Towards a coupled Greenland ice sheet in E3SM

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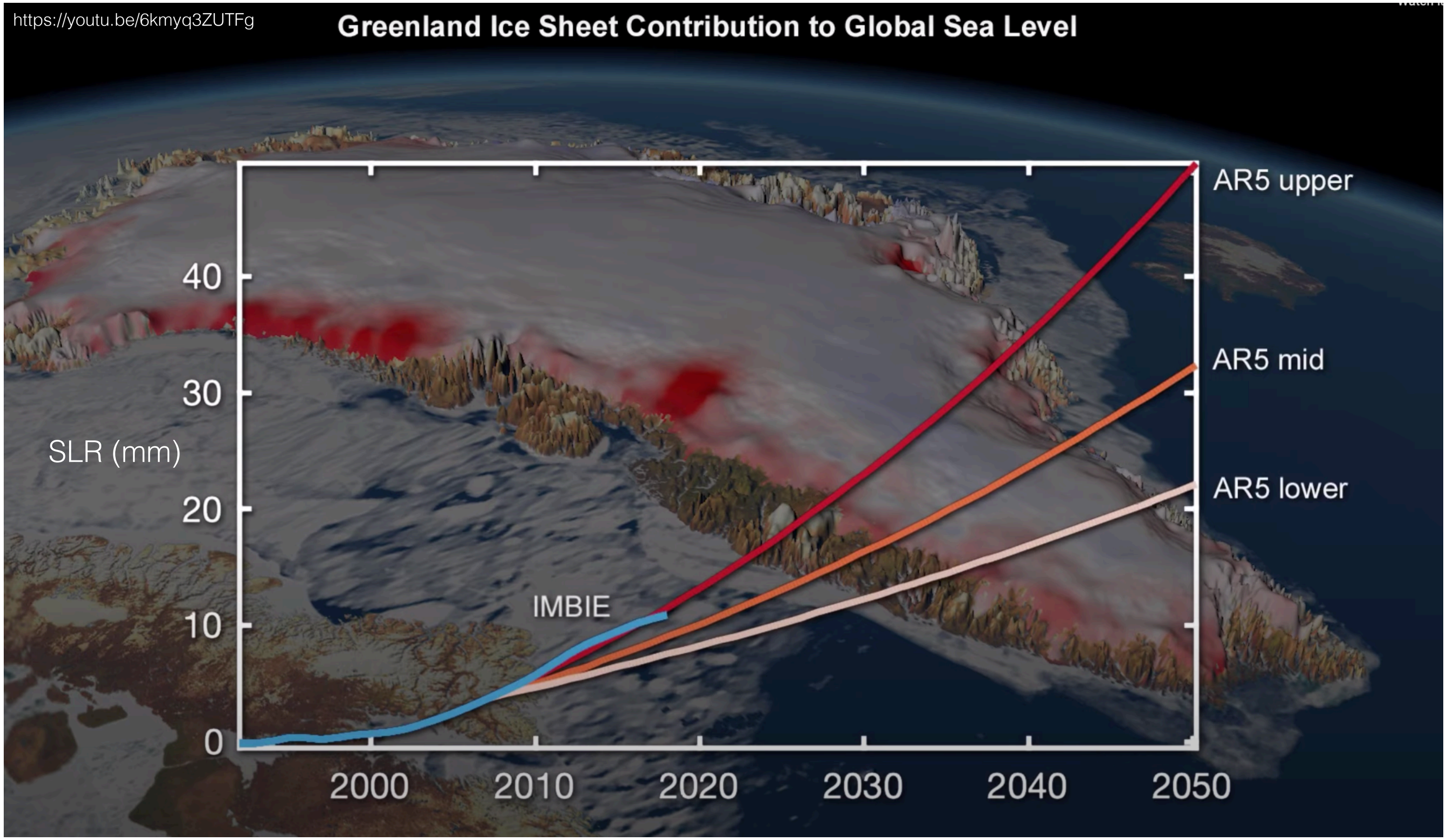


Observed and projected rates of SLR from Greenland with observations (blue line) paralleling high end projections (IMBIE, *Nature*, 2020). Colored image in back shows mass loss (red=more loss) as measured by ICESat2 (Smith et al., *Science*, 2020)

Motivation

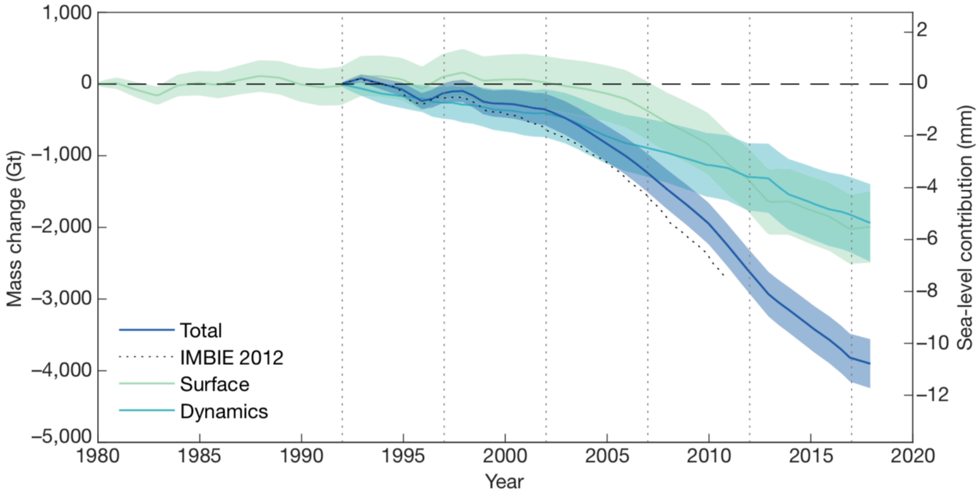
The Greenland ice sheet (GIS) has contributed 12 mm of sea-level rise (SLR) since the 1990s (upper right)

The GIS is currently the single largest contributor to rates of global SLR.

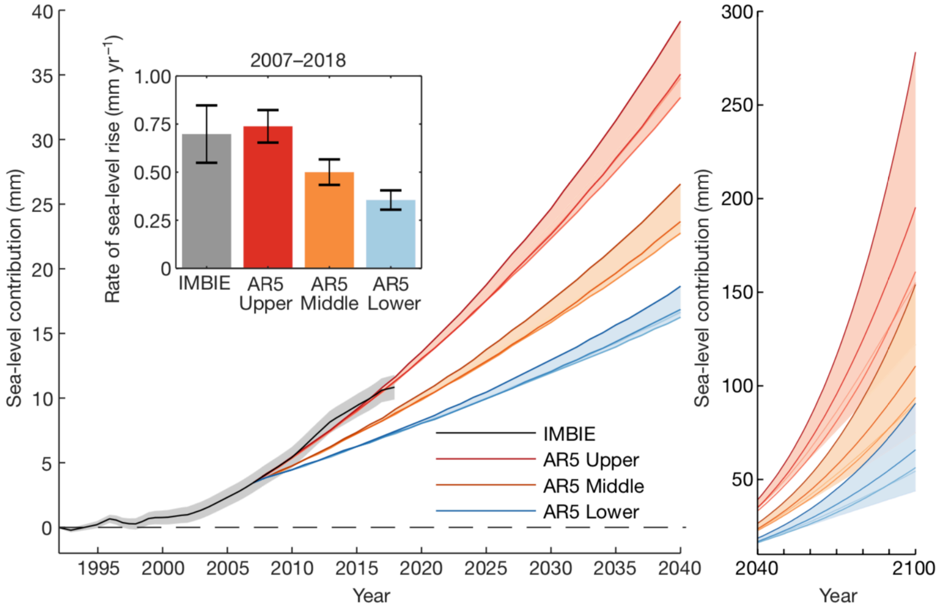
Recent community efforts towards IPCC AR6 project 90 +/- 50 mm of SLR from the GIS by 2100 under RCP 8.5.

Current rates of mass loss parallel those estimated from high-end emissions scenarios from IPCC AR5 (lower right).

Current and future rates of GIS mass loss are a strong function of surface climate processes (as opposed to ocean forcing and ice dynamics for Antarctica)



Figures from IMBIE team (*Nature*, 2020)



Goal & Current Efforts

Goal: A scientifically validated, coupled, Greenland ice sheet in E3SM.

Current efforts:

1. A new, high-resolution Greenland ice sheet initial condition for MALI[1,2] in E3SM
2. High-resolution, basin-scale simulations of Greenland to investigate the impacts of improved optimization, mesh resolution, and ice sheet model physics on recently observed outlet glacier changes[1]
3. A new snowpack model in ELM – appropriate for simulating the evolution of the deep snowpack ("firn") over ice sheets – which is critical for accurate simulation of surface mass balance (snow accumulation minus melt) [1,2]
4. Analysis of E3SM atmosphere processes controlling GIS melt[2]
5. New E3SM compsets with an active MALI GIS component[1,2]

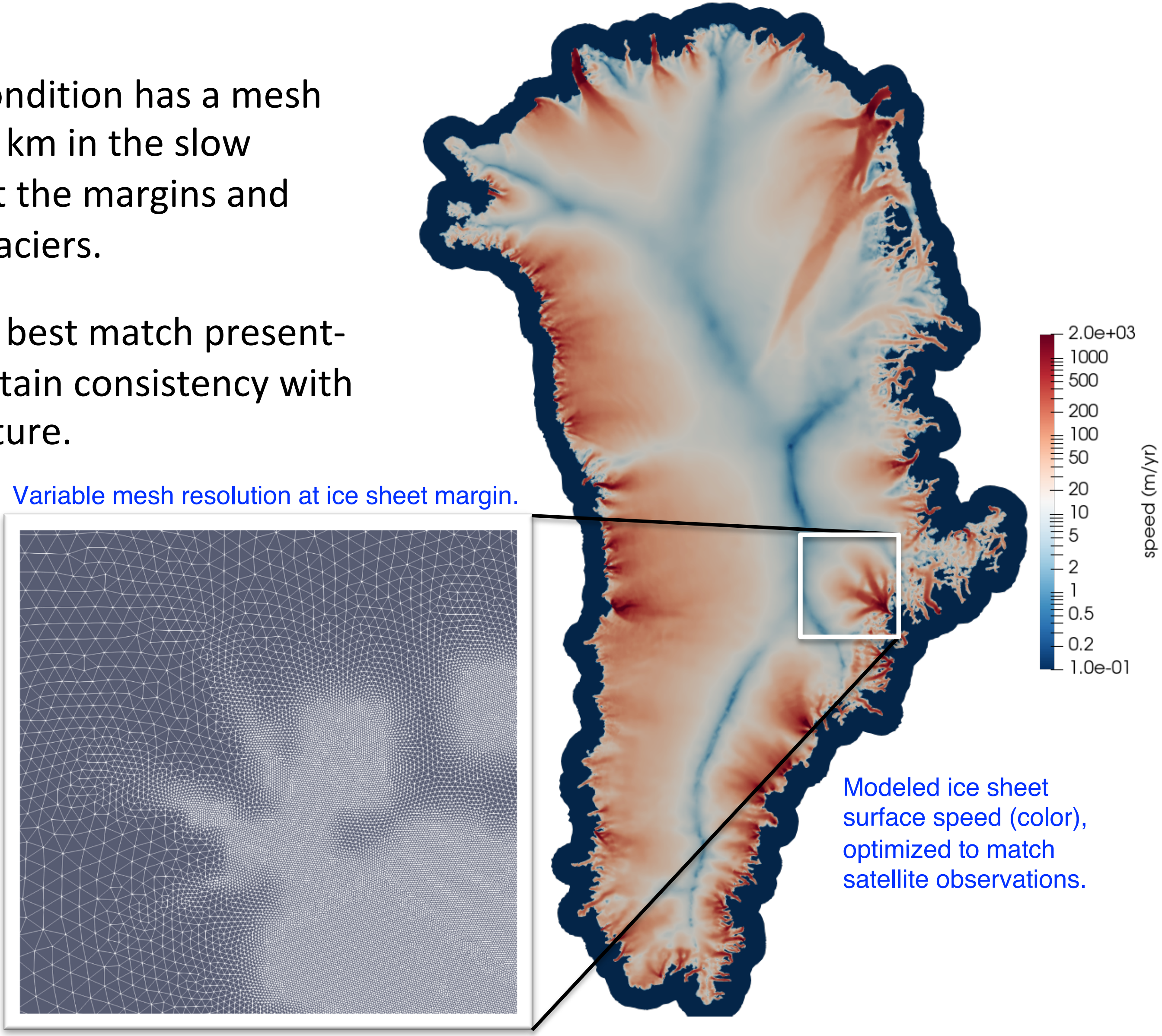
Work supported by (1) SciDAC *ProSPect*, (2) E3SM

High-Resolution, Optimized Initial Condition

The new MALI GIS initial condition has a mesh resolution ranging from 10 km in the slow flowing interior to <1 km at the margins and along fast flowing outlet glaciers.

Velocities are optimized to best match present-day observations and maintain consistency with internal ice sheet temperature.

Ongoing work is focused on additional optimization constraints and degrees of freedom to minimize transient shocks when coupling MALI to climate forcing from E3SM.



Variable mesh resolution at ice sheet margin.

Modeled ice sheet surface speed (color), optimized to match satellite observations.

Work by M. Perego (SNL)

Basin-scale Simulations (Humboldt)

Humboldt Glacier is a wide, marine-terminating glacier in NW Greenland.

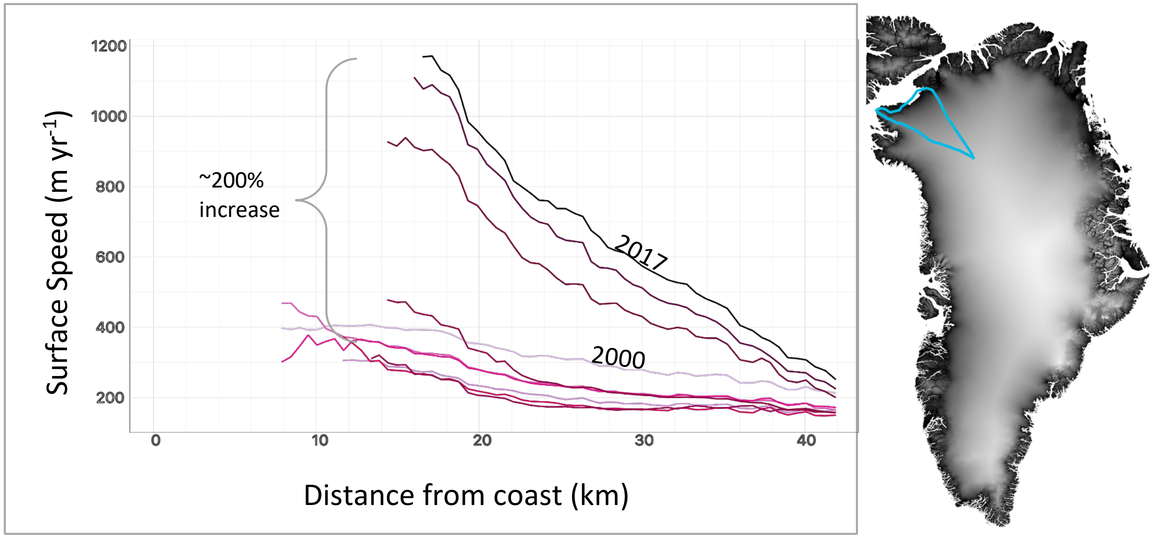
It is a close analogue to Antarctic glaciers vulnerable to the “marine ice sheet instability”, which can result in sudden, rapid, and sustained retreat.

We are simulating Humboldt’s response to a range of ocean and atmospheric forcings to constrain its future sea level contribution.

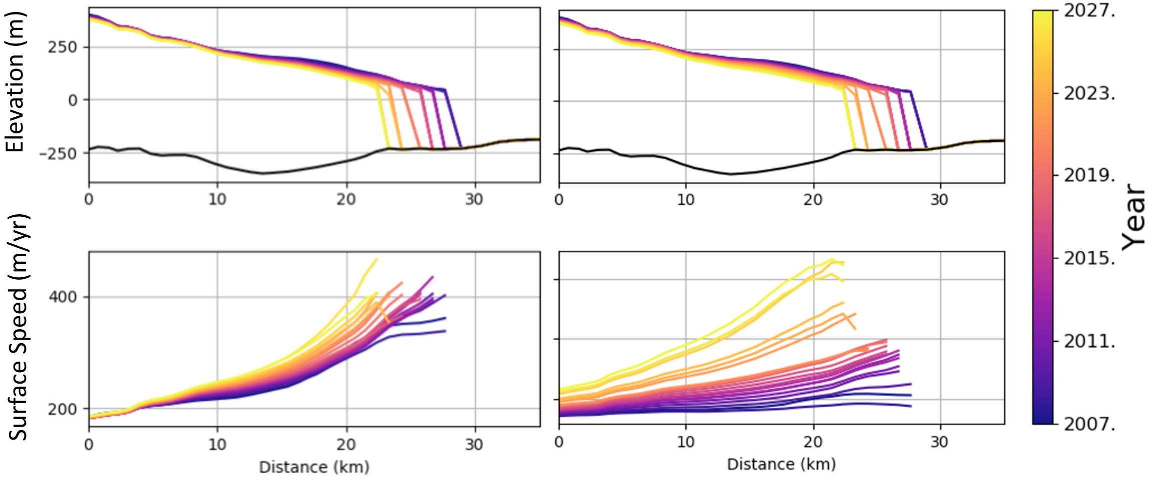
These simulations also allow us to experiment with and investigate the impacts of mesh resolution, new ice sheet model physics, and improved optimization methods.

What we learn will ultimately be applied to improve our whole-ice-sheet simulations.

See also poster by *Hillebrand et al.* (PS1).



Humboldt Glacier catchment (right) and observed speed changes from 2000-2017.



MALI modeled speed changes for Humboldt Glacier using linear (left) and nonlinear (right) sliding laws. The nonlinear law results in a significant improvement in terms of matching observations but still underestimates the observed speed up.

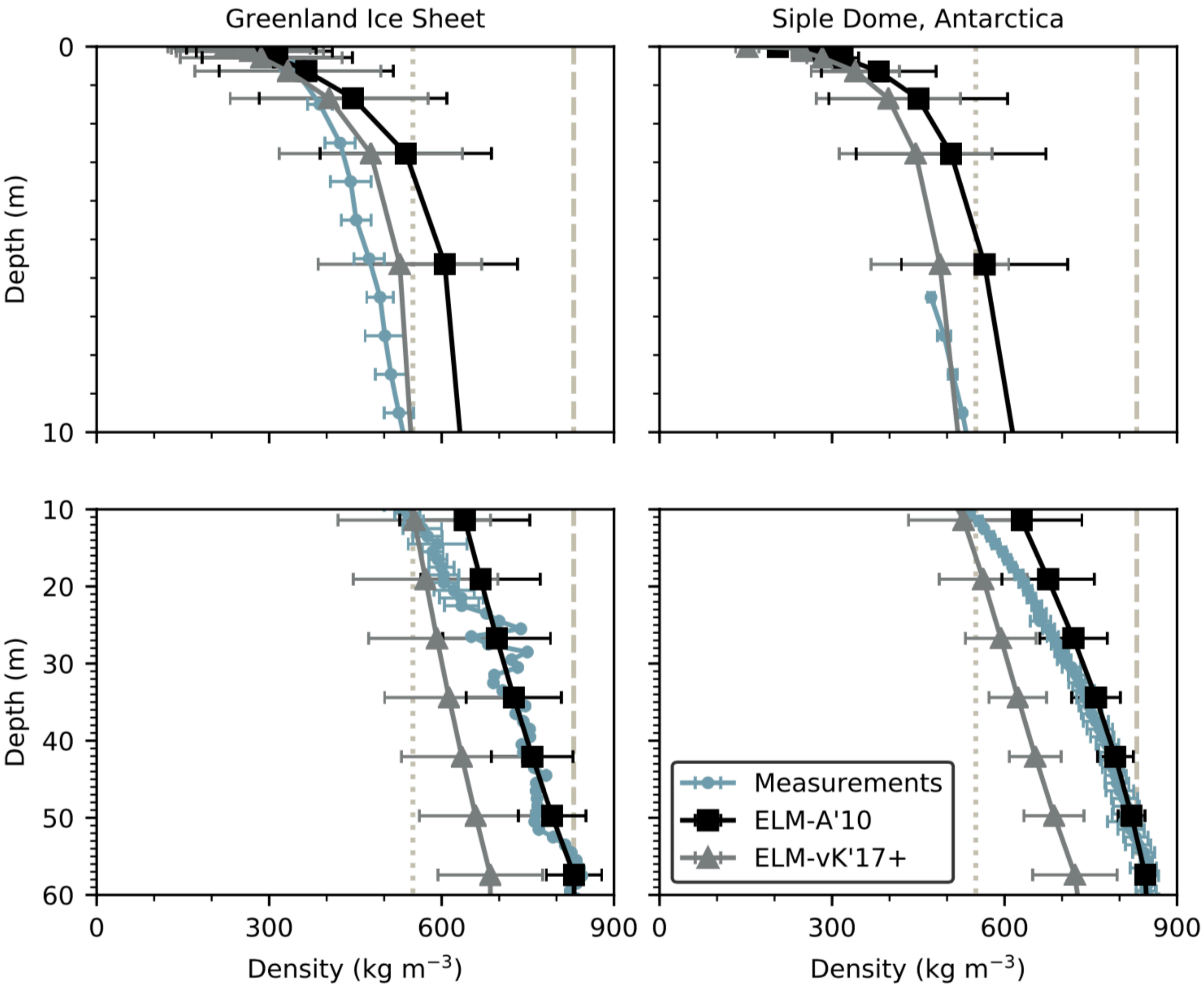
New & Improved Snowpack Model in ELM

The default snow model in ELM is not adequate for simulating the thick (up to 100 m) snowpack, or “firn”, found at the surface of ice sheets.

This thick snowpack is essential for accurately simulating surface mass balance – its timescale of evolution is much longer than for a seasonal snowpack and can store and refreeze substantial amounts of surface melt (it can serve as a strong buffer to the ice sheet response to short-term atmospheric forcing).

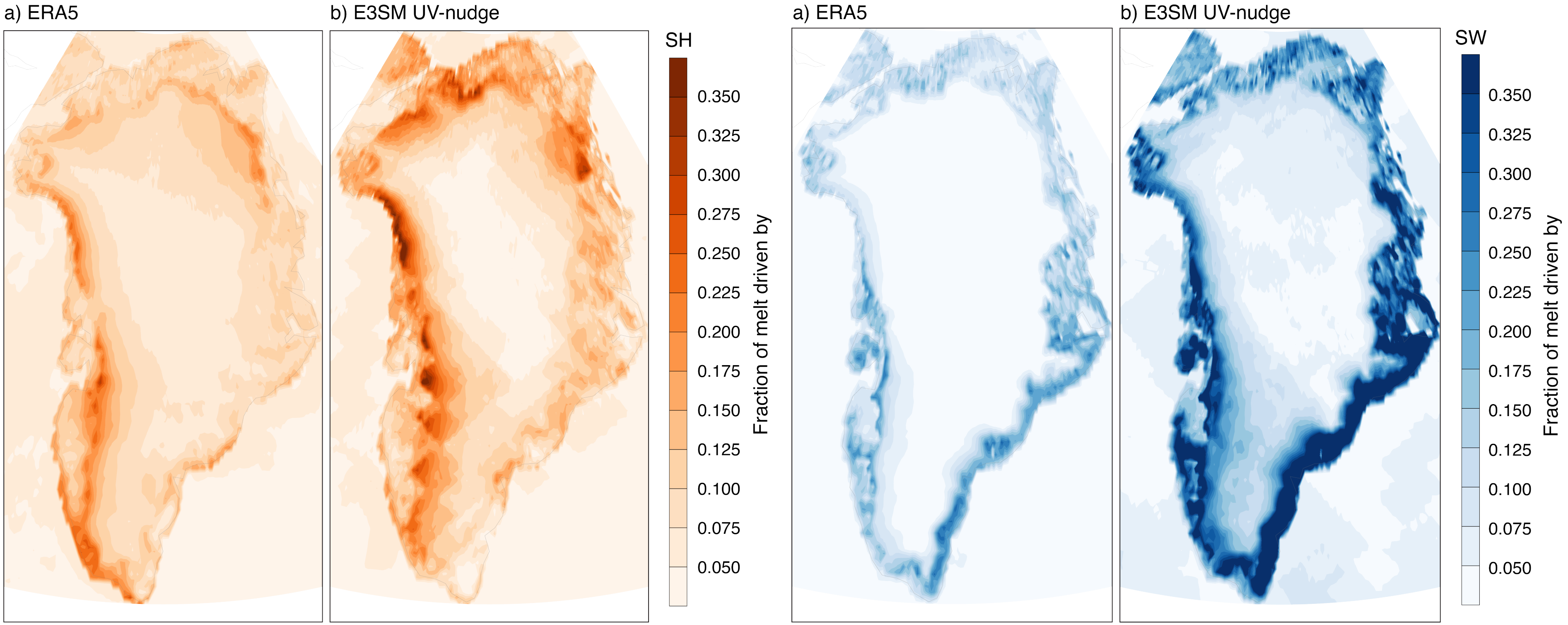
This new snowpack model compares well to measurements from both the Greenland and Antarctic ice sheets (right).

See also poster by *Schneider et al.* (PS1).



Late 20th century firn density profiles simulated with ELM (black, gray) compared to firn-core measurements from Greenland (left column) and Antarctica (right column). From Schneider et al. (in review, *GMD*, doi:10.1594/gmd-2020-247).

Factors Controlling GIS Surface Melt in E3SM



Fraction of GIS surface melt driven by sensible heat (SH, left) and short wave radiation (SW, right) (daily and seasonal cycles removed). Analysis of simulation from Tang et al. (*GMD*, **12**, 2019, https://doi.org/10.5194/gmd-12-2679-2019)

Melt from SH is overestimated at margins but very good overall (e.g., improved over RACMO)

Melt from SW is overestimated, which may be indication of:

- too low albedo (snow grain metamorphism? excess melt refreezing?) => *land biases*
- snowfall, rain, or cloud biases => *atmosphere biases*

See *W. Wang et al.* presentation in Cryosphere breakout (D4S1; Thursday @ 11:35 a.m.)

New Compsets in E3SM

To support simulations of Greenland in E3SM, we have added two new compsets, both supporting a dynamic, high-resolution GIS using MALI:

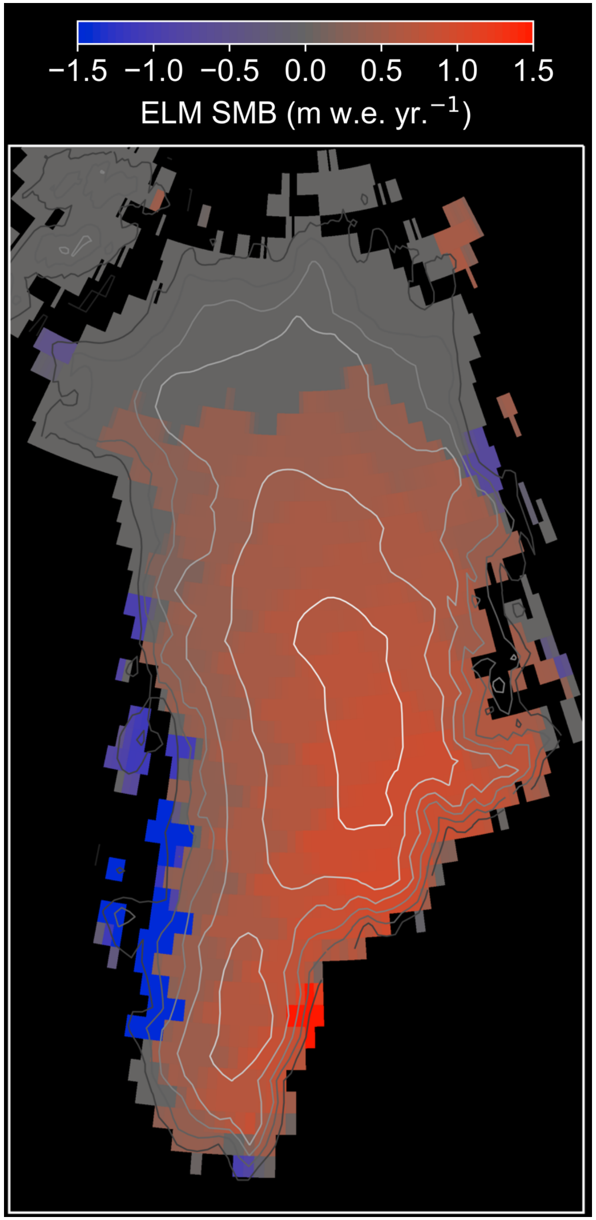
- "IG" – active *lnd*, *glc* with data *atm*
- "BG" – all components active, including *glc*

Currently, we are:

- spinning up a realistic present-day surface mass balance for Greenland using the IG compset and the new ELM snowpack model
- testing and tuning MALI performance when run as a coupled component of IG and BG compsets

To the right, we show preliminary, spun-up surface mass balance from an IG simulation, using the new snowpack model. Coarse-grid imprinting from the ne30 atmosphere is apparent.

Once we are comfortable with coarse-resolution results, a higher resolution atmosphere (e.g., from the v2 Water Cycle configuration) should result in substantial improvements.



Next Steps & Future Work

Next Steps:

- Complete snowpack spin-up using IG compset and repeat 1980-1990's forcing; compare against observations and reanalysis products
- Analyze and address atmos. and land model biases impacting surface mass balance
- Apply spun-up initial condition to fully coupled simulations of surface mass balance
- Assess and improve MALI performance and robustness when coupled to E3SM

Future Work:

- Assess ice sheet surface climate with higher-resolution atmos. and land
- Conduct historical and scenario-based simulations
- Update MALI initial condition with new optimization; apply new MALI physics
- Couple ice sheet model physics (e.g., hydrology) with climate forcing