Modeling Marine Ice Cliff Instability: Higher Resolution Leads to Lower Impact

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Joint work with:

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- Esmond Ng (LBNL)
- Stephen Price (LANL)

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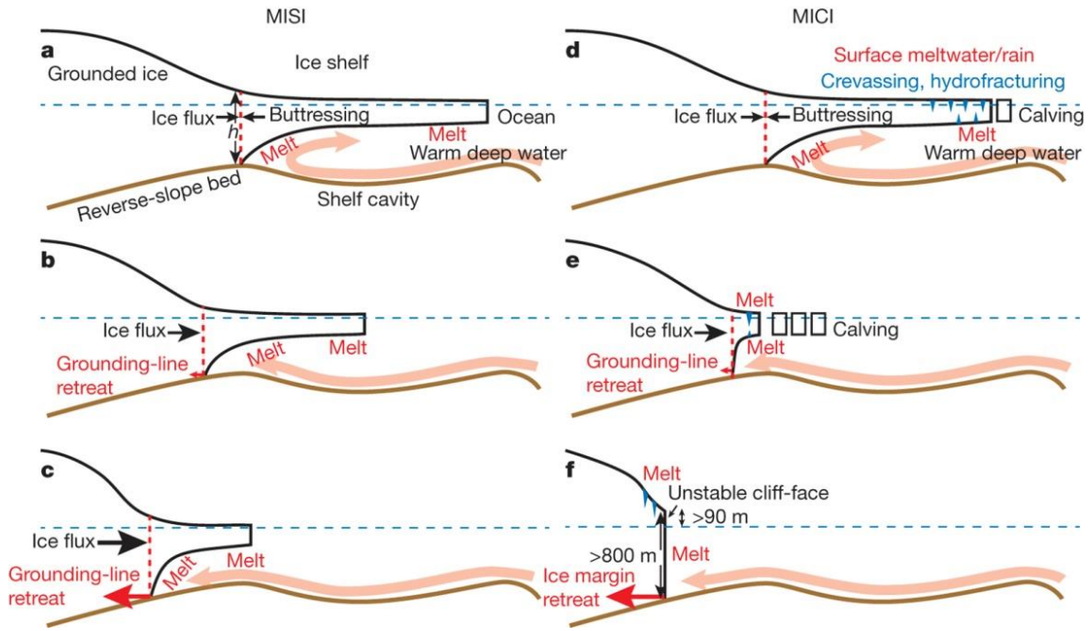
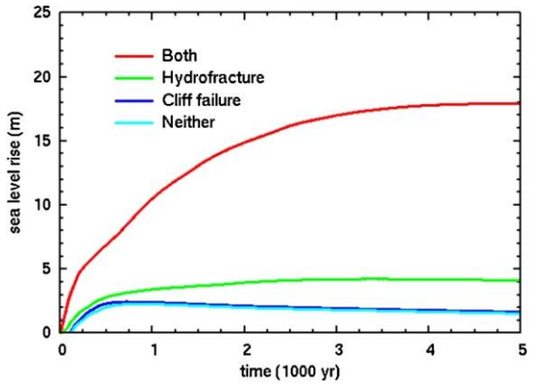
Marine Ice Cliff Instability

- Deconto and Pollard (2015) – wanted to be able to match paleorecord of large SLR

- Surmised mechanism:
  - hydrofacture (eliminate ice shelves)
  - Resulting ice cliffs exceed yield strength of ice.
  - Cliff collapse (drive retreat into EAS basins)
  - Allows for much greater SLR



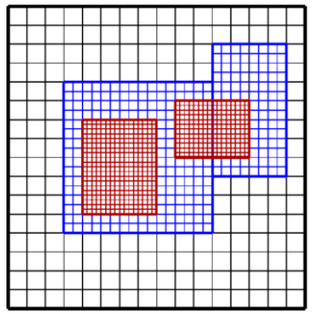
(above) Pollard and Deconto (2016)
(right) Pollard et al, (2015)

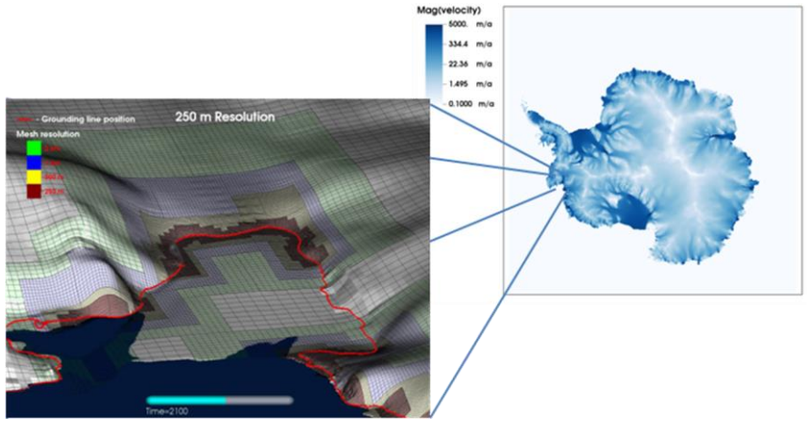


- Matches current observations of hydrofracture and max cliff size…

BISICLES Ice Sheet Model

- Scalable adaptive mesh refinement (AMR) ice sheet model
  - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin…

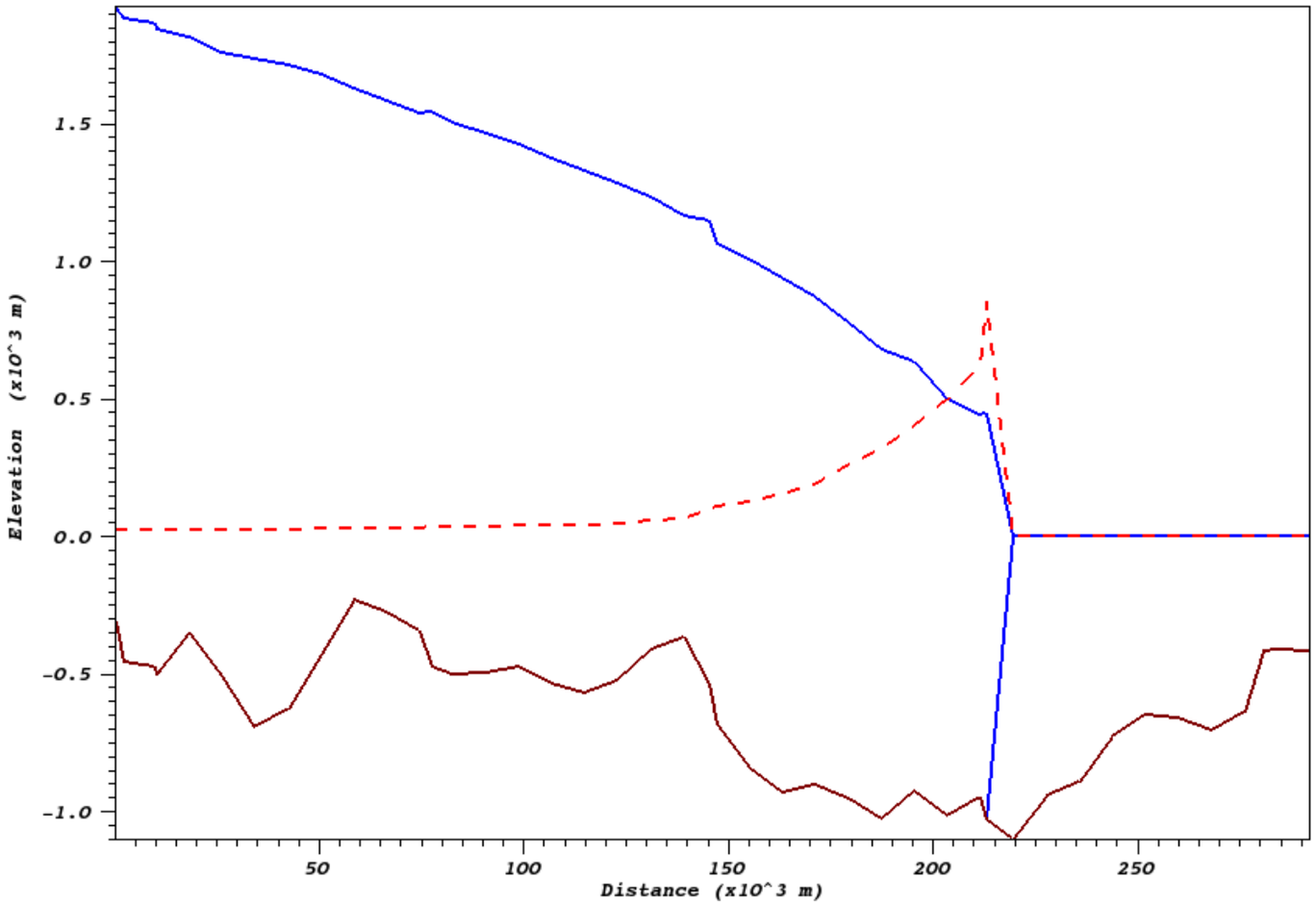




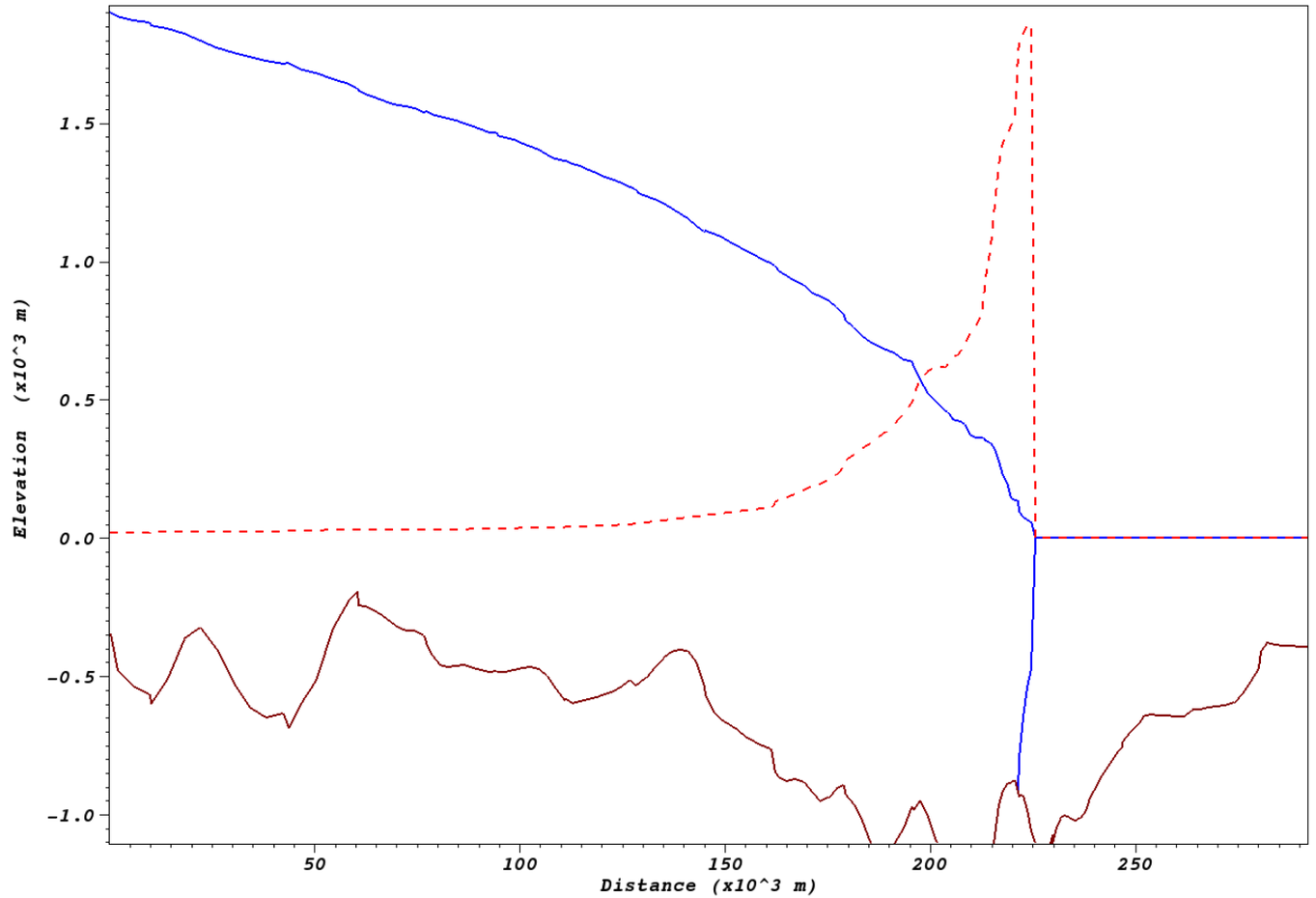
MICI and BISICLES…

- We've been doing Antarctic melt-sensitivity studies.
- High (sufficient) resolution for GL dynamics --
  (O(1km) at GLs with a subgrid friction scheme)
- No MICI mechanism, but wanted to evaluate the potential impact.
- Can look at local surface slopes to see if we get "cliffs"
  - Yes, but sporadic and ephemeral

8km resolution - cliffs!



But 1km resolution…



Time= 15.00 years

Can MICI be a symptom of under-resolution?

BISICLES cliff-collapse scheme

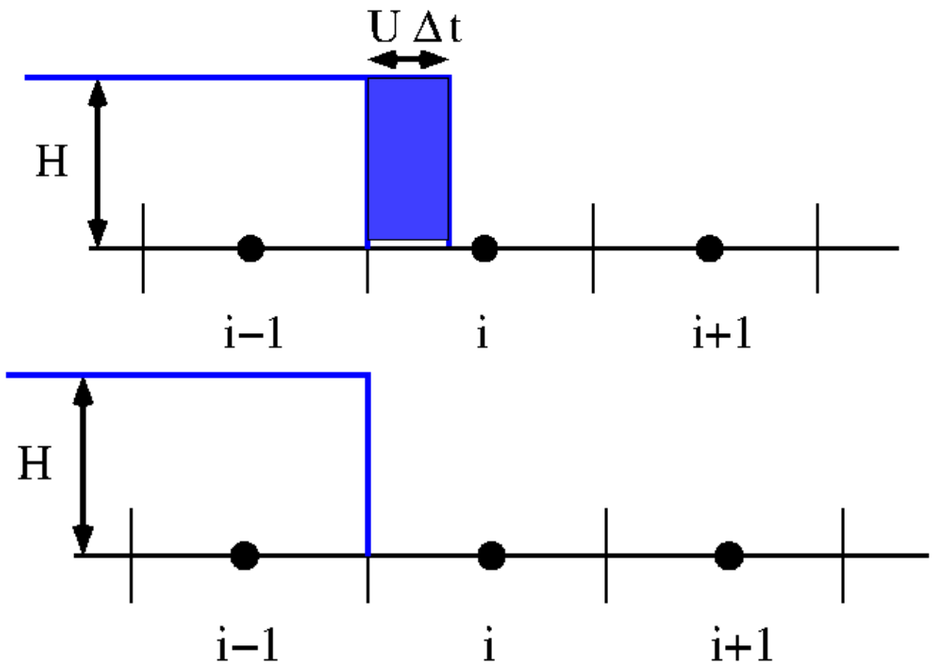
- Extend existing partial-cell scheme (designed for shelf-regrowth in MISOMIP)
- BISICLES is a finite-volume code; compute cell-averaged quantities which are updated by ice thickness fluxes across the cell faces.
- Maintain an area fraction φ, which is the fraction of the cell area (2d) which contains ice
- Wind up with an effective thickness:

$$\tilde{h} = \frac{h}{\varphi}$$

- If there is a cliff,

$$\varphi^{new} = \varphi - r\frac{\Delta t}{\Delta x}$$

$$h^{new} = h\frac{\varphi^{new}}{\varphi}$$

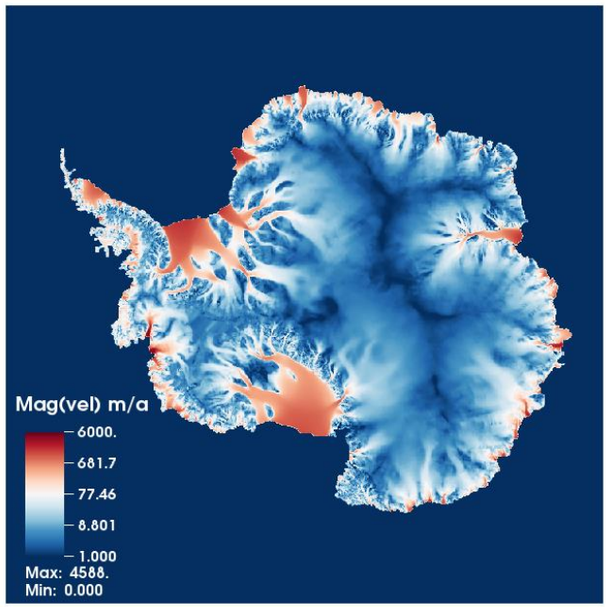


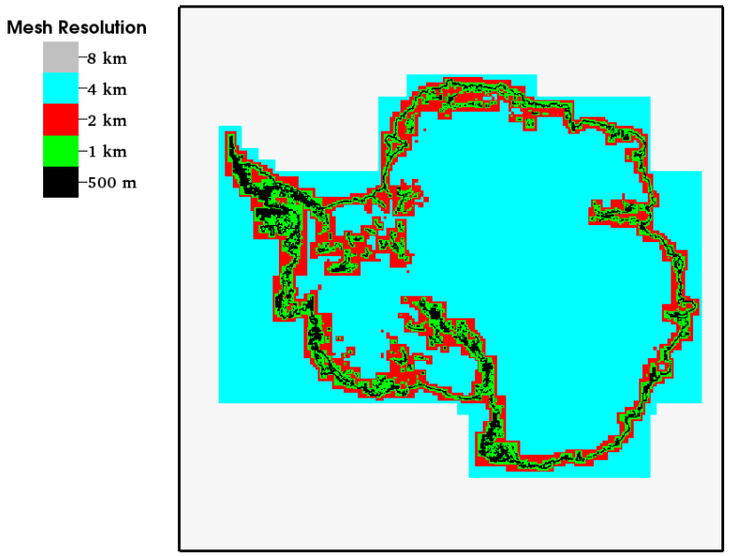
Experiment – 250-year Antarctic simulations

- Designed to trigger MICI wherever possible
- Range of finest resolution from 8 km (no refinement) to 1km (3 levels of factor-2 refinement)
- Shelf-thinning: Initiate an aggressive shelf-thinning/weakening regime – thins most shelves down to O(400m) to weaken enough to be susceptible to hydrofracture.
- Hydrofracture: calve off any floating ice thinner than 500m.
- Run with and without MICI
  - Use Pollard and Deconto MICI parameters:
  - 1km threshold,
  - 3km/year recession rate

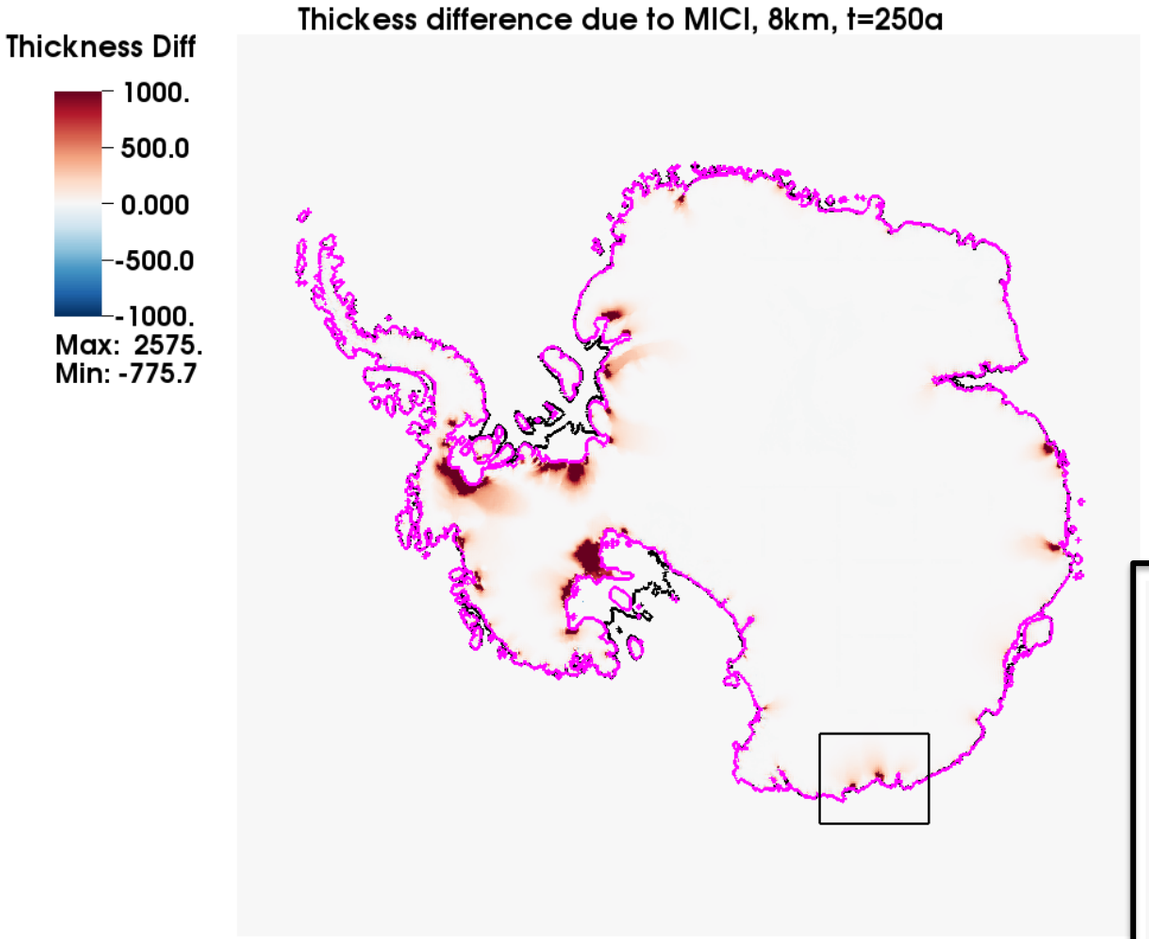
Initial Condition for Antarctic Simulations

- Full-continent Bedmap2 (2013) geometry
- Temperature field from Pattyn (2010)
- Initialize basal friction to match Rignot (2011) velocities
- SMB: Arthern et al (2006)
- AMR meshes: 8 km base mesh, adaptively refine to Δx_f

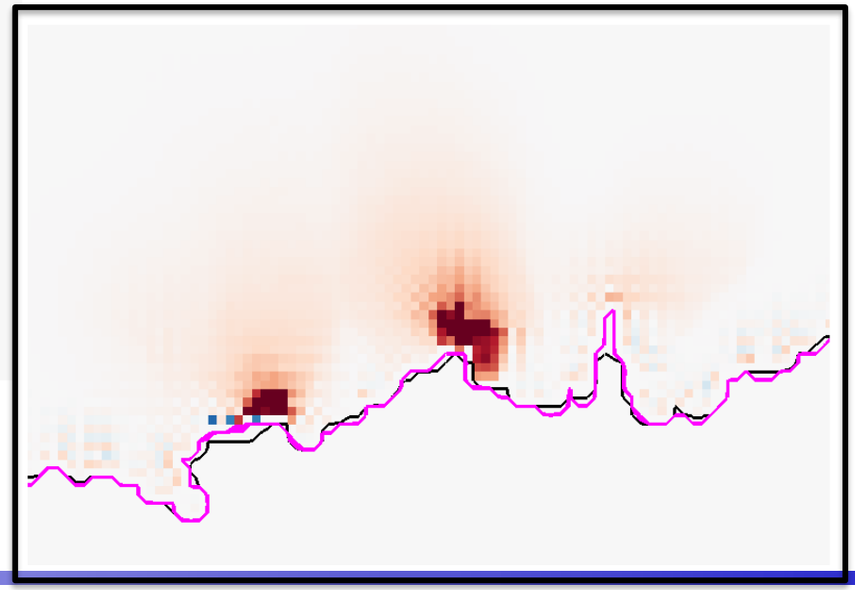




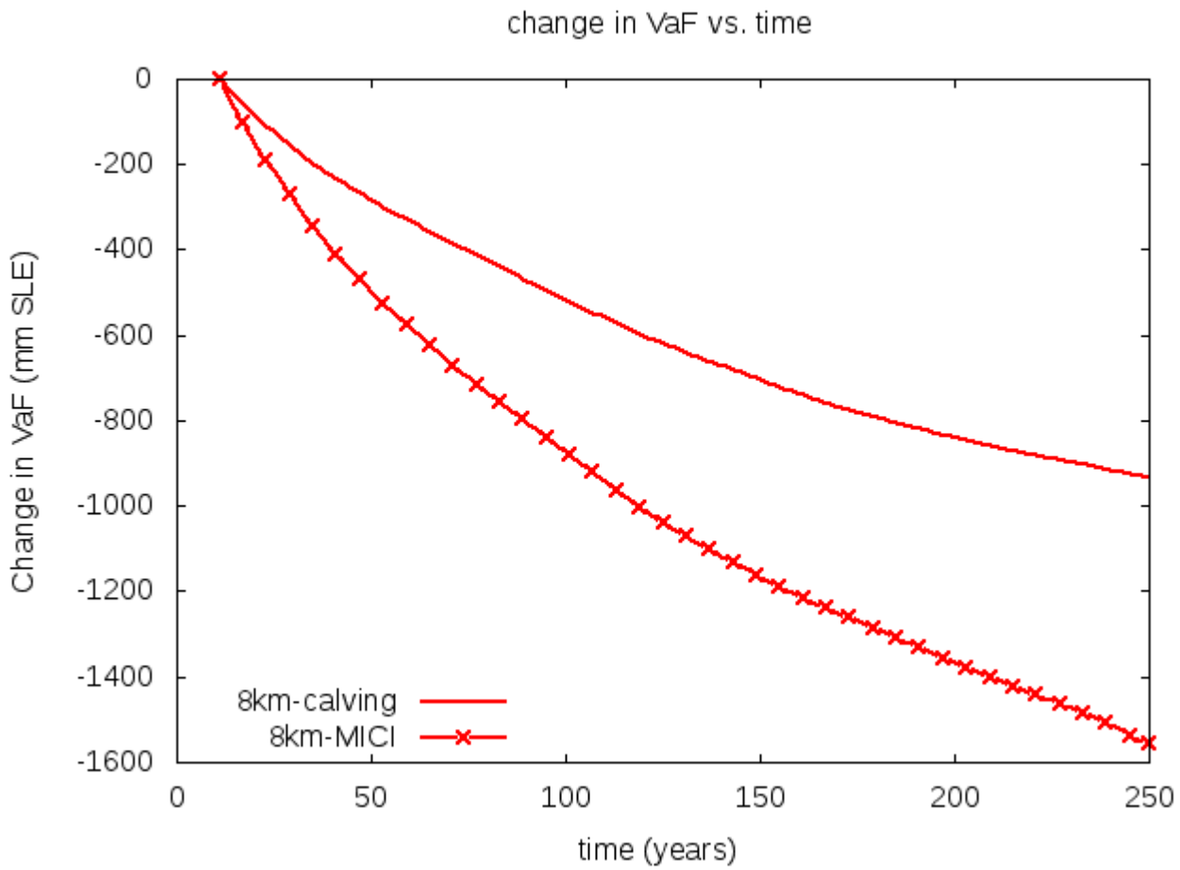
Results - 8km resolution



- Ice thickness differences between 8m MICI and no-MICI runs
- Shown at final time (t=250)
- Inset shows Wilkes Basin



Volume above Flotation…



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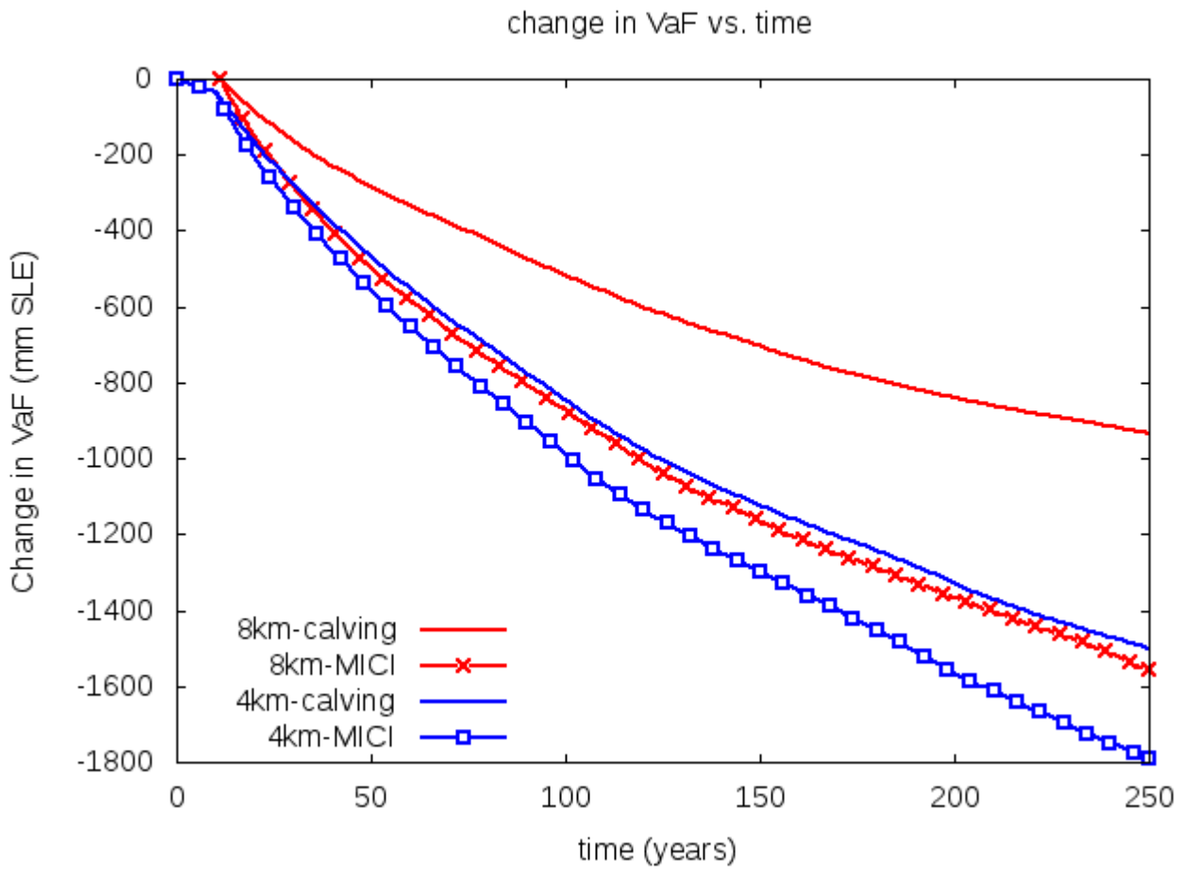

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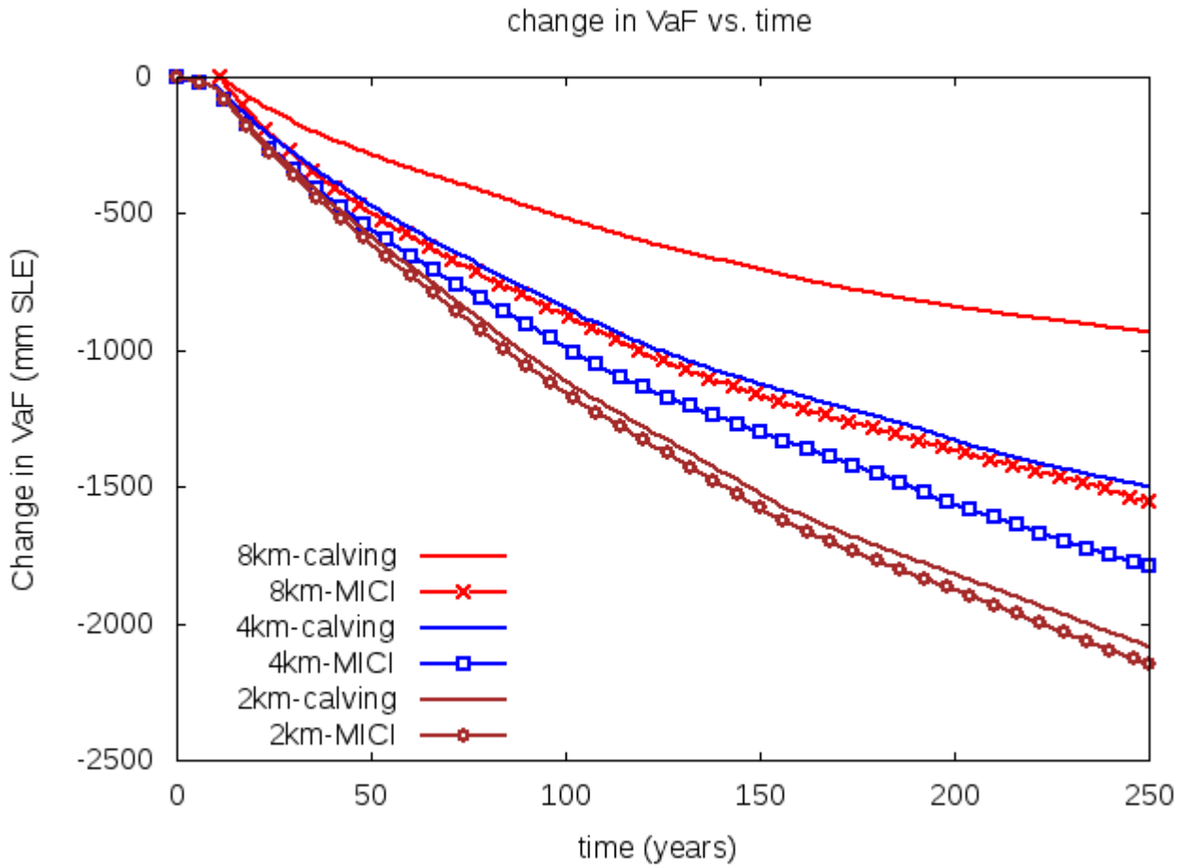

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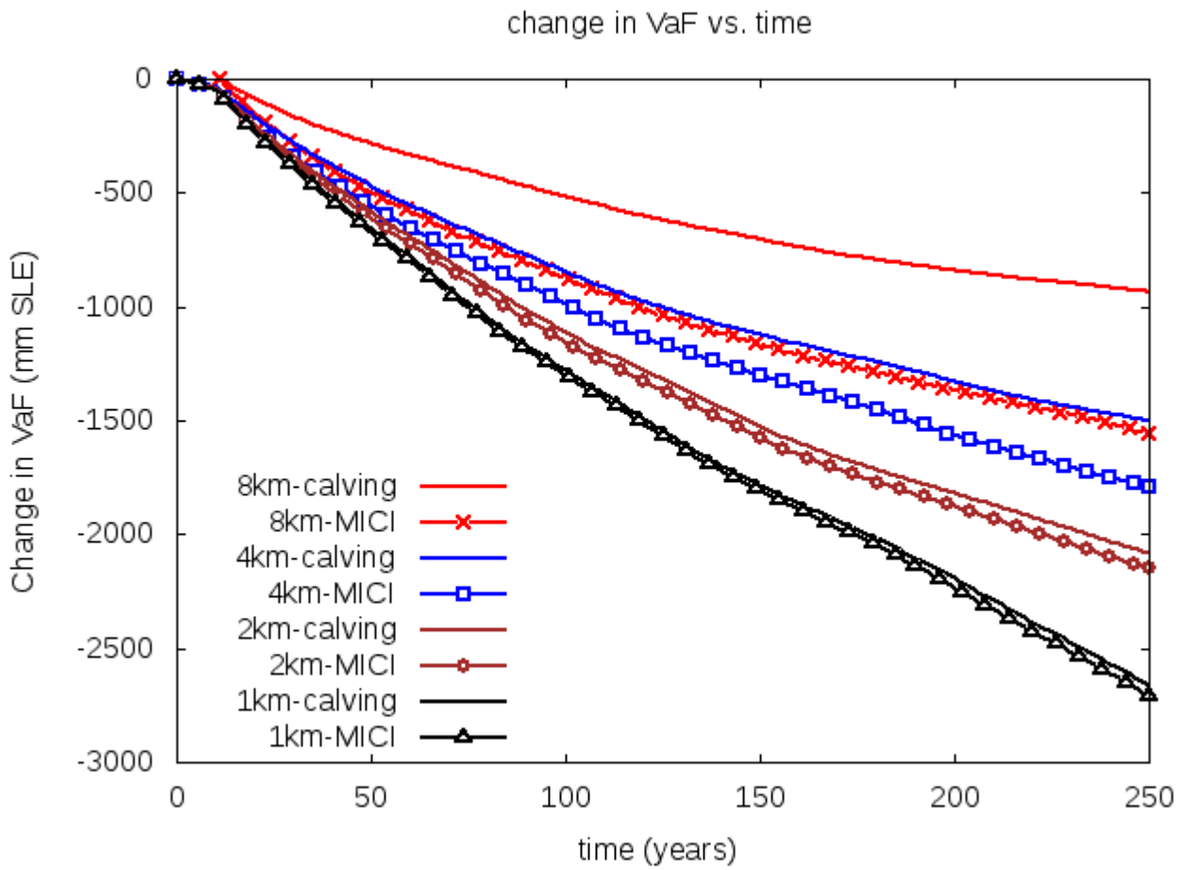


Alternative hypothesis

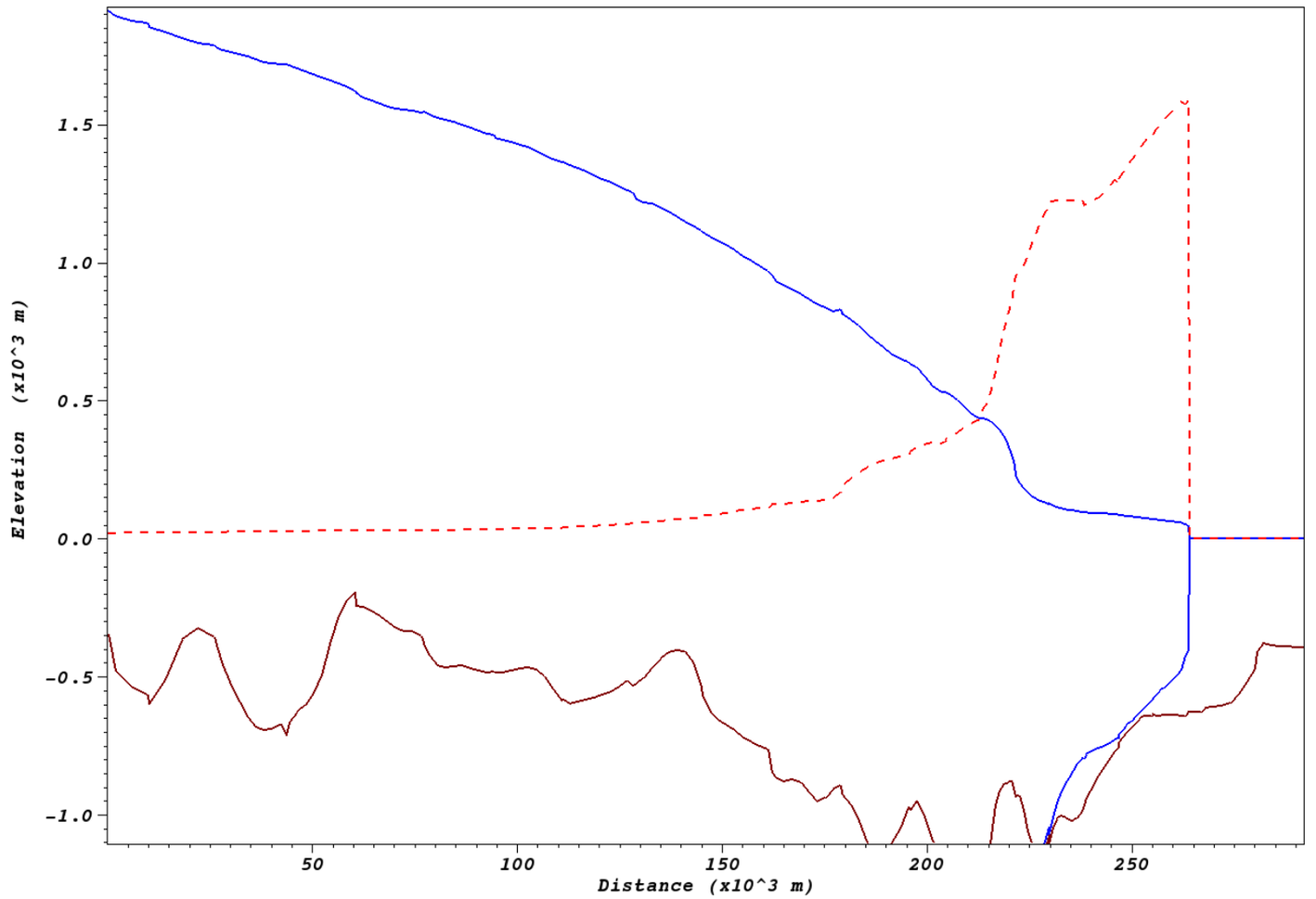
- Ice dynamics works to prevent/remove ice cliffs on macro scales
  - Local acceleration
  - Upstream thinning

- These ice dynamics operate on “fine” scales in the context of continental-scale ice sheet models
  - Likely O(a few GL ice thicknesses)

- Suggest that we need to resolve these scales to get retreat dynamics correct.

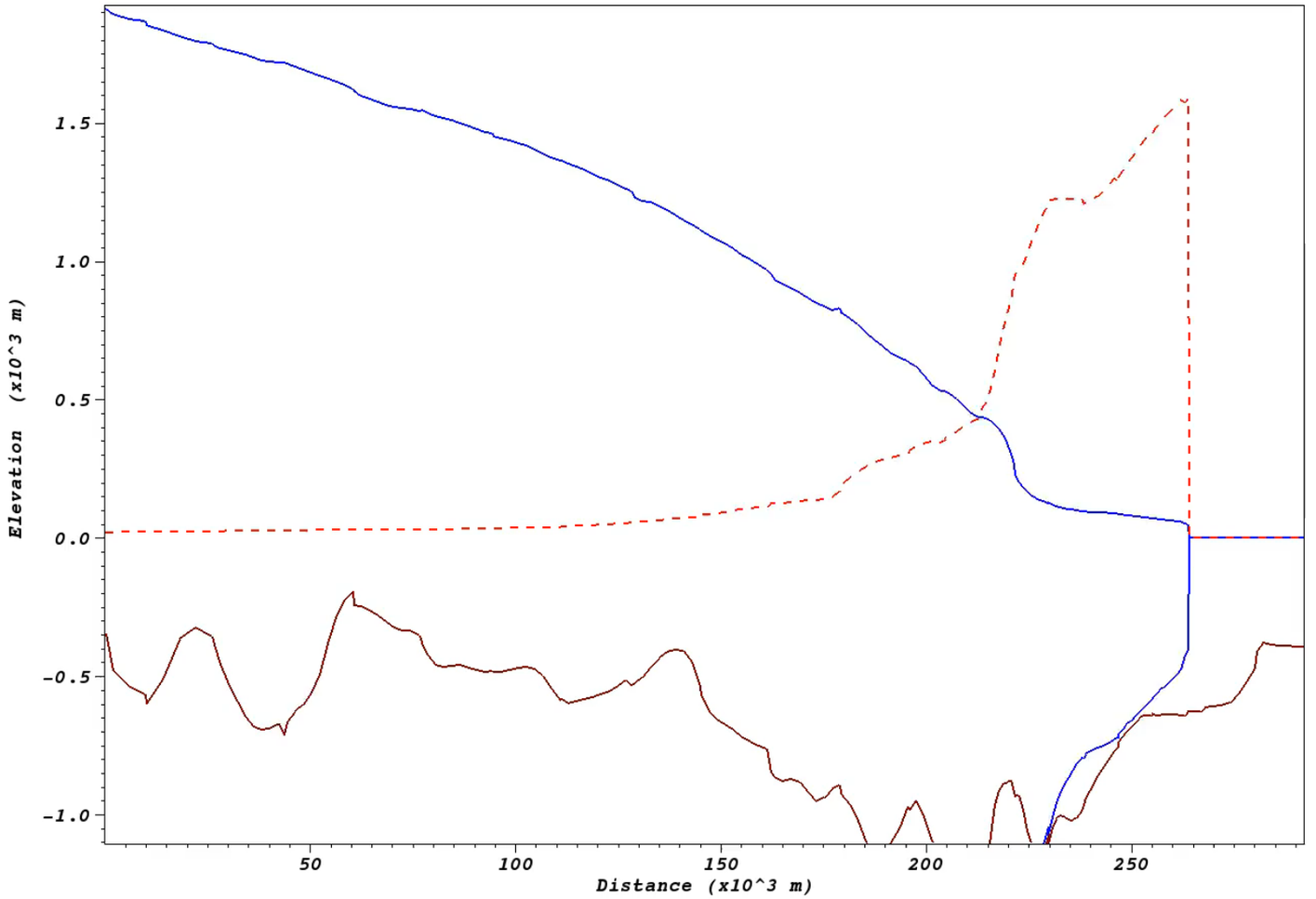
- Thinning/weakening phase is important – upstream adjusts to reduced buttressing

One example - Wilkes Basin: 1km resolution



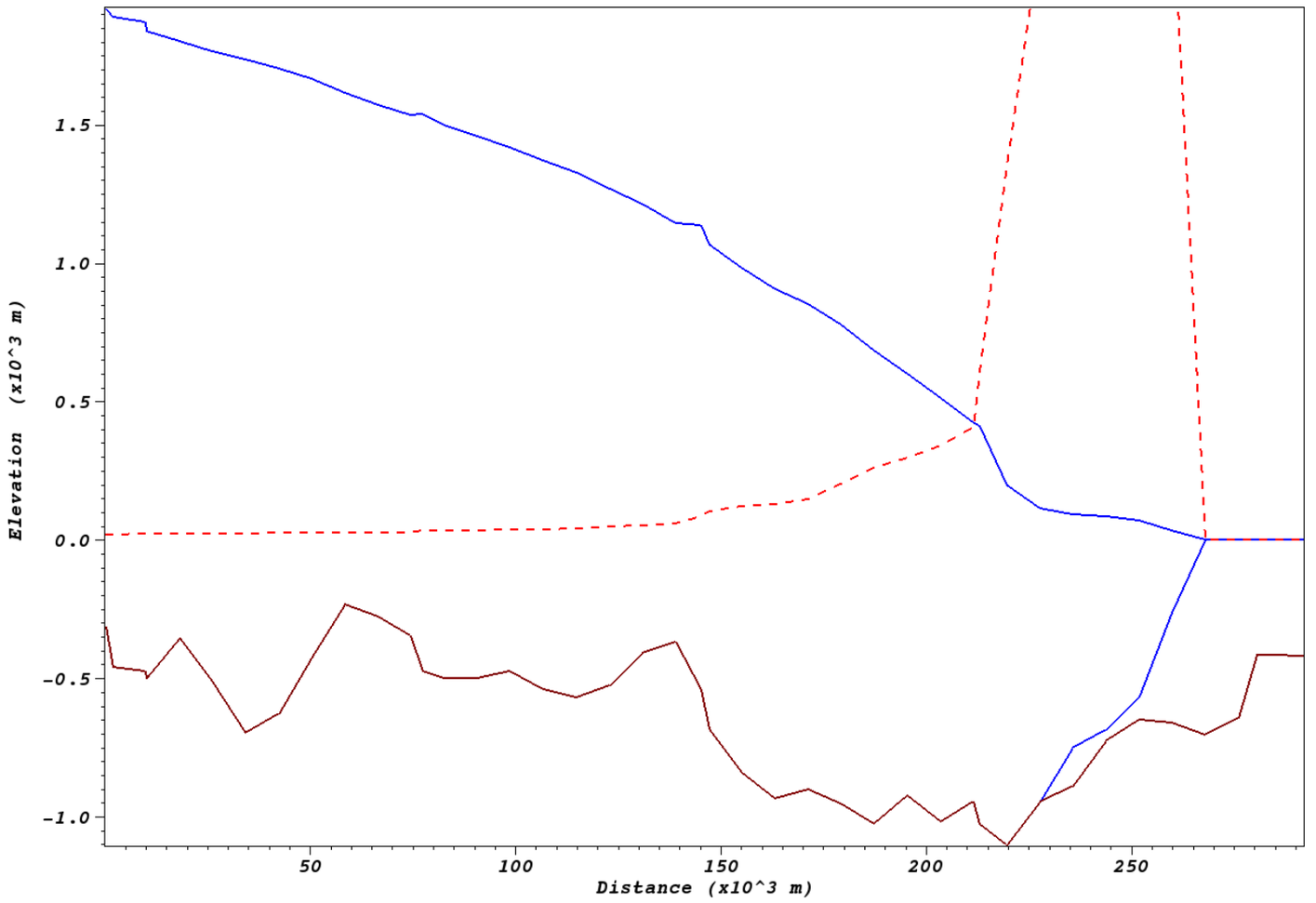
Time= 0.00 years

One example - Wilkes Basin



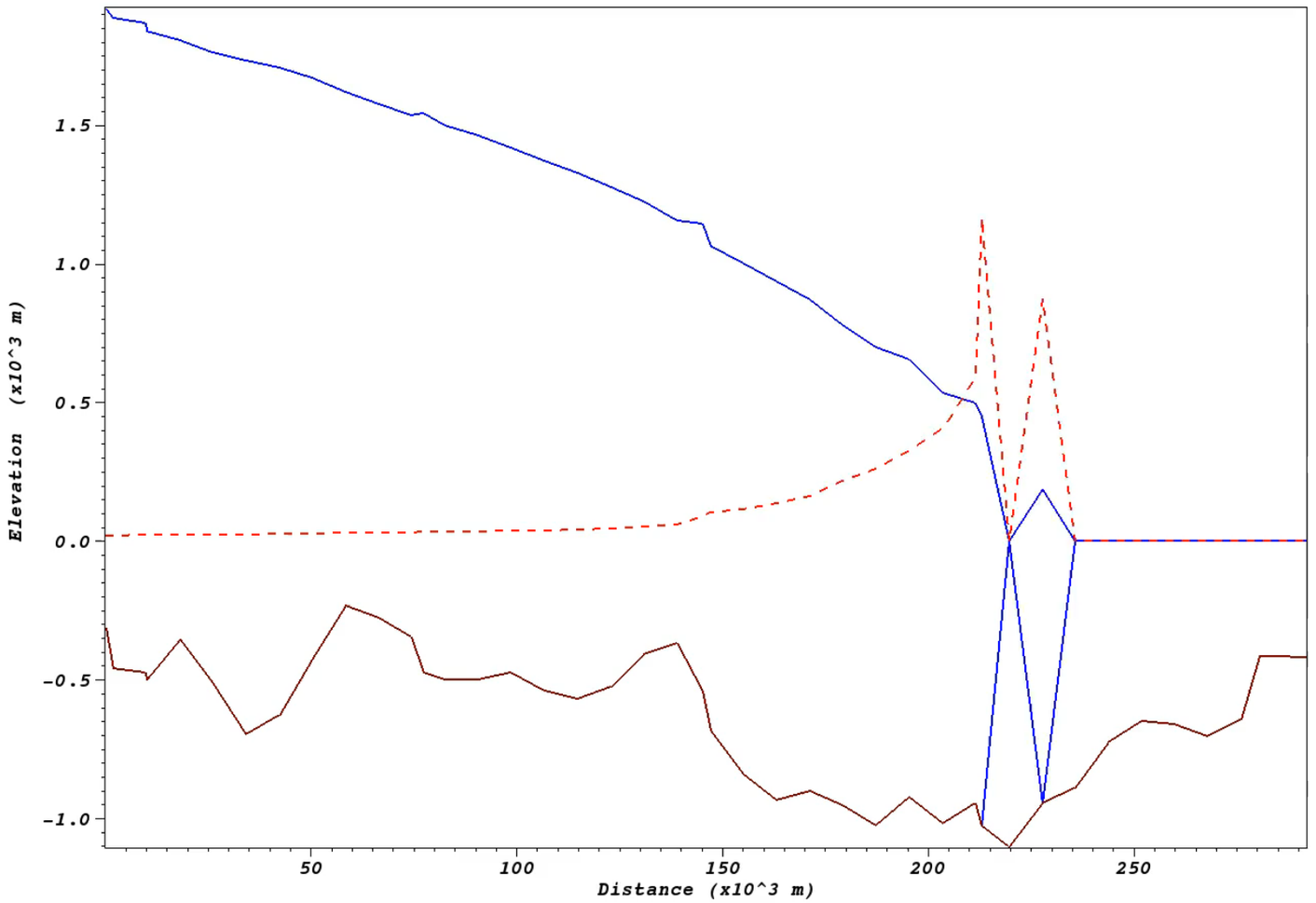
Time= 0.00 years

Wilkes Basin: 8km resolution



Time= 0.00 years

Wilkes Basin: 8km resolution



Time= 11.00 years

Conclusions

- There seems to at least be some indication that some MICI might be a result of some under-resolution.

- Hypothesis: (relatively) fine-scale ice dynamics works to prevent or destroy ice cliffs

- Future work: Incorporate a full damage model to better capture hydrofracture dynamics. See poster:

Poster C31C-1518: Simulating Pine Island Glacier Extents Under Multiple Forcing Scenarios Using Damage Mechanics, Morgan Whitcomb

Thank you!