Improving snow compaction and *firn densification* on E3SM's ice sheets

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E3SM Energy Exascale Earth System Model

U.S. DEPARTMENT OF ENERGY

1. Introduction

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The worst is yet to come for the Greenland ice sheet

An assessment of past, present and future ice loss from the Greenland ice sheet shows that rates of loss in the twenty-first century will be much higher than those at any time during the past 11,700 years.

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Left: Briner et al., featured in a recent edition of *Nature* (https://doi.org/10.1038/d41586-020-02700-y), predict unprecedented Greenland Ice Sheet (GrIS) mass loss this century, contributing *2.4-9.9 cm to sea level rise*. GrIS mass loss is dominated by its change in *surface mass balance (SMB)*.

By Jenessa Duncombe 10 December 2019

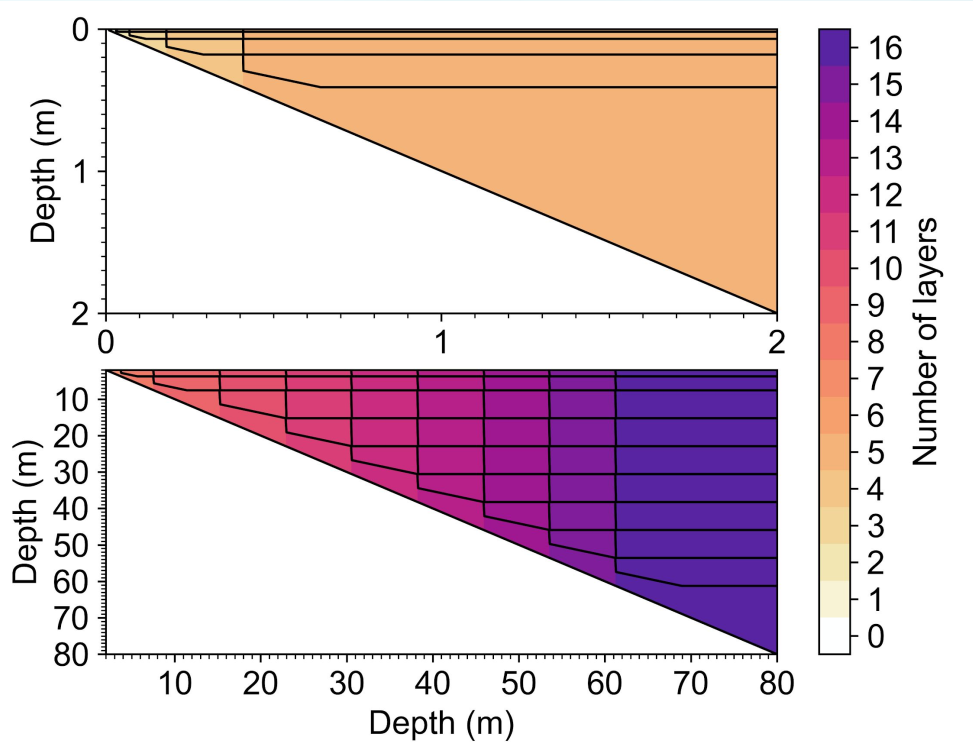
The interior of Greenland's ice sheet doesn't usually make headlines: It's a layer of compact snow and glacial ice at high elevations that typically doesn't contribute to runoff that drives sea level rise.

But a new study suggests that this may change: More runoff may come from Greenland's interior because of a newly discovered phenomenon called ice slabs. The slabs are layers of ice that exist just below the snow's surface, where porous snow usually sits. Ice slabs can extend for tens of

Ice slabs can extend for tens of kilometers and grow to over 16 meters thick.

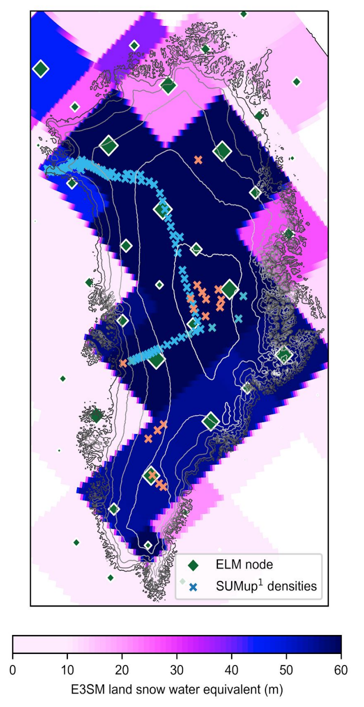
Left: *EOS* article covering observations of "ice slabs" forming near the GrIS surface (https://eos.org/articles/a-new-source-of-sea-level-rise-from-greenland-ice-slabs). It is unclear how *firn densification* will impact future *SMB*.

2. E3SM Land Model (ELM) development



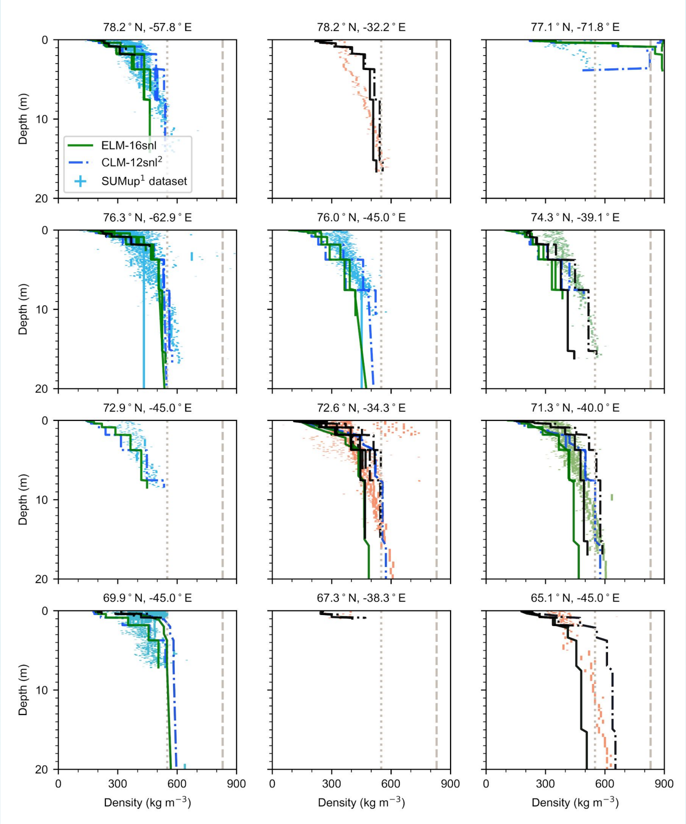
Left: ELM 1D-snowpack grid: default in v2 (top, max. of 5 layers) and with *"use_extrasnowlayers"* (bottom, max. of 16 layers). The maximum number of snow layers and the maximum allowed snowpack depth have been increased to improve the simulation of snow compaction and *firn densification* needed for future *SMB* studies.

3. GrIS firn density profiles



Left: Map of GrIS ELM snowpack and SUMup (Montgomery et al., 2018) locations.

Right: Variation of density in depth, including density measurements (SUMup dataset, scattered), as simulated with the CESM Land Model v5 snowpack configuration (CLM-12snl, blue), and with our expanded E3SM land snowpack configuration (ELM-16snl, green/black). SUMup density measurements are sorted into 12 groups, each representing the nearest ELM node (indicated by subplot lat-lon coordinates) for ease of geographical comparisons.



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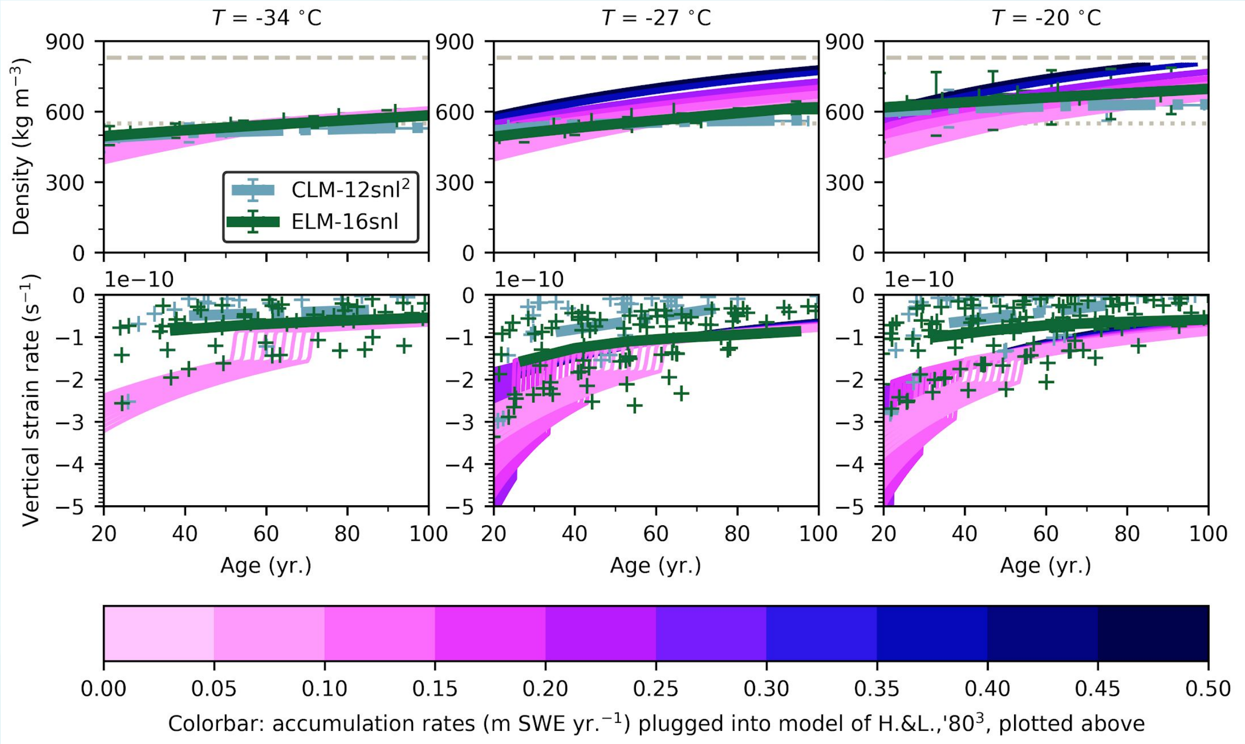
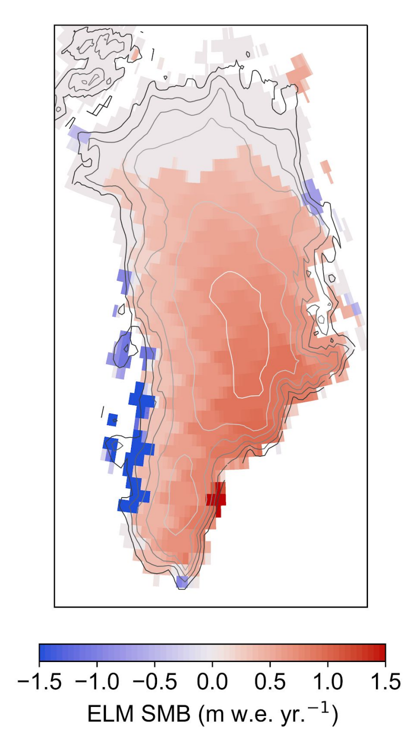
4. Polar *firn densification* through 100 years



Left: Variation of densities (top) and advective strain rates (x 1e-10, bottom) as a function of firn age in CLM-12snl, (light-blue), and in (ELM-16snl, green/black) and compared against the model of Herron & Langway, 1980 (see colorbar label). Results are sorted into 3 groups representing the mean annual temperature indicated in subplot titles.

5. Conclusions and future work

- Developments enable deep (~50 m) firn simulations
- Top 10 m firn densities compare well with measurements
- Optimization (in “ELM-16snl”) improves simulation of deeper (>10 m) *firn densification*:
    - RMSE 10% lower in ELM-16snl vs. CLM-12snl for majority of gridcells
    - Deep firn strain rate bias corrected in ELM-16snl vs. CLM-12snl
- Improvements enable testing and initialization of GrIS *SMB* (right)



Left: GrIS *SMB* from year 27 in a coupled ELM-MALI configuration with *“use_extrasnowlayers”*. Ongoing simulations are further testing and initializing snowpack conditions with downscaling enabled by multiple elevation classes.

6. Acknowledgements

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7. References

- Briner, J.P., Cuzzone, J.K., Badgeley, J.A. et al. Rate of mass loss from the Greenland Ice Sheet will exceed Holocene values this century. *Nature* 586, 70–74 (2020). https://doi.org/10.1038/s41586-020-2742-6
- Herron, M., & Langway, C. (1980). Firn Densification: An Empirical Model. *Journal of Glaciology, 25*(93), 373-385. doi:10.3189/S0022143000015239
- Montgomery, L., Koenig, L., and Alexander, P.: The SUMup dataset: compiled measurements of surface mass balance components over ice sheets and sea ice with analysis over Greenland, Earth Syst. Sci. Data, 10, 1959–1985, https://doi.org/10.5194/essd-10-1959-2018, 2018.
- van Kampenhout, L., Lenaerts, J. T. M., Lipscomb, W. H., Sacks, W. J., Lawrence, D. M., Slater, A. G., & van den Broeke, M. R. (2017). Improving the representation of polar snow and firn in the Community Earth System Model. *Journal of Advances in Modeling Earth Systems*, 9, 2583–2600. https://doi.org/10.1002/2017MS000988