Framework for Antarctic System Science in E3SM

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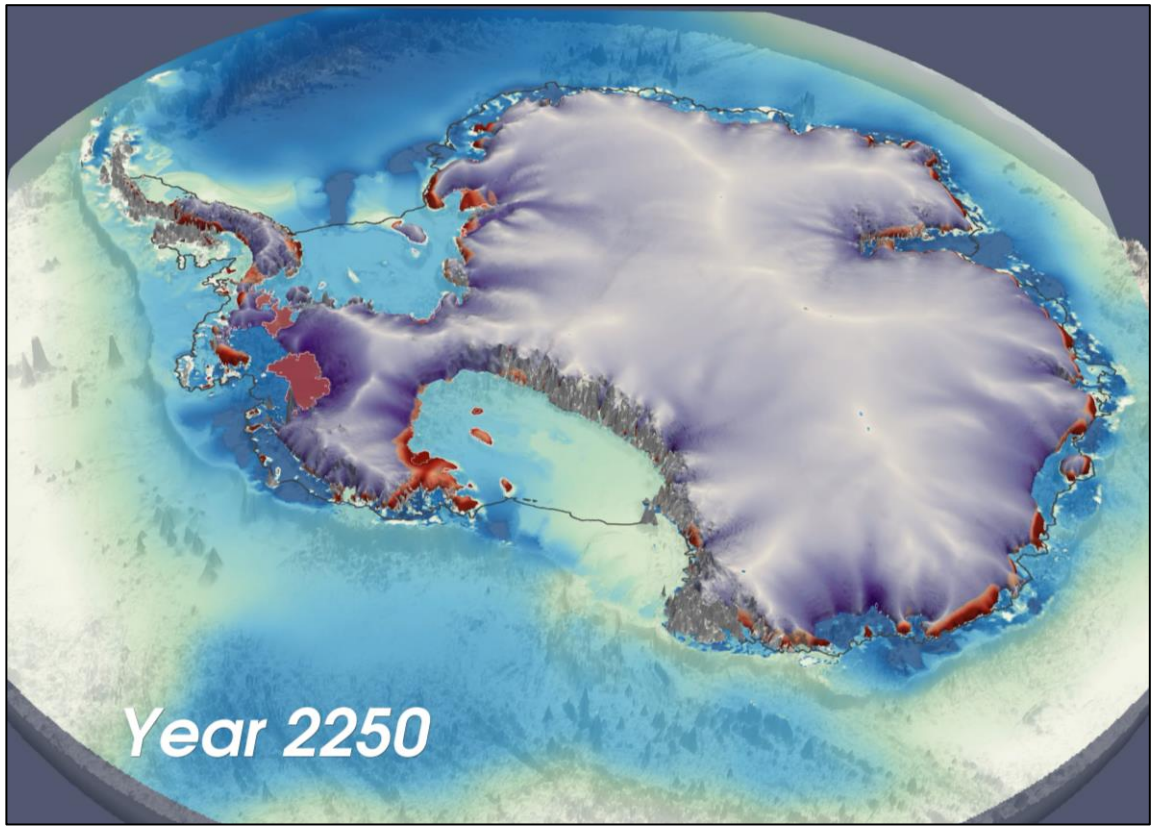

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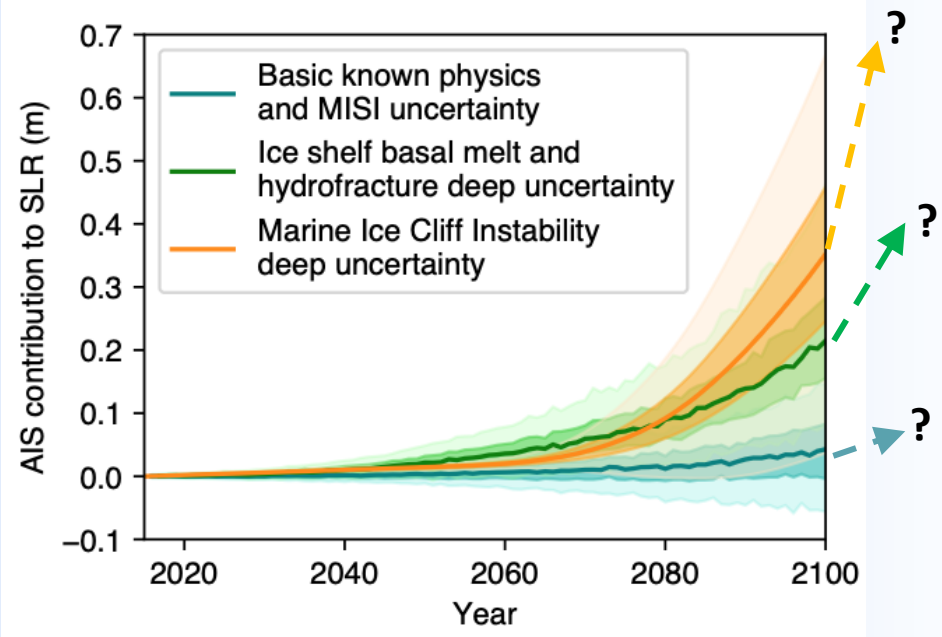
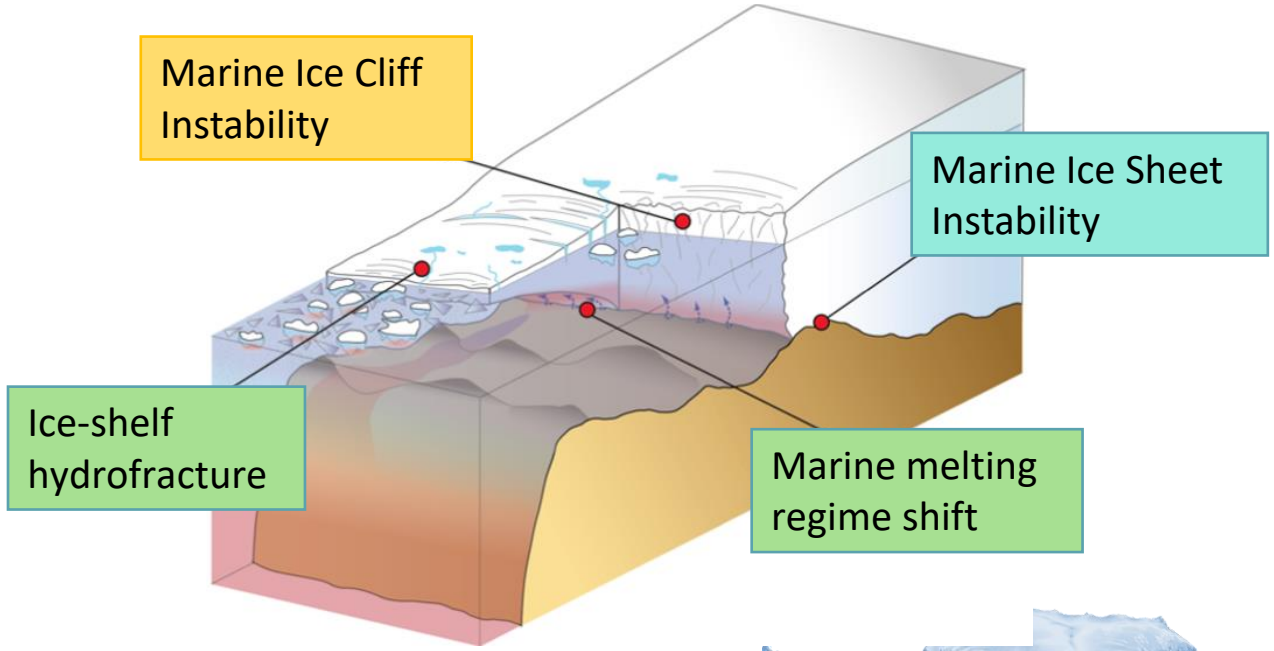
SciDAC
Scientific Discovery through Advanced Computing

Motivation: Antarctic Ice Sheet is largest uncertainty in future sea-level change



Problem: Inadequate model representation of feedbacks and tipping points in AIS processes and coupling

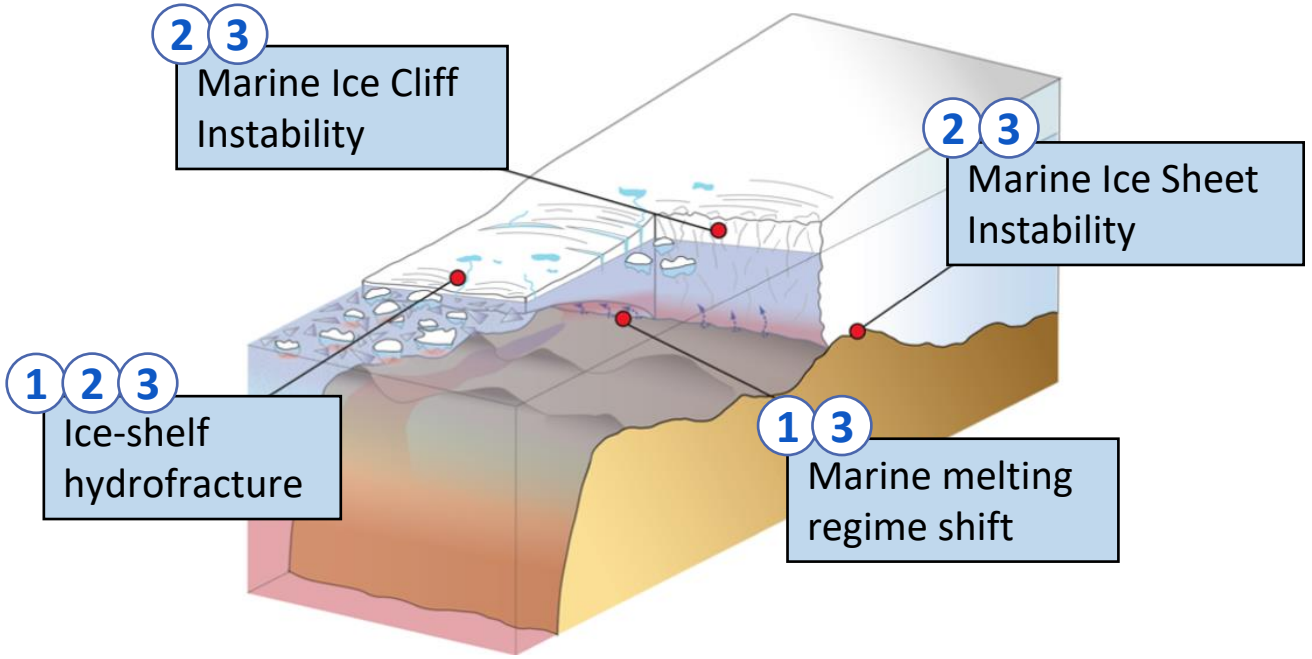


FAnSSIE Project Focus Areas

FANSSIE
Framework for Antarctic System Science in E3SM

EESM Linkages:
High Latitude, Coastal, Water Cycle, Extreme Events

1. Coupling of climate and Antarctic Ice Sheet in E3SM
2. MALI ice-sheet model enhancements
3. Probabilistic projections of the Antarctic Ice Sheet



How will threshold processes linking the coupled ice sheet, ocean, and atmosphere impact the contribution of the Antarctic Ice Sheet to sea-level?

Goal: Create <u>accurate</u>, <u>performant</u>, <u>coupled</u> AIS component for E3SM

1 Coupling AIS to E3SM: Ice-sheet/Ocean

Computational Innovation

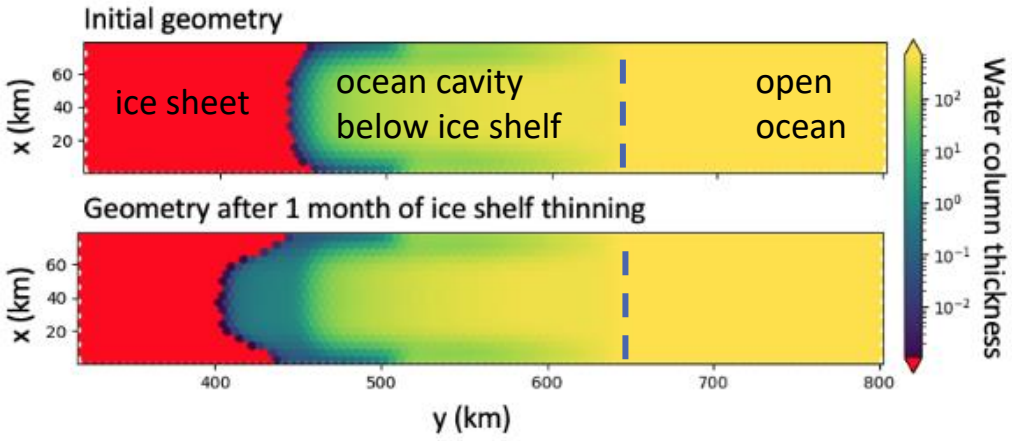
C. Begeman
X. Asay-Davis *LANL*

Grounding line motion

Generalized MPAS-Ocean coastline migration

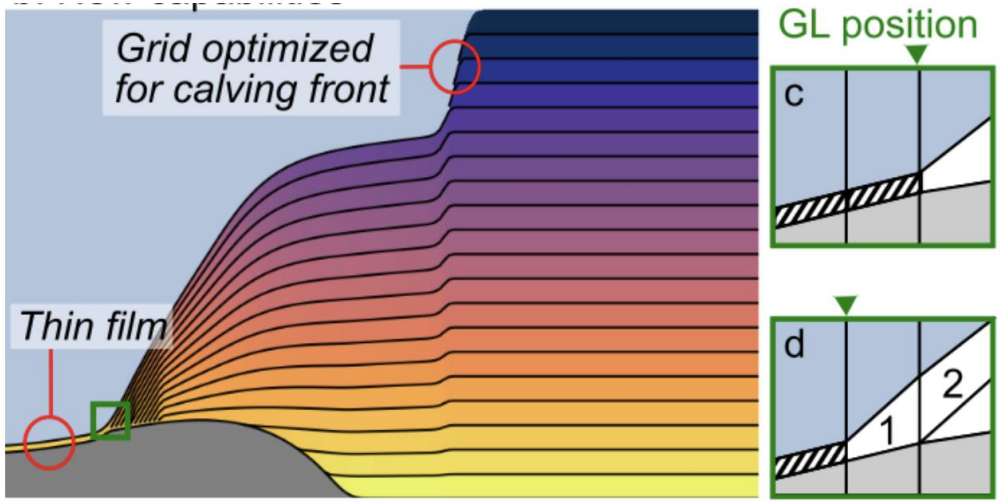
- Shallow-water to 3d Boussinesq Navier-Stokes
- RK4 to Split-Explicit time integration

[ICoM, E3SM Polar]



Challenge: Strong pressure gradients

- Land ice pressure limiter in the dynamics, but not the coastline migration algorithm
- Mode-splitting for drag at ocean floor and ice base to damp unphysical oscillations



1 Coupling AIS to E3SM: Ice-sheet/Ocean

Model Frameworks

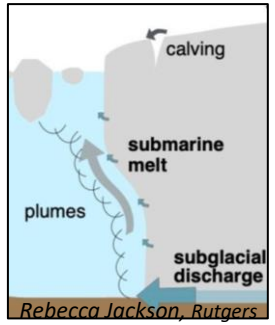
See Vaňková poster

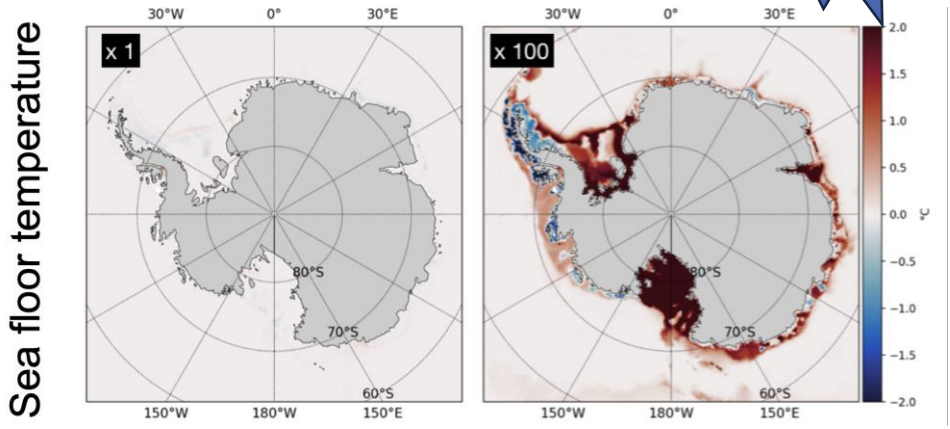
Subglacial discharge into ocean

I. Vaňková *LANL*

Influence of subglacial runoff on ocean conditions and Antarctic melt?

- Runoff increases melt near grounding line (Vaňková et al. In review. *The Cryosphere*)
- Significant impact requires order of magnitude increase





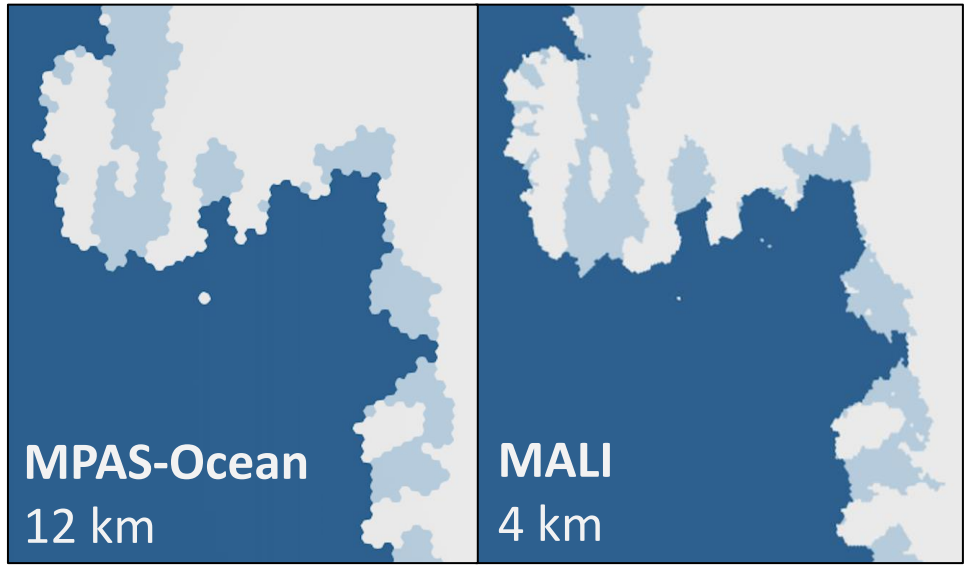
Coupled AIS compsets

X. Asay-Davis *LANL*

Currently fixed grounding line in ocean

- consistent ice-shelf geometry AIS and ocean
- new 4 km and 8 km AIS meshes in E3SM
- utilize ice-shelf basal melt calculation in coupler instead of ocean model

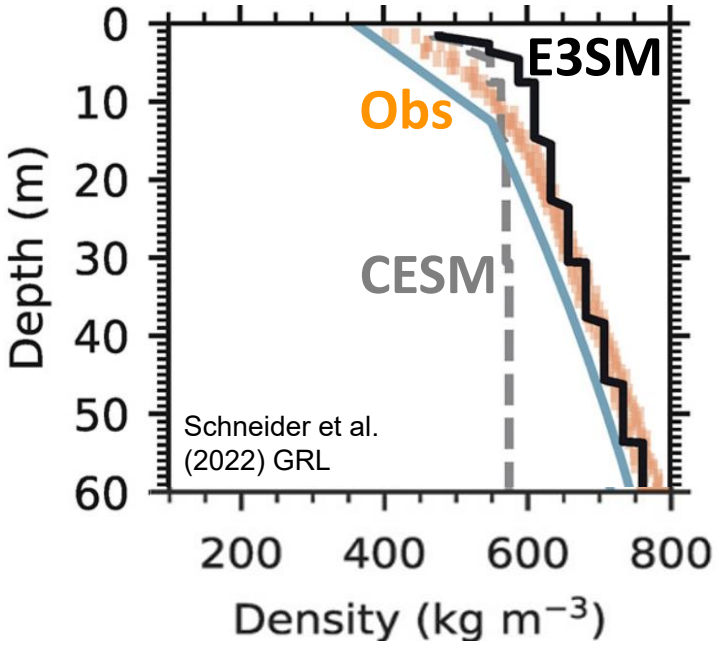
[E3SM Polar]



1 Coupling AIS to E3SM: Ice-sheet/Surface climate

Chloe Whicker-Clarke
Charlie Zender *UCI*

- Improved snow physics
  - snow layers increased from 5 to 16
  - improved densification, thermal conductivity, albedo

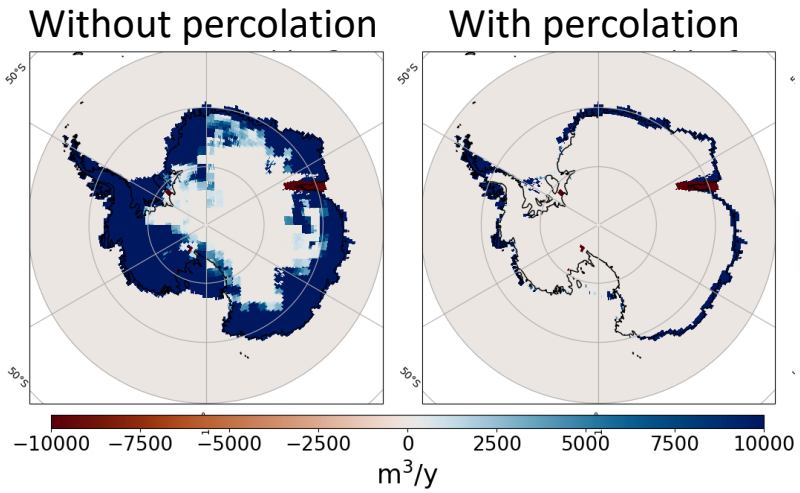


- added meltwater percolation & refreezing into snowpack

Model Biases, Testbeds

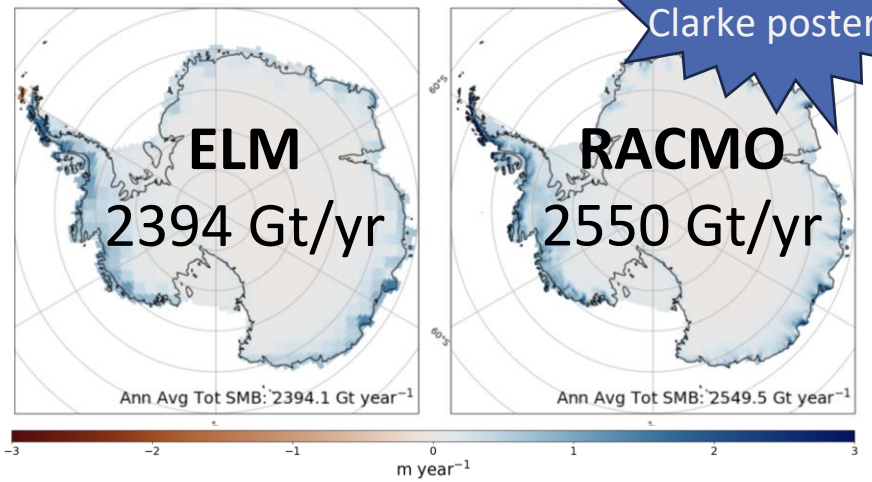
[E3SM Polar]

Liquid Runoff to Ocean

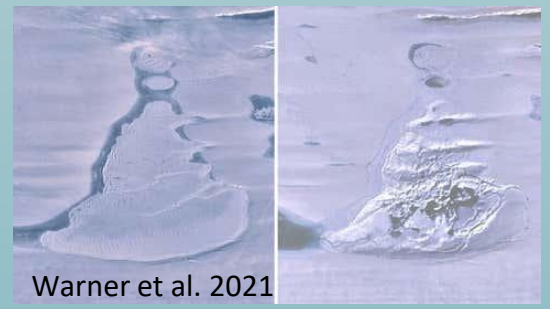


- 1000-yr firn spinup with ERA5 1980 climate

See Whicker-Clarke poster



Next Steps:
Couple firn water content to ice-sheet stress state to enable hydrofracture



Schneider at al. (2022) GRL
Whicker-Clarke et al. (2024) JGR-A
Tolenta et al. (2024) JGR-A
Manzo et al. (in review) JGR-A

2 Ice-Sheet Model Enhancements

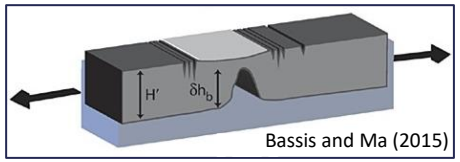
Trevor Hillebrand *LANL*
Mauro Perego *SNL*
Jeremy Bassis *Michigan*
Sam Kachuck *Michigan*

Fracture mechanics for rifts and calving

Computational Innovation

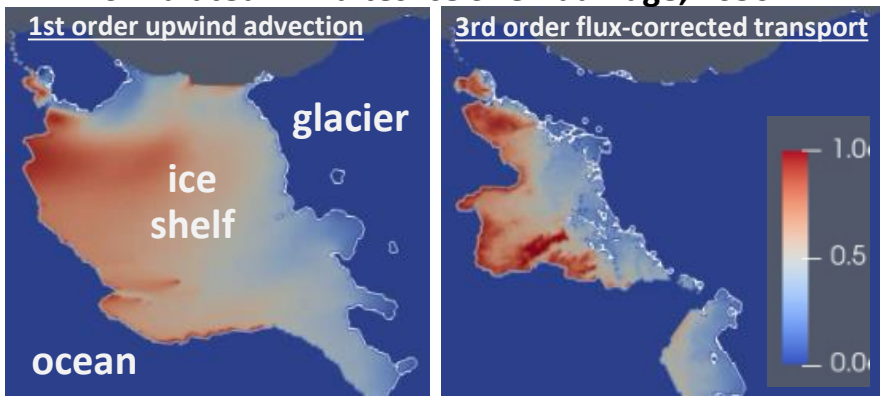
Introduce ice damage coupled to ice viscosity

- Damage softens ice, leading to localized flow and plastic necking
- Improved advection and time-stepping accuracy from 1st to 3rd order
- Ongoing: introducing mesh adaptivity to follow rifts



Bassis and Ma (2015)

Simulated Thwaites Ice Shelf damage, 2050



Initial condition optimization

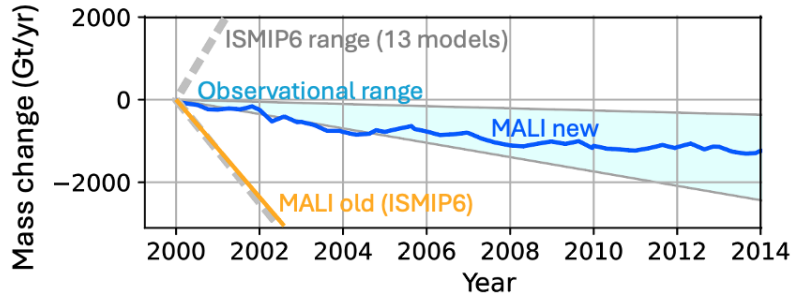
Mauro Perego *SNL*

Model Biases, Computational Innovation

Match both historical state and flux

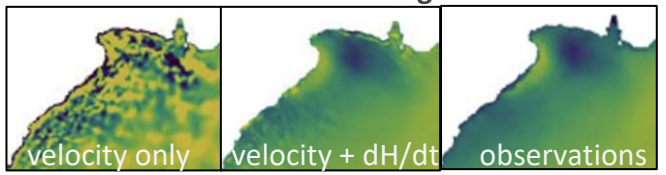
- 10x improvement in transient
- Ability to accommodate ESM biases

Realistic Simulated Historical Ice Sheet Transients



Ice thickness change rate

Ice-sheet model initialization improvements



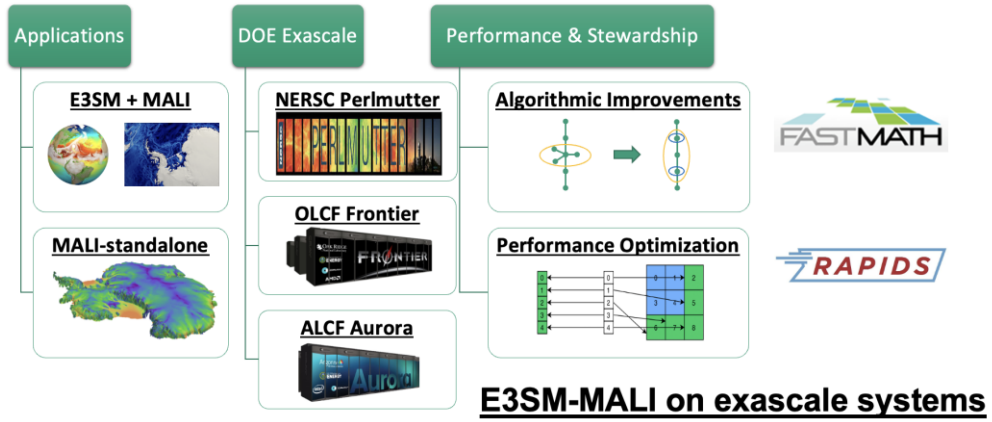
2 Ice-Sheet Model Enhancements

Computational Innovation, Modeling Frameworks

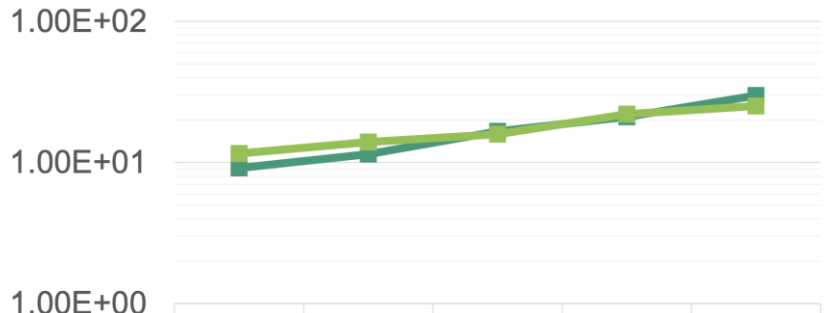
MALI performance portability

Jerry Watkins *SNL*

- Enabled MALI to use GPUs
  - First MALI AIS science production runs on GPUs (Perlmutter): July 2023
- Utilization of Kokkos abstraction layer to handle architecture-specific operations
- Preconditioner improvements (2x speedup on GPUs)
- Refactorization to reduce memory footprint and data movement
- Solver parameter autotuning



GPU Velocity Solver Weak Scalability
Wall-clock time (s) vs. Nodes



	1	4	16	64	256
Resolution (km)	16	8	4	2	1
Perlmutter	9.15	11.46	16.63	21.08	29.85
Frontier	11.58	13.97	15.85	22.03	25.15

Problem size ranges form 2M to 566M unknowns.

3 Probabilistic AIS Projections

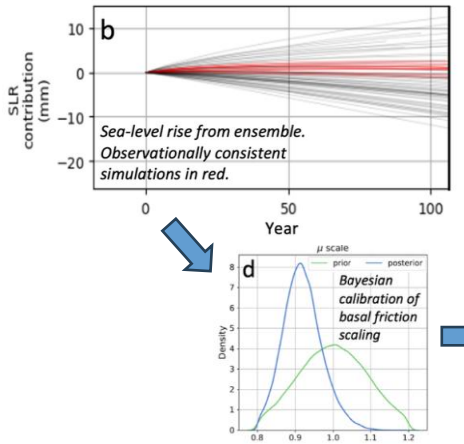
Model Biases, Computational Innovation

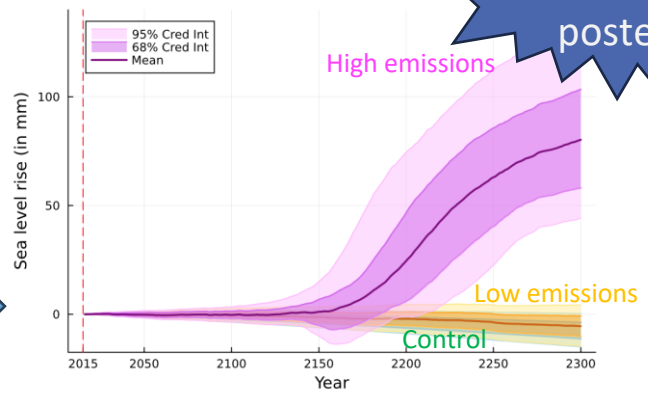
Nathan Urban *BNL*
Sanket Jantre *BNL*
John Jakeman *SNL*
Mauro Perego *SNL*

Uncertainty Quantification

- Large MALI ensembles
- Emulation
- Historical calibration
- Future projection
- Multi-fidelity UQ

Bayesian Calibration

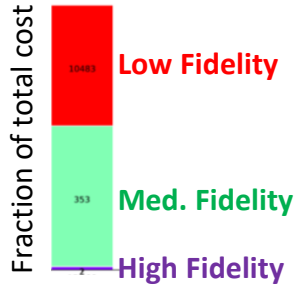




Jantre et al. In review. *The Cryosphere*

See Hoffman poster

Multifidelity UQ



35x reduction in cost

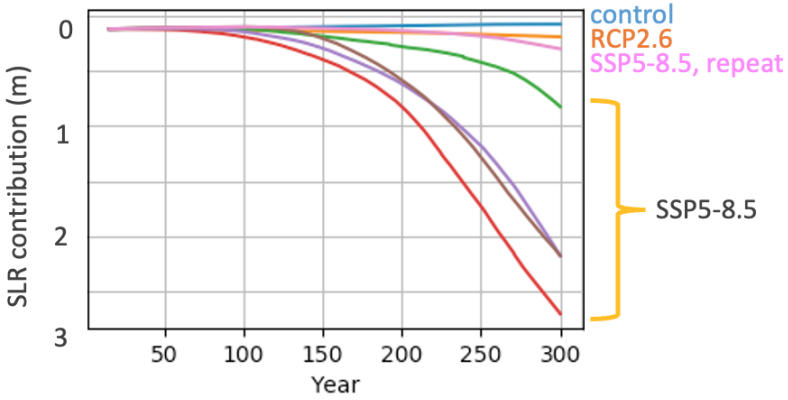
Jakeman et al. In review. *Earth System Dynamics*

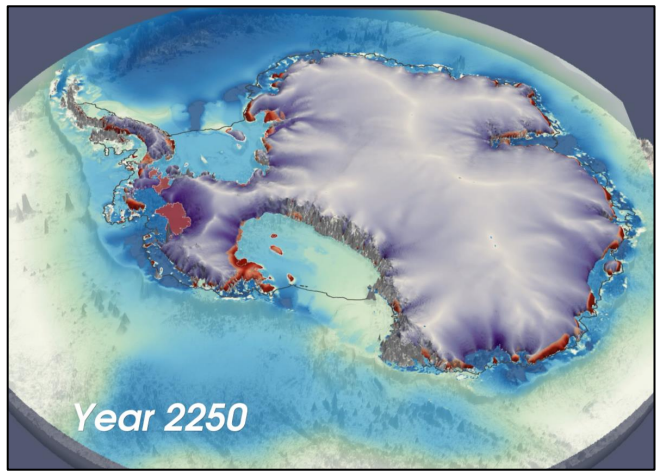
AIS projection and sensitivities

- ISMIP6-AIS-2300
- 13 forcing experiments (CMIP5/6)
- +50 sensitivity tests

Seroussi et al. Accepted. *Earth's Future*

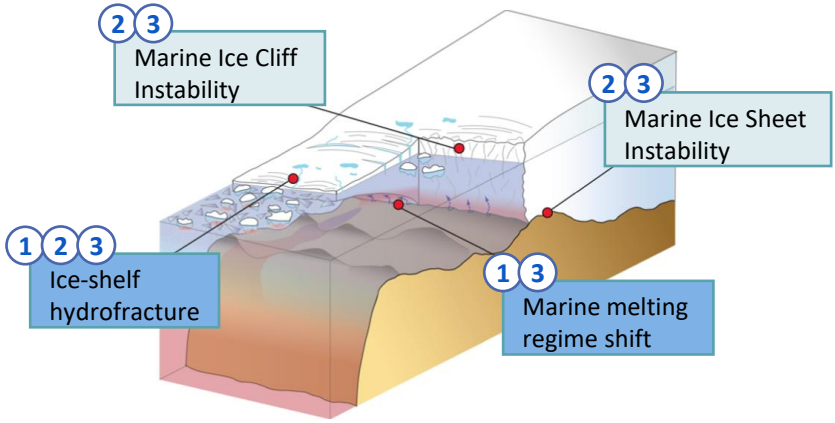
Trevor Hillebrand *LANL*





FAnSSIE Summary & Outlook

1. Coupling of climate and Antarctic Ice Sheet in E3SM
2. Ice-sheet dynamics & fracture mechanics
3. Probabilistic projections of the Antarctic Ice Sheet



- Addressing AIS deep uncertainty requires integrated computational/domain science collaboration
- Close coordination with E3SM project and other ecosystem projects
- Maintaining DOE leadership in ice-sheet science and model development

Acknowledgements

- Scientific Discovery through Advanced Computing (SciDAC) program
- Biological and Environmental Research
- Advanced Scientific Computing Research

High performance computing resources

- National Energy Research Scientific Computing Ctr
- Los Alamos National Laboratory Institutional Computing Program