Probabilistic Sea-Level Projections from Ice Sheet and Earth System Models 1: New Model Physics

Subglacial Hydrology

Goals:

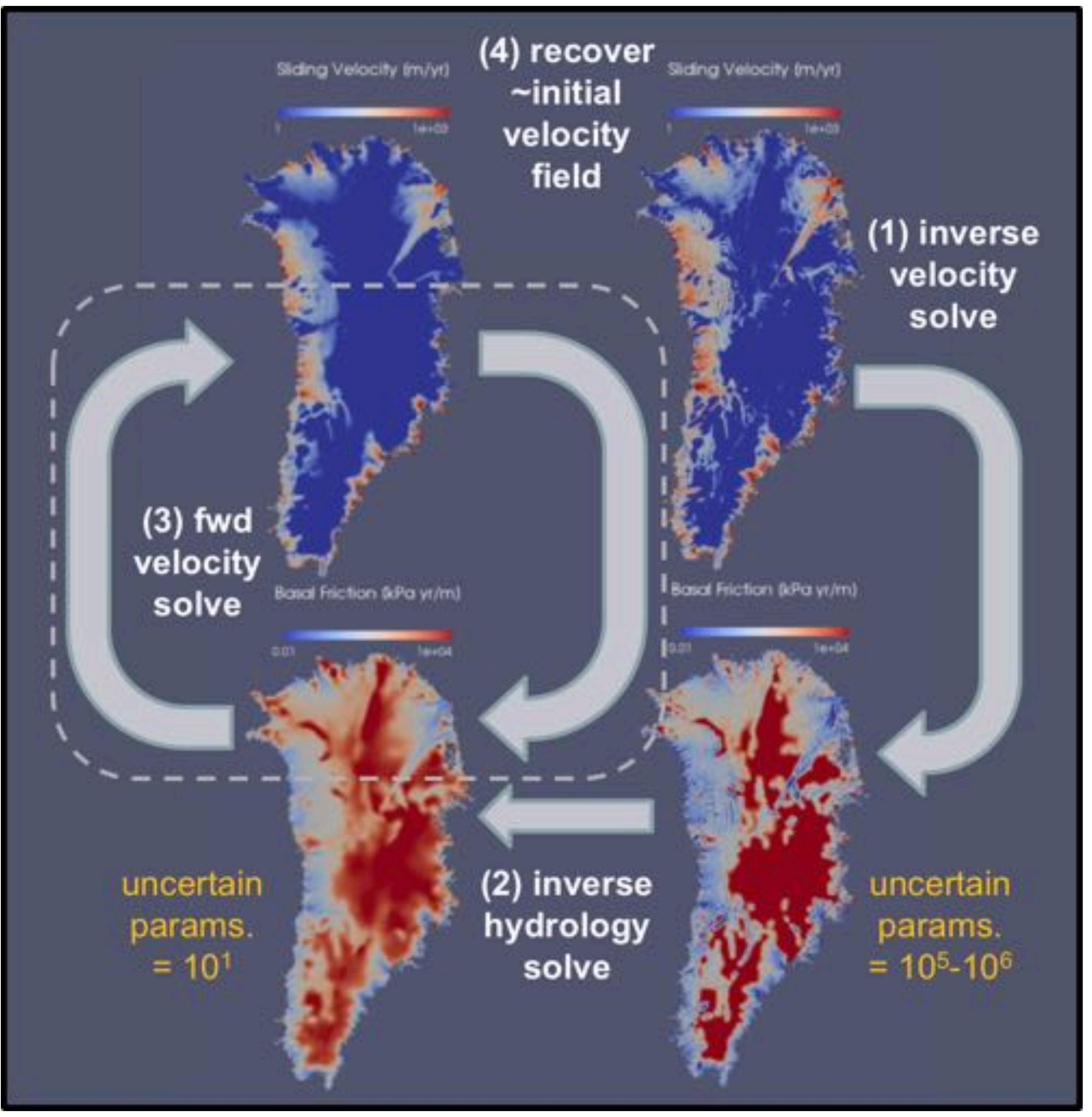
- improve the representation of glacial sliding – the primary control on the flux of ice to the ice sheet margins – by coupling glacier sliding with physically motivated, evolutionary subglacial hydrology models
- explore parameter space reduction for optimization and UQ efforts

Progress:

- stand-alone hydrology solver working and tested on idealized problems from literature (uncoupled)
- inversion of hydrology model for hydrology and sliding law parameters working (one-way coupling with sliding)
- solver for inversion through iterative (weak) coupling of ice and hydrology problem almost complete (two-way coupling with sliding)

Next steps:

- complete and test two-way coupled, iterative solver
- adapt MALI solver libraries for simultaneous (coupled) solution of ice dynamics and subglacial hydrology
- exploit small hydrology model parameter space for UQ experiments



Left: Workflow for iterative coupling of ice flow and subglacial hydrology optimization:

1) invert velocity solver to obtain map of spatially-varying basal friction parameters from observations of ice surface velocity

2) using map of inverted basal friction parameters, invert subglacial hydrology solver to obtain 5, spatially-uniform hydrology and sliding law parameters

3) use forward velocity solve with new updated sliding law to obtain modeled sliding velocity field

4) iterate steps 2-3 (dashed-box) until convergence (e.g., no change in sliding velocity)

Damage, Fracture, & Calving

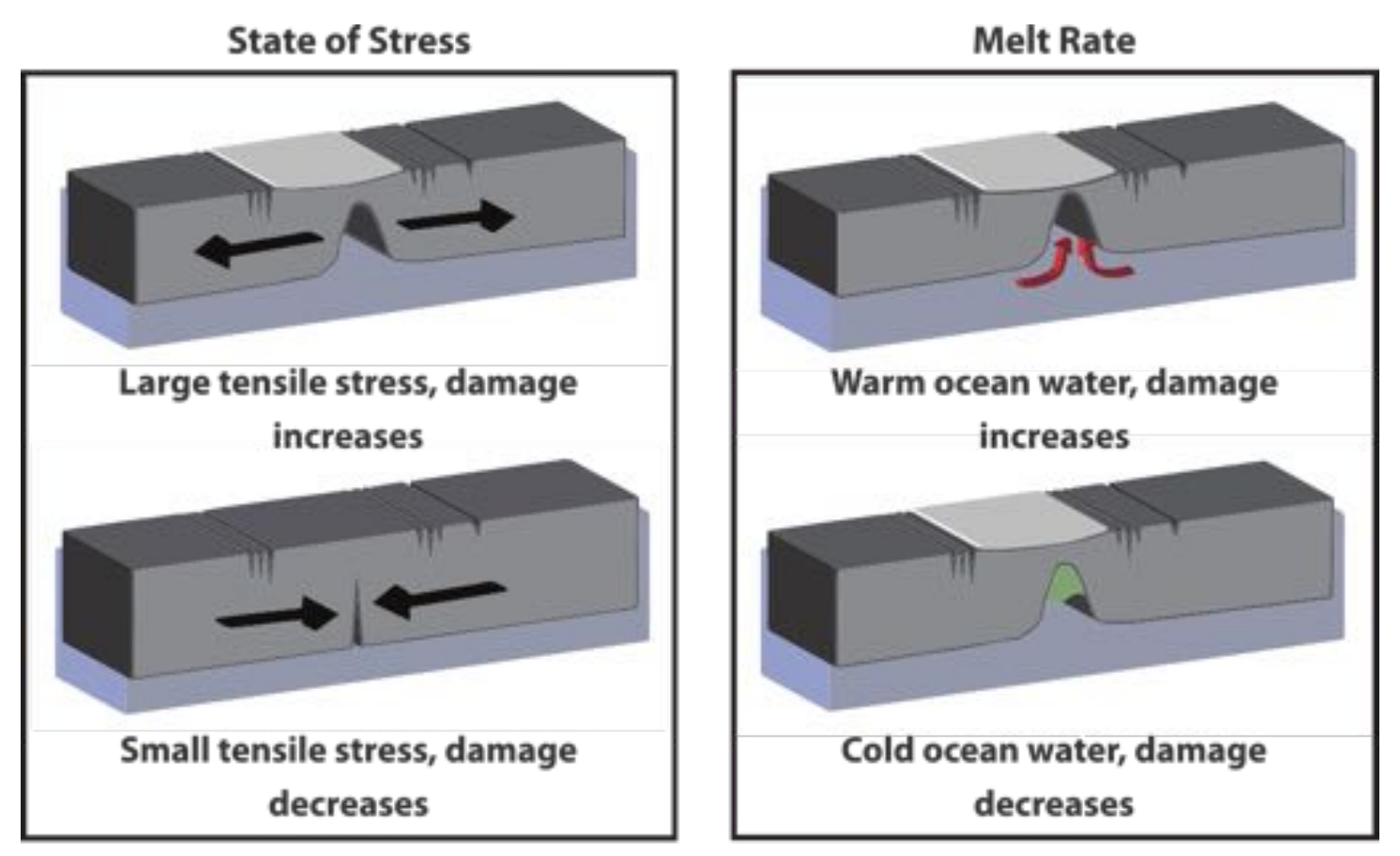
Goals:

- iceberg calving accounts for up to 50% of the mass lost from ice sheets
- link a physically-motivated model for iceberg calving to climate forcing for improved sea level projections
- better understand and reduce uncertainty in Antarctic sea level projections
- parameterize crevasse distributions as a continuum damage variable to investigate the stability of ice shelves in the Amundsen Sea over decadal to century timescales

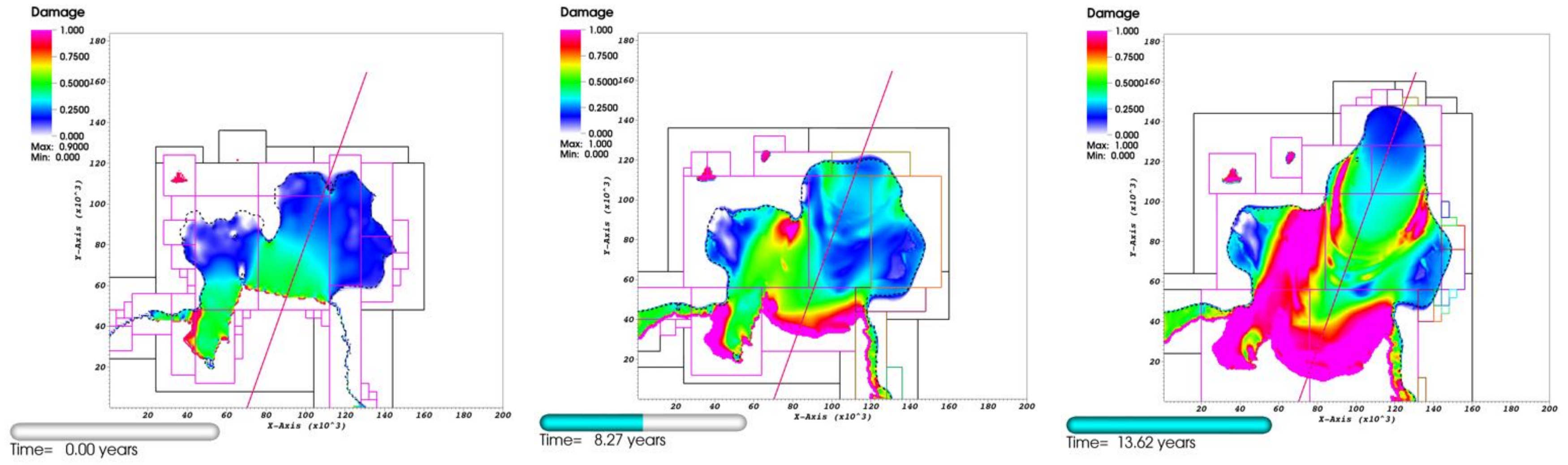
Progress:

- incorporated long-wavelength form of the *Bassis and Ma* (2015) damage model into BISICLES (ongoing for MALI)
- validated the model with established analytic and idealized test cases from previous work with CISM
- ran preliminary simulations of Pine Island Glacier with damage included, using different submarine melt parameterizations

Below: Schematic diagram of crevasse evolution mechanisms (after Bassis and Ma, 2015).



Below: Damage evolution in a BISICLES adaptive mesh refinement simulation of the Pine Island Glacier under a representative subshelf-melt forced scenario. (left) initial condition, (center) after 8.27 years, and (right) after 13.62 years. Damage values of 1 indicate where ice would have likely calved based on the damage evolution. Black and magenta boxes illustrate locations of refined meshes.



Next steps:

- verify prototype damage model in MALI (ongoing)
- couple damage model to ocean and atmospheric forcing
- couple damage evolution to iceberg calving
- apply models with mature damage physics to simulations of Amundsen Sea Embayment evolution

Citations:

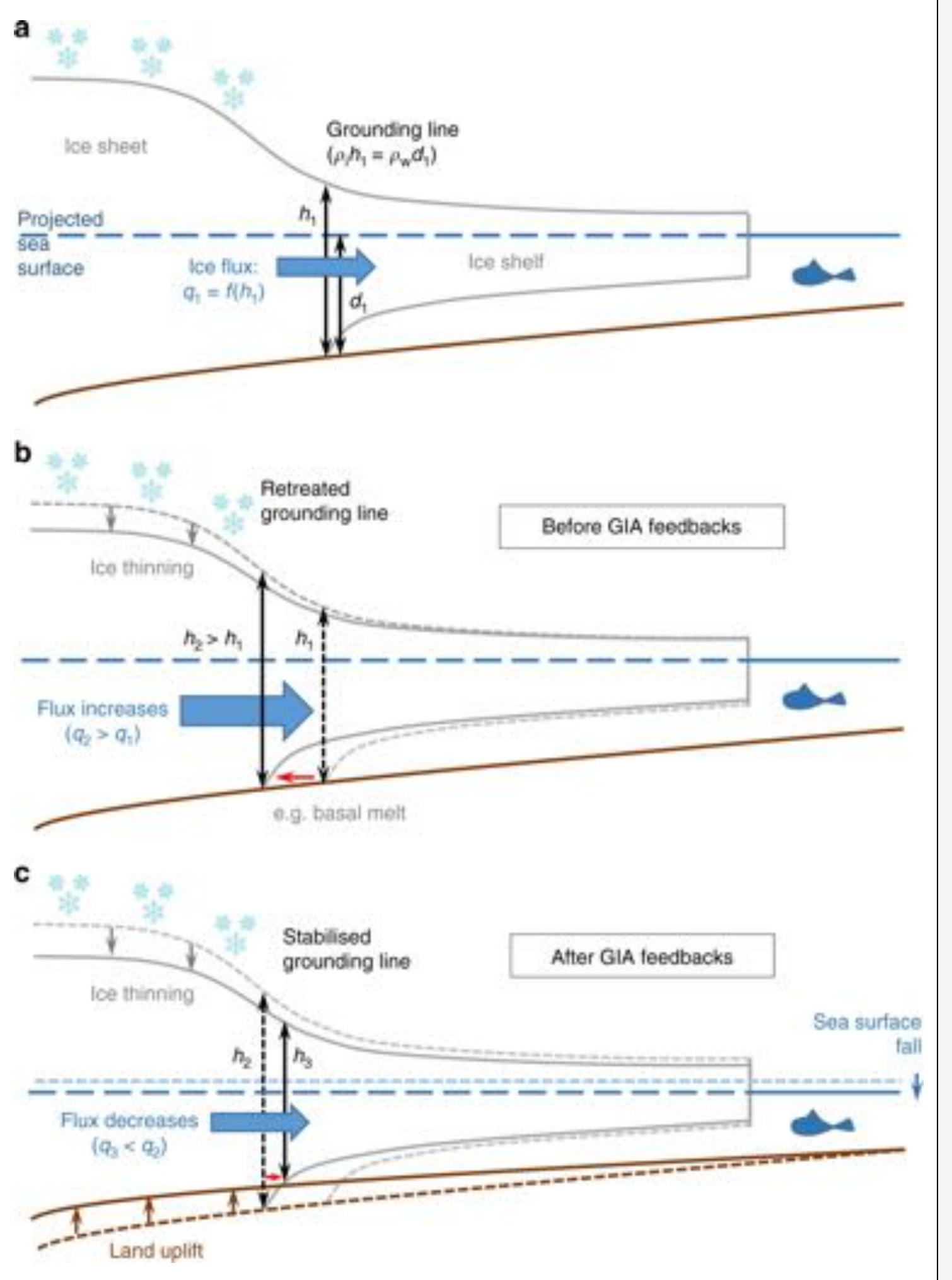
- Bassis, J. N., & Ma, Y. (2015). Evolution of basal crevasses links ice shelf stability to ocean forcing. *EPSL* (**409**), 203-211.

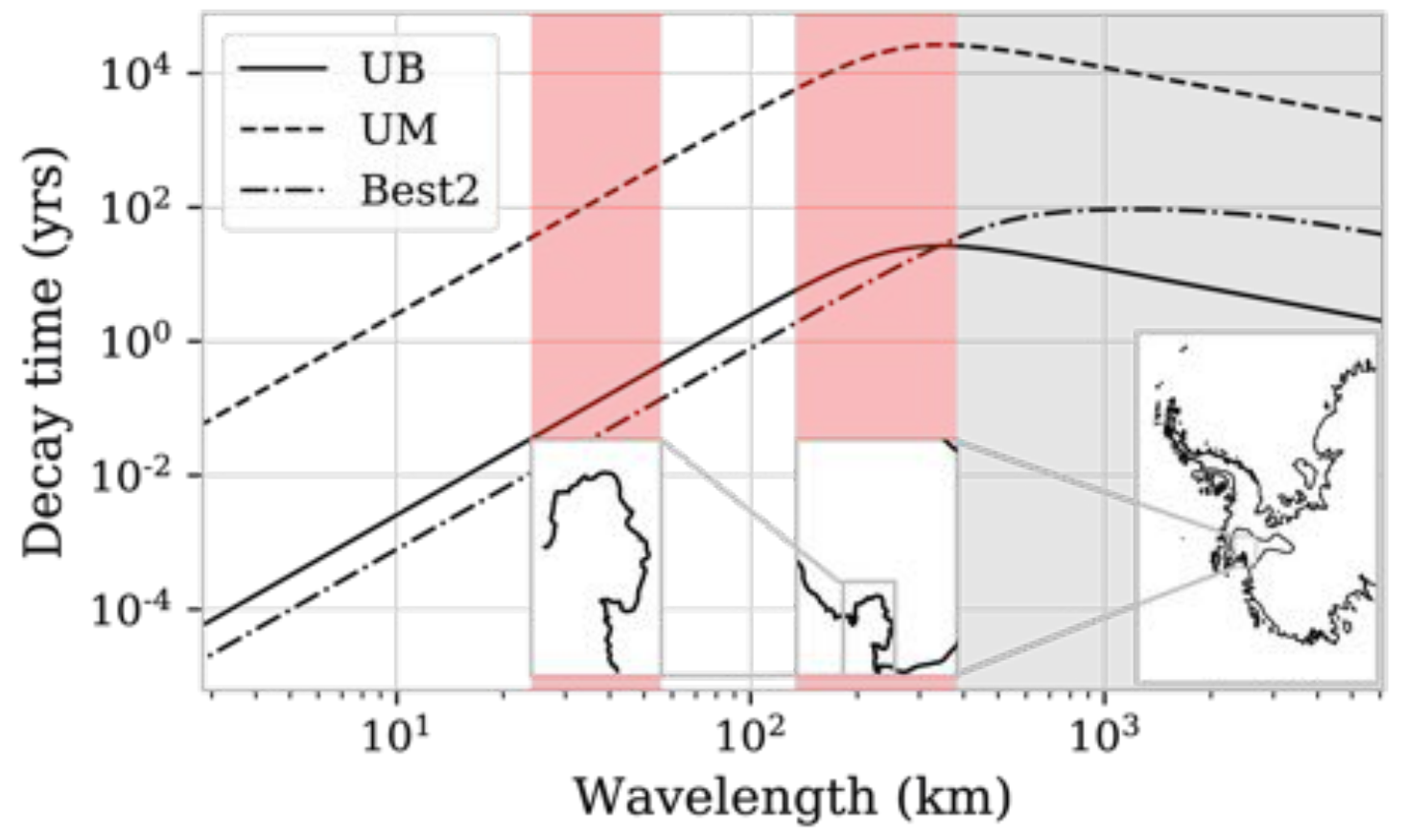
Solid Earth Physics

Goals:

- solid earth response to ice sheet load changes can stabilize marine ice sheet retreat by raising the bed elevation at the grounding line
- observations suggest that parts of West Antarctica are underlain by very weak (thin lithosphere, low viscosity) mantle (e.g., Nield et al., 2014; Barletta et al., 2018), which implies substantial stabilizing feed-backs for ongoing grounding line retreat

Below: Schematic showing the impacts and importance of ice sheet and solid earth feedbacks (glacial isostatic adjustement, or GIA) with respect to marine ice sheet evolution (after Whitehouse et al., 2019).





Left: Decay time τ by load wavelength. A weak mantle (UB, solid; 1E18 Pa s) responds much more quickly to load changes than the average upper mantle (UM, dashed; 1E21 Pa s). Wavelengths appropriate for Pine Island Glacier and its grounding line are shaded in red.

Progress:

- implemented coupling with spectral, time-domain, flat-earth GIA model of Bueler et al., 2007 (see eq. below) in BISICLES and MALI

$$\hat{U}_{\mathbf{k}}^{n+1} = \frac{(\tau - \frac{1}{2}\Delta t)\hat{U}_{\mathbf{k}}^{n} + \beta^{-1}\Delta t(\hat{L}_{\mathbf{k}}^{n+1})}{(\tau + \frac{1}{2}\Delta t)}$$

Uplift U_{n+1} is updated after time Δt using previous uplift U_n and computed ice load change L. τ is decay time (shown above) and β contains information about the lithosphere

- model captures local viscoelastic behavior (distances < 1000 km).
- (currently) ignores spherical geometry, self-gravitation effects, bulk elastic deformation, rotation perturbations, all of which are important over larger areas and longer timescales (e.g., Larour, et al., 2019)
- Pine Island simulation results submitted to GRL (Kachuck, et al., 2019).

Next steps:

- apply models to simulations of entire Amundsen Sea Embayment (ASE)
- couple GIA model and damage model physics to further assess sensitivity of ASE to marine ice sheet instability

Project Members: Stephen Price (PI; LANL), Esmond Ng (PI; LBNL), Xylar Asay-Davis (LANL), Jeremy Bassis (UM), L. Bertagna (SNL), C. Book (LANL), Darin Comeau (LANL), Matt Dunlop (NYU), Katherine Evans (ORNL), Matthew Hoffman (LANL), John Jakeman (SNL), Sam Kachuck (UM), Joseph Kennedy (ORNL), Dan Martin (LBNL), Mauro Perego (SNL), Mark Petersen (LANL), Andrew Salinger (SNL), Adam Schneider (UCI), Chad Sockwell (SNL), Georg Stadler (NYU), Irina Tezaur (SNL), Raymond Tuminaro (SNL), Brian Van Straalen (LBNL), Jerry Watkins (SNL), Tong Zhang (LANL)

https://doe-prospect.github.io/