Online material for:
Initialisation versus climate forcing in coupled ice sheet-ocean modelling:
lessons from Pope, Smith and Kohler glaciers

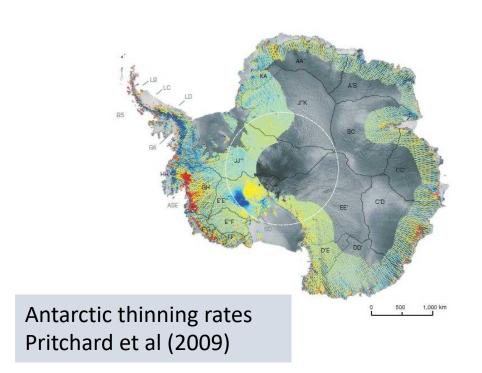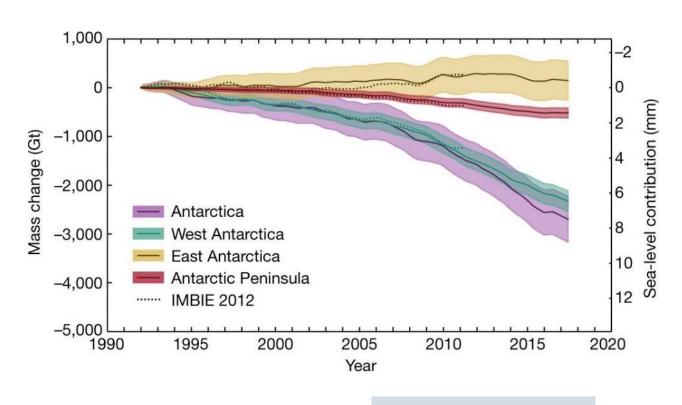## EGU 2022

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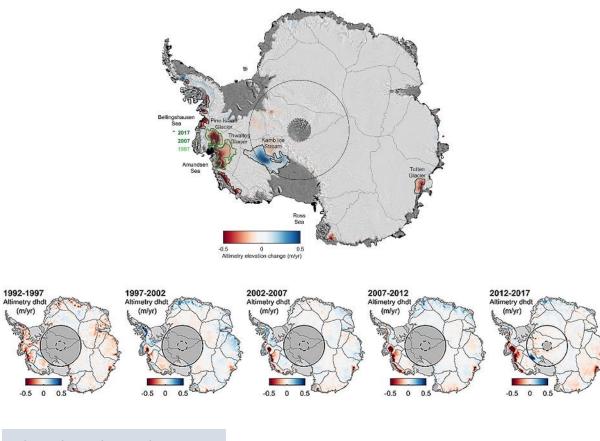See also: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021JF006570
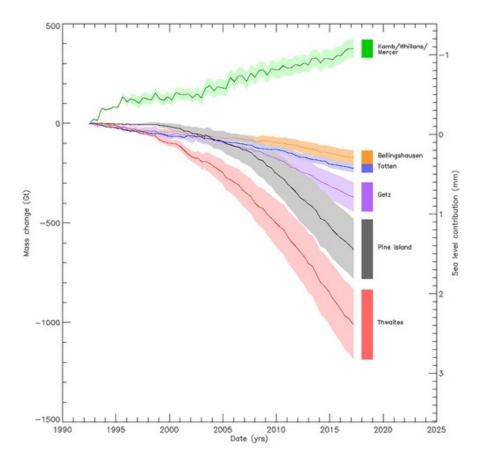
Extensive ice-sheet thinning in W. Antarctica

Antarctic thinning rates
Pritchard et al (2009)

IMBIE team, *Nature* (2018)

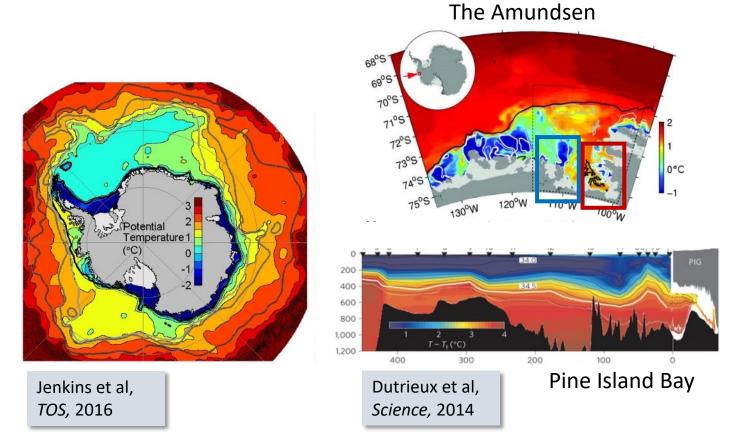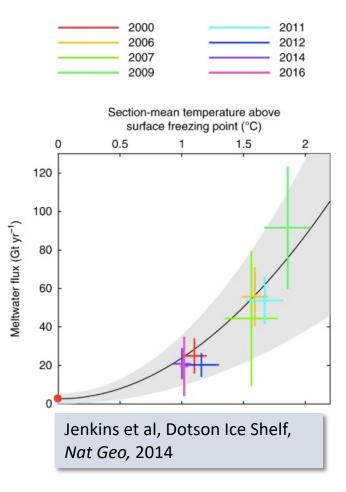# Focussed thinning in Amundsen Embayment

Shepherd et al, *GRL* (2019)

Warm oceans on continental shelf

- Amundsen and Bellingshausen Seas experience intrusions of warm water from ACC due to climatic and bathymetric factors (*Petty et al, 2013*)

The Amundsen

Pine Island Bay

Jenkins et al, *TOS,* 2016

Dutrieux et al, *Science,* 2014

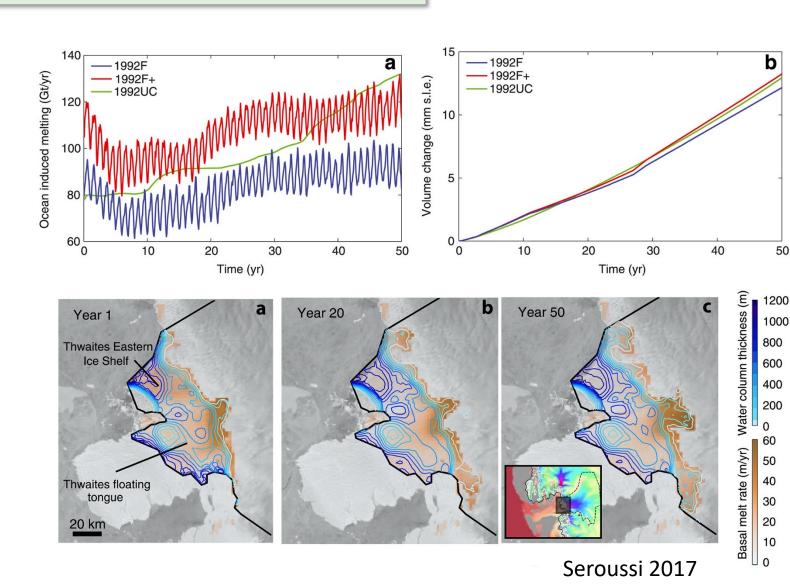Jenkins et al, Dotson Ice Shelf, *Nat Geo,* 2014

Coupled ice-ocean modelling

A way to understand how ice sheets may respond to future ocean changes and warming

However, extensive work has not yet been done

Questions arise regarding coupled response:
- Can our coupled models represent "reality"?
- How critical is the way in which they are initialized, relative to climate change?
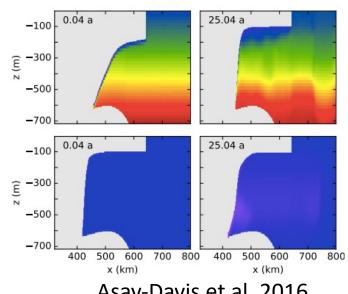

Seroussi 2017

Initialisation of coupled ice-ocean models

Coupled ice-ocean models provide powerful tools to understand how ice sheets may respond to future ocean changes and warming
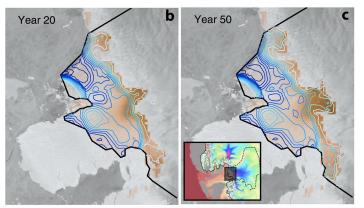
However, coupled initialization is an issue:

- **Long Memory**: adjustment to "initialization shock" (Goldberg et al, 2012; Seroussi et al, 2017)
- **Interactions:** Nonphysical behaviour can *potentially* "feed back" between ice and ocean
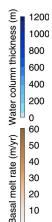
Does mode of initialization "matter" for century-scale simulation?
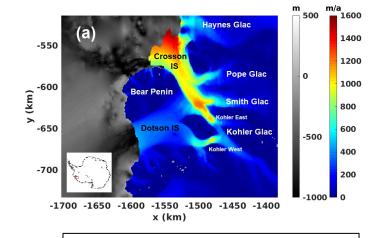

Asay-Davis et al, 2016

Seroussi et al, 2016
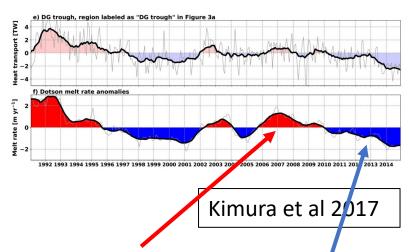
Forcing vs Initialisation: Methods

Multiple experiments with coupled model of Smith Glacier *(from 2011)*, examining:
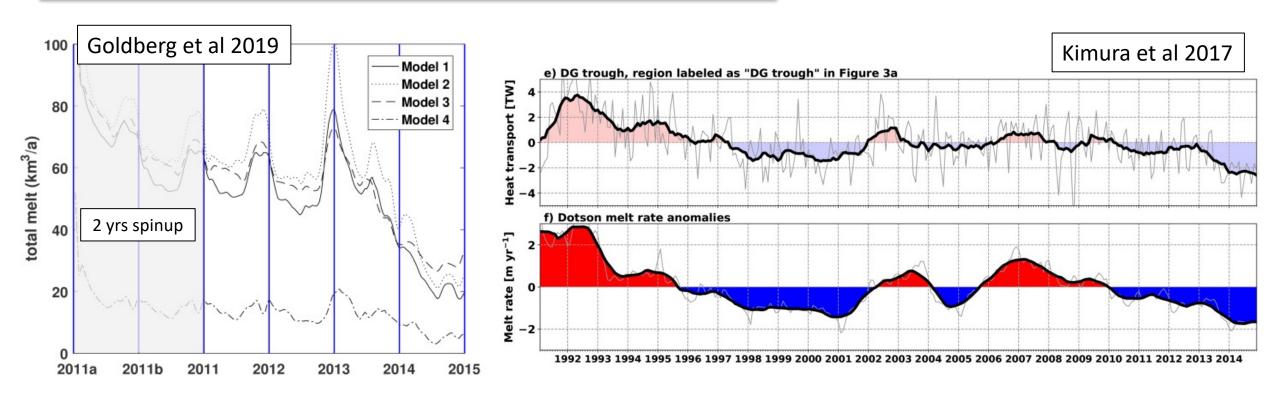
- **Forcing**: Cycle 2011-2015 boundary conditions continuously *(Historical)*, or cycle 2007 continuously *(Warm)*

- **Initialisation**: Constrain velocities only in 2011 *(Snapshot)*, or constrain vel + 2011-2015 thinning *(Transient)*

- **Ice dynamics**: Weertman sliding or Cornford sliding (Cornford et al, 2020)

Goldberg and Holland, 2022

Kimura et al 2017

Factors considered: climate forcing
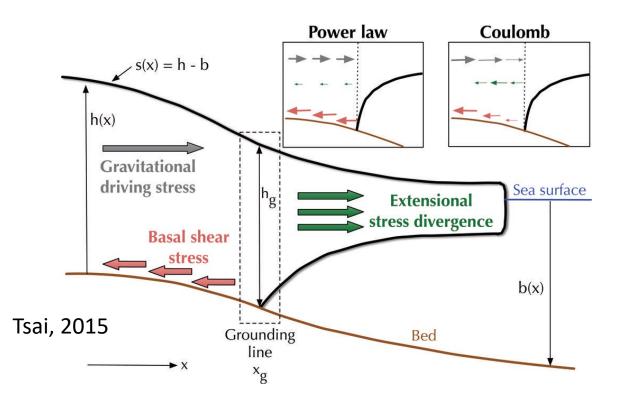

Goldberg et al 2019

2 yrs spinup

Kimura et al 2017

- Ocean model forced either with 2011-2015 (*Historical*) conditions (repeated) or 2007 conditions (*Warm*) (repeated after 2015)
- Rationale: Amundsen undergoes interannual variability but under global warming ***warm years might become more frequent*** (Holland et al 2018)

Factors considered: ice-sheet bed conditions

Tsai, 2015

Power Law (Weertman)

$$\tau_b = Cu^{1/3}$$

Coulomb-limited

$$\tau_b = \frac{\alpha^2 C N u^{1/3}}{[C^2 u + (\alpha^2 N)^3]^{1/3}}$$

$$N = \rho_i g H + \rho_w g z_b$$
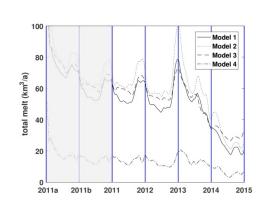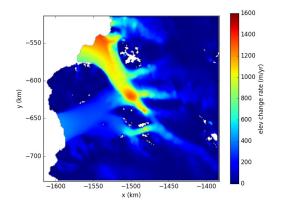
- Weertman more common, but Coulomb-limited law increasingly used
- Where ice is near floatation, bed cannot support high basal stress demanded by Weertman
- *Assumes sufficient hydraulic connectivity to ocean cavity*

Factors considered: Coupled initialisation

Method 1: Snapshot initialisation
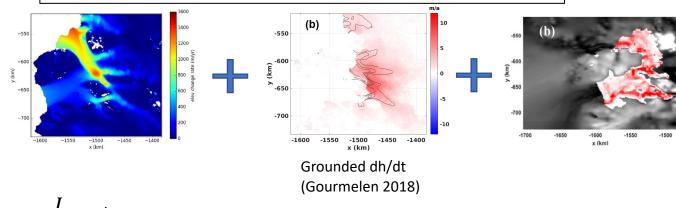

1. Spinup ocean model

2. Snapshot ice-sheet initialisation

$$J_{snapshot} = \sum \frac{\left|\mathbf{U}_i - \mathbf{U}_i{}^{obs}\right|^2}{\sigma^2{}_i} + reg.\, terms$$

…And start coupled simulation

Method 2: Transient initialisation

Grounded dh/dt
(Gourmelen 2018)

$$J_{transient}$$
$$= C_1 \sum \frac{\left|\mathbf{U}_i - \mathbf{U}_i{}^{obs}\right|^2}{\sigma(u)^2{}_i} + C_2 \sum \left|\frac{dh}{dt}_i - \frac{dh}{dt}_i{}^{obs}\right|^2 + reg.\, terms$$

- ***dh/dt*** is evaluated from a 2011-2015 ice-sheet simulation

- Simulation forced by melt rates from a 2011-2015 ocean-melt simulation with *static cavity*

- *Rationale*: result is an ice model which has the *correct transient response* to the (hopefully) correct ocean state

Ice-ocean coupling

Jordan et al 2018
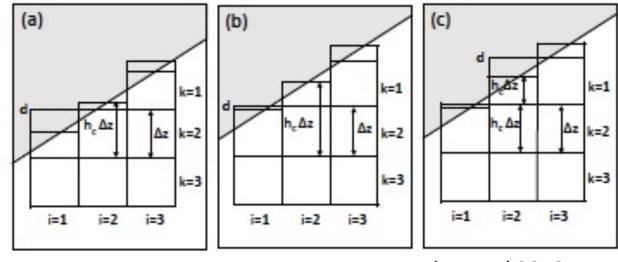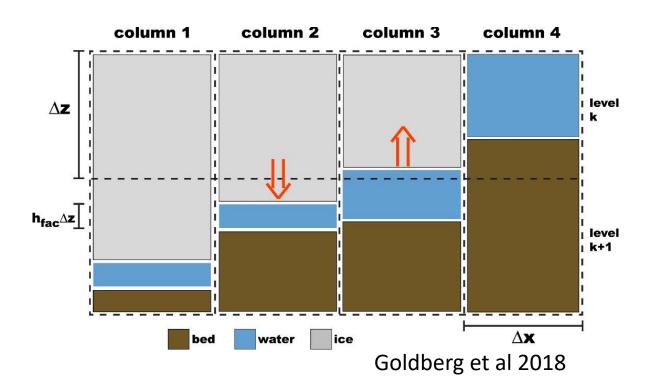
Synchronous coupling within MITgcm
- Model is never started or stopped

Computational cells adapt to changing upper surface

Thin (~1 m) layer under ice allows flooding of new cavity space (vs extrapolation of properties, DeRydt et al 2016)

Goldberg et al 2018
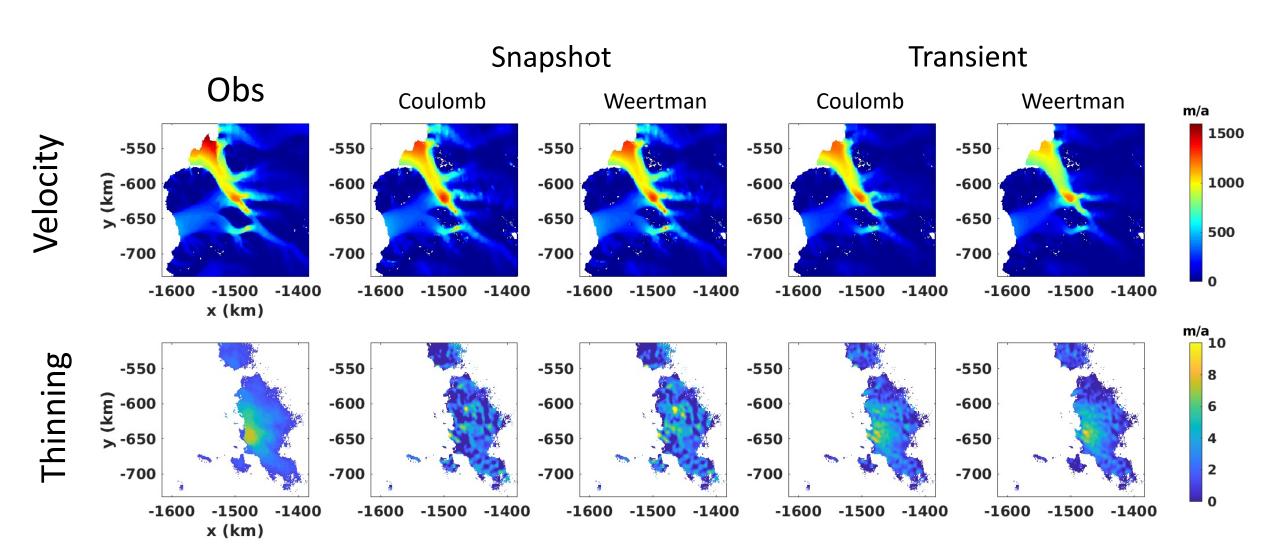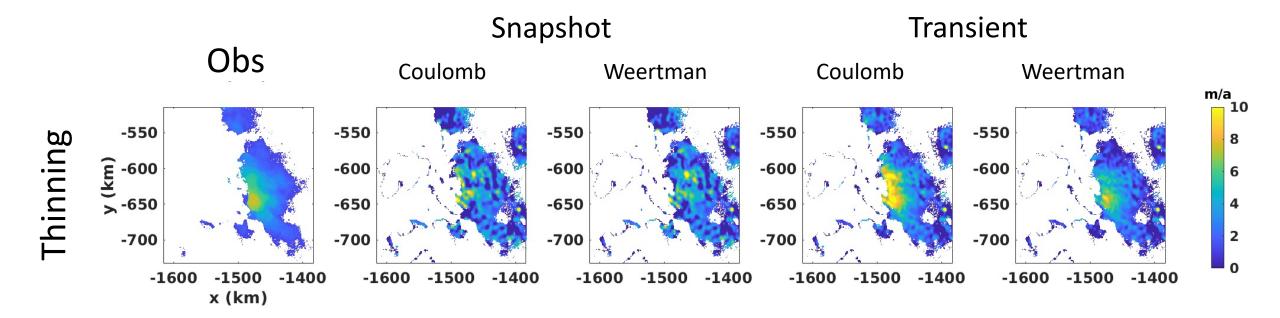
Results: Initialisation

Velocity and 2011-2015 **grounded** thinning as a result of the ice-sheet calibration

Results: Short (4 yrs) term

- Thinning in coupled runs 2011-2015

- Transient runs by construction should yield similar thinning rate to calibration
- True for Weertman – *not* true for Coulomb..
- *Initialisation methodology for Coulomb-limited sliding needs revisiting*
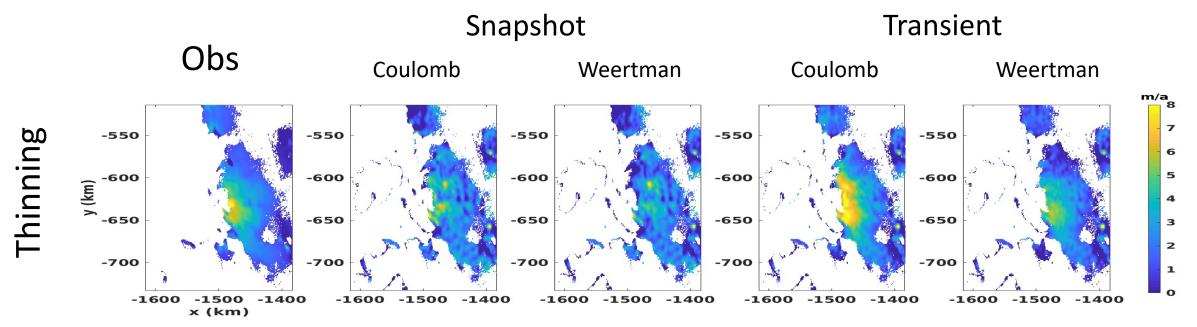
Results: Medium (10 yrs) term

So far: have only tested model performance over period used to calibrate the model!
- **The performance is only as good as the tuning**.

Are there other periods we can use to evaluate fit?
- *CPOM Cryosat SEC product* **2011-2021** (publicly available on 5km grid). How does average **grounded** thinning 2011-2021 in coupled runs compare?

- Shown with Warm conditions for ocean, but Historical runs identical
- Transiently Calibrated with Weertman sliding seems to provide the best fit – *though this does not mean it is more physical*
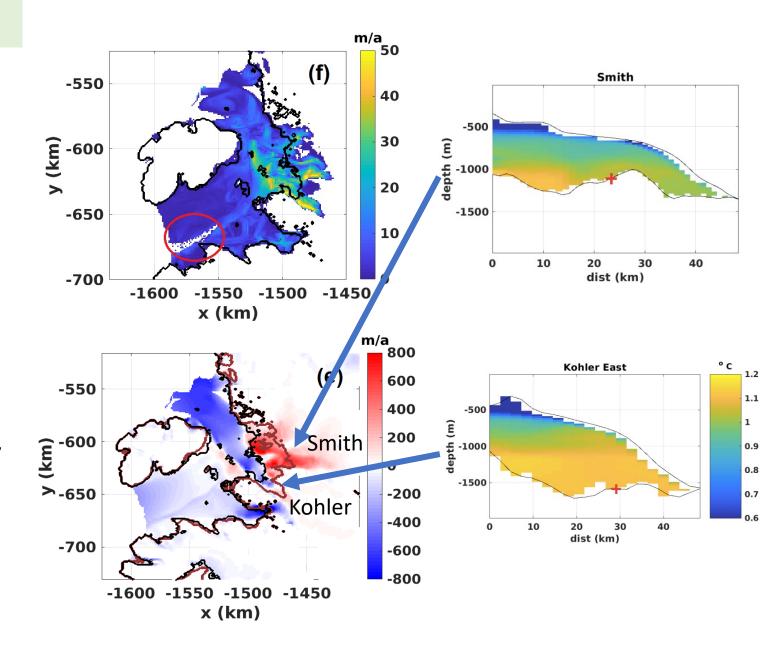
Longer-term Behaviour

- Loss and retreat rates initially depend on initialization type
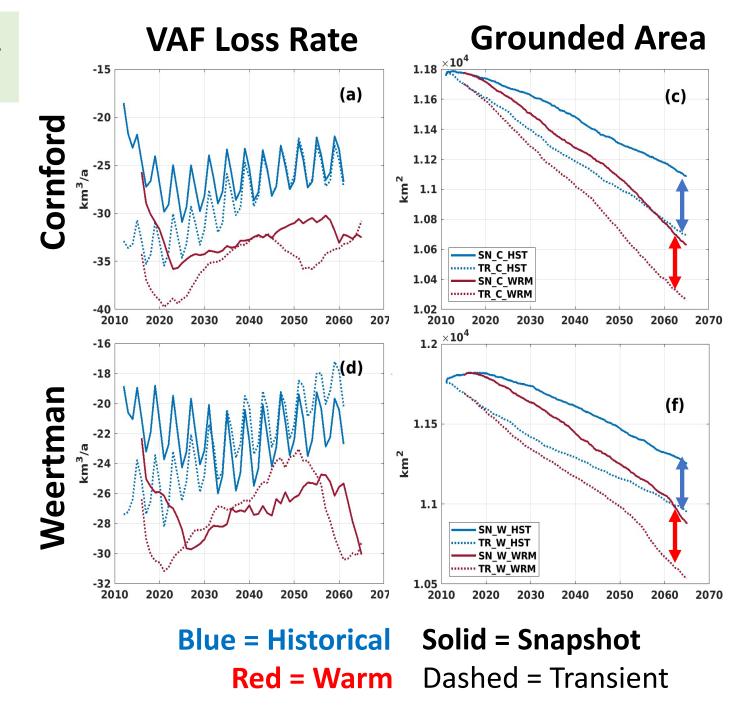
- Over ~15-20 years, rates converge according to forcing

- **However, initialization still determines overall loss over half-century**

VAF Loss Rate   **Grounded Area**

Blue = Historical   **Solid = Snapshot**

Red = Warm   Dashed = Transient

Lessons from Smith

- Within 40-50 years, channel on Dotson melts through (Gourmelen et al, 2017)

- This does not affect speed strongly, nor does Kohler retreat – **but Smith retreat has large effect**

- Though future Smith retreat may be limited by sill which blocks warmest waters

Main takeaways

Coupled ice-ocean initialization

- Coupled transient initialization may improve **short/medium** term predictions – **but more work is needed in implementation**
- Initialisation/Initial "state" has strong influence initially, but eventually climate forcing is stronger influence – ***"Crossover" time scale may depend on ice stream***

Smith / Pope / Kohler Glaciers

- Retreat determined by climate forcing on the multidecadal scale (rather than inherent instability) *cf. Lilien et al 2019*
- Retreat may be slowed by deep sills preventing spread of warm water, and narrow troughs
- Dotson may melt through (and calve away?) in future – **though unclear how much this will impact ice stream retreat**

Further thoughts..

When does physics "take over"?

- For these experiments, climate forcing determines loss/retreat rates after ~2 decades. But how universal is this **crossover time?**

- Control of forcing on multidecadal scales might be particular to Smith Glacier (*cf* Lilien et al, 2019). *What is the crossover time for e.g. Filchner-Ronne glaciers? For Thwaites glacier?*

- Strategies for improved initialization of coupled models are needed in order to determine ... *whether improved initialization strategies are needed!*