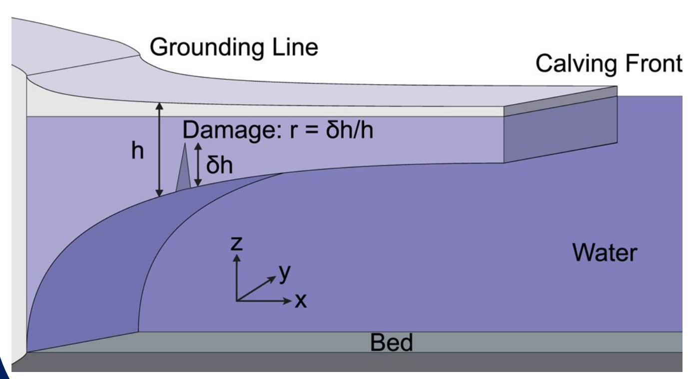
Does Damaged Ice affect Ice Sheet Evolution?

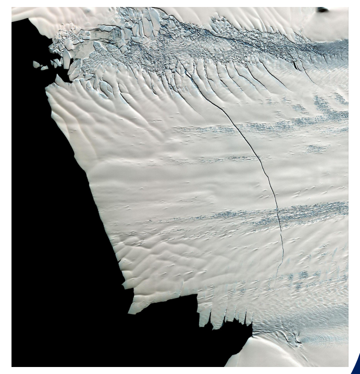
Duncan Carpenter[1], Anjali Sandip[1], Samuel B. Kachuck[3], D.F. Martin (DFMartin@lbl.gov)[2]

1. University of North Dakota, Grand Forks, ND, USA 2. Lawrence Berkeley National Laboratory, Berkeley, CA, USA 3. University of Michigan, Ann Arbor, MI, USA

Abstract

Ice damage and its impact on ice sheet evolution is a large source of uncertainty in mass-loss projections from the Antarctic ice sheet [1,2]. One definition of ice damage is the ratio of the total crevasse depth to local ice sheet thickness [3]. Here, we investigate the relationship between ice damage and ice sheet evolution in an idealized ice-shelf geometry.





Figures depicting damage (left) and an aerial view of the Pine Island Glacier (right). Note the heavily crevassed (damaged) ice at the top and bottom of the image.

Ice Damage Implementation

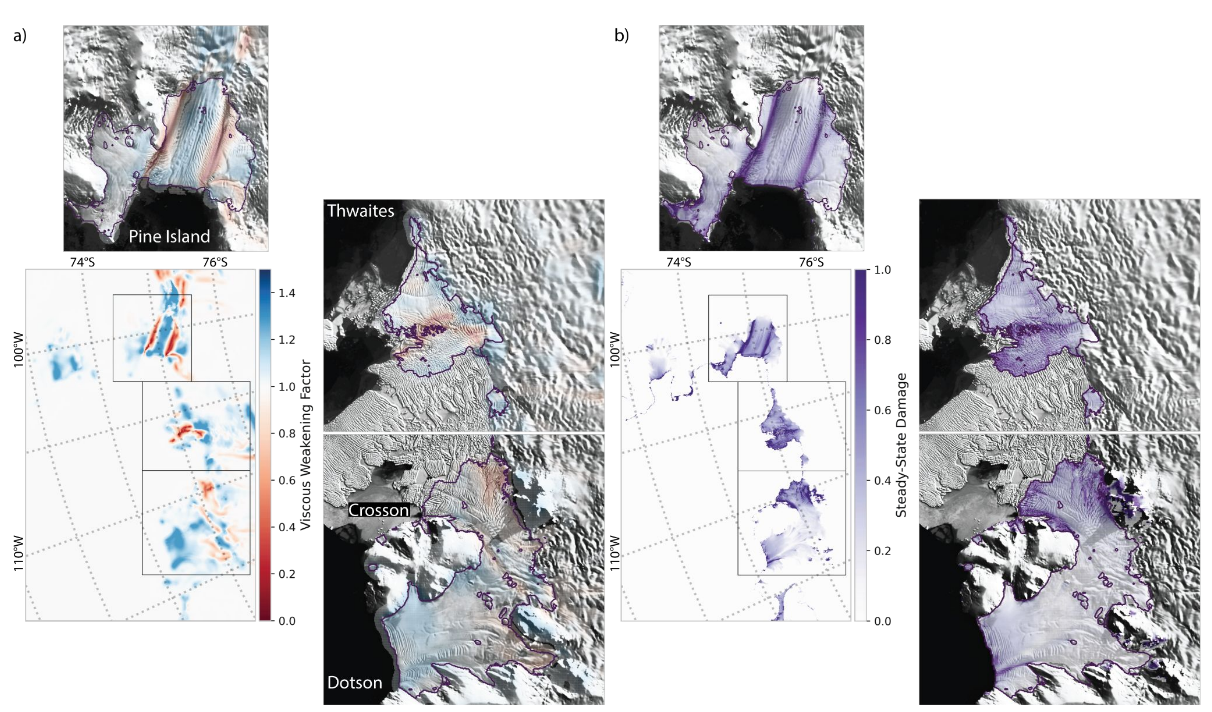
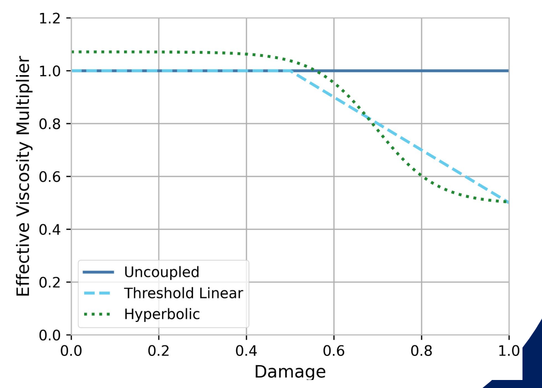


Figure 3. *Damage and ice viscosity are related. Above, areas with lower than normal viscosity (left, in red) correlated with damage (purples, right).*

We incorporate damage into an effective ice viscosity with:

effective ice viscosity = μ x (1-(1-a)*max(0,(D-b)/(1-b))

where μ is the viscosity of undamaged ice, ***D*** represents damage and ***a*** and ***b*** are parameters that control how damage affects ice viscosity and when it begins to take effect. We chose 0.5 for ***a*** and ***b*** based on previously gathered data. A hyperbolic tangent function represents the best fit between inferred viscosity and damage at Pine Island Glacier



Results

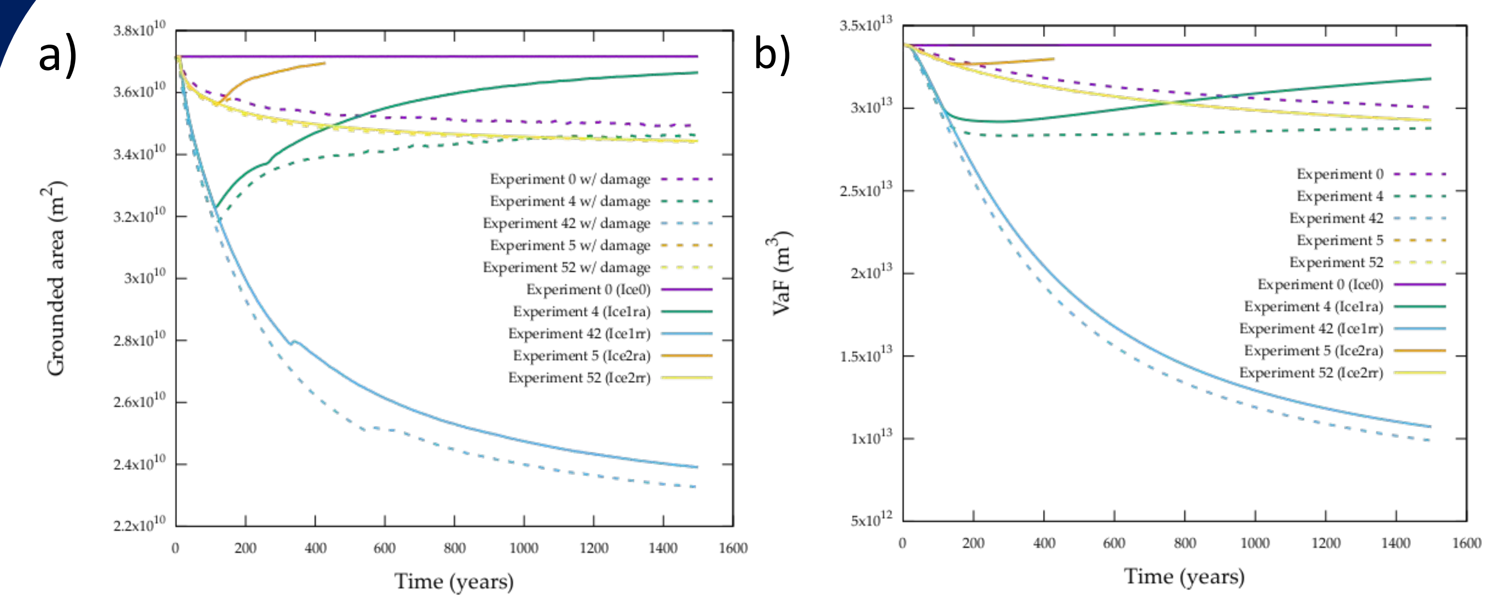


Figure 4. *Ice sheet evolution results from the BISICLES simulations with and without damage incorporated (a) grounded area, and (b) volume above flotation, whose change represents the contribution to sea level rise [5].*

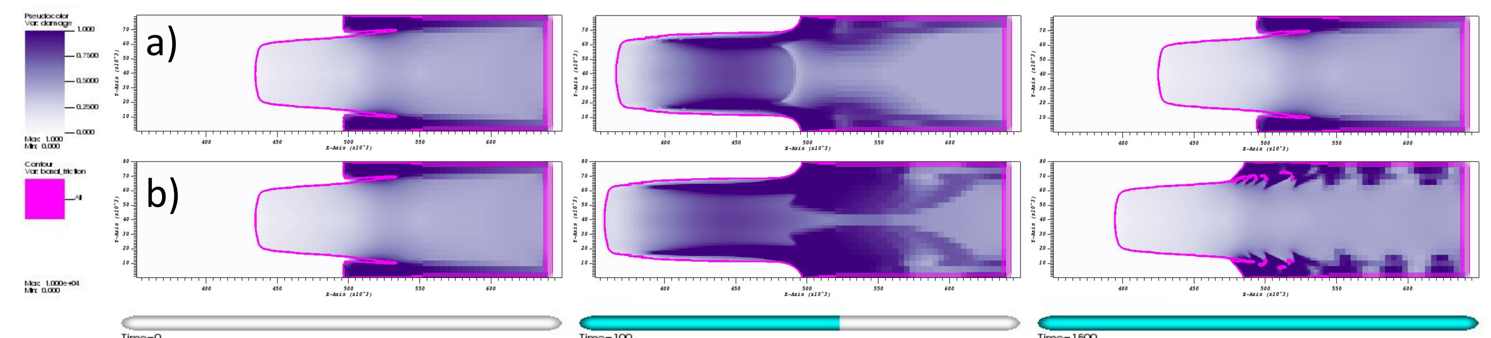


Figure 5. *Top-down view of the ice sheet evolution results from BISICLES simulations (a) without damage, and (b) with damage for the MISMIP+ Ice4 experiment.*

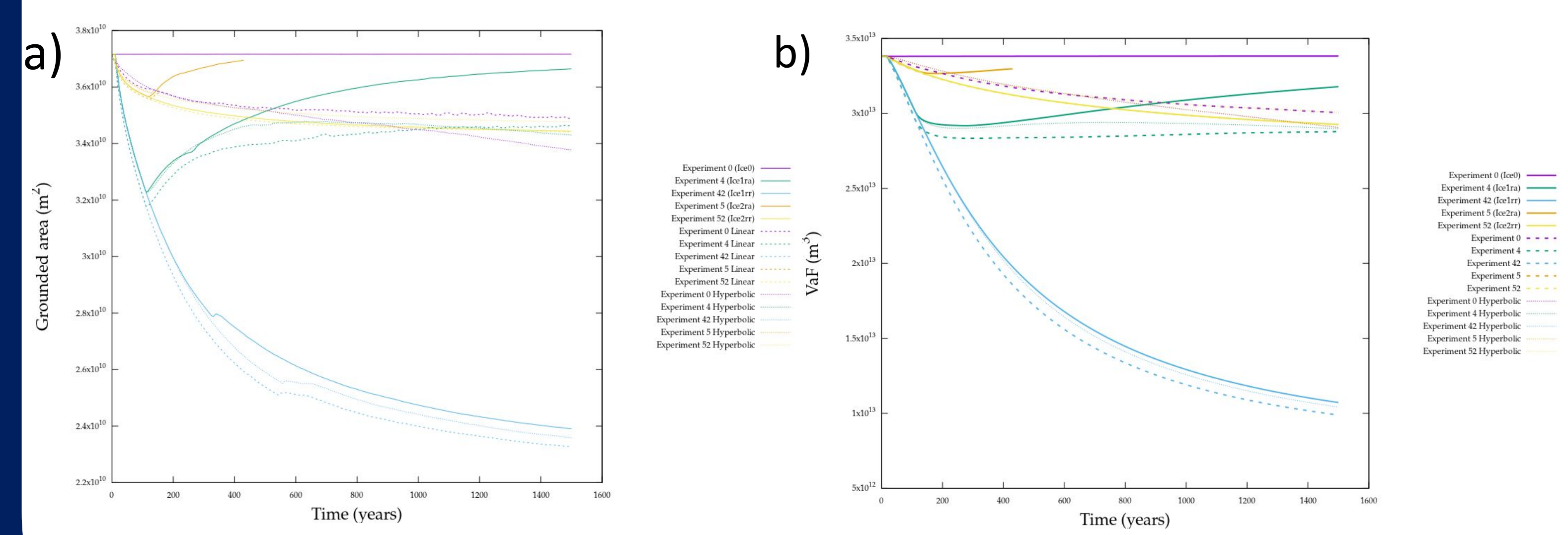


Figure 6. *More Ice sheet evolution results from the BISICLES simulations with and without damage incorporated linearly and with a hyperbolic tangent. (a) grounded area, and (b) volume above flotation*

References

[1]. Pachauri, R.K., et al: Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). Ipcc. 2014.

[2] Frank Pattyn, Mathieu Morlighem, The uncertain future of the Antarctic Ice Sheet. Science 367,1331-1335(2020).

[3]. Kachuck, S.B., Whitcomb, M., Bassis, J.N., Martin, D.F. and Price, S.F., 2022. Simulating ice-shelf extent using damage mechanics. Journal of Glaciology, 68(271), pp.987-998.

[4]. Asay-Davis, X. S., et al: Experimental design for three interrelated marine ice sheet and ocean model intercomparison projects: MISMIP v. 3 (MISMIP +), ISOMIP v. 2 (ISOMIP +) and MISOMIP v. 1 (MISOMIP1), Geosci. Model Dev., 9, 2471–2497, https://doi.org/10.5194/gmd-9-2471-2016, 2016.

[5]. Cornford, S.L., et al: Adaptive mesh, finite volume modeling of marine ice sheets. Journal of Computational Physics, 232(1), pp.529-549. , https://doi.org/10.1016/j.jcp.2012.08.037, 2013

Idealized Experiment – MISMIP+

The Marine Ice Sheet Model Intercomparison Project, or MISMIP+ experiment, is a marine ice sheet in a channel with a retrograde bed section, designed to highlight mechanical effect of an ice shelf on the state of stress at the grounding line or ice shelf buttressing effects [4].

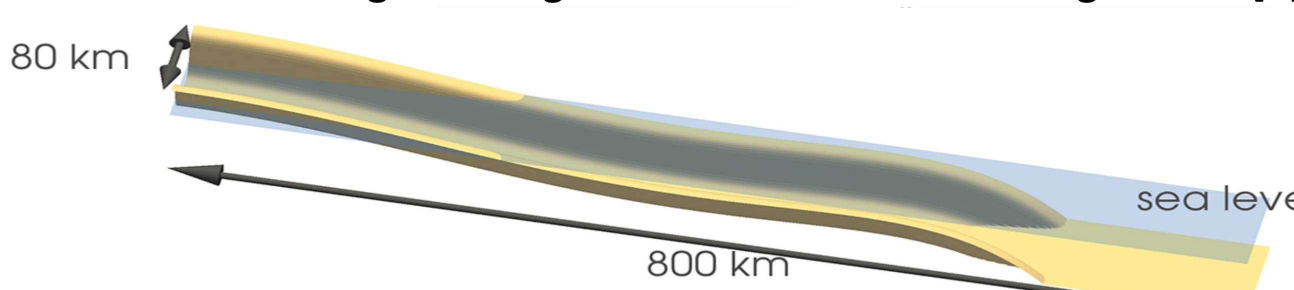


Figure 2. *The bedrock topography for the MISMIP+ cross-section showing channel walls (brown) and steady-state ice upper and lower surfaces.*

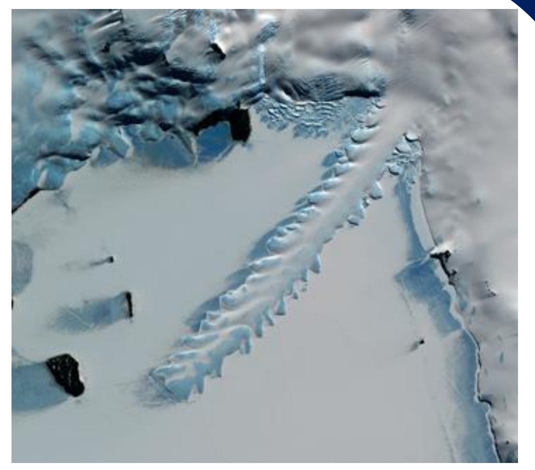
MIP	Experiment	Description
MISMIP+	Ice0	100-year control simulation with no melting
MISMIP+	Ice1r	100-year run with melt-induced retreat
MISMIP+	Ice1ra	100-year (or optionally up to 900-year) simulation from end of Ice1r with no melting
MISMIP+	Ice1rr	Continue Ice1r for a further 900 years (optional)
MISMIP+	Ice2r	100-year "calving-event" simulation
MISMIP+	Ice2ra	100-year (or optionally up to 900-year) simulation from end of Ice2r with no melting
MISMIP+	Ice2rr	Continue Ice2r for a further 900 years (optional)

Table 1. *List of MISMIP+ experiments.*

In the ice sheet evolution experiment, the prescribed subshelf melt weakens the ice shelf, causing thinning and retreat for 100 years. After 100 years, the perturbation is removed, allowing recovery [4].

Conclusion

The primary contributor to rising sea levels is enhanced polar ice discharge due to climate change. However, their dynamic response to climate change remains a fundamental uncertainty in future projections. Ice damage and its impact on ice sheet evolution is a large source of uncertainty in mass-loss projections from the Antarctic ice sheet [1,2].



Erebus Ice Tongue, Antarctica. Ice damage may determine extent and shape of ice tongues

Based on the preliminary results gathered, ice damage does affect ice sheet evolution (Fig. 3 and 4). Next steps will include extending the linear and hyperbolic tangent relationship between damage and ice viscosity implemented in this study to quadratic and investigating its effects on ice sheet evolution for the MISMIP+ experiment. The long term goal for this work is to extend to projections of the Antarctic Ice Sheet.

U.S. DEPARTMENT OF ENERGY | Office of Science | BERKELEY LAB | UNIVERSITY OF MICHIGAN | UND UNIVERSITY OF NORTH DAKOTA