Úa-MITgcm coupling

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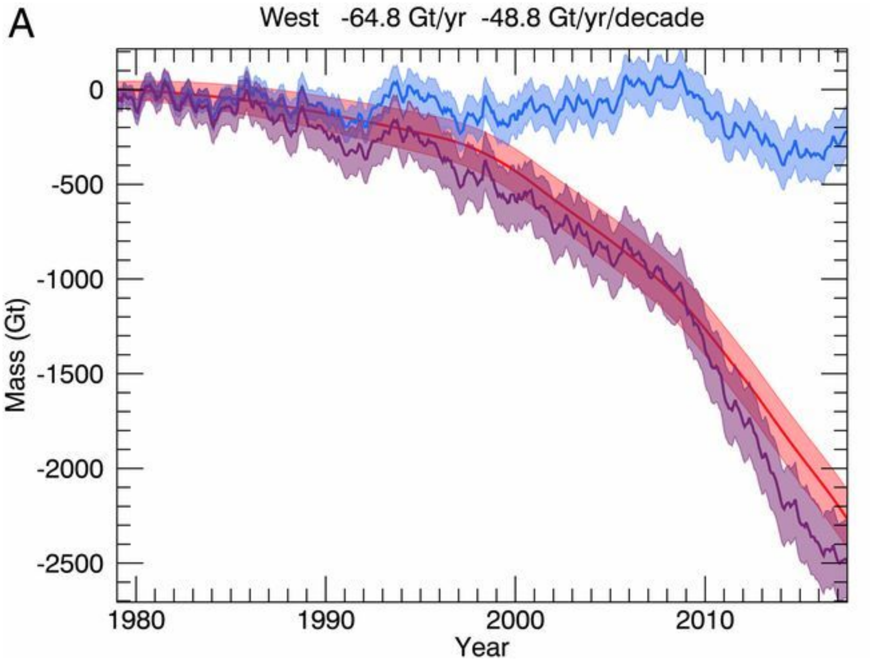
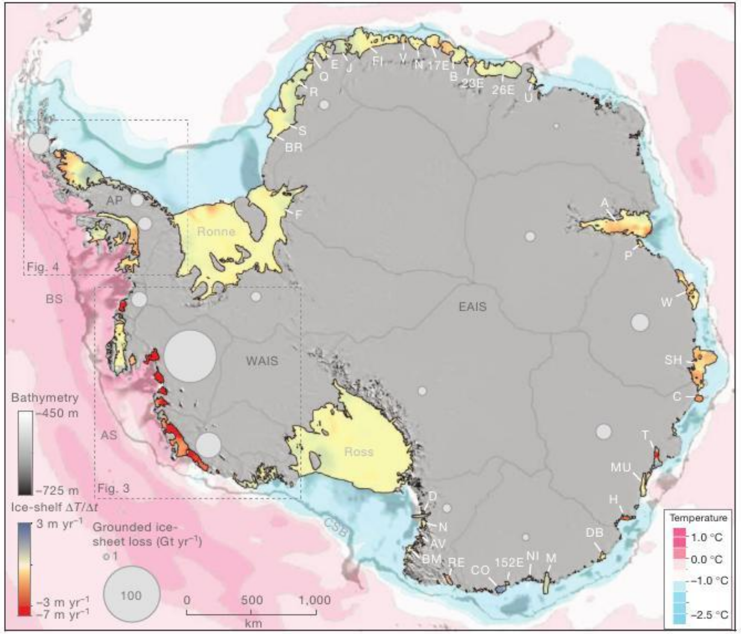
Why does ice-sheet/ocean coupling matter?



Rignot et al. 2018

- Antarctica is losing mass
- Attributed to ice-ocean interactions
- Major controller of future sea level rise

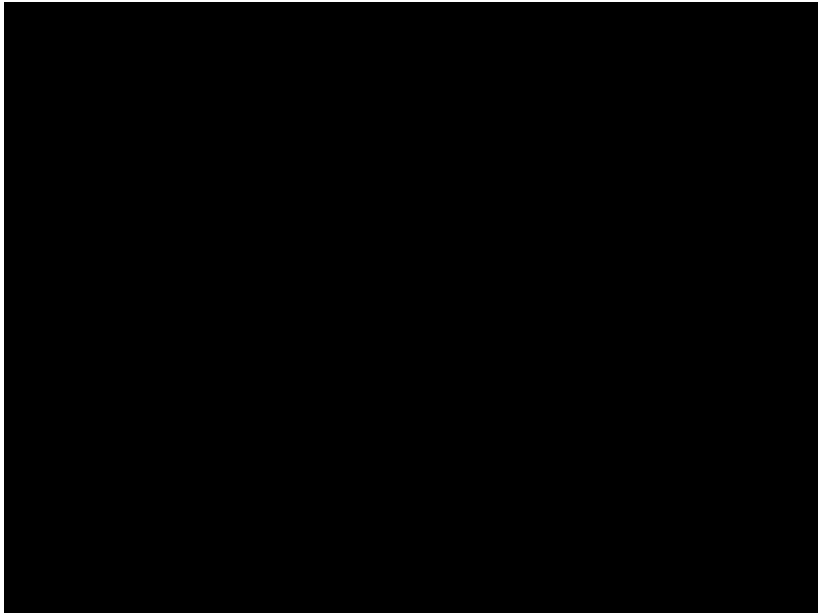
Why does ice-sheet/ocean coupling matter?



Pritchard et al. 2012

- Warm water already melting WAIS
- Likely that Totten is at risk
- Some suggestion FRIS will be at risk (Hellmer et al., 2012)

Why does ice-sheet/ocean coupling matter?

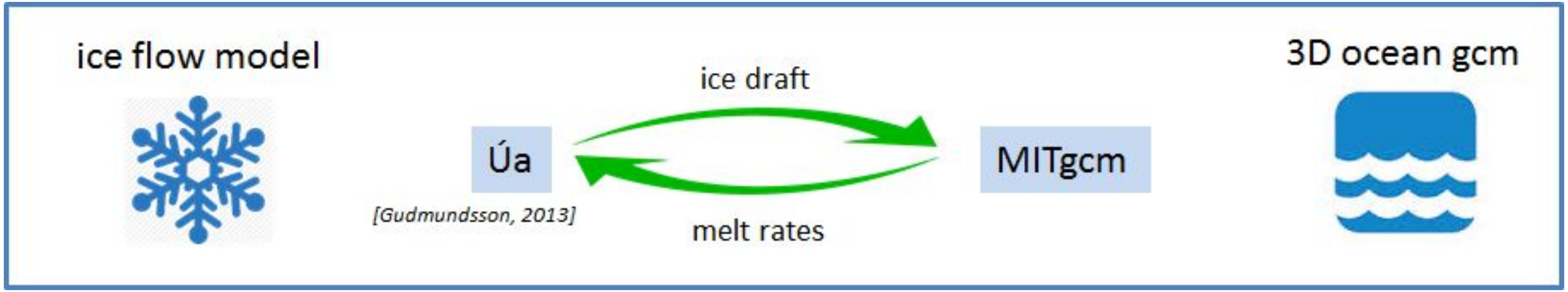


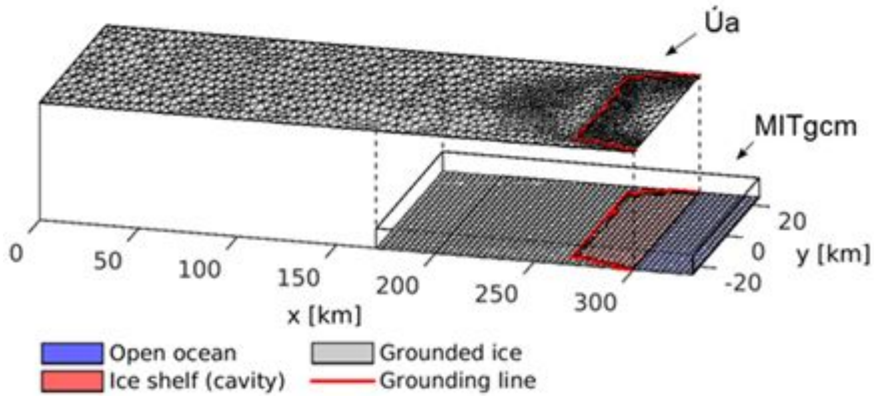
- Inherently a 2-way system with complex feedbacks

$$\frac{\partial h}{\partial t} = -\vec{\nabla}.(h\vec{v}) + m_b + m_s$$

- Changing cavity geometry may affect ocean state
- Crude parameterisations of basal melting lack predictive skill

Basic communication framework





Evolution of Úa-MITgcm coupling

Version -1: email exchange

Version 0: ‘discontinuous coupling’ (De Rydt et al. 2016)

- Spinup from uniform ocean conditions at each coupling timestep
- No memory of previous ocean state
- Models run on two different servers, bash scripts for file exchange

Evolution of Úa-MITgcm coupling

Version 1: ‘asynchronous coupling’

- Retain information about ocean temperature and salinity at each coupling step
- Still a loss of information for momentum and free surface
- Only supports certain ocean model configurations

Evolution of Úa-MITgcm coupling

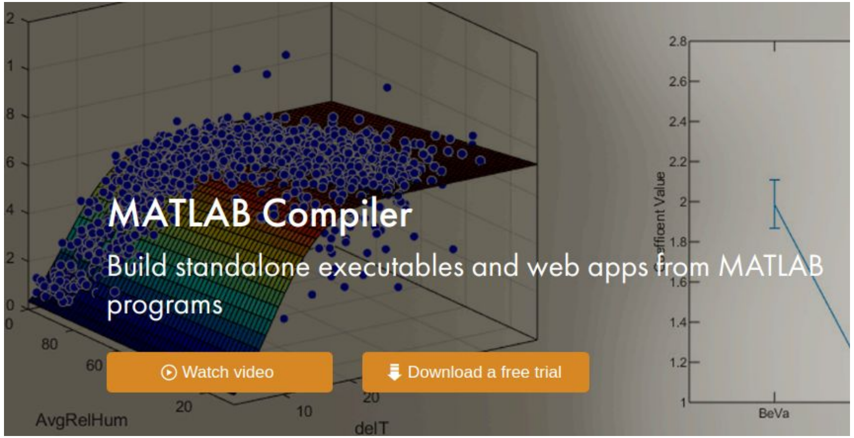
New version: opportunity to start “from scratch”:

- Both models run on same machine
- Flexible for wide range of configurations (including time-varying forcing, sea ice, etc.)
- User-friendly

Evolution of Úa-MITgcm coupling

Version 2

- Matlab Compiler allows both models to run on Archer supercomputer
- Python coupling code
- All ocean state variables preserved at each coupling step



Code demonstration

https://github.com/knaughten/UaMITgcm

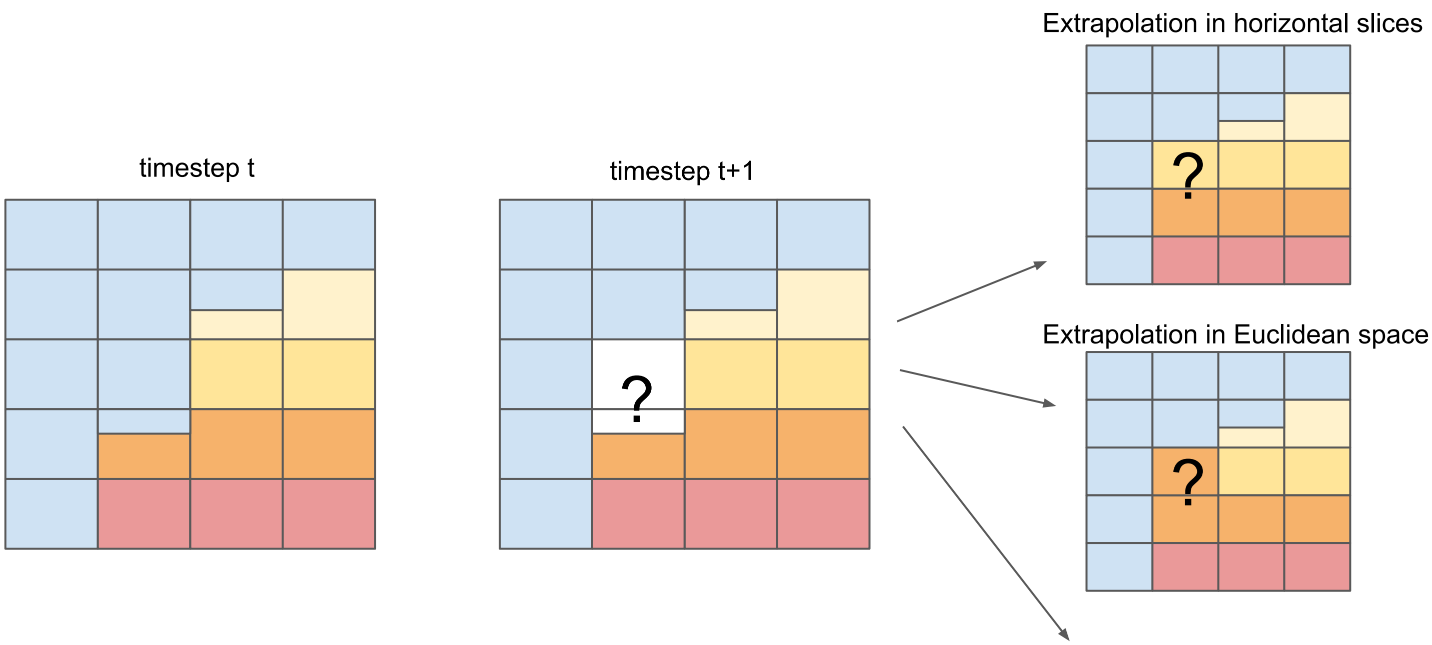
Technical challenges: restarts

At each coupling timestep, Úa and MITgcm require a restart.

- Úa: use restart file written by model, update basal melt rate file
- MITgcm: more complicated because geometry changes
  - Option 1: New model run starting at time 0. Geometry and initial conditions (temperature and salinity) are set by end of previous run. Initial momentum is zero.
  - Option 2: Hack the restart file to impose the new geometry, and preserve all the information (including momentum) we can.

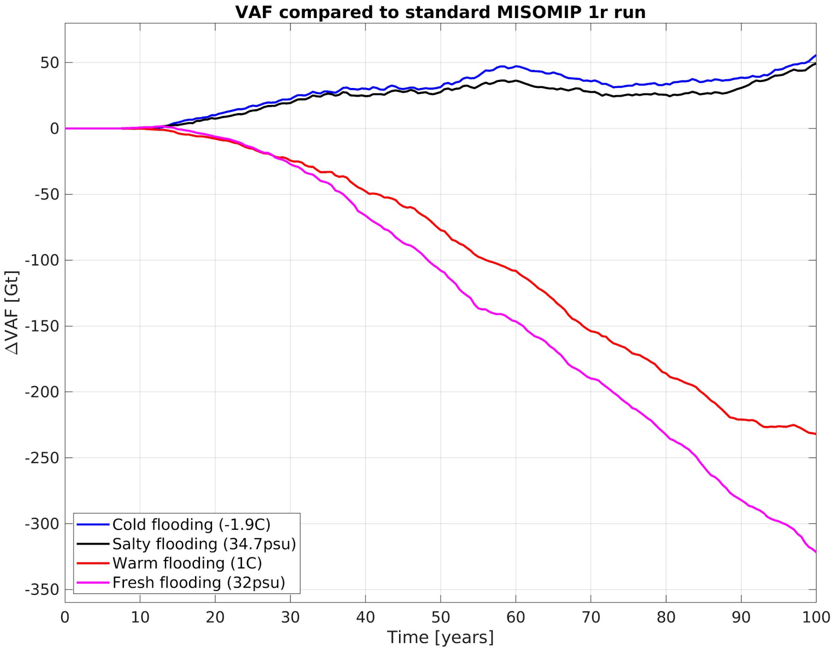
Technical challenges: properties of new cells

How do we extrapolate temperature and salinity into newly opened ocean cells?



Technical challenges: properties of new cells

Step-changes in geometry and extrapolation of T/S violate heat and volume conservation. But does it matter?



Test extreme scenarios:

- Cold or salty cells: about 1% higher ice volume
- Warm or fresh cells: about 6-8% lower ice volume
- Cold/salty is more likely than warm/fresh in the context of plume theory

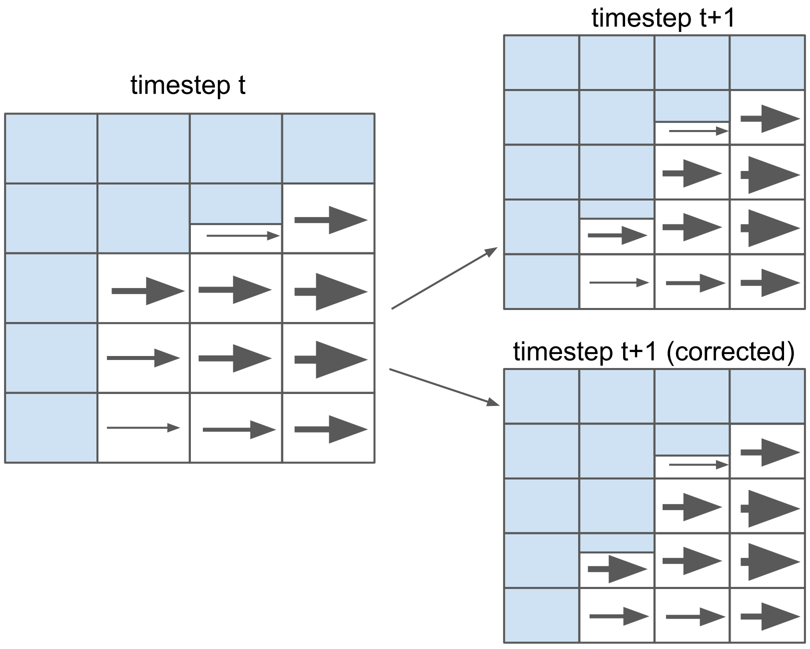
Technical challenges: properties of new cells

Step-changes in geometry and extrapolation of T/S violate heat and volume conservation. But does it matter?

- This would not be acceptable in a fully-coupled Earth System Model where everything needs to be conserved.
- To conserve everything, need ice sheet model on same grid and timestep as the ocean.
- Inefficient: ice sheet models naturally want higher resolution and lower timestep than ocean models.
- Fully conserving models do exist for small-scale process studies (eg MITgcm Streamice package)

Technical challenges: barotropic mode

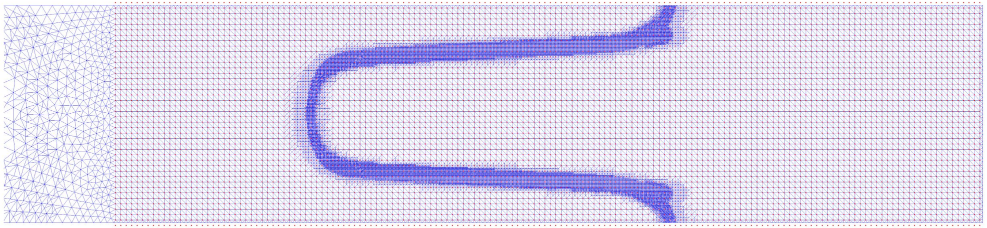
Preserving ocean barotropic transport (i.e. depth-integrated velocities)

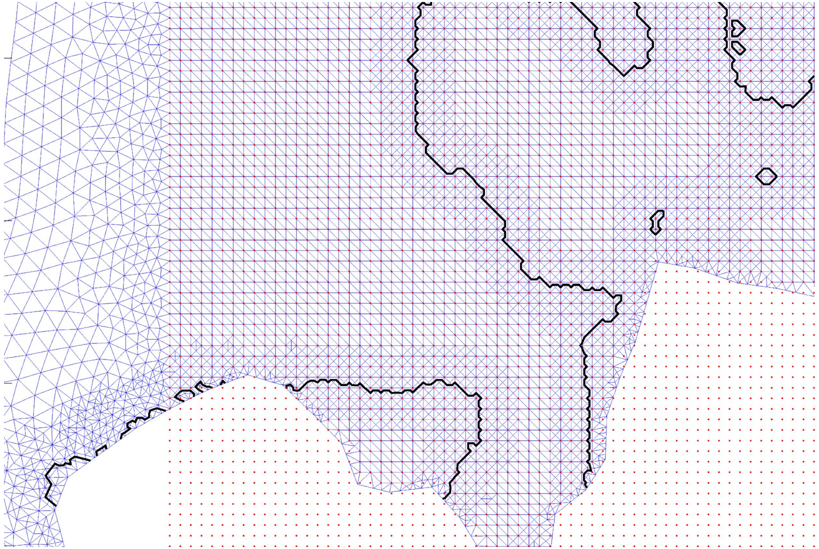


- Geometry changes but velocities stay the same: barotropic transport changes
- Can cause “tsunamis” and ocean model blows up
- Correct velocities to preserve barotropic mode before and after coupling

Technical challenges: grids

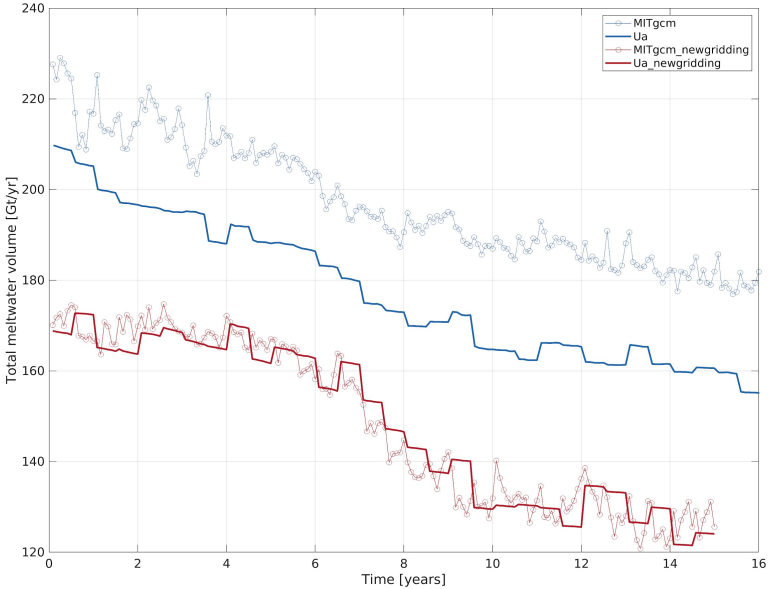
- Úa and MITgcm are on different grids.
- Minimise interpolation errors by making MITgcm gridpoints a subset of Úa nodes.





Technical challenges: grids

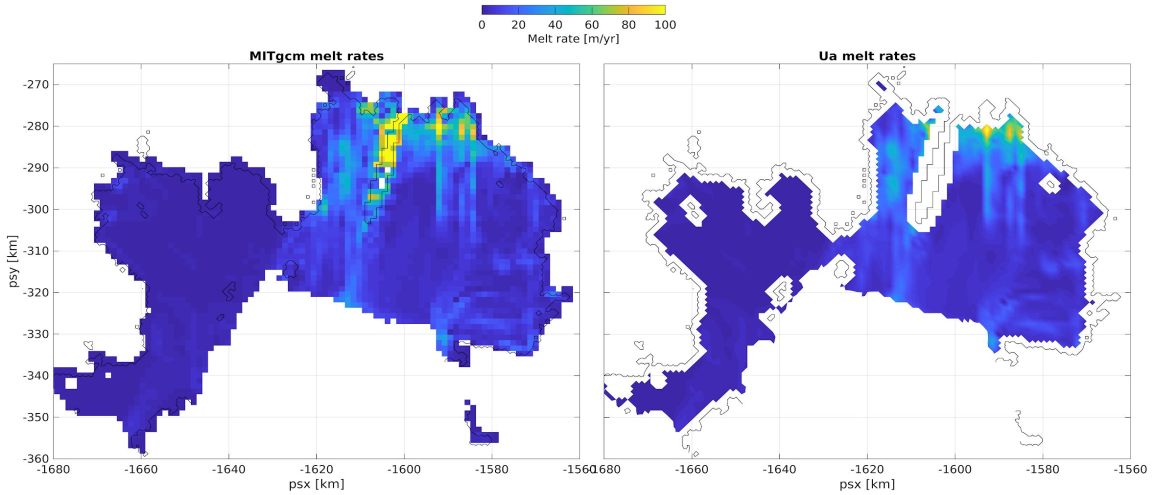
- Úa and MITgcm are on different grids.
- Minimise interpolation errors by making MITgcm gridpoints a subset of Úa nodes.
  - In some cases, greatly improves match between melt rates in the two models.



Technical challenges: grids

Differences in resolution can cause problems:

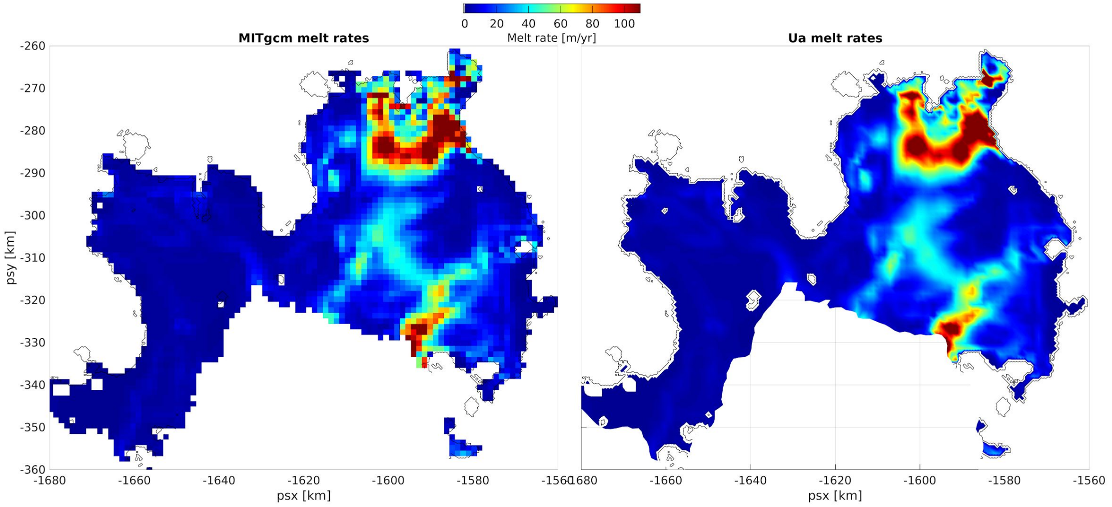
- MITgcm does not resolve details of grounding line
- Melt nodes in Úa should not be directly connected to grounded nodes (Seroussi et al. 2018)



Technical challenges: grids

Can alleviate some problems:

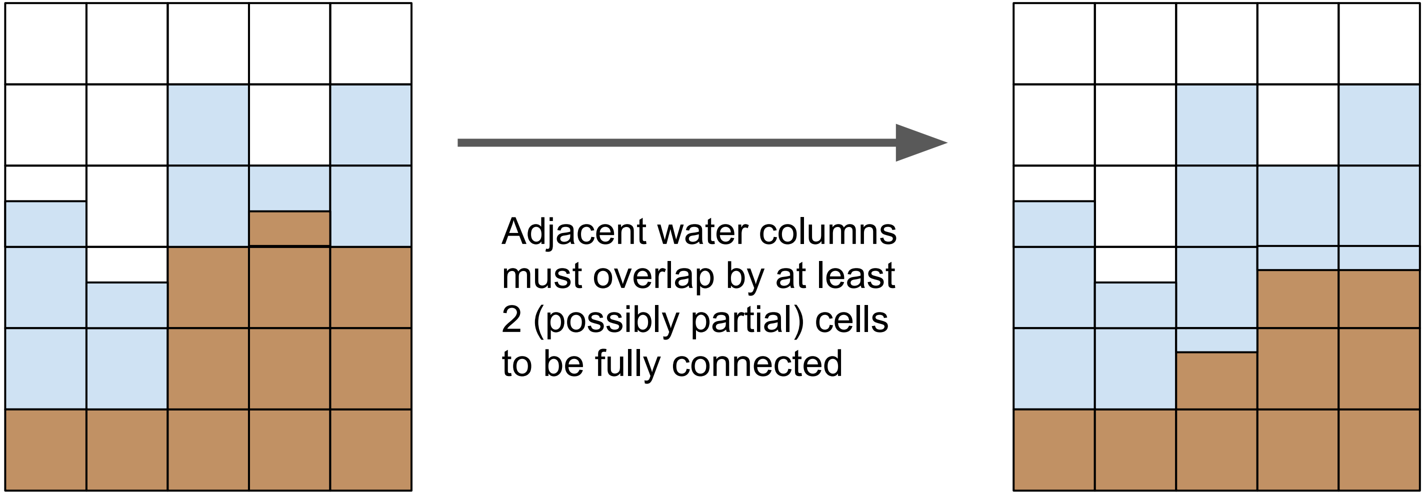
- Increased grounding line resolution in Úa
- Careful choice of grounded/floating mask sent to MITgcm



Technical challenges: digging

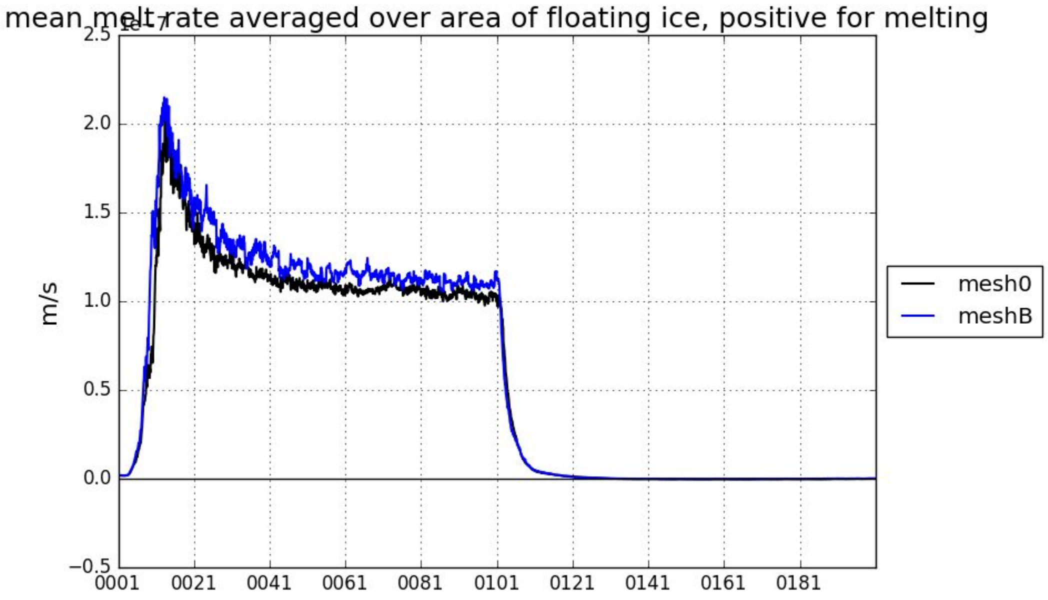
Spurious subglacial lakes can form in MITgcm.

- Artifact of finite resolution, plus interpolation of ice shelf draft
- “Dig” the bathymetry to reconnect the cells



Technical challenges: digging

- Effect of digging: slightly increases melt rates near grounding line
- No longer any disconnected regions that become extremely cold and fresh



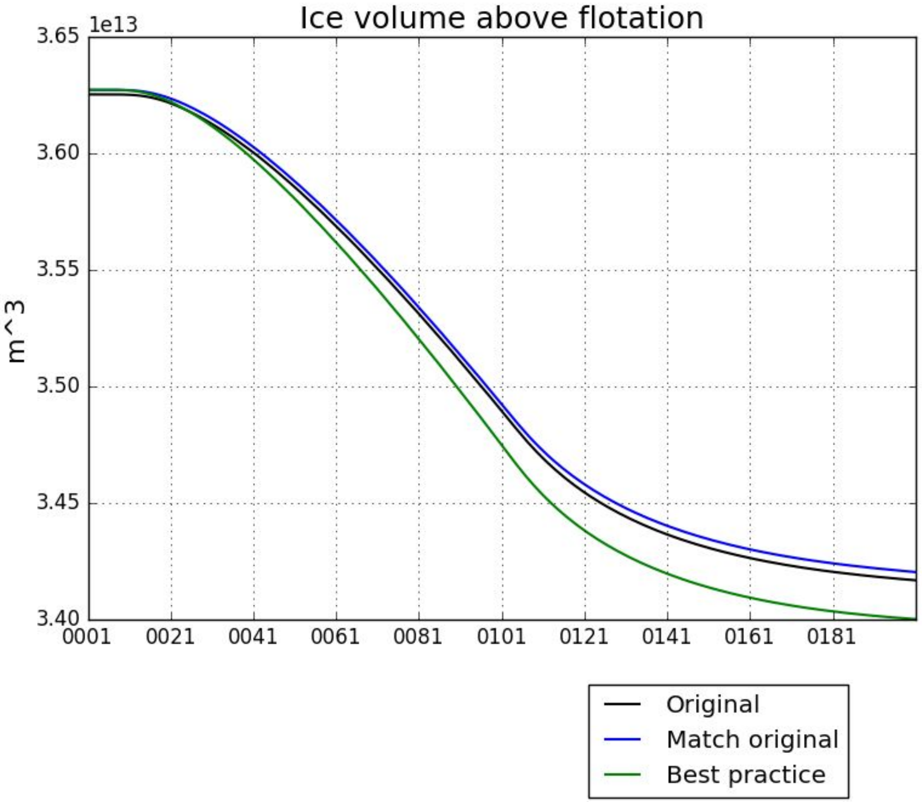
Technical challenges: sea ice

- Sea ice can only exist outside the ice shelf cavities.
- If calving front remains fixed, the sea ice domain never changes.
- No problems so far, but have not tested evolving calving front.

Technical challenges: computational efficiency

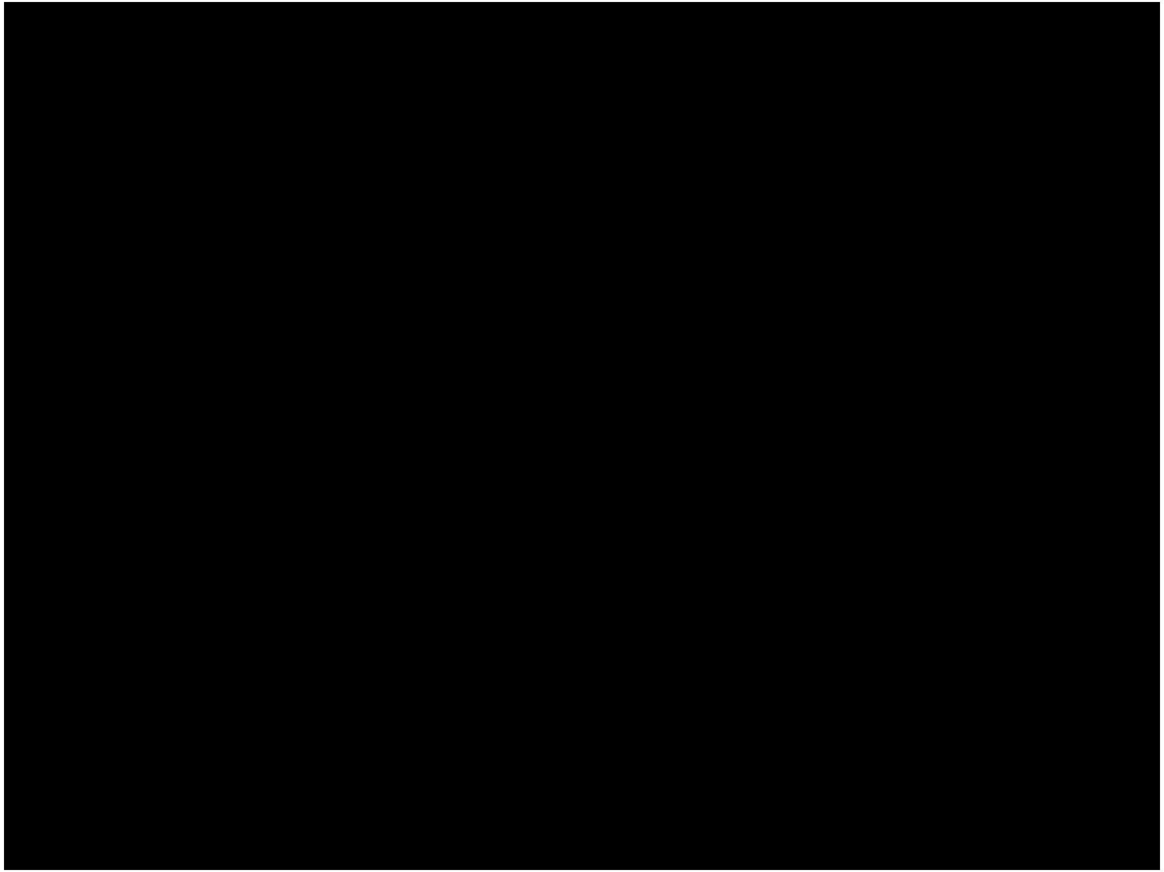
- Usually MITgcm is the slower model, even though it's massively parallelised
- Sometimes Úa is slower (eg at beginning of simulation)
- Computational expense only very slightly higher than ocean-only simulation
- Spend more time queueing, because every coupling timestep is a new set of jobs
- Not currently using parallelisation in Úa: only possible on special Archer queue where I/O is very slow

Case studies: MISOMIP idealised domain

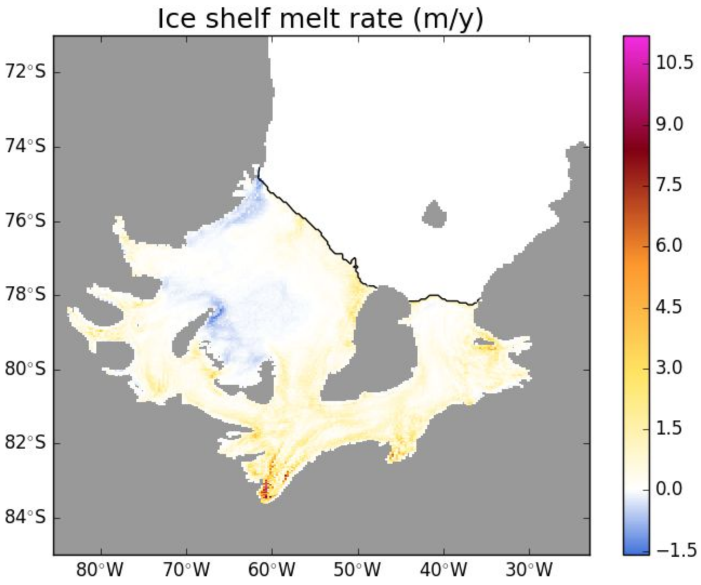


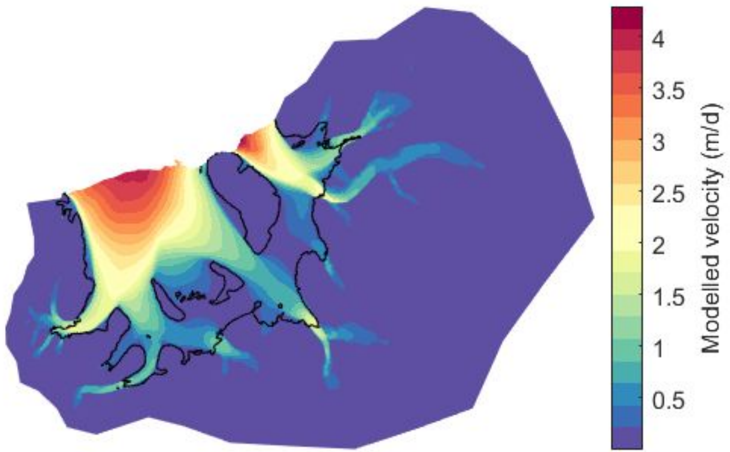
- Almost identical results to original submission when momentum is not preserved
- Very similar results in “best practice” configuration (preserve restart, barotropic mode, digging)
- Best practice doesn’t make much of a difference in this case...but might for realistic domains

Case studies: Amundsen Sea



Case studies: FRIS





Combining existing standalone configurations for MITgcm (Kaitlin) and Úa (Sebastian)

Is ice-sheet/ocean coupling important for you?

- Slower and more expensive - can run a few centuries at best
- Need access to HPC facility for ocean simulations
- Need expertise in ocean modelling
- Initial state matters
- Some options are configuration-specific (best coupling timestep, best floating mask algorithm….) and will require experimentation
- ….But sometimes it is necessary! Depends on the science question you are asking.