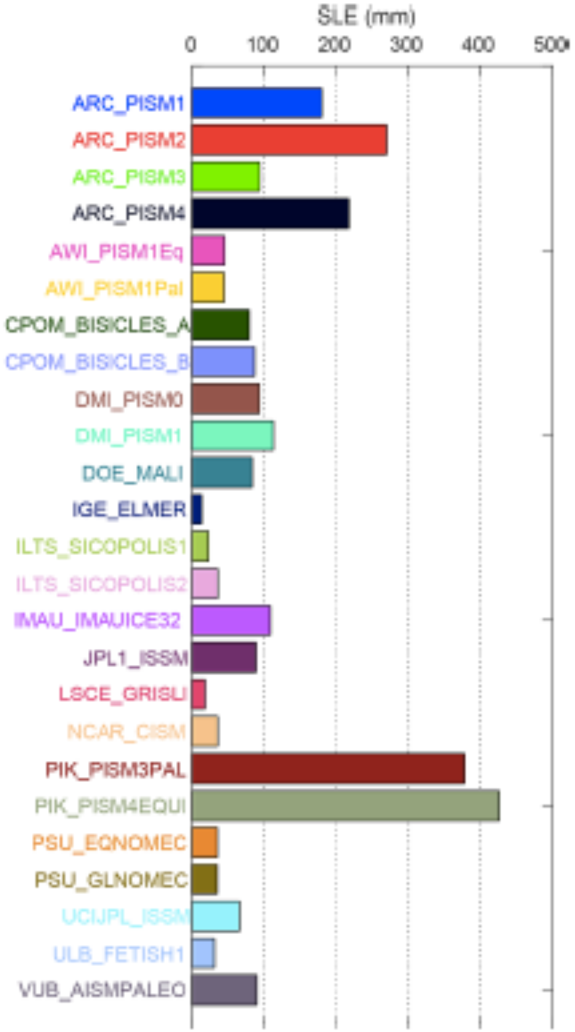
A comparison of Antarctica models



SLR after 100y in CTRL



Perturbed by ice-shelf melt
(Relative to CTRL)

InitMIP-Antarctica (Seroussi et al, 2019)

- Leading Antarctic models initialised to current state, and then forced with *identical* marine forcing
- Models vary widely in response to initialisation procedures

  … as well as response to marine forcing

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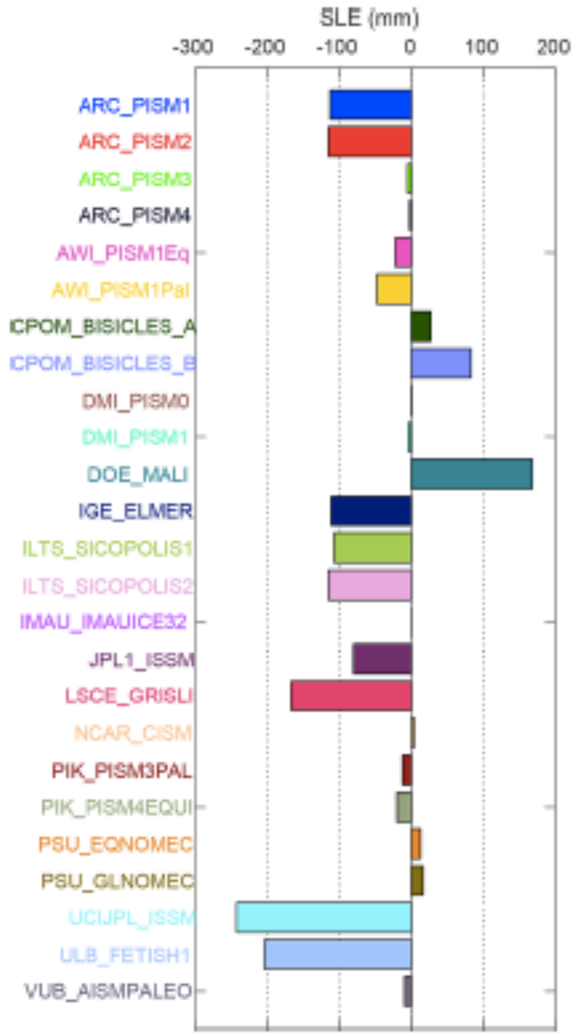
A comparison of Antarctica models



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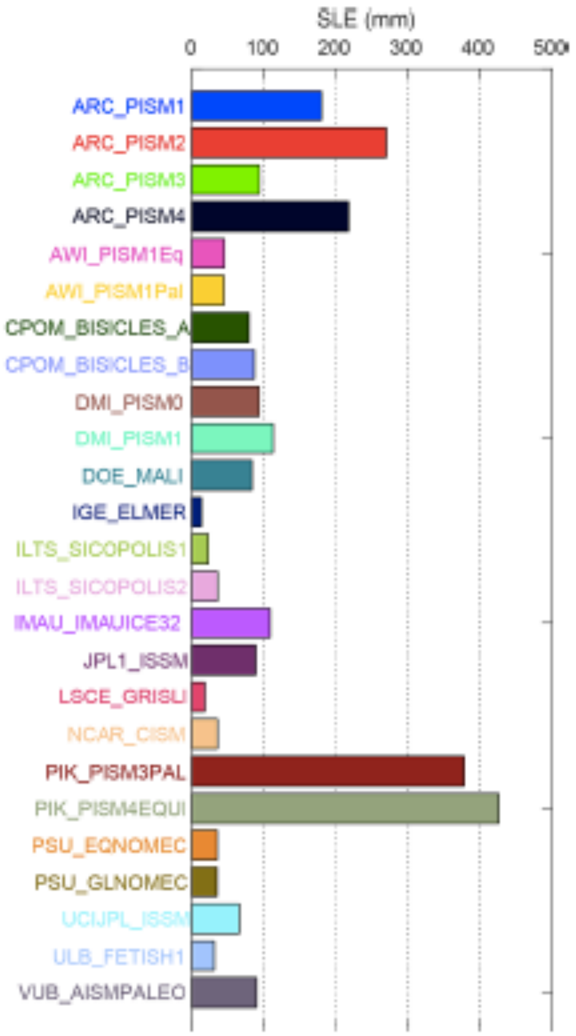

Perturbed by ice-shelf melt
(Relative to CTRL)

InitMIP-Antarctica (Seroussi et al, 2019)

- Spread of models attributed in part to assimilation of ice velocities at a single “snapshot” in time

- A framework for ice-sheet initialisation is needed that ensures *not only* velocity agrees with observations, but **trends in thinning as well**

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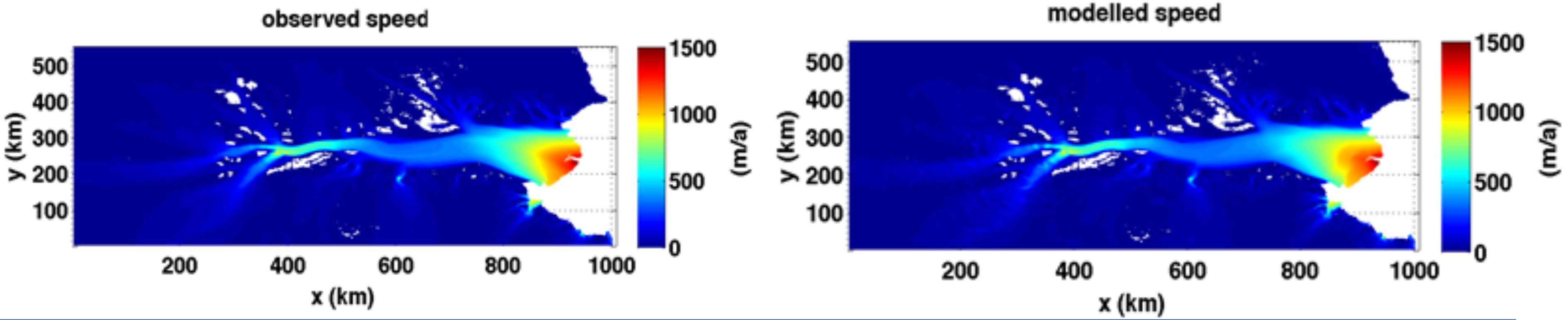
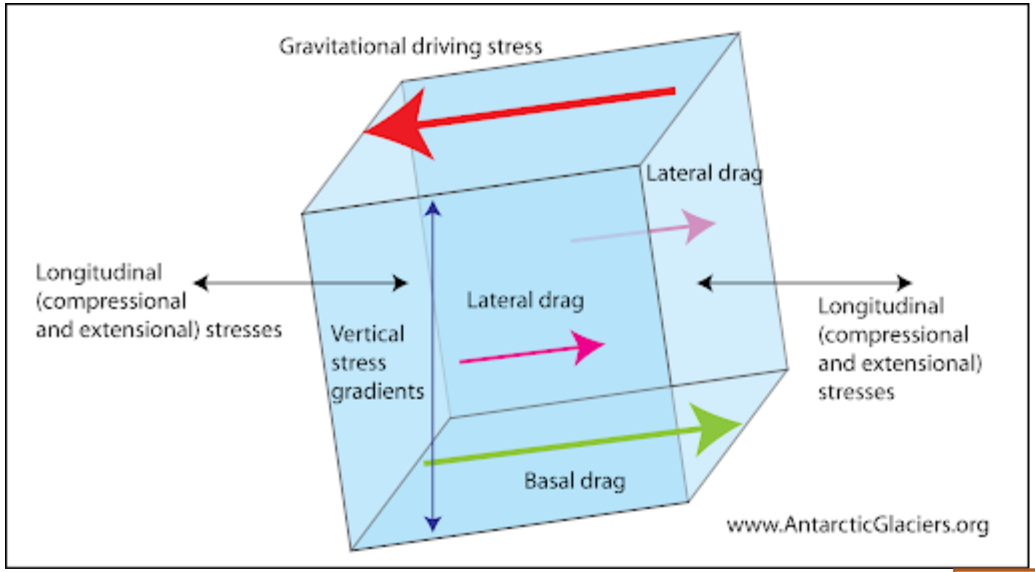
Ice-sheet data assimilation

Wearing, unpubl.

How is assimilation implemented?



- Ice-sheet flow is determined by basal drag and internal deformation
- Model parameters which govern these processes are difficult to observe directly
- Parameters must be *calibrated* with observations. Methods are.. complicated..



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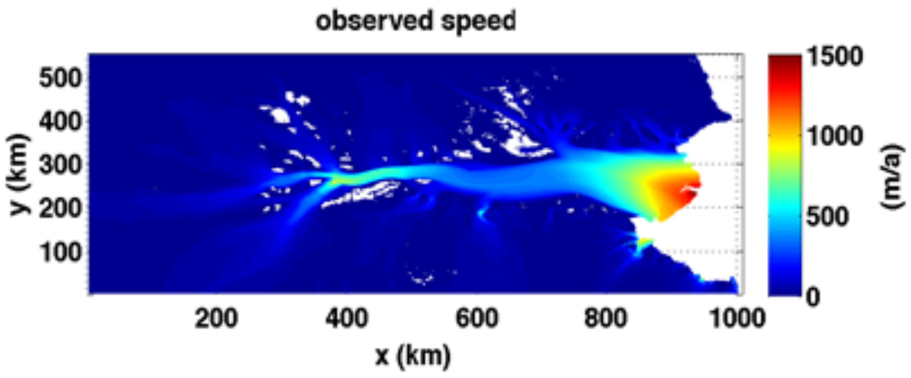
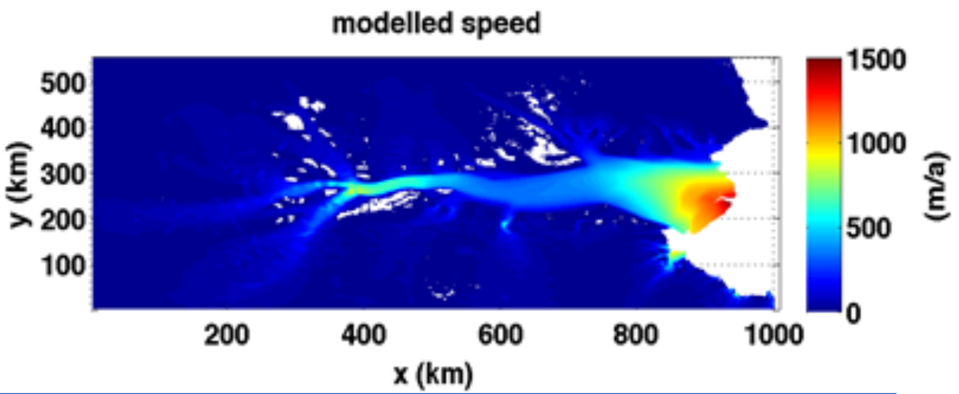
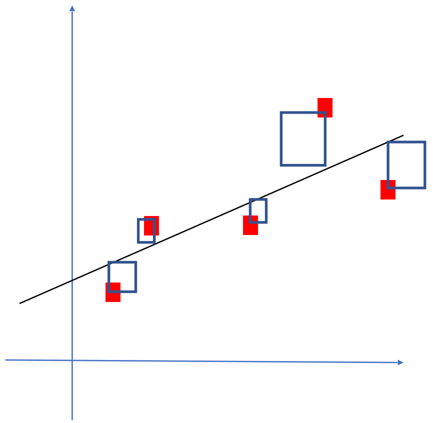




An analogue: Linear Regression (Deconstructed)



"Forward model"

$$y = ax + b$$

$$a = \frac{Cov(x, y)}{\sigma_x^2}$$

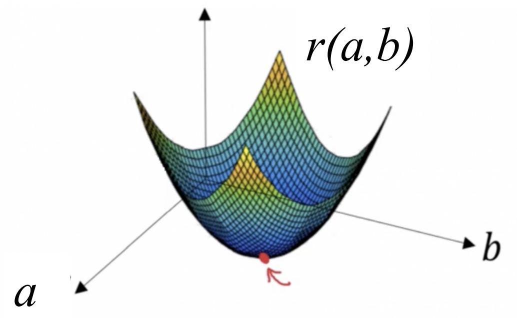
$$b = \bar{y} - a\bar{x}$$

"Parameters"

$$\min_{a,b} r \stackrel{\text{def}}{=} \min_{a,b} \sum \left(y_i - ax_i - b\right)^2$$

solve $\nabla_{a,b}(r) = 0$

Model-obs misfit is minimised to find parameters



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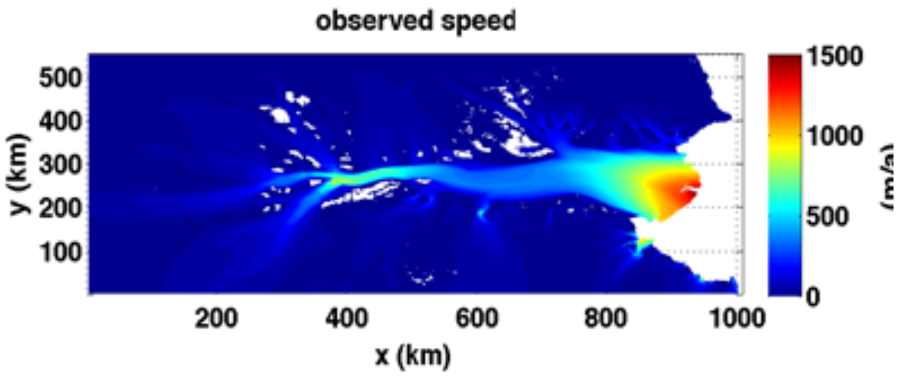
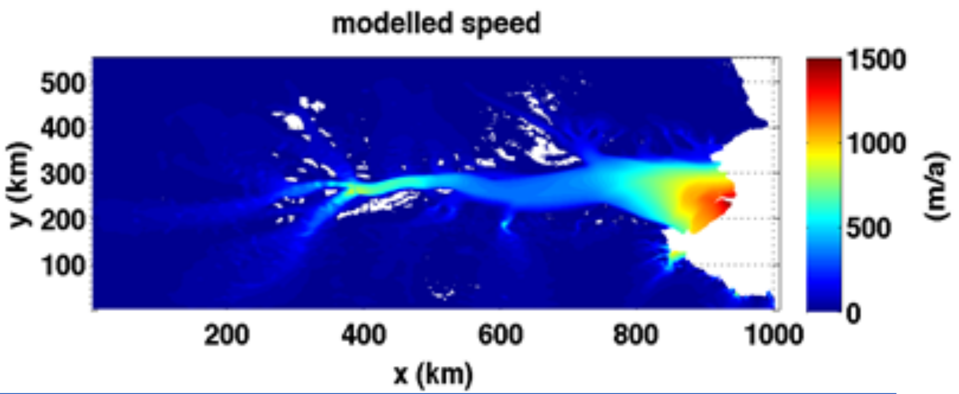
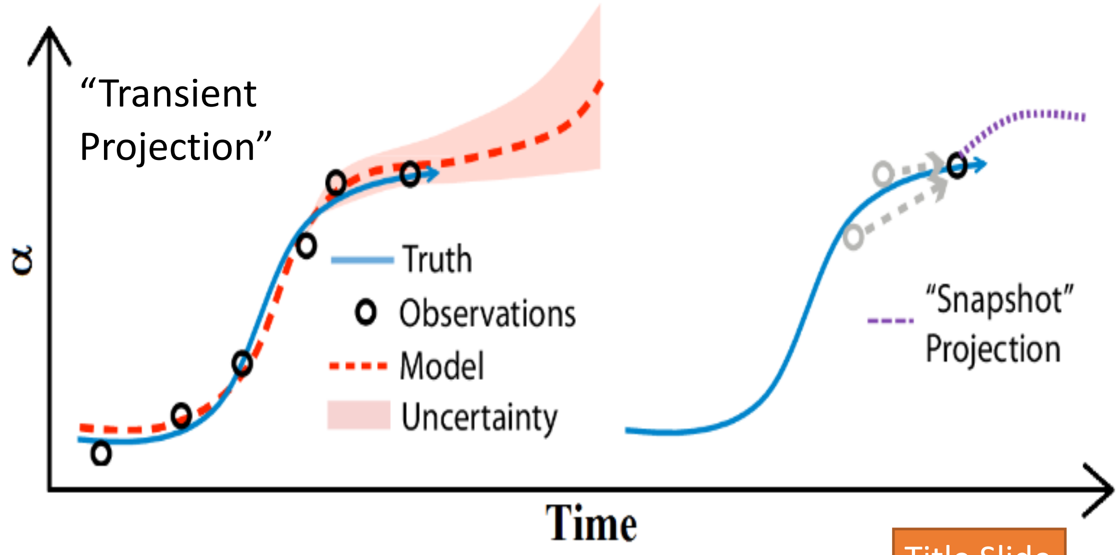




We do the same for ice sheet models!

The differences are:

- 10,000s of parameters (*c.f.* 2)
- Forward model very complicated to solve, ***as is its gradient***
- In *most efforts,* forward model is *time-independent* (”snapshot” data)



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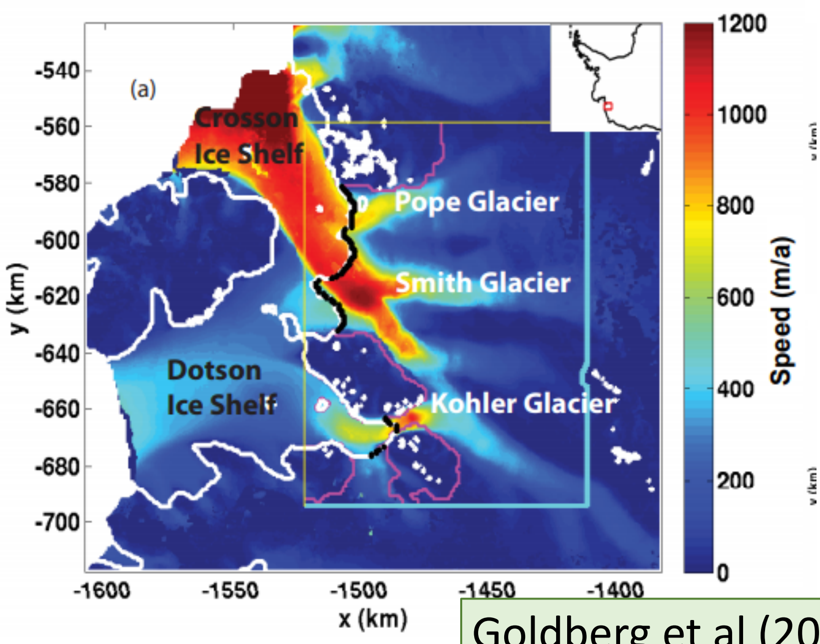
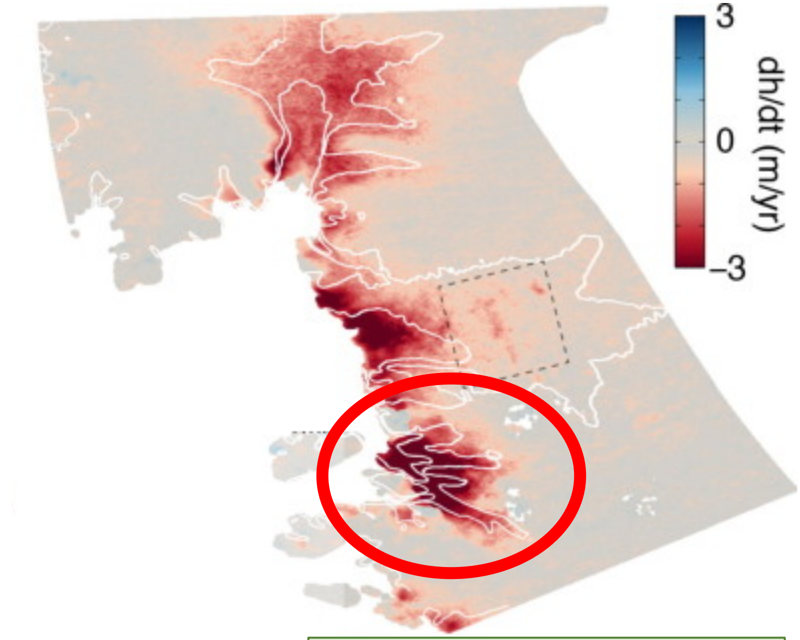
Study Area: Smith Glacier

- Fast-thinning glacier on the Amundsen Coast
- Strongly melting ice shelves (Dotson/Crosson)
- Relatively small compared to Pine Island/ Thwaites, but responsible for ~1/6 of observed Antarctic mass loss
- Small size, dynamic state, coupling with ocean makes ideal test site for new methods



Goldberg et al (2015)



Gourmelen et al (2018)

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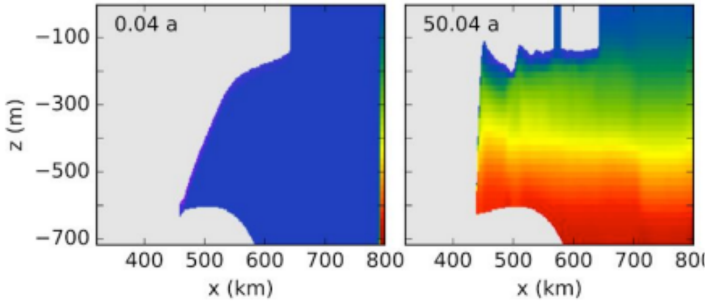
Transient initialisation of a coupled model

THE CHALLENGE:

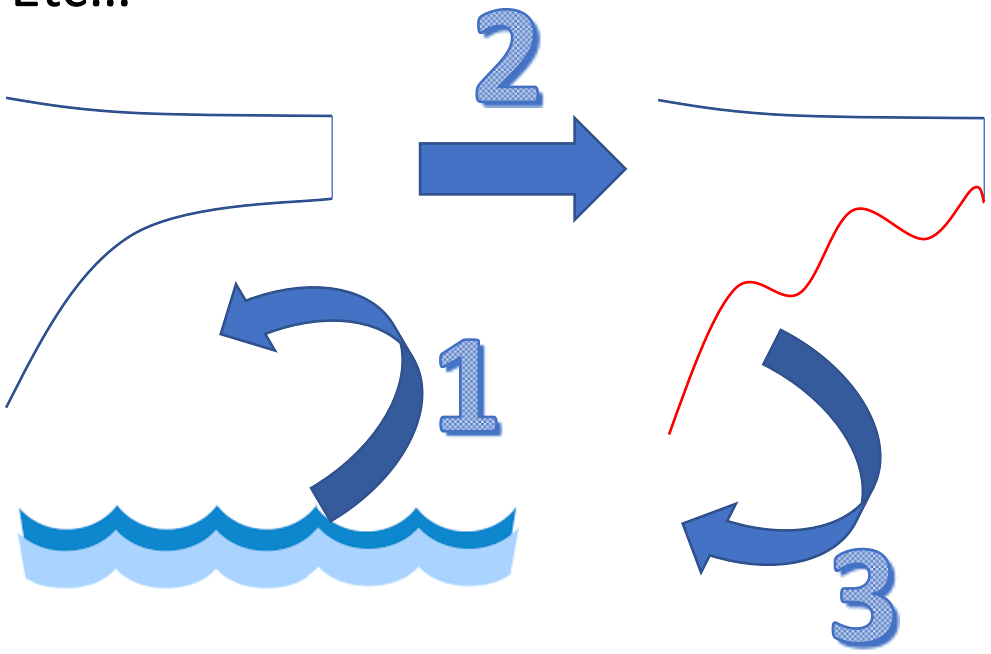
Most coupled ice-ocean studies to date assume an initial steady ice sheet and quiescent ocean



Asay-Davis et al, GMD, 2016

THE POTENTIAL ISSUES:

1. Ocean-derived melt applied to out-of-balance ice sheet
2. Ice-sheet model diverges from obs. dynamic state
3. Modified geometry causes ocean state to diverge
4. Etc…



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Coupled initialisation: a new strategy

Presenter notes do not display well — ask about modelling details if interested

Strategy 1: "Snapshot" initialisation

1. Snapshot calibration of ice model (velocities)
2. Begin coupled evolution

Strategy 2: "Transient" initialisation

1. Multiannual ocean simulation with static ice shelf (i.e. at $T=T_0$)
2. Transiently calibrate ice-sheet model (velocities, DhDt, melt)
3. Begin Coupled evolution at T_0

Result:

- Ice model that will not need to "adjust" to ocean state
- Ocean model that can be "meaningfully" perturbed immediately (e.g change in winds, deep water heating)

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Coupled initialisation: Smith Glacier expt.

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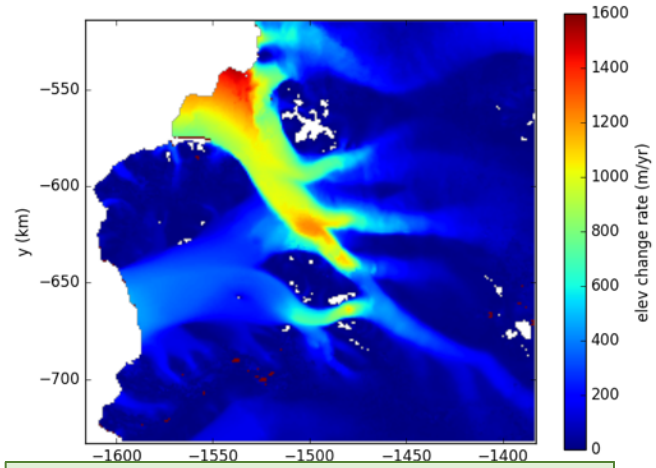


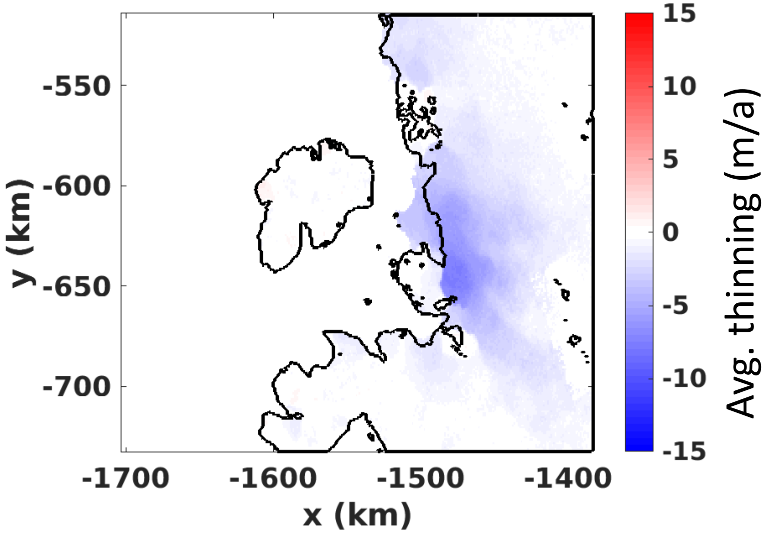
Velocities (Mouginot 2014)

Ocean Model:

- Boundary cond's downscaled from Regional ocean simulation (P. Holland)
- Melt consistent with CryoSat observations

Ice Model:

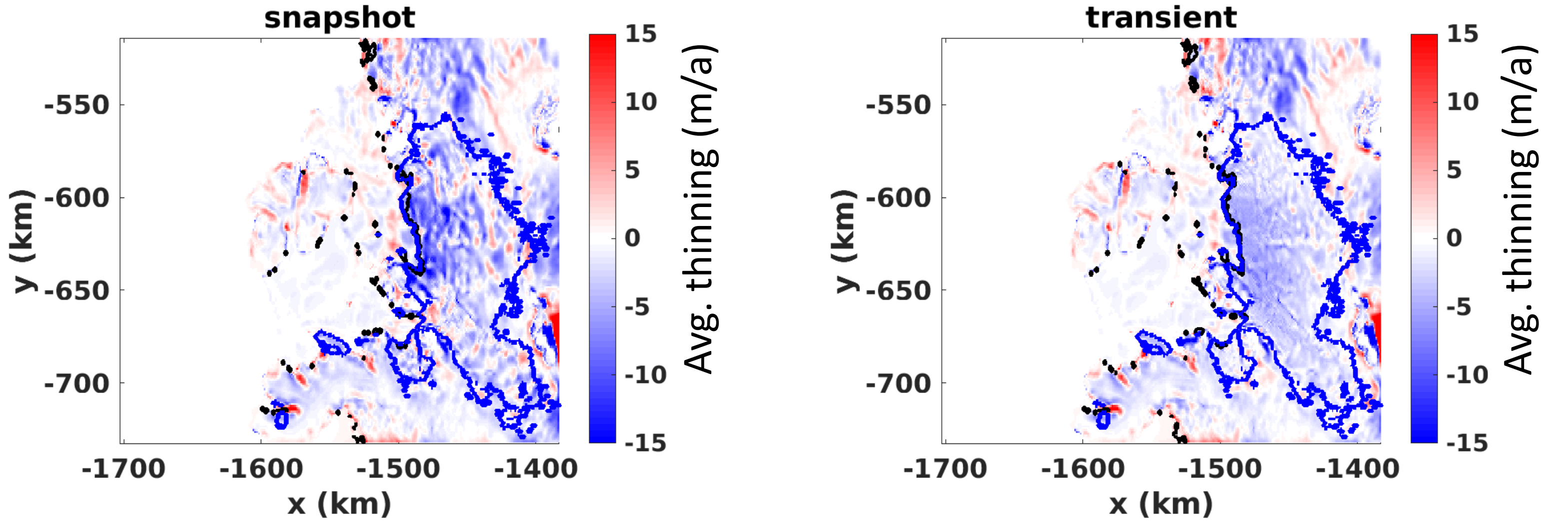
- BedMachine bathymetry & initial thickness, RACMO s.m.b.
- Calibrated to 2011 velocity (snapshot) or velocity + CryoSat 2011-2015 thinning (transient)



2011-2015 thinning (Gourmelen)

Modelled DhDt over 4-year period

Note: DhDt only constrained within thick blue contour (and only in transient expt)



Coupled initialisation: Smith Glacier expt.

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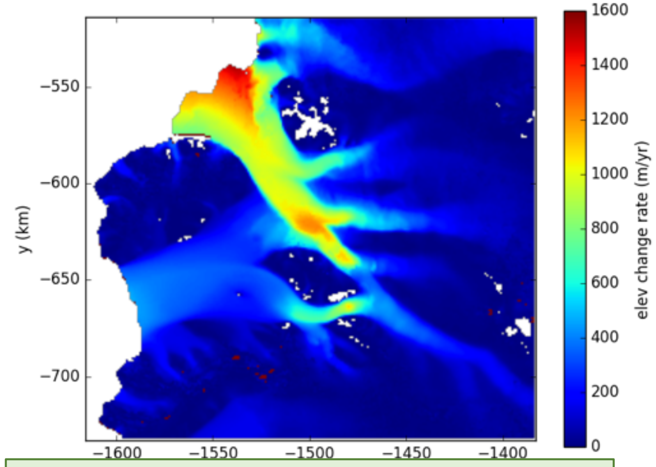

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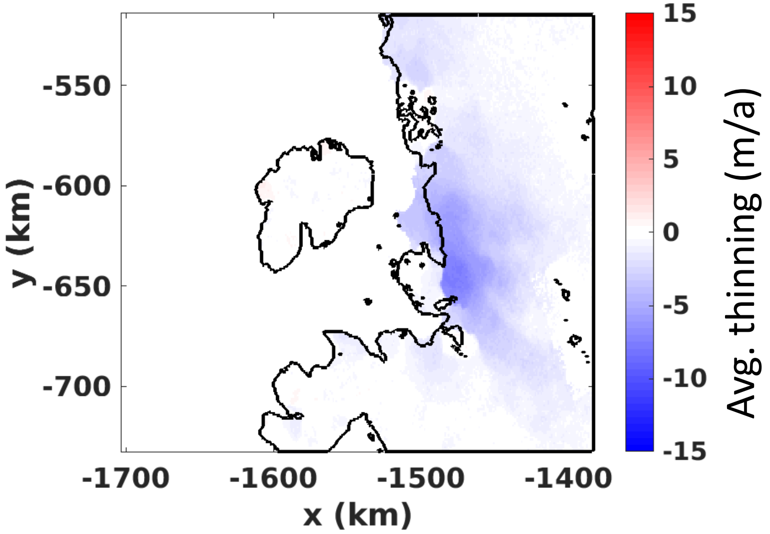

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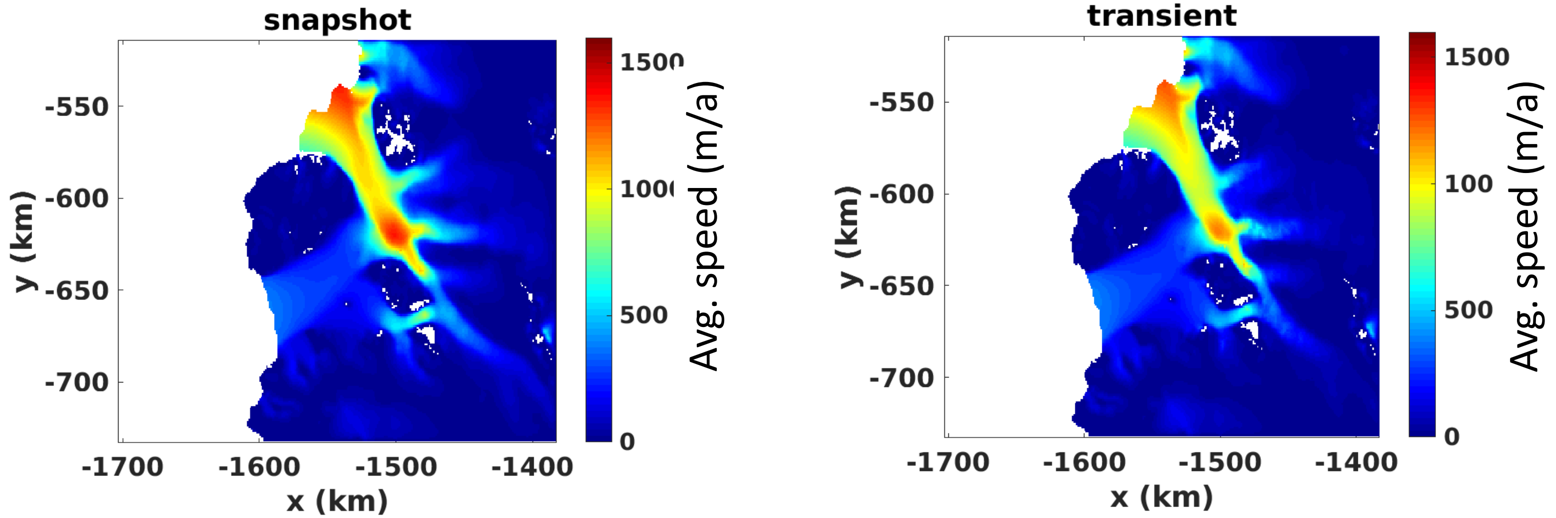
Modelled Average Speed over 4-year period

Note: In snapshot, only initial speed is constrained



Coupled initialisation: Smith Glacier expt.

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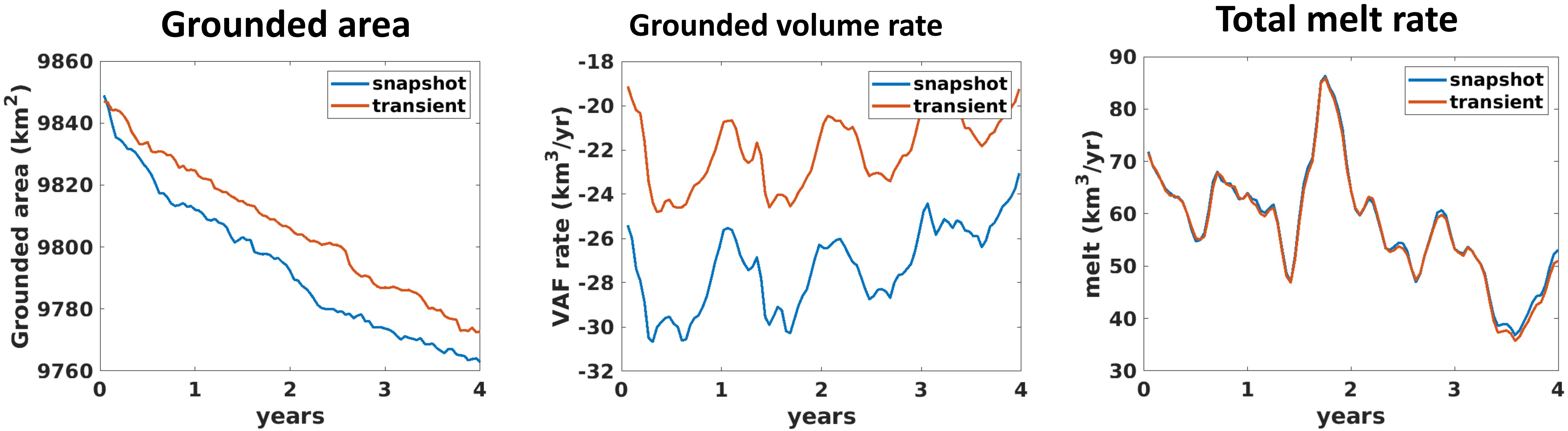
- Both models have similar grounded mass loss variability, **superimposed on differing trends**
- Important to note: models differ only in ice stiffness and sliding parameters

Simulations not diverging as predicted — **but what about longer term?**

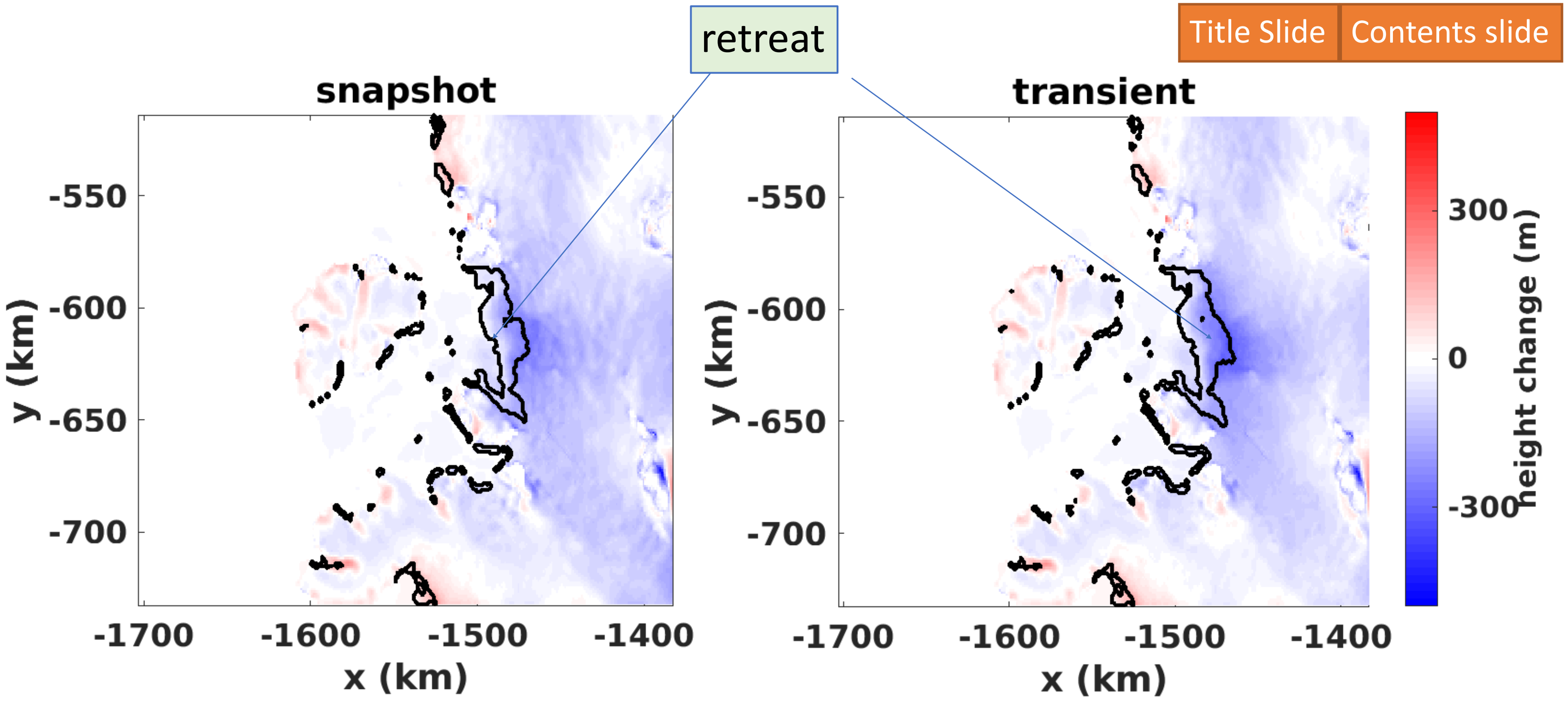


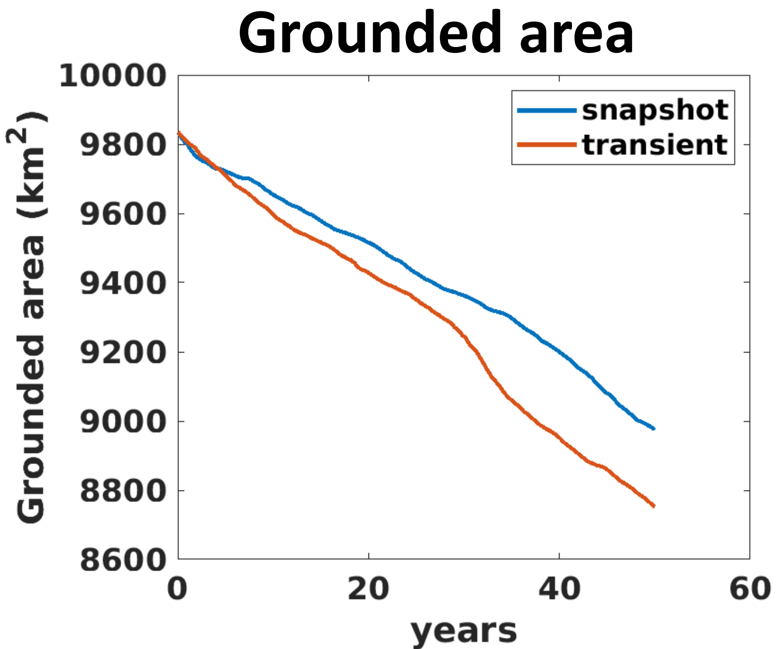
“Warm” Experiment

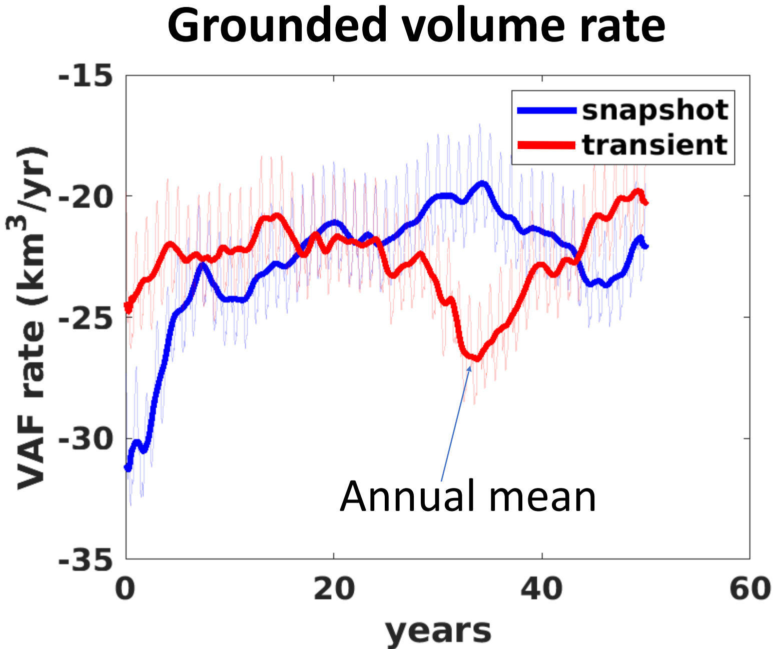
Run for 50 years, applying 2007 forcing -- warmest year in Dotson Trough

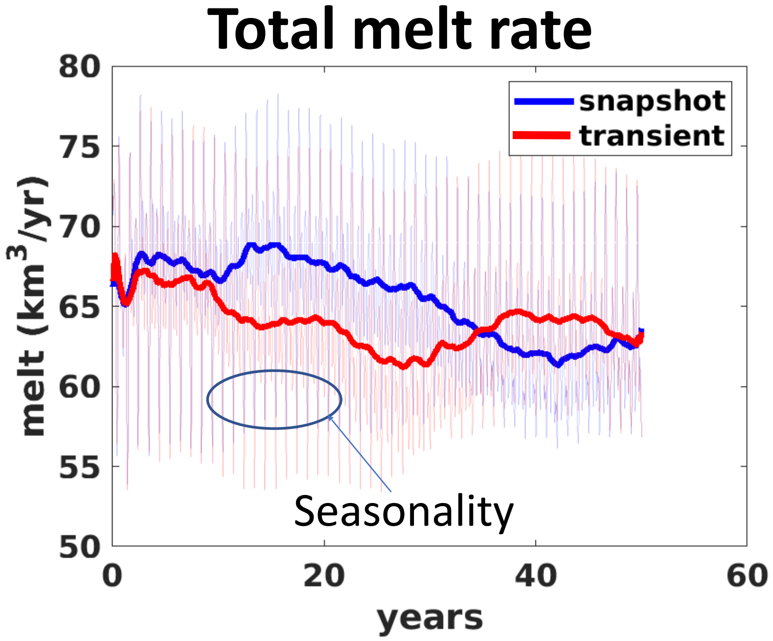
(in lieu of climate projection)

- Snapshot lags ~15 years









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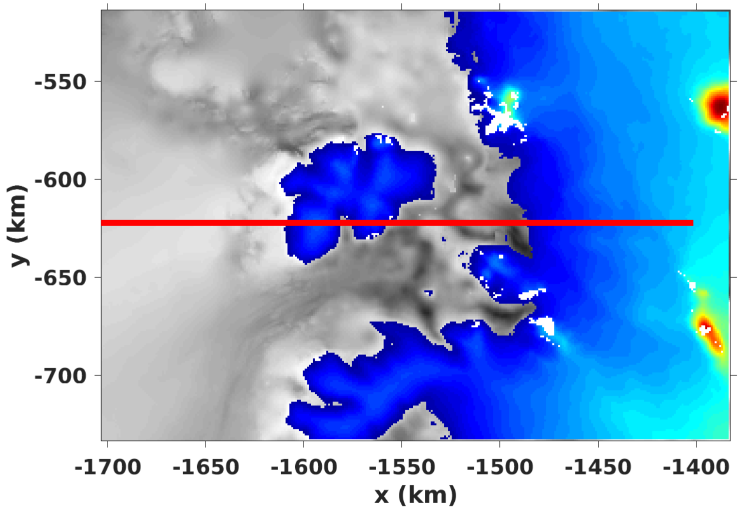
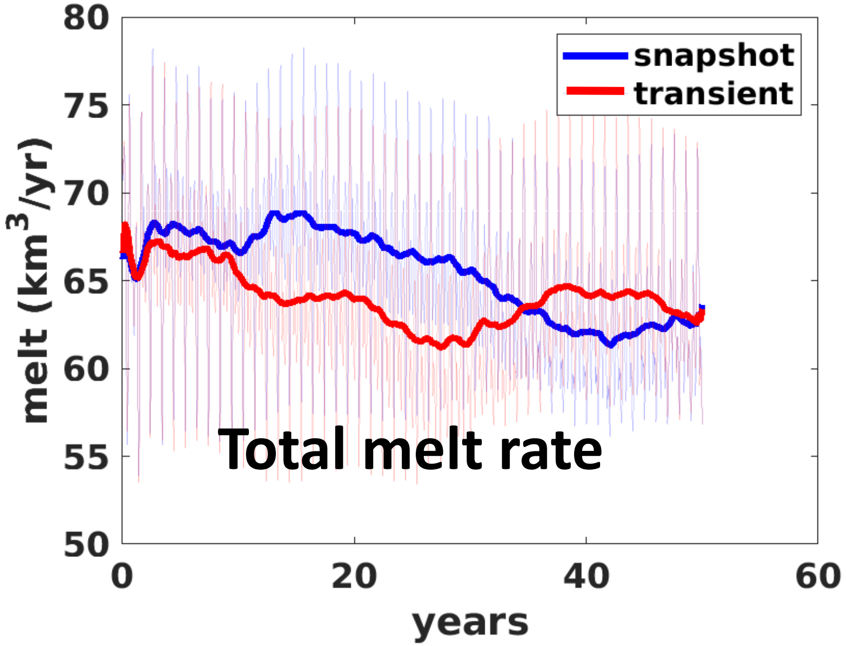
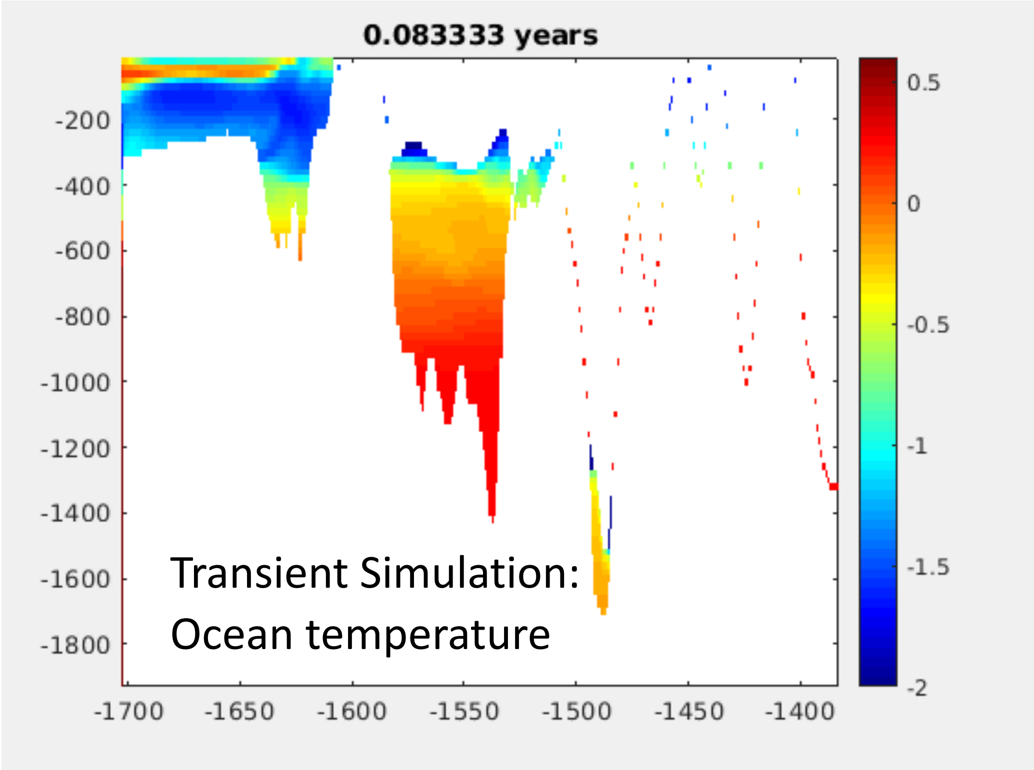
Movie… (only viewable in Keynote or Powerpoint, sorry…)



- Ocean properties gives insight as to how melt evolves in coupled evolution…
- Ice shelf thinning changes geometry of cavity, allowing new pathways for CDW

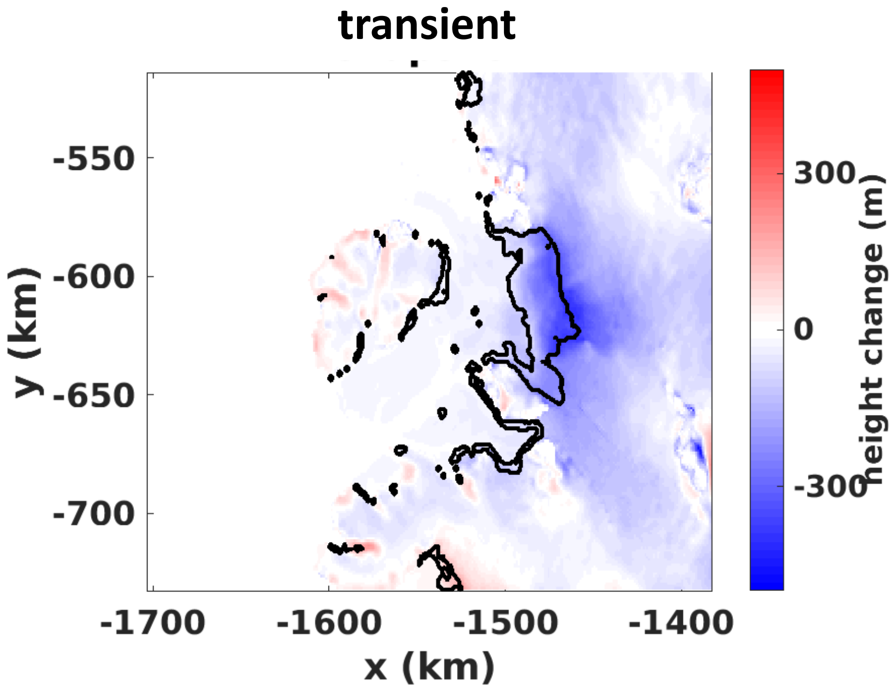




"Hot" Experiment

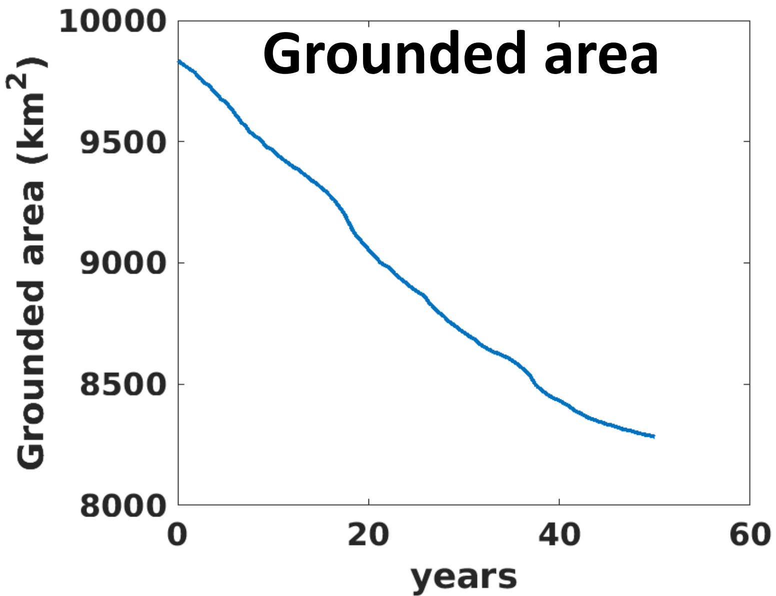
Run for 50 years, stuck in **January** 2007 forcing with warmed CDW

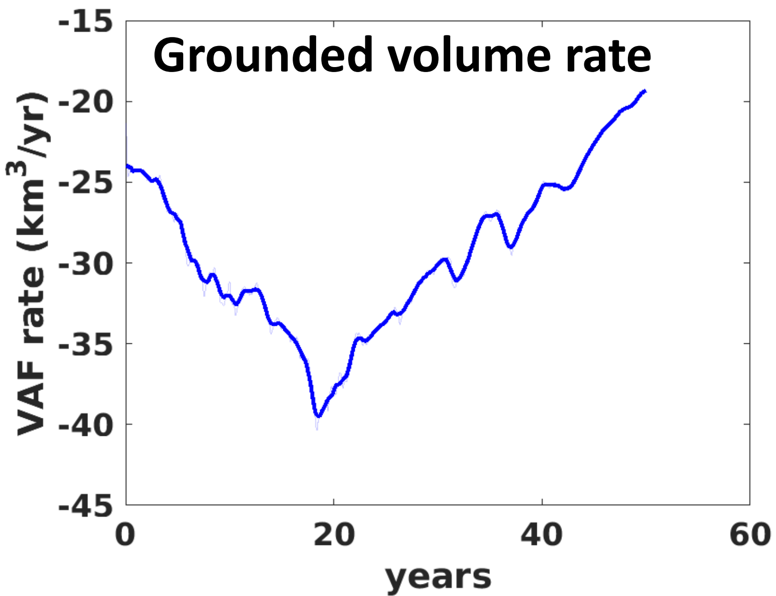
- Transient experiment only
- No seasonal forcing

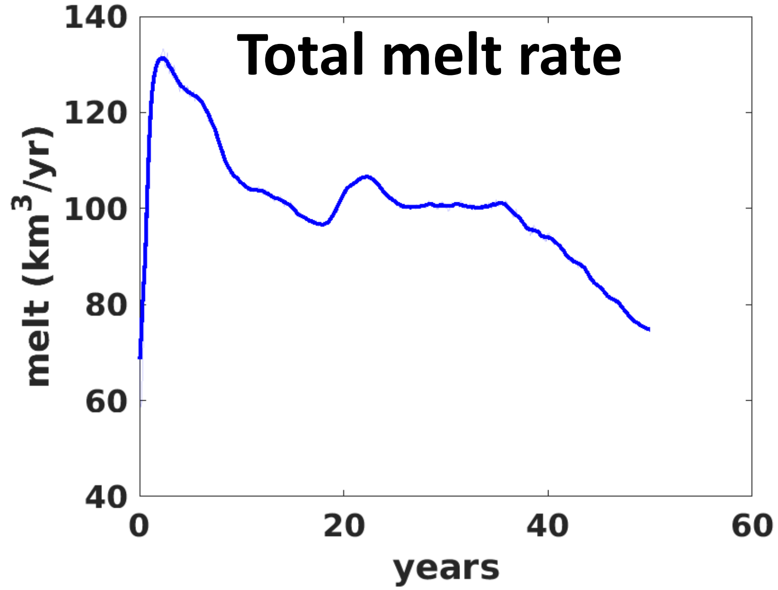


Note:

- Melt rate **falls** as glacier retreats
- Grounded mass loss **slows** (as in other experiments)







Outlook and Next Steps

Science Results

- Even under extreme scenarios*, Marine Instability of Smith Glacier not observed
- Choice of init. methodology introduced uncertainty of ~15-20 years (but not complete divergence of trajectories)
- **However, Smith might be inherently stable – while other catchments may not (PIG, TG, Getz, Totten)**

Methodology

- Coupled Transient Initialisation requires accurate ocean melt model/melt rates – need to improve models of cavity circulation
- What is the uncertainty associated with the initialisation? How can it be quantified? How does it affect projections?

***Breakup of ice shelves not considered**

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Thank you for your time

Questions?