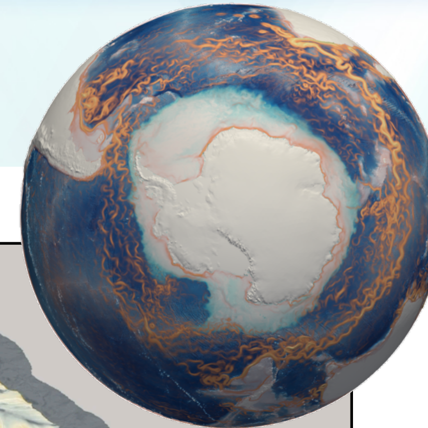
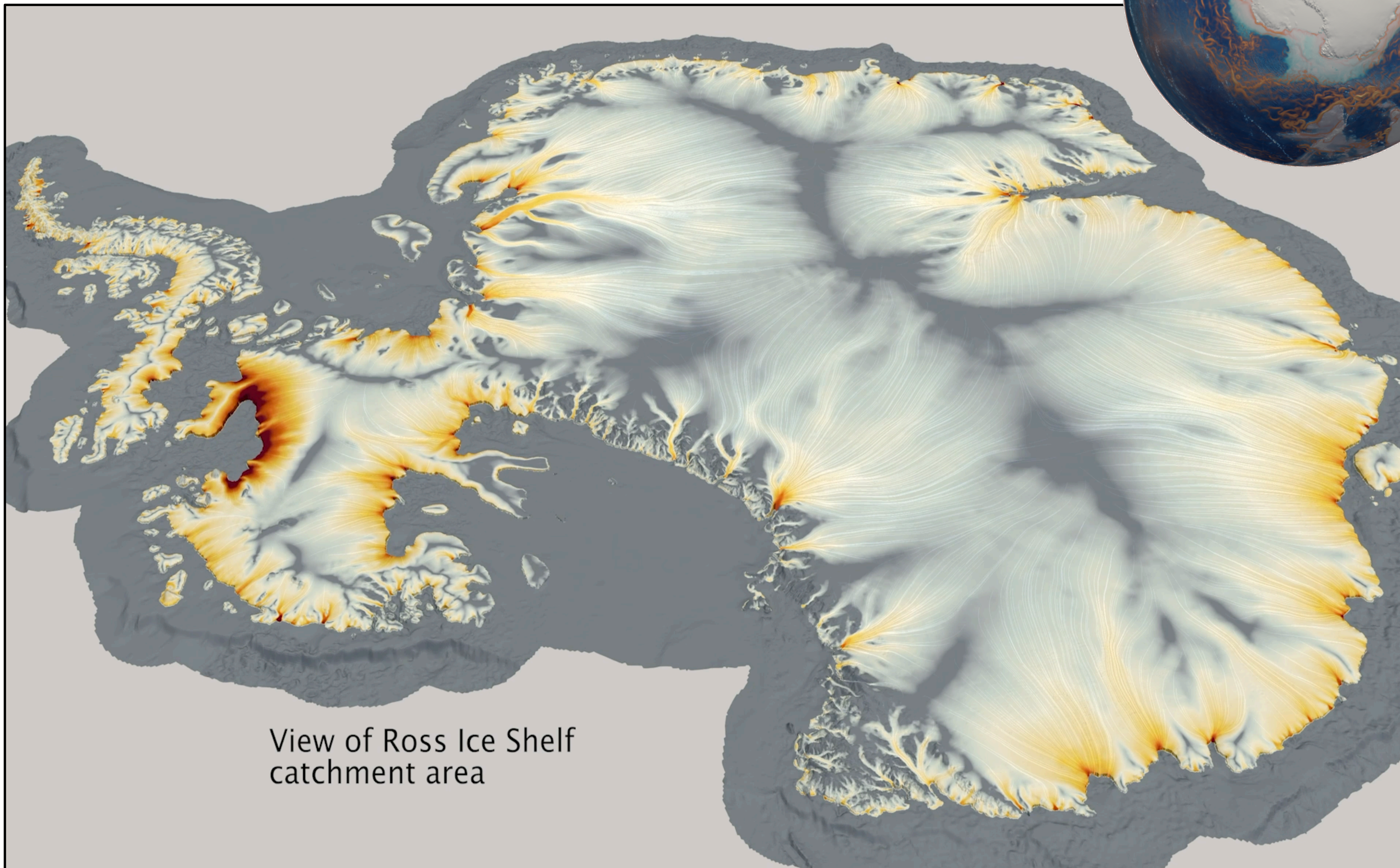
SciDAC ProSPect

Probabilistic Projections of Sea Level from Ice Sheet and Earth System Models

Stephen Price (LANL), Esmond Ng (LBNL), and *ProSPect* team





Visualization by J. Patchett (LANL) with support from BER Data Management Program

ProSPect goals

ProSPect aims to address limitations to current DOE ice sheet models (ISMs) and Earth system models (ESMs) preventing accurate sea-level projections. Specific focus areas include:

1. critical, but currently missing or inadequate ISM physics
2. missing coupling between ISMs and ESMs
3. ISM initialization methods targeting coupling with ESMs
4. uncertainty propagation for probabilistic sea-level projections

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology

ice sheet physics that are coupled to climate and impact the rate of retreat and SLR

- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling

  Strong *negative* feedback on rate of retreat and SLR
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization

ice sheet and E3SM developments important for ice sheet and ESM coupling

- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)

necessary for assigning prob-
abilities to SLR projections

- verification and validation (V&V)
- computational performance
- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance

model fidelity & performance portability / new architectures

- simulations

(all) Project Focus Areas

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

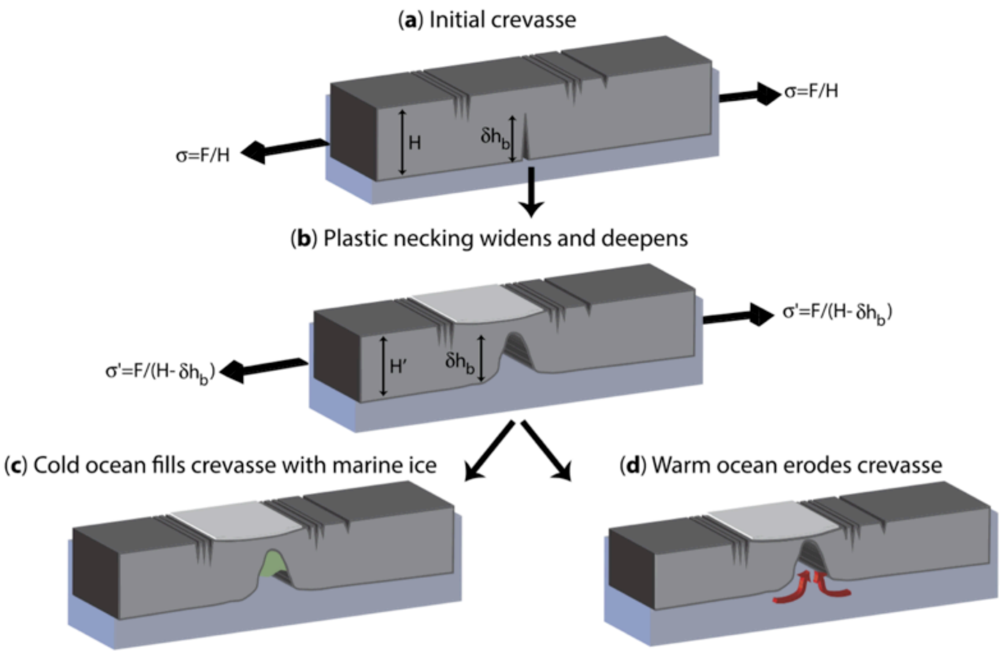
synthesis of project efforts

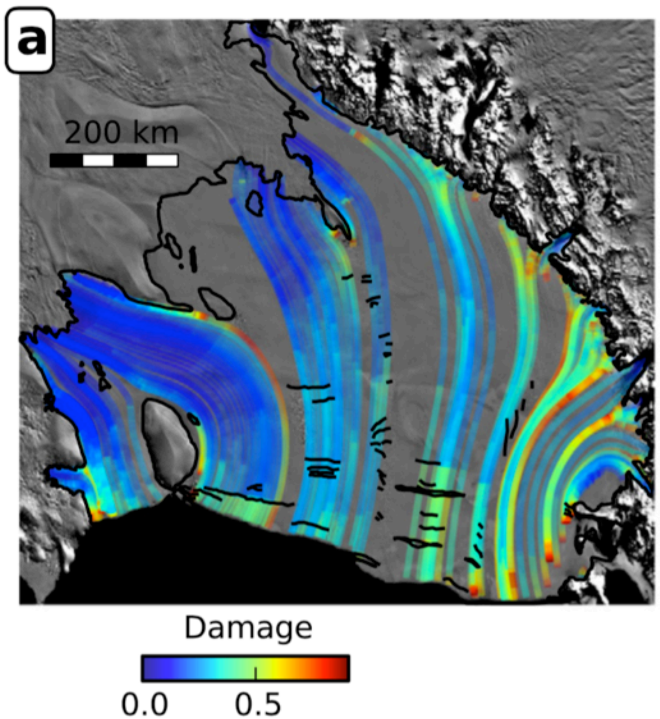
Project Focus Areas (this talk)

- damage, fracture, calving
- subglacial hydrology
- ice sheet & solid earth coupling
- ocean model development
- ESM coupler development
- surface mass balance (new / added scope)
- optimization & initialization
- uncertainty quantification (UQ)
- verification and validation (V&V)
- computational performance
- simulations

Damage, Fracture, and Calving

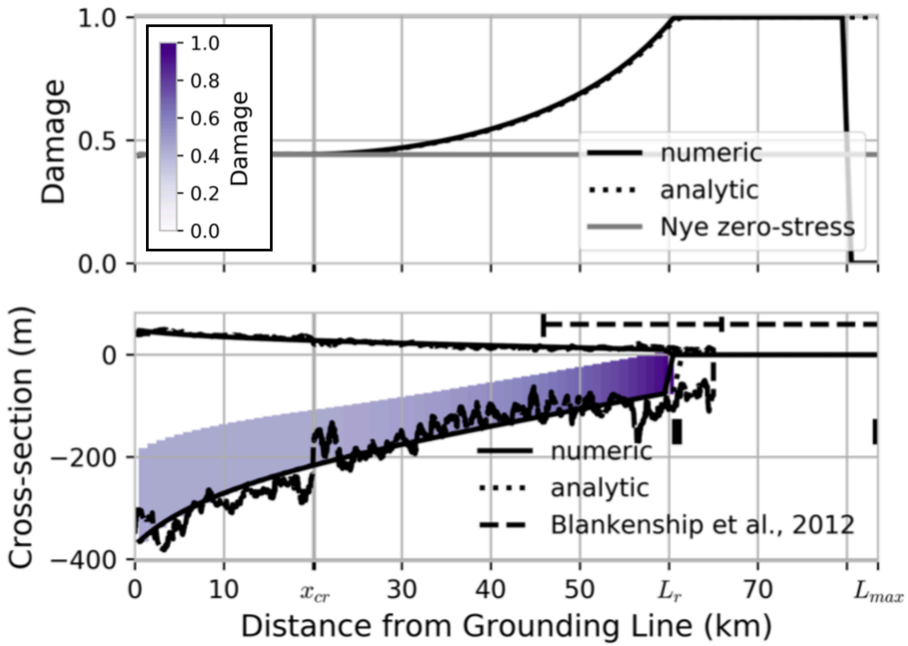
- ice shelves limit ("buttress") ice sheet flux to the ocean; ice shelf thinning & iceberg calving reduce ice shelf area and buttressing
- ice shelf integrity is a function of fracture, a poorly modeled process; ocean and atmos. forcing impact fracture initiation and growth
- detailed, physics-based models of ice shelf fracture (LEFM) & its coupling to climate are complex and costly
- damage mechanics provides a tractable alternative (scalar tracer evolution)



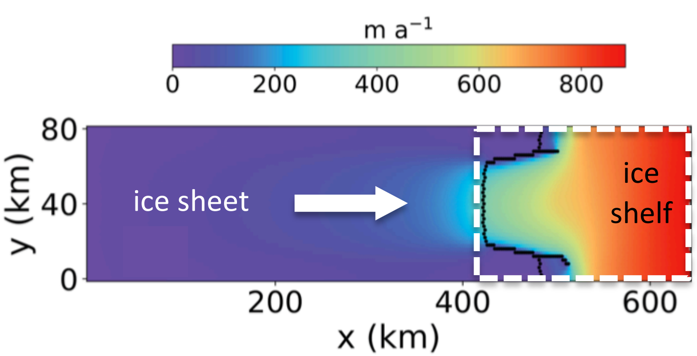


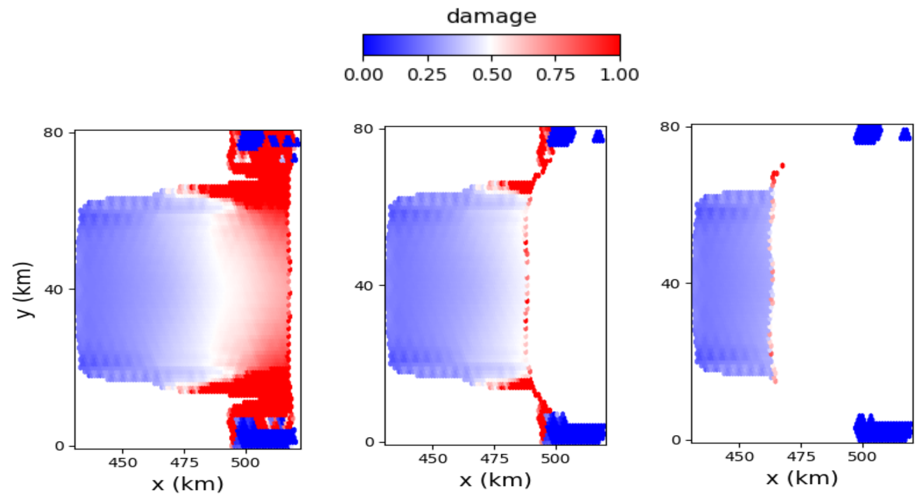
Bassis and Ma (2015)

Damage, Fracture, and Calving



- **Left:** damage evolution in BISICLES compared with analytic results and Antarctic ice tongue observations (Kachuck et al., *in prep.*)
- **Below:** damage evolution in MALI tied to calving front retreat for idealized test case (Zhang et al., *in prep.*)

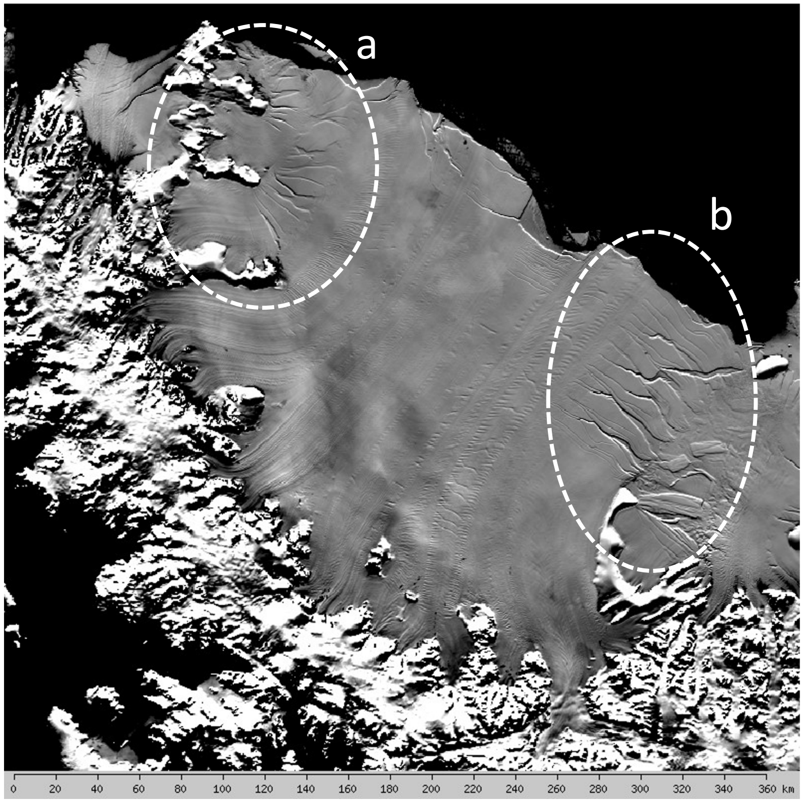




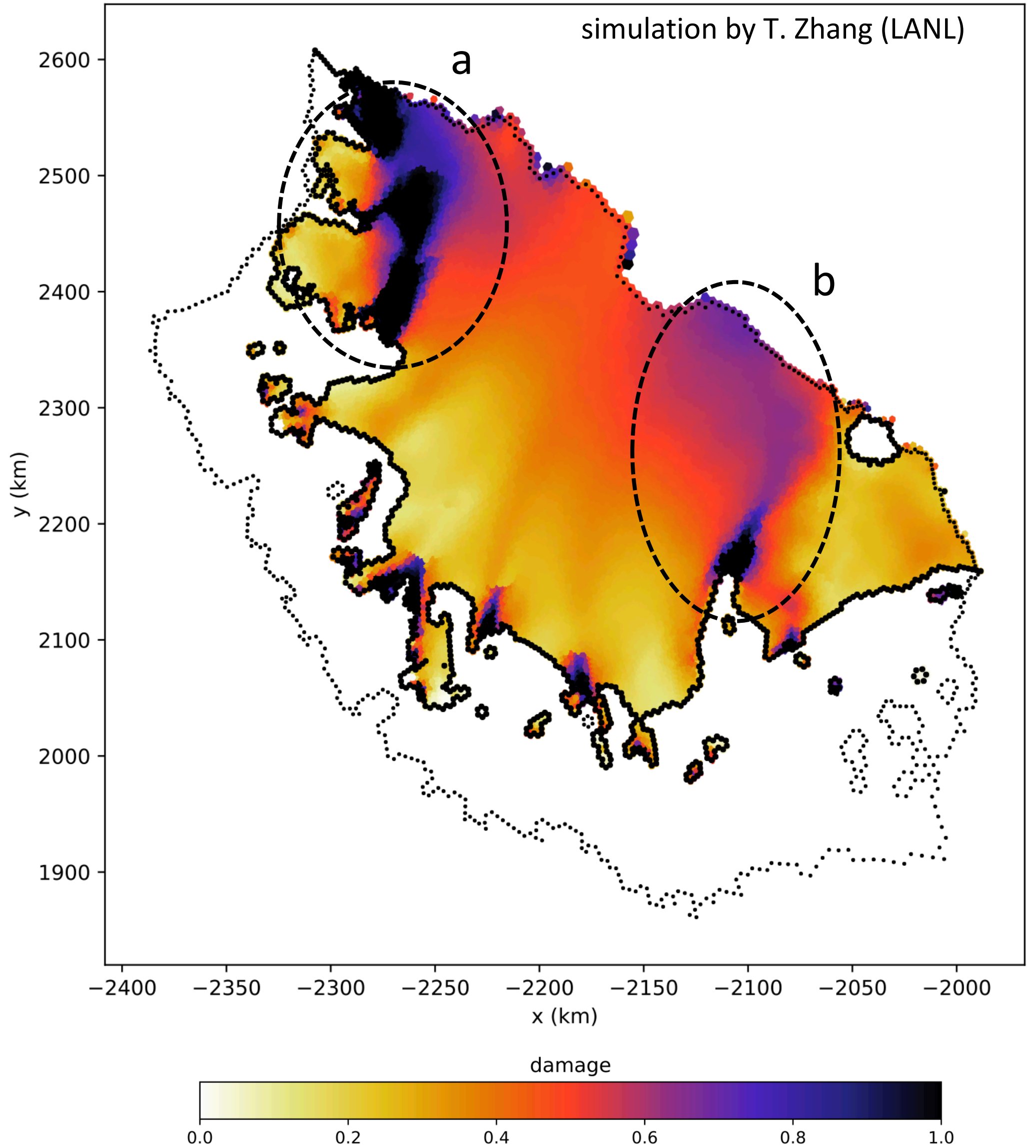
40 yrs | 50 yrs | 60 yrs

** see *Zang et al.* poster, PS2 **

Damage, Fracture, and Calving



MOA imagery from NSIDC

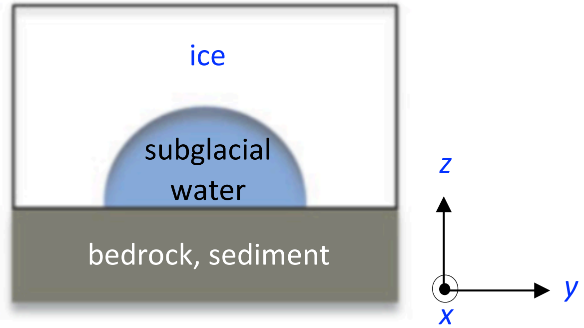


Comparison between damage simulated by MALI (right) and observed regions of fracture and rifting on Larsen C (left)

Subglacial Hydrology

<u>channelized drainage:</u>

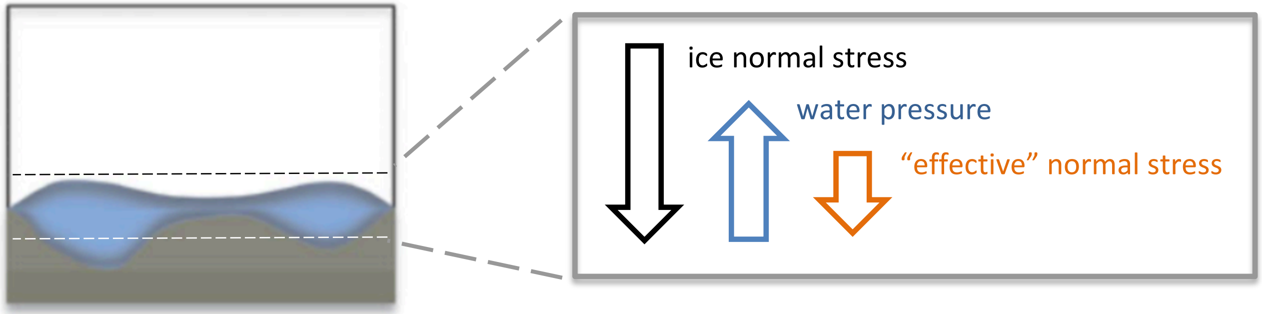
- arborescent channel network
- ***LOW water pressure***
- high effective pressure and basal friction



Flowers (2015)

<u>distributed drainage:</u>

- anastomosing (narrow) conduit network
- ***HIGH water pressure***
- low effective pressure and basal friction

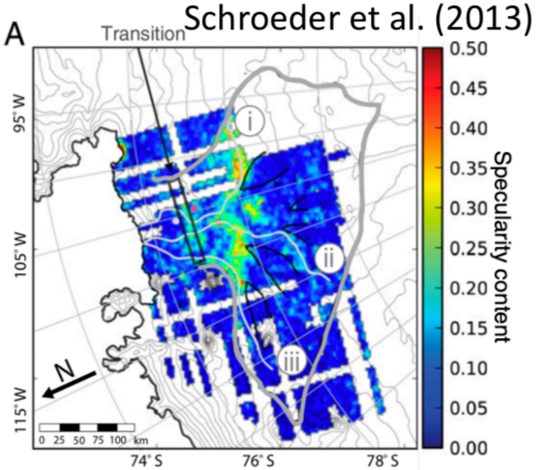


- basal sliding is a first-order control on ice flux to ocean
- subglacial hydrology is a first-order control on the spatial location and rate of sliding
- subglacial hydrology is coupled to climate:
  - increased melt input from atmos. warming
  - ocean impacts via submarine "runoff"
- spatial dependence of sliding on hydrology important for (1) realistic evolution of sliding over time, (2) optimization & UQ

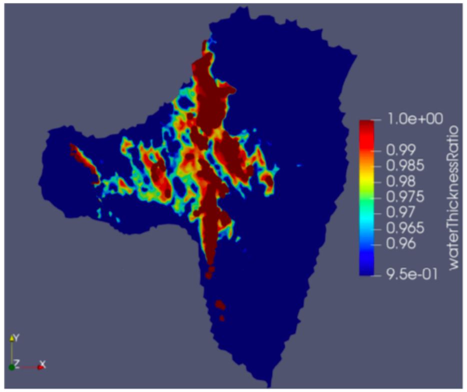
Subglacial Hydrology: Thwaites Glacier

Observed Radar Specularity

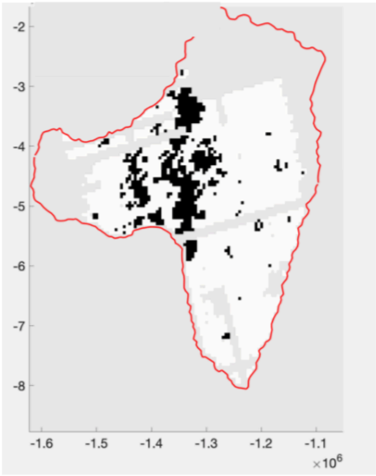
Schroeder et al. (2013)

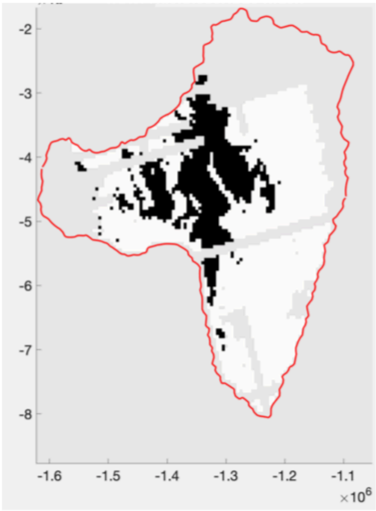


Modeled Water Thickness Ratio



compare observed "specularity", an observable proxy for water at bed, with modeled subglacial water layer thickness





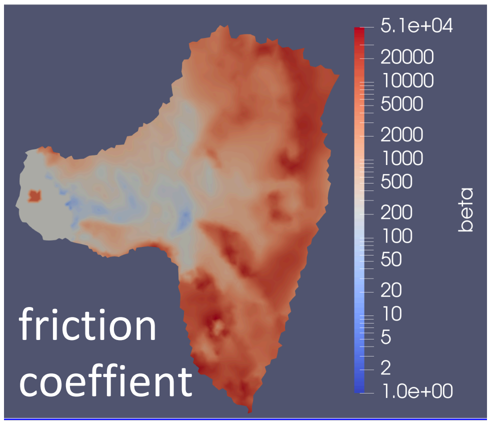
- stable, channelized drainage likely possible beneath Thwaites Glacier
- near-terminus channelization would increase basal friction (*stabilize against further retreat*)
- channelized discharge would lead to buoyant plumes, which may promote increased submarine melting (*promoting further retreat*)

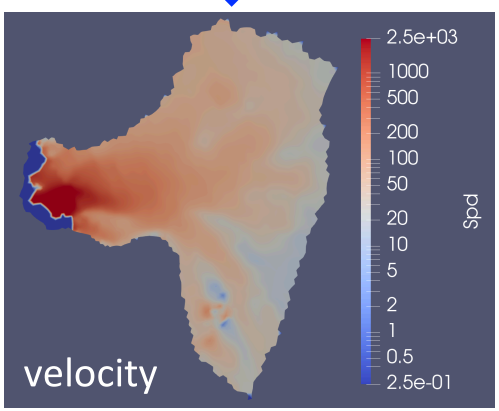
work by A. Hager (U. Oregon), M. Hoffman (LANL), M. Perego (SNL), and L. Bertagna (SNL)

**** see *Hager et al.* poster, PS2 ****

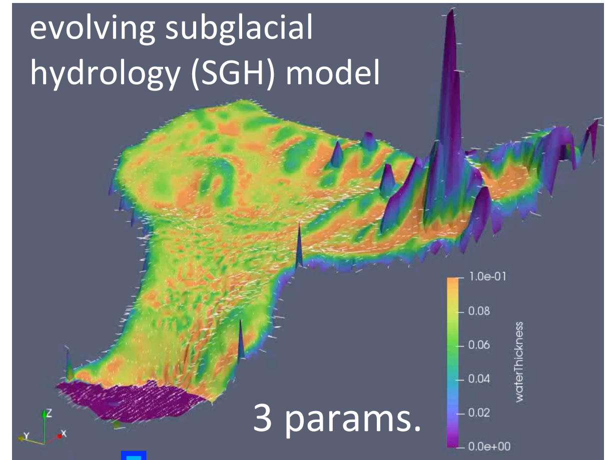
Subglacial Hydrology: Optimization & UQ

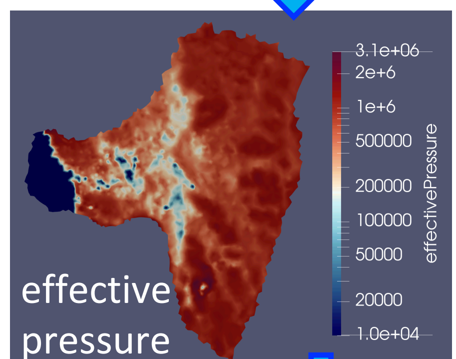
<u>standard optimization</u>
75,000 ***static*** basal friction parameters

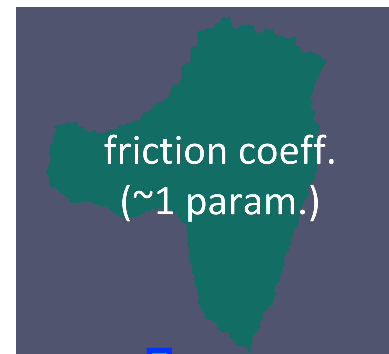


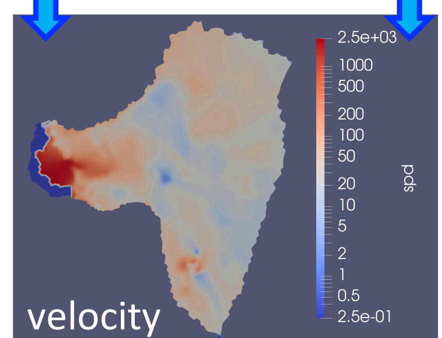


<u>new optimization</u>
<10 basal friction parameters (via ***evolving*** SGH model)





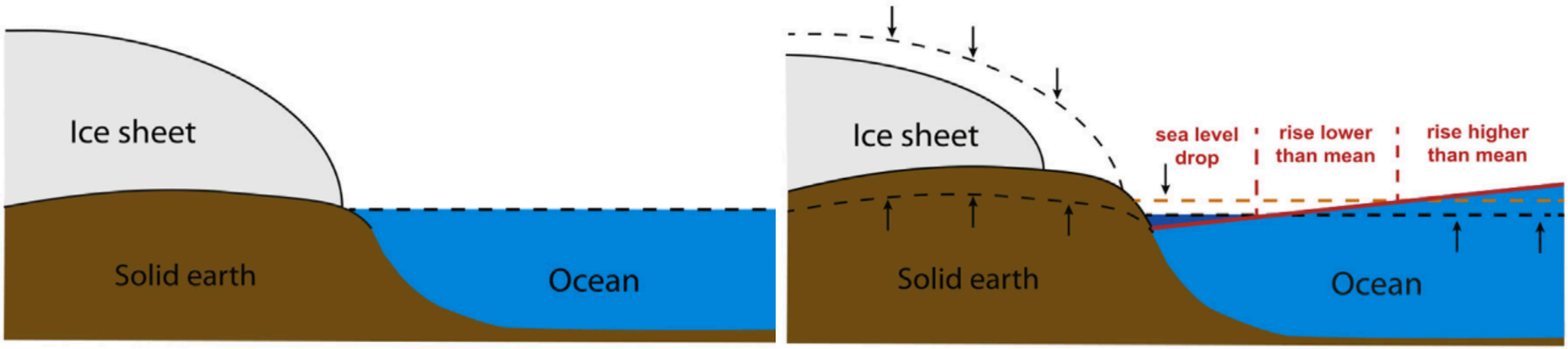




work by M. Hoffman (LANL), L. Bertagna (SNL), M. Perego (SNL), and A. Hager (U. Oregon)

Ice Sheet & Solid Earth Coupling

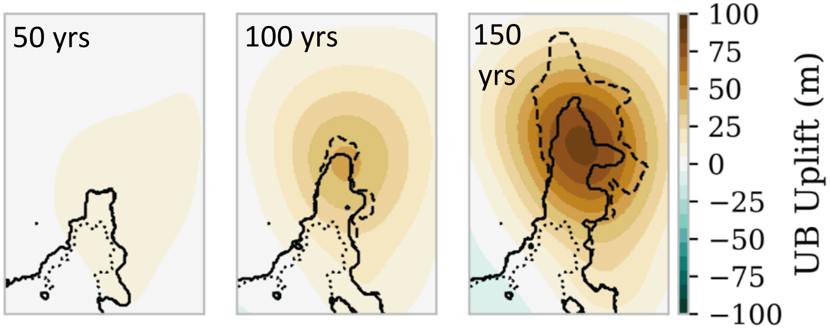
- the solid earth responds to ice sheet mass loss via isostatic adjustment and changes to the gravitational field:
  - local to regional scale uplift
  - regional lowering of geoid
- both are strong *negative feedbacks* on further ice sheet mass loss (particularly for marine ice sheets)
- ignoring these will result in an over estimate of SLR from ice sheets

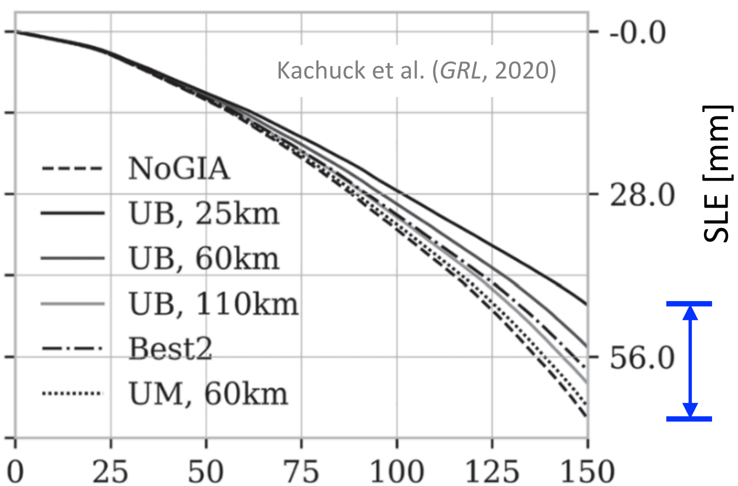


De Boer et al. (*QSR*, 2018)

Ice Sheet & Solid Earth Coupling

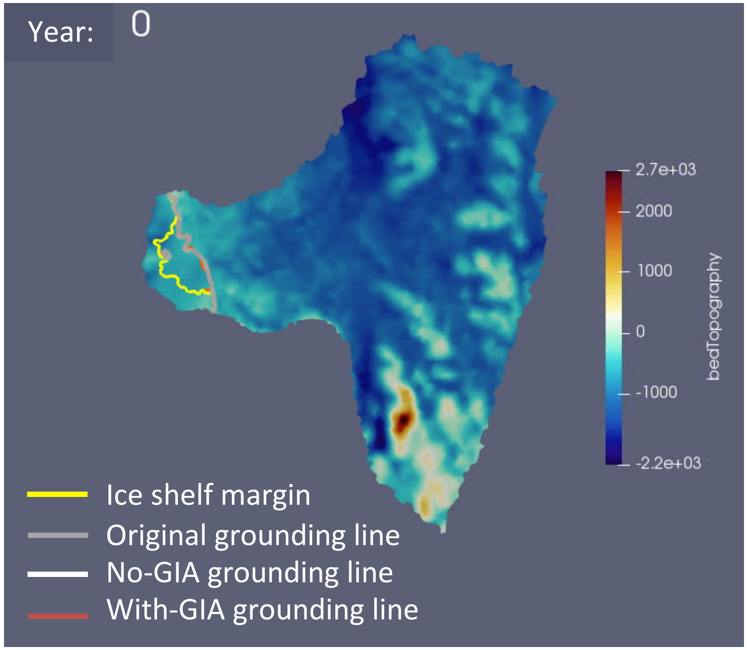
Pine Island Glacier (BISICLES)

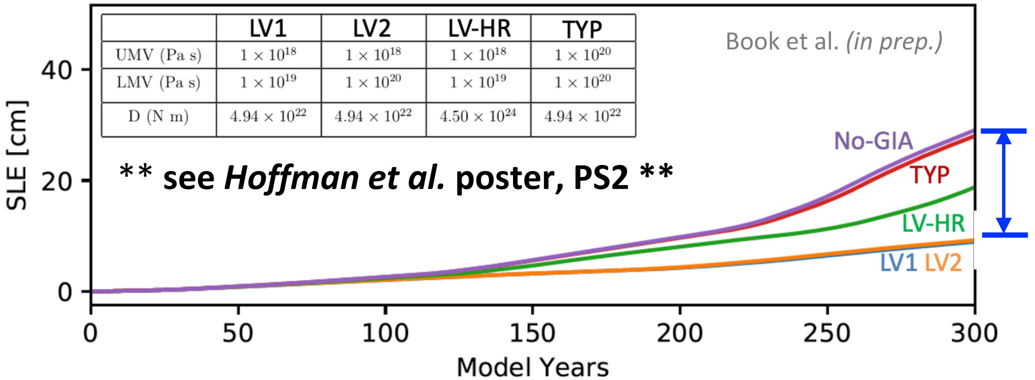




- **PIG:** up to 30% less SLE in 150 yrs
- **TG:** up to 70% less SLE in 300 yrs
- Ice sheet & GIA coupling (here, solid earth only) can significantly *reduce* SLR from marine ice sheet dynamics

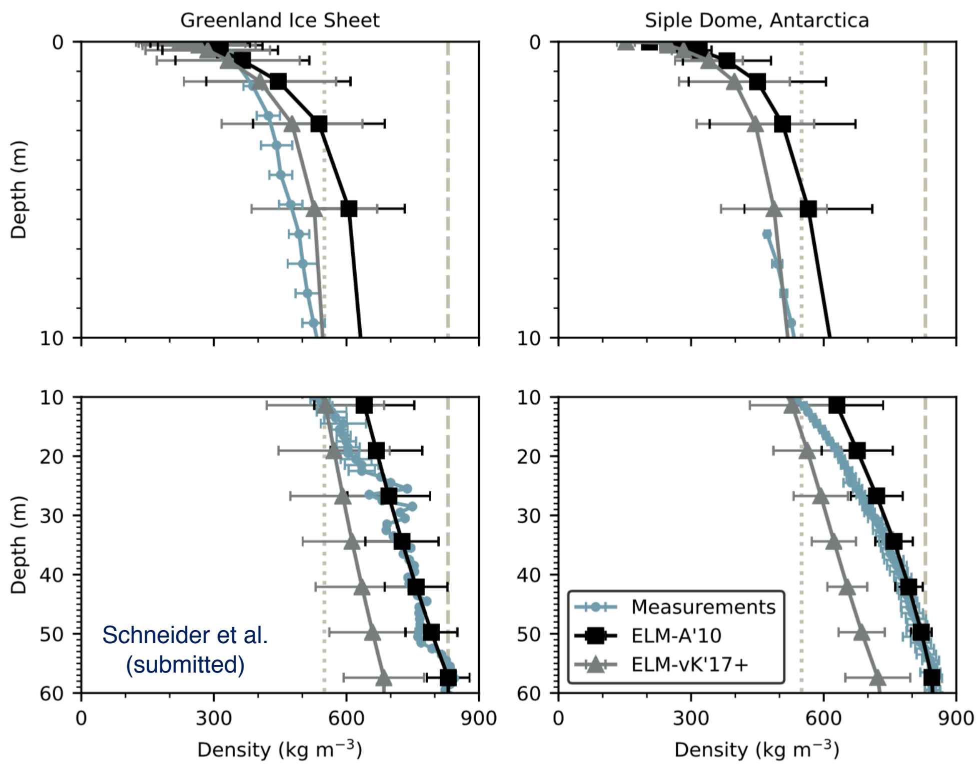
Thwaites Glacier (MALI)

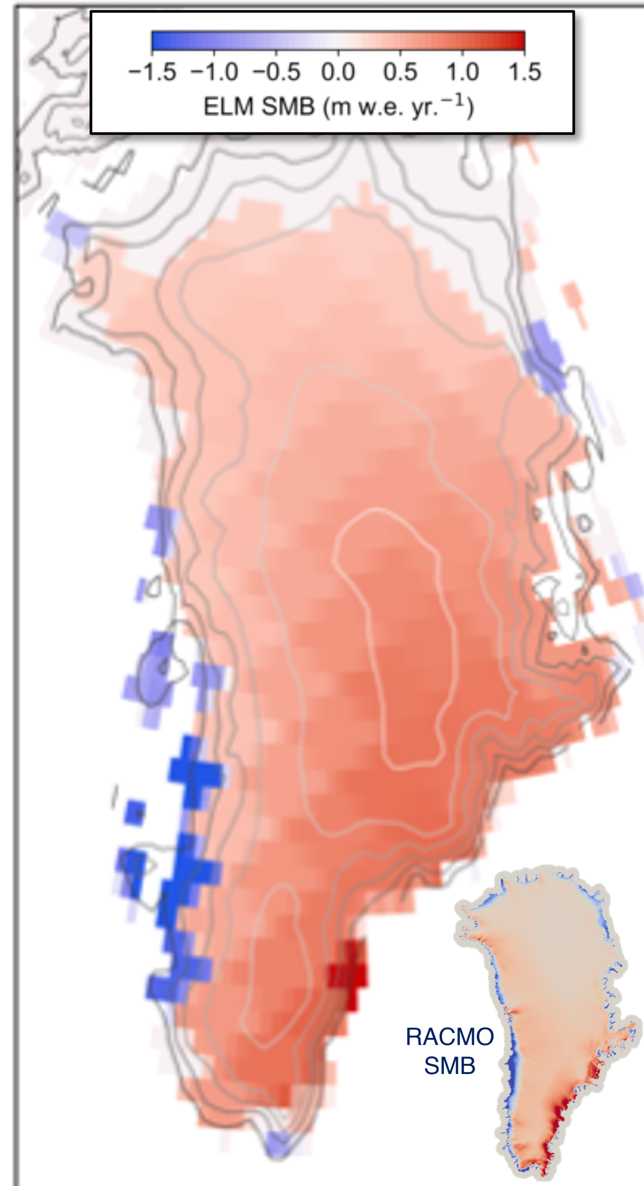




	LV1	LV2	LV-HR	TYP
UMV (Pa s)	1×10^{18}	1×10^{18}	1×10^{18}	1×10^{20}
LMV (Pa s)	1×10^{19}	1×10^{20}	1×10^{19}	1×10^{20}
D (N m)	4.94×10^{22}	4.94×10^{22}	4.50×10^{24}	4.94×10^{22}

Greenland Surface Mass Balance (from E3SM)





New ELM snowpack model (above) vs. Greenland (left column) and Antarctic (right column) observations

Spin-up of new snowpack model in E3SM over Green-land (~1980-1990 forcing) for calculating ice sheet surface mass balance (right)

** see *Schneider et al., Price et al.* posters (PS1, PS2) **

Simulations: ISMIP6 Contributions

Goelzer, H. and 30 others. 2018. Design and results of the ice sheet model initialisation experiments initMIP-Greenland: an ISMIP6 intercomparison, *The Cryosphere*, **12**, 1433-1460, doi:10.5194/tc-12-1433-2018.

Seroussi, H. and 38 others. 2019. initMIP-Antarctica: an ice sheet model initialization experiment of ISMIP6, *The Cryosphere*, **13**, 1441-1471, doi:10.5194/tc-13-1441-2019.

Levermann, A. and 34 others. 2020. Projecting Antarctica's contribution to future sea level rise from basal ice-shelf melt using linear response functions of 16 ice sheet models (LARMIP-2), *Earth System Dynamics*, **11**, 35–76, doi:10.5194/esd-11-35-2020.

Sun, S. and 29 others. 2020. Antarctic ice sheet response to sudden and sustained ice shelf collapse (ABUMIP), *Journal of Glaciology*. doi:10.1017/jog.2020.67.

Nowicki, S. A. J. Payne, A. Abe-Ouchi, C. Agosta et al. 2020: Contrasting contributions to future sea level under CMIP5 and CMIP6 scenarios from the Greenland and Antarctic ice sheets. *Geophys. Res. Lett.* (in review).

Nowicki, S. et al. 2020: Experimental protocol for sea level projections from ISMIP6 standalone ice sheet models, *The Cryosphere*, **14**, 2331–2368, doi:10.5194/tc-14-2331-2020.

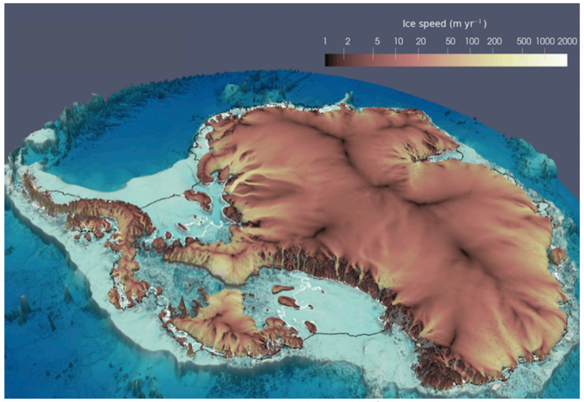
Jourdain, N. C., X. Asay-Davis, T. Hattermann, F. Straneo, H. Seroussi, C. M. Little, and S. Nowicki. 2020. A protocol for calculating basal melt rates in the ISMIP6 Antarctic ice sheet projections. *The Cryospheres*, **14**, 3111-3134, doi:10.5194/tc-14-3111-2020.

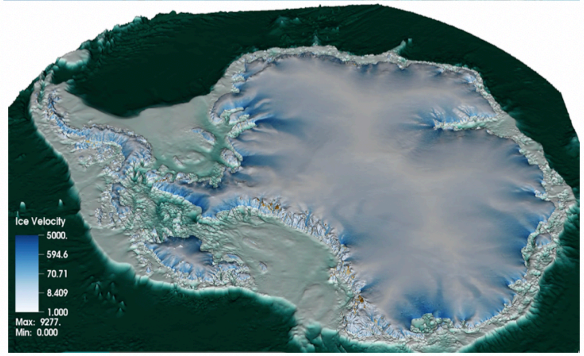
Seroussi, H., S. Nowicki, A. J. Payne, H. Goelzer et al. 2020. ISMIP6 Antarctica: a multi-model ensemble of the Antarctic ice sheet evolution over the 21st century. *The Cryosphere*, **14**, 3033-3070, doi:10.5194/tc-14-3033-2020.

Lipscomb, W. H., G. R. Leguy, N. C. Jourdain, X. S. Asay-Davis, H. Seroussi, S. Nowicki. 2020. ISMIP6 projections of ocean-forced Antarctic Ice Sheet evolution using the Community Ice Sheet Model. *The Cryosphere* (accepted).

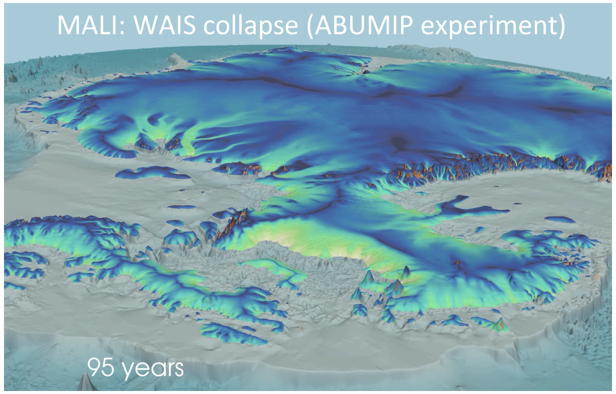
Cornford, S. L., H. Seroussi, X. S. Asay-Davis, G. H. Gudmundsson et al. 2020: Results of the third Marine Ice Sheet Model Intercomparison Project (MISMIP+). *The Cryosphere*, **14**, 2283–2301, doi:10.5194/tc-14-2283-2020.

Edwards, T. L., S. Nowicki, H. Goelzer, H. Seroussi et al. 2020: Quantifying uncertainties in the land ice contribution to sea level rise this century. *Nature* (submitted).



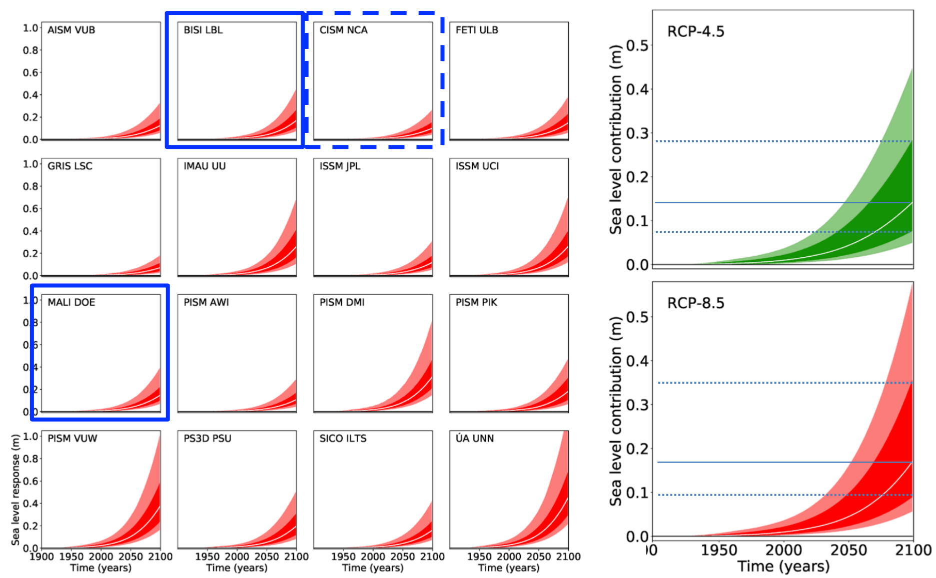


Antarctic ice sheet 200 years after all floating ice shelves are removed. Shown are simulation results from *ProSPect* MALI (top) and BISICLES (bottom) ice sheet models.

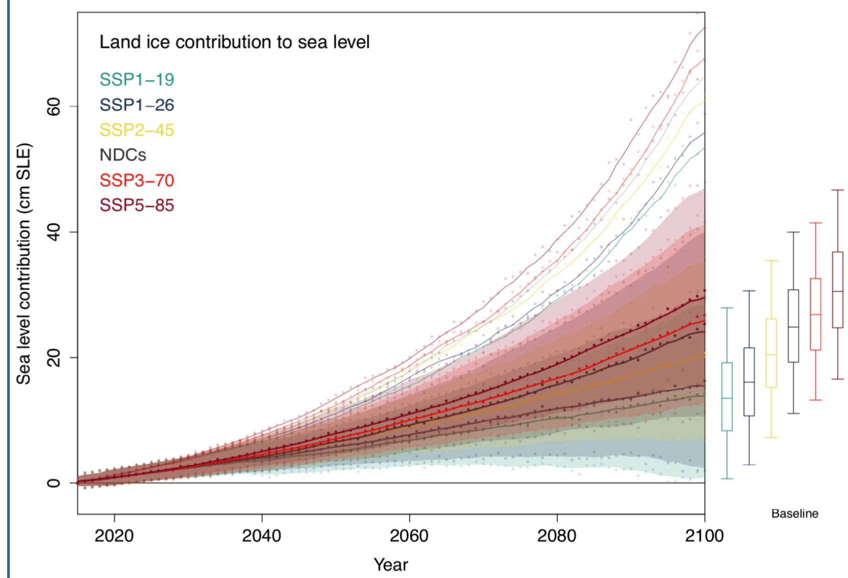


visualization by ***RAPIDS*** (N. Woods, J. Patchet; LANL)

Simulations: Ice Sheets & SLR under ISMIP6



Levermann et al. (*Earth Sys. Dyn.*, 2020)



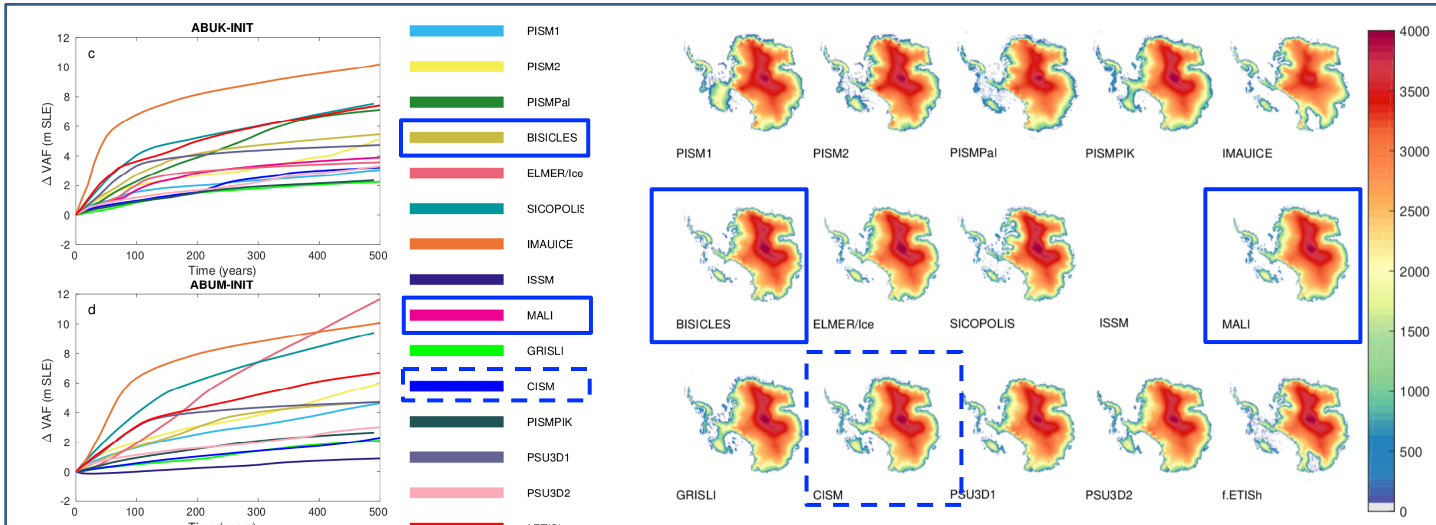
Edwards et al. (*Nature*, in review)

Future Antarctica sea level contribution under rapid ice shelf melting (top left) and ice shelf collapse (bottom right).

PDF of future sea-level rise from all land ice from emulation of ISMIP6 and GlacierMIP model projections (upper right).

~20% of ice sheet contributions from DOE-developed models

Most other models are 2d, *ad hoc* hybrids, or are run at relatively coarse resolution



Sun et al. (*J. Glaciol.*, 2020)

Synthesis: towards regional sea level & coastal impacts

Ice Sheet Model

physics, dynamics, surface & basal mass balance, earth and geoid shape

Freshwater Flux

Solid Earth Model

physics, dynamics, ice sheet geometry & history, freshwater flux

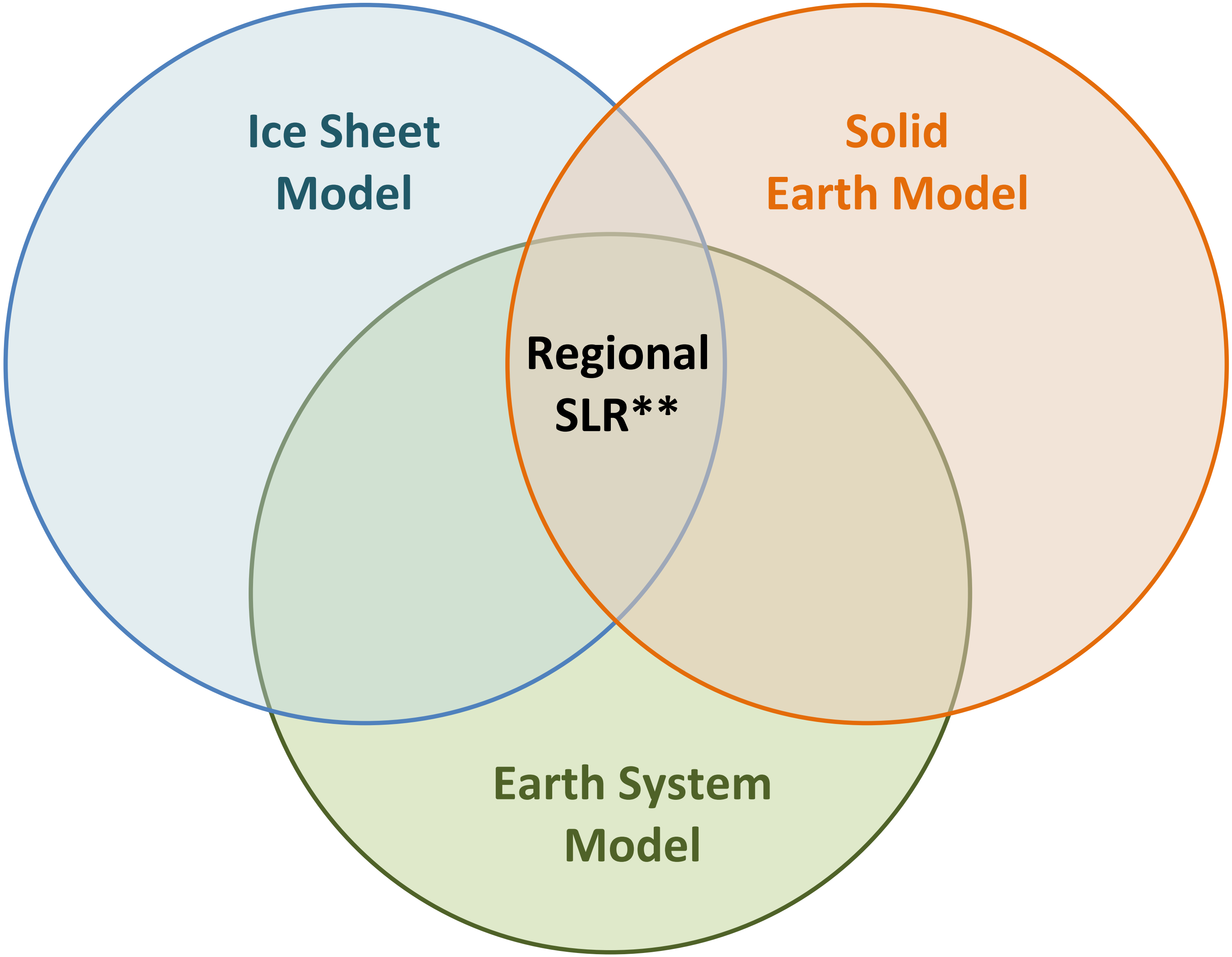
Solid Earth & Geoid Shape

Earth System Model

atmos., ocean, sea ice, land dynamics, ice sheet freshwater flux, earth and geoid shape

Surface & Basal Mass Balance

Synthesis: towards regional sea level & coastal impacts



** ultimately to be enabled by M. Hoffman Early Career project

Related Work (this meeting)

Hoffman et al. – towards a regional sea-level enabled E3SM (Tues. afternoon)

Price et al. – towards a coupled Greenland ice sheet in E3SM (PS2)

Hillibrand et al. – future SLR contribution of Humboldt glacier, Greenland (PS2)

Haeger et al. – subglacial drainage beneath Thwaites Glacier, Antarctica (PS2)

Hoffman et al. – coupled solid earth & Thwaites Glacier evolution, Antarctica (PS2)

Schneider et al. – improved ELM snowpack model for ice sheets (PS1)

Martin et al. – BISICLES ice sheet model NGD (PS2)