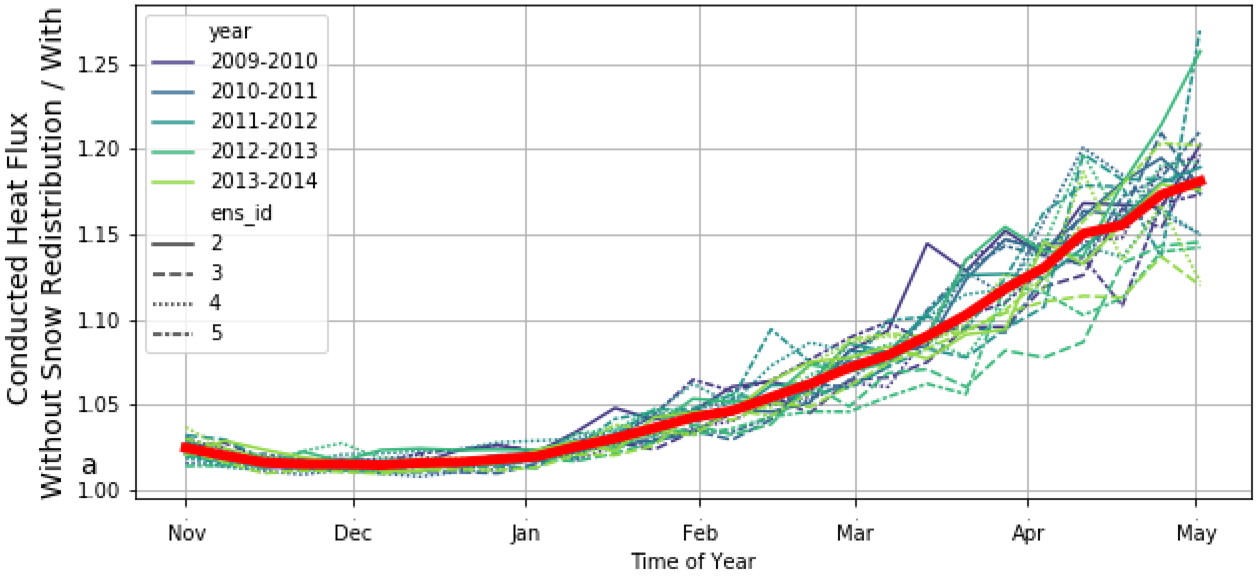
The Impacts of Snow Redistribution onto Young Arctic Sea Ice

David Clemens-Sewall[1], Marika M. Holland[2], Don Perovich[1], Chris Polashenski[1,3], Ian A. Raphael[1], Madison M. Smith[4], Melinda Webster[5]

[1]Dartmouth [2]NCAR [3]USACE-CRREL [4]UW-APL [5]UAF

Key Takeaways

- Observations show that wind-driven snow redistribution preferentially accumulates 0.025 – 0.08 m of snow on young Arctic sea ice—a process not represented in climate models.
- Snow limits conductive heat flux (i.e. wintertime ice growth).
- Offline analysis of CESM2 output suggests that neglecting this snow redistribution could lead to current climate models overestimating wintertime heat flux by 3-8% on average in the Arctic in the winter.



Outline

- **Mechanisms of preferential snow accumulation on young ice**
- Observations of preferential snow accumulation on young ice
- Offline snow redistribution scheme for CESM2
- Zero-layer thermodynamics model heat flux
- Modeled impacts on heat flux
- Impacts due to changing model setup and future climate states
- Conclusion and next steps

Mechanisms of Preferential Accumulation

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 99, NO. C8, PAGES 16,341–16,350, AUGUST 15, 1994

Surface characteristics of lead ice

Donald K. Perovich and Jacqueline A. Richter-Menge
U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

"The Physical Properties of Snowcover on Sea Ice in the Central High Arctic"

Gregory B. Crocker

Arctic and Alpine Research, Vol. 12, No. 2, 1980, pp. 215-226

THE SNOW COVER OF SEA ICE DURING THE ARCTIC ICE DYNAMICS JOINT EXPERIMENT, 1975 TO 1976

ARNOLD M. HANSON
24306 Timber Lane
Edmonds, Washington 98020

1964 ПРОБЛЕМЫ АРКТИКИ И АНТАРКТИКИ 17

УДК 551.578.46

В. С. ЛОЩИЛОВ

СНЕЖНЫЙ ПОКРОВ НА ЛЬДАХ ЦЕНТРАЛЬНОЙ АРКТИКИ

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE
10.1002/2017JC012865

Special Section:
Atmosphere-ice-ocean-ecosystem Processes in a Thinner Arctic Sea Ice Regime: The Norwegian Young Sea ICE Cruise 2015 (N-ICE2015)

Thin Sea Ice, Thick Snow, and Widespread Negative Freeboard Observed During N-ICE2015 North of Svalbard

Anja Rösel[1], Polona Itkin[1], Jennifer King[1], Dmitry Divine[1], Caixin Wang[1], Mats A. Granskog[1], Thomas Krumpen[2], and Sebastian Gerland[1]
[1]Norwegian Polar Institute, Tromsø, Norway, [2]Alfred Wegener Institute, Bremerhaven, Germany

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. C10, PAGES 18,221–18,232, OCTOBER 15, 1990

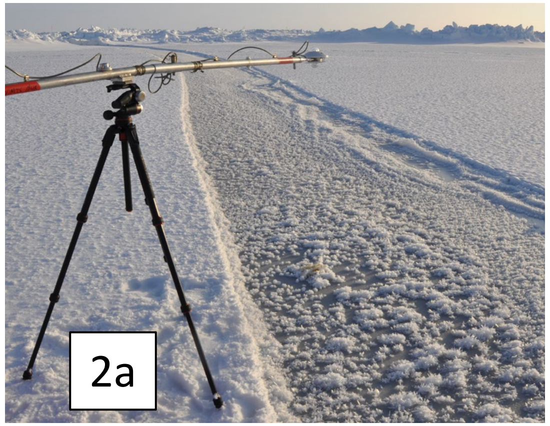
The Anatomy of a Freezing Lead

ANTHONY J. GOW, DEBRA A. MEESE, DONALD K. PEROVICH, AND WALTER B. TUCKER III
U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

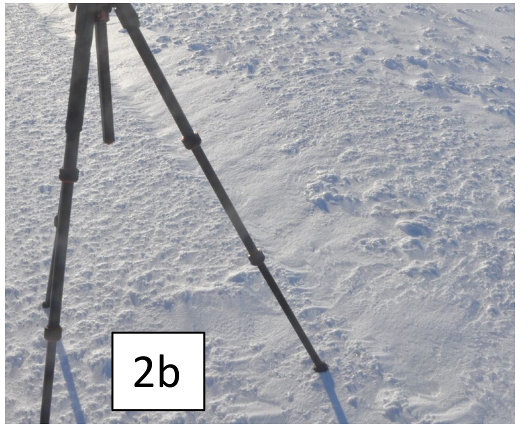
Mechanisms of Preferential Accumulation

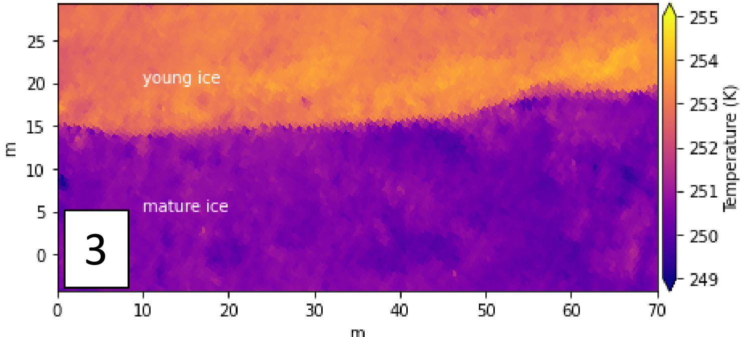
1. Brine skim creates a sticky surface that traps wind-blown snow[10]
2. Frost flowers create aerodynamic obstacles a few cm high, trapping wind blown snow in microdrifts[10]
3. Thinner snow and ice create a warmer surface than on mature ice. Leads to an enhanced sintering rate[2] and reduced remobilization
4. Sharp lead edges and deformed ice are aerodynamic obstacles, creating snow drift traps

time



wind





time

Thanks to Linda Thielke for TIR image[13]. Other photos D. Clemens-Sewall

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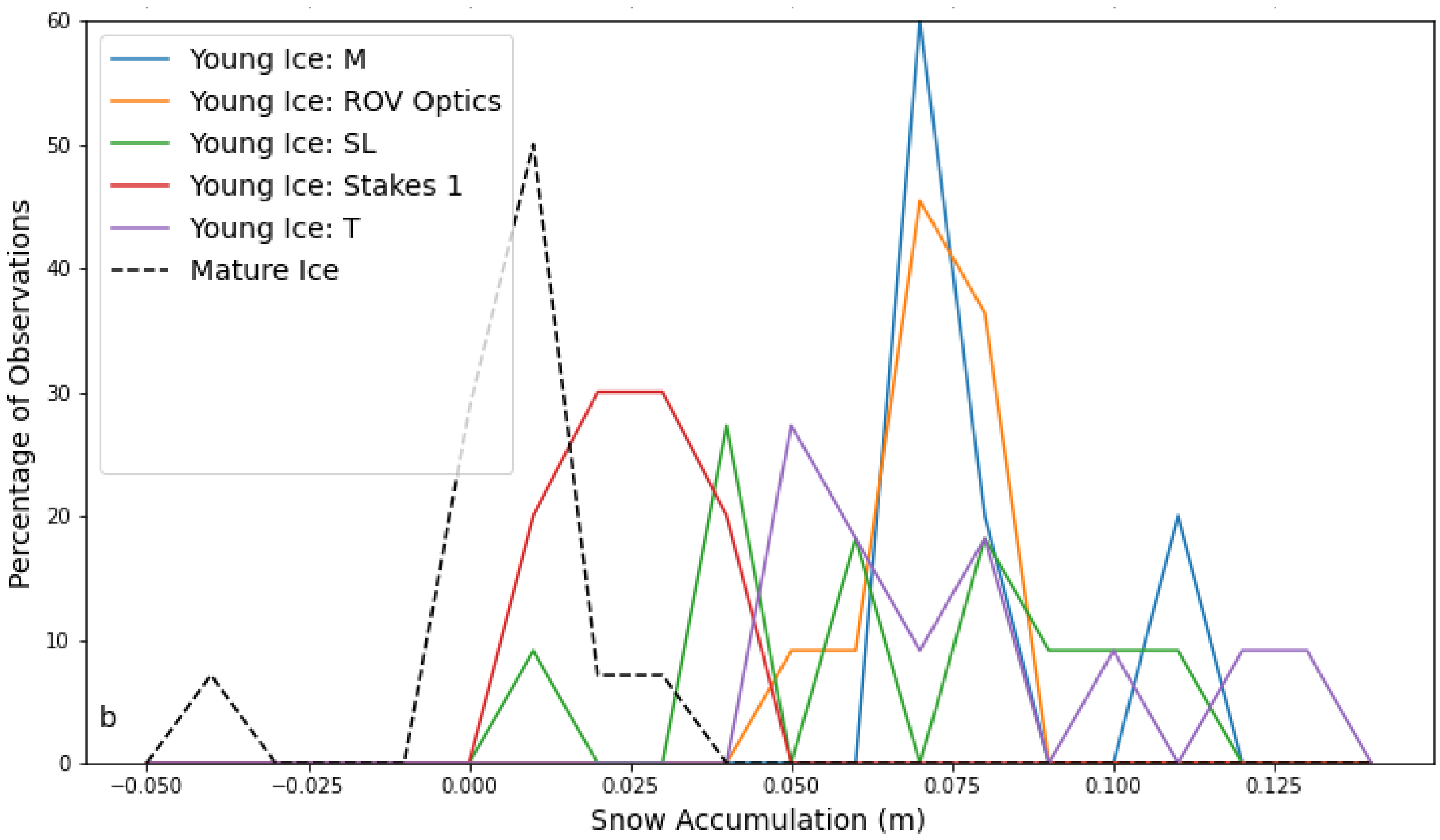
Observations of Preferential Accumulation



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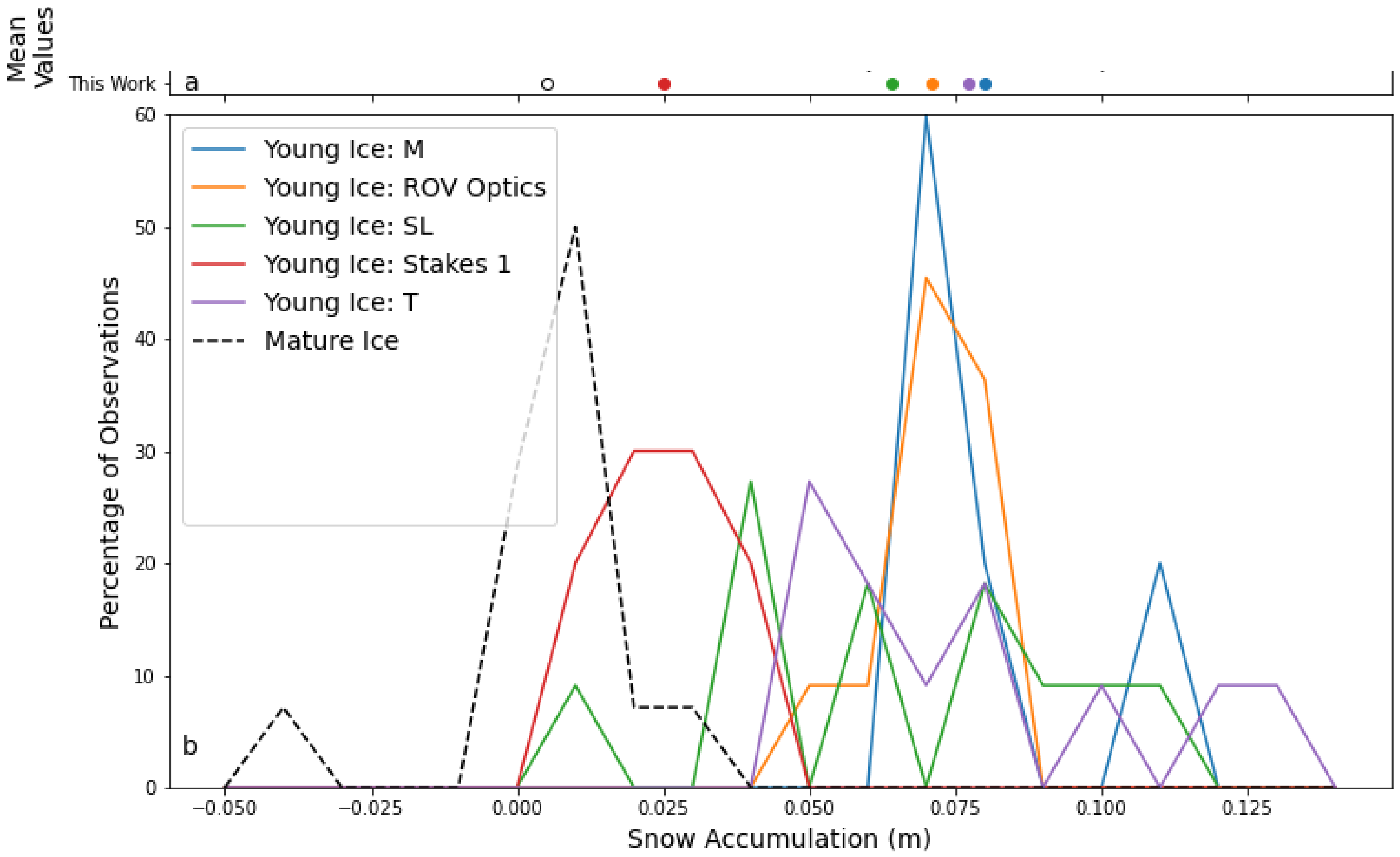

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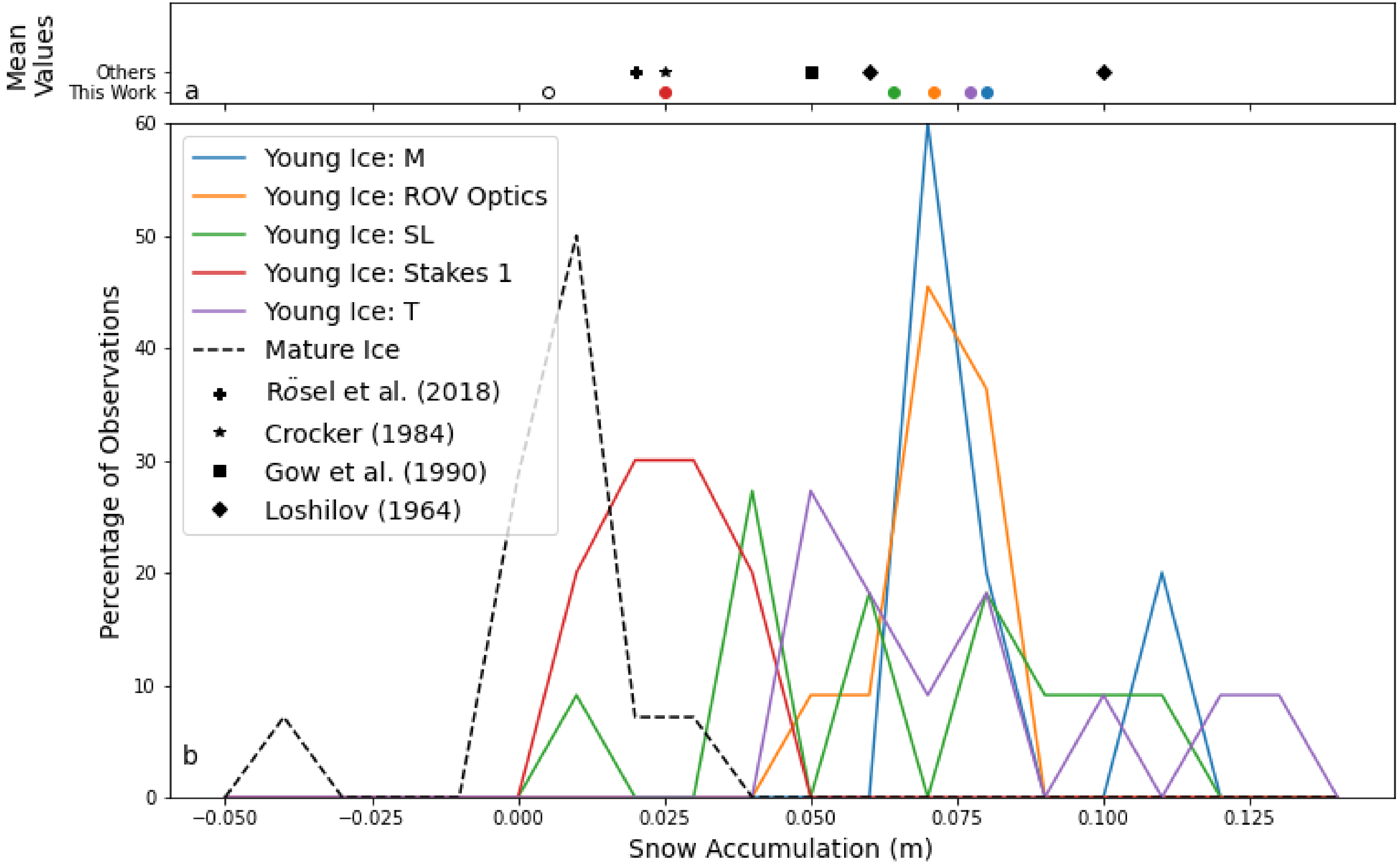
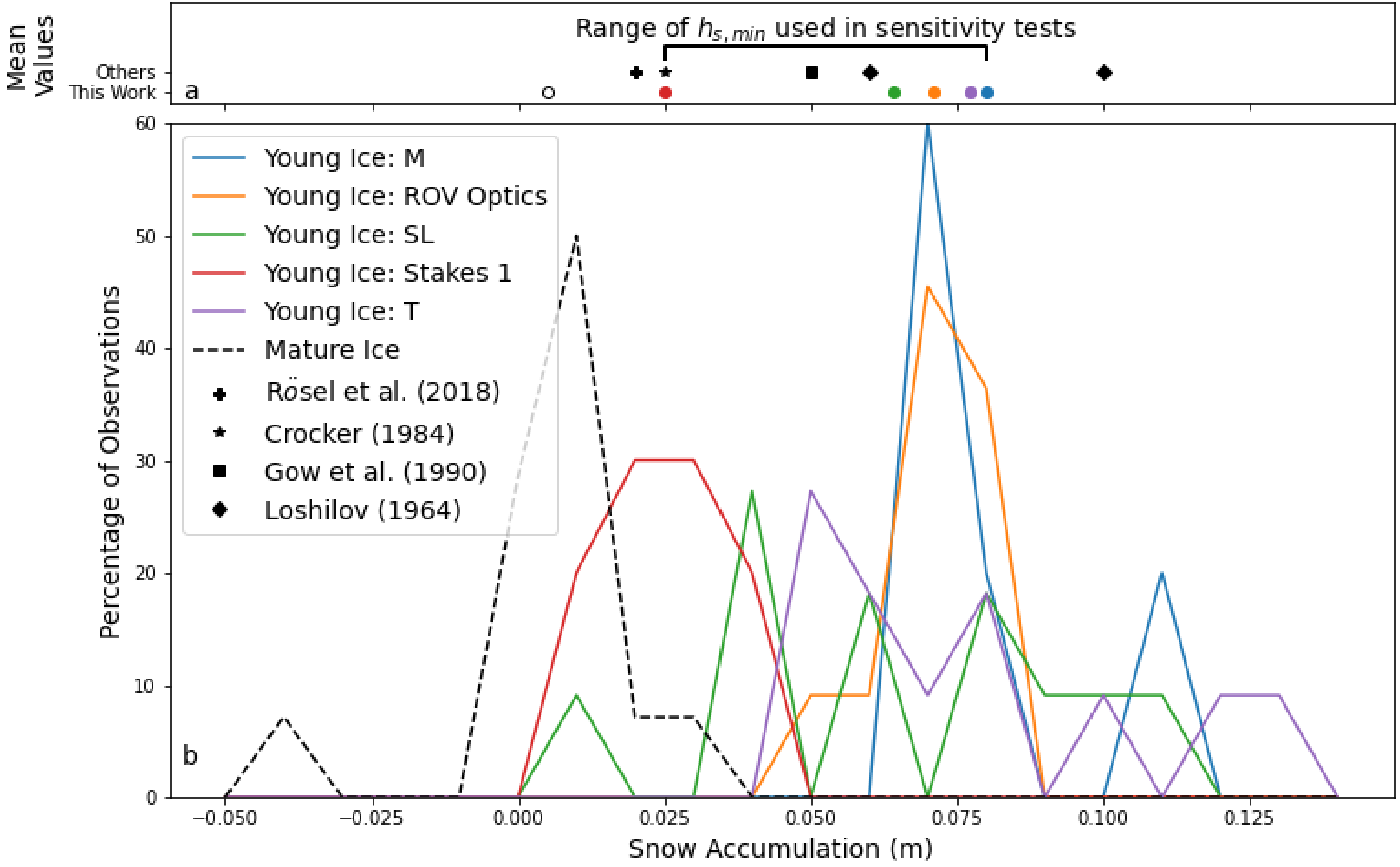


Observations of Preferential Accumulation



Mean Accumulation:
0.06 m

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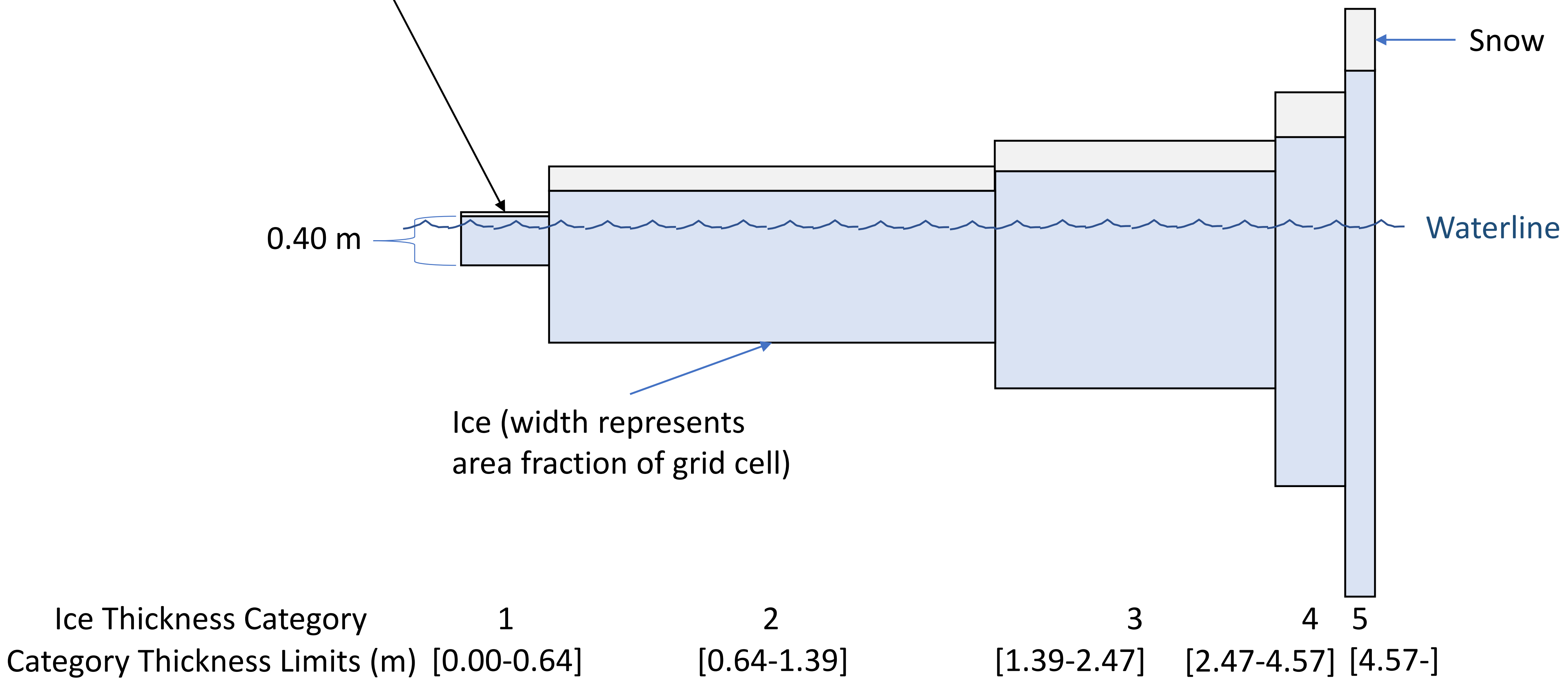
CESM2[4]/CICE[7] Representation of Ice Cover[1,8,14]

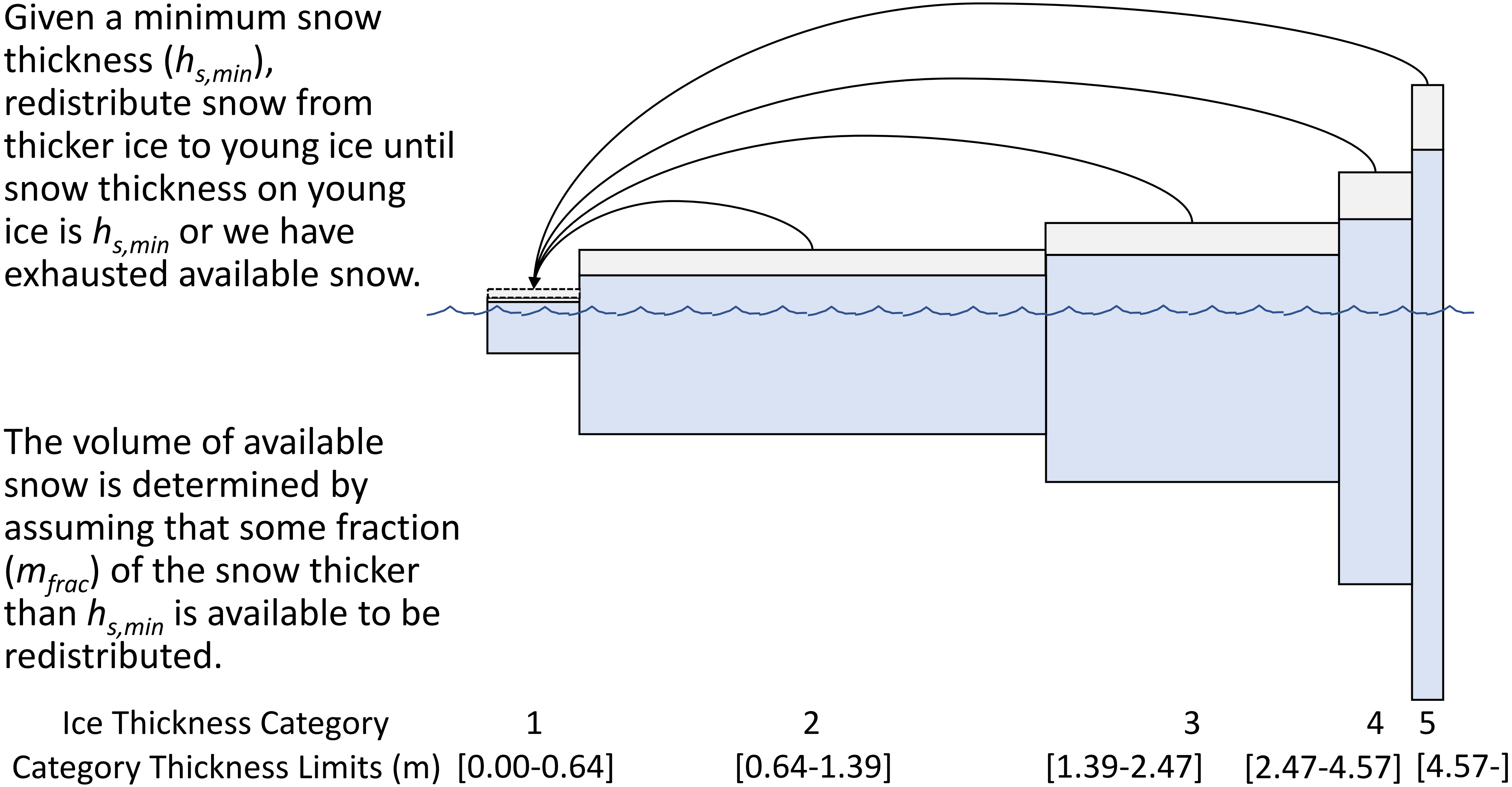
Snow is added uniformly in each precipitation event.
The youngest ice has experienced few or no precipitation events, thus has very thin snow.



Offline Snow Redistribution Scheme

Given a minimum snow thickness ($h_{s,min}$), redistribute snow from thicker ice to young ice until snow thickness on young ice is $h_{s,min}$ or we have exhausted available snow.

The volume of available snow is determined by assuming that some fraction (m_{frac}) of the snow thicker than $h_{s,min}$ is available to be redistributed.



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Zero-Layer Thermodynamics Heat Flux

The zero-layer thermodynamic model of snow and sea ice[12] computes the vertical heat flux (F_{cond}) through the snow and sea ice assuming that the system is at steady-state:

$$F_{cond}[c,j,i] = \frac{k_s(T_o - T_a[j,i])}{h_s[c,j,i] + h_i[c,j,i](k_s/k_i)}$$

$$F_{cond}[j,i] = \sum_{c=1}^{N_c} F_{cond}[c,j,i]a[c,j,i]$$

Where subscript indices *j* and *i* specify a particular model grid cell and *c* is the ice thickness category within that grid cell. T_a is the air-snow interface temperature. T_o is the ice-ocean interface temperature. h_s and h_i are snow and ice thicknesses. k_s = 0.3 $Wm^{-1}K^{-1}$ and k_i = 2.0 $Wm^{-1}K^{-1}$ are snow and ice thermal conductivities. *a* is the fractional area of the thickness category within the grid cell.

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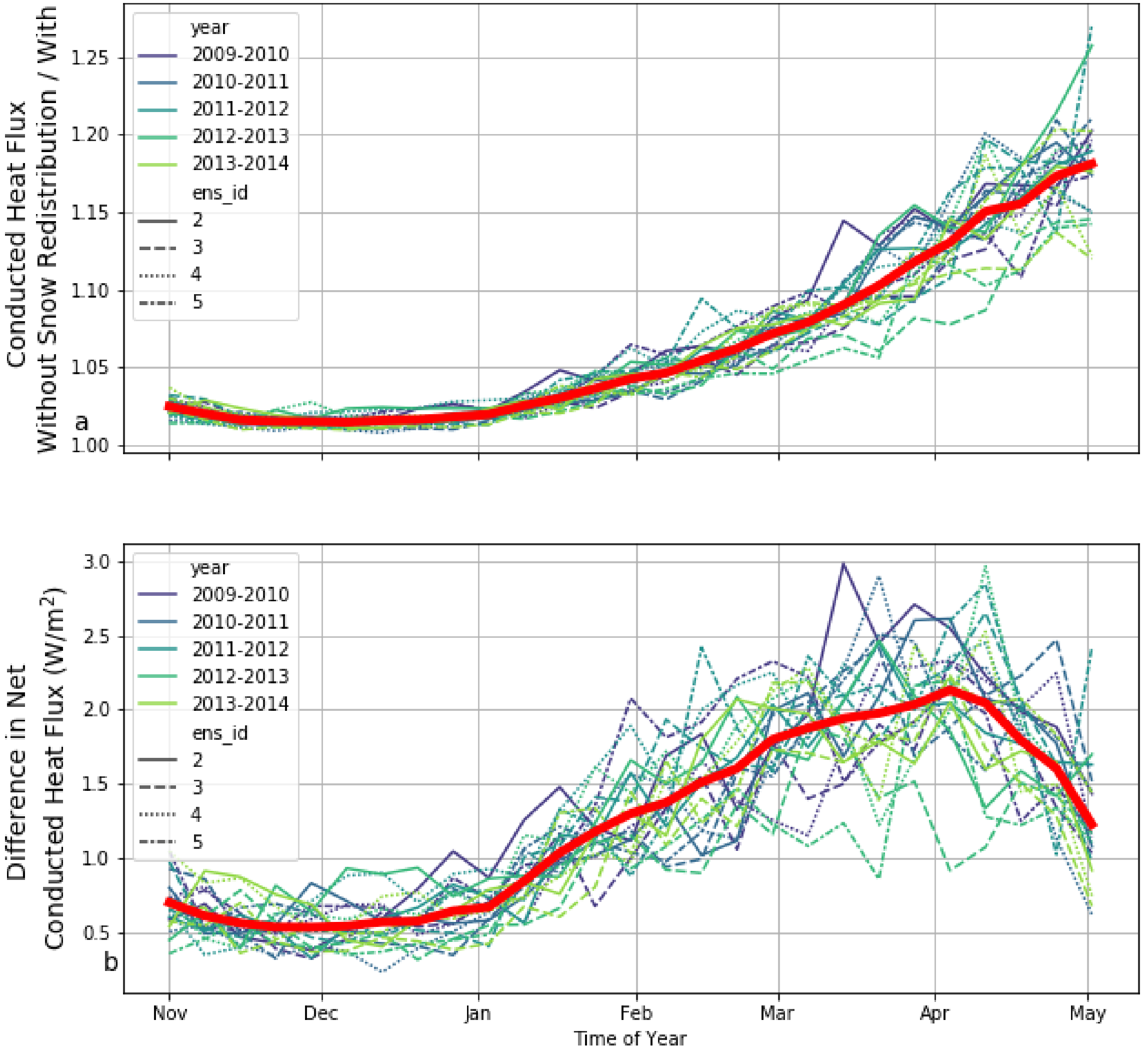
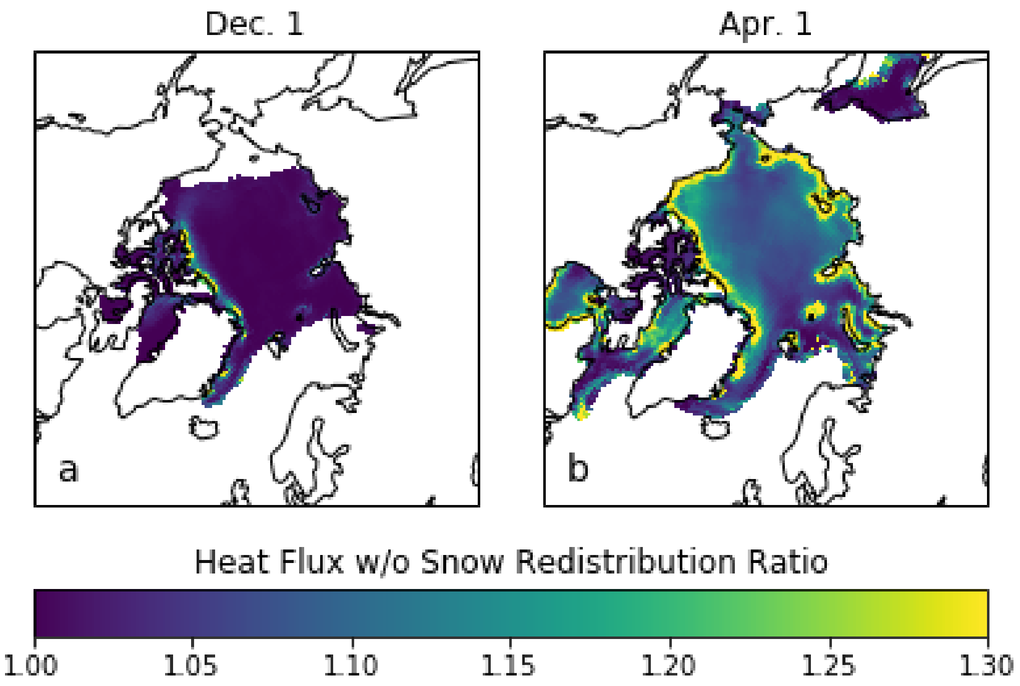
Modeled Impacts on Heat Flux



- Analyzed CESM2 output for the historical period from a four member ensemble in which albedo has been tuned to improve the mean sea ice state (Kay et al in review).
- Averaged across four ensemble members and five years to reduce internal variability.
- Arctic-averaged overestimation ratio ranges from 1.015 in December to 1.18 in May, with a mean of 1.06.

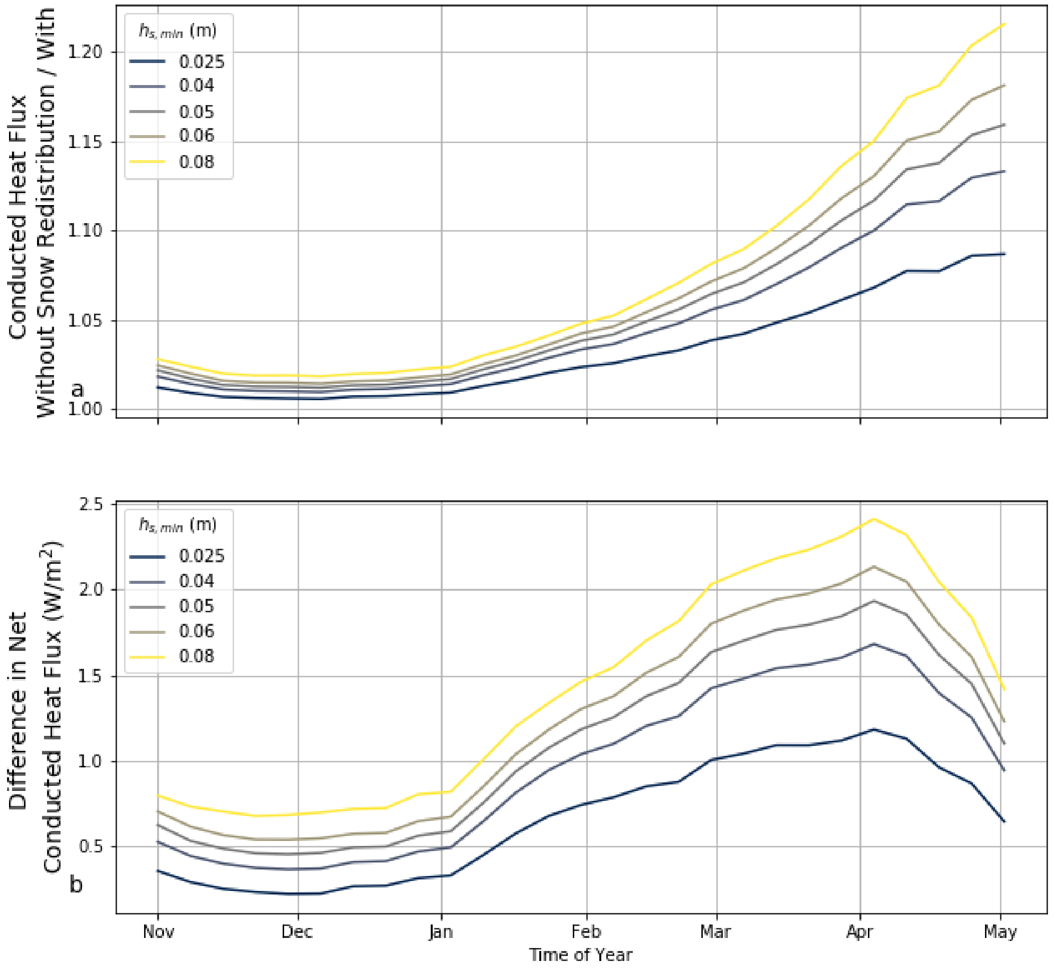
Modeled Impacts on Heat Flux



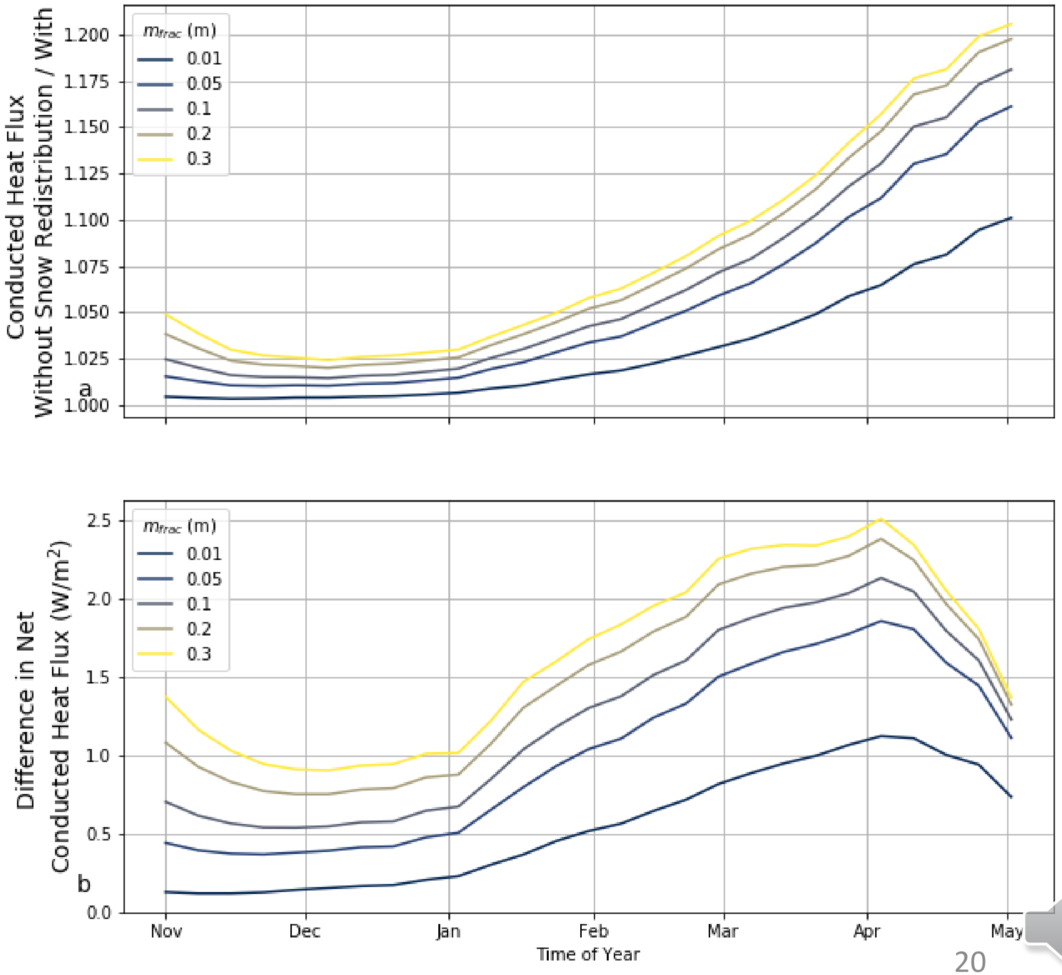
- Impacts are greatest in coastal regions where ice deformation creates lots of young ice.
- Early in the season, much of the ice is in the thinnest thickness category, and precipitation is sufficient to keep the snow thickness above $h_{s,min}$
- Later in the season, overestimation occurs throughout the Arctic basin.

Sensitivity Tests

Minimum Snow Thickness ($h_{s,min}$)



Mobile Fraction of Snow (m_{frac})



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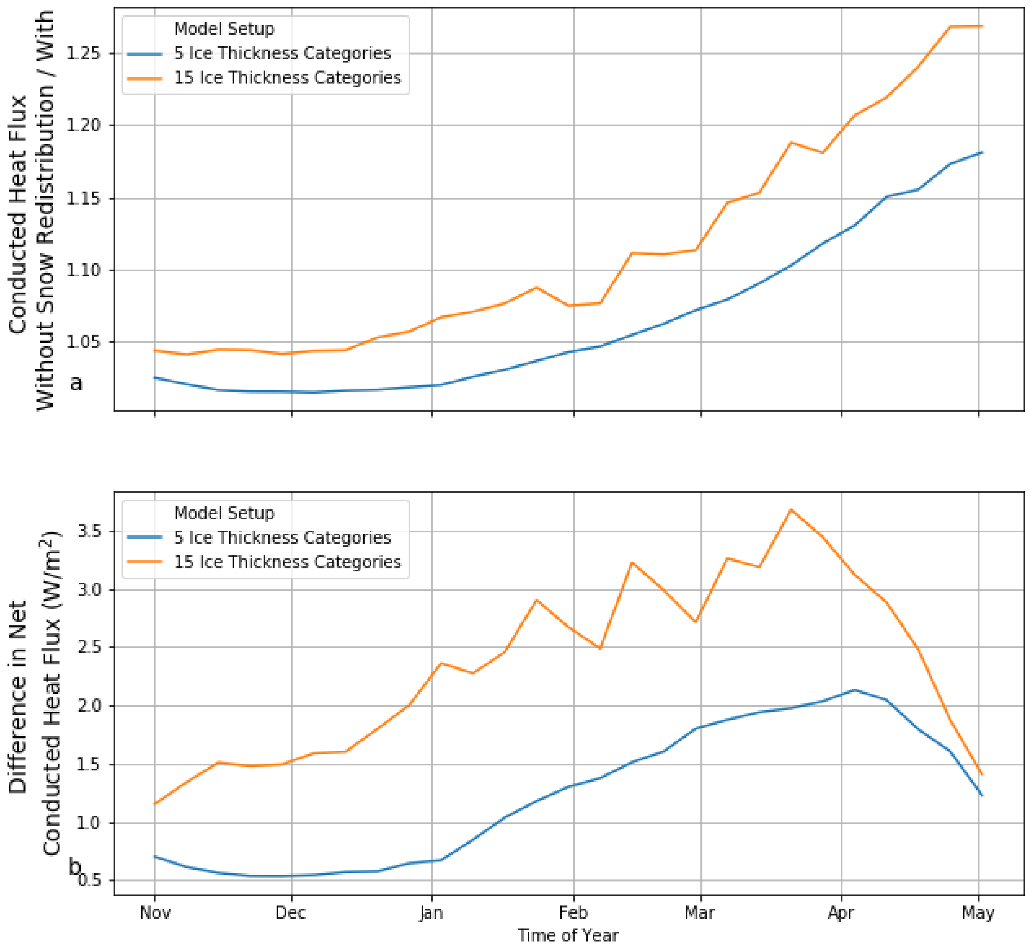
Does This Need to be Explicitly Represented?

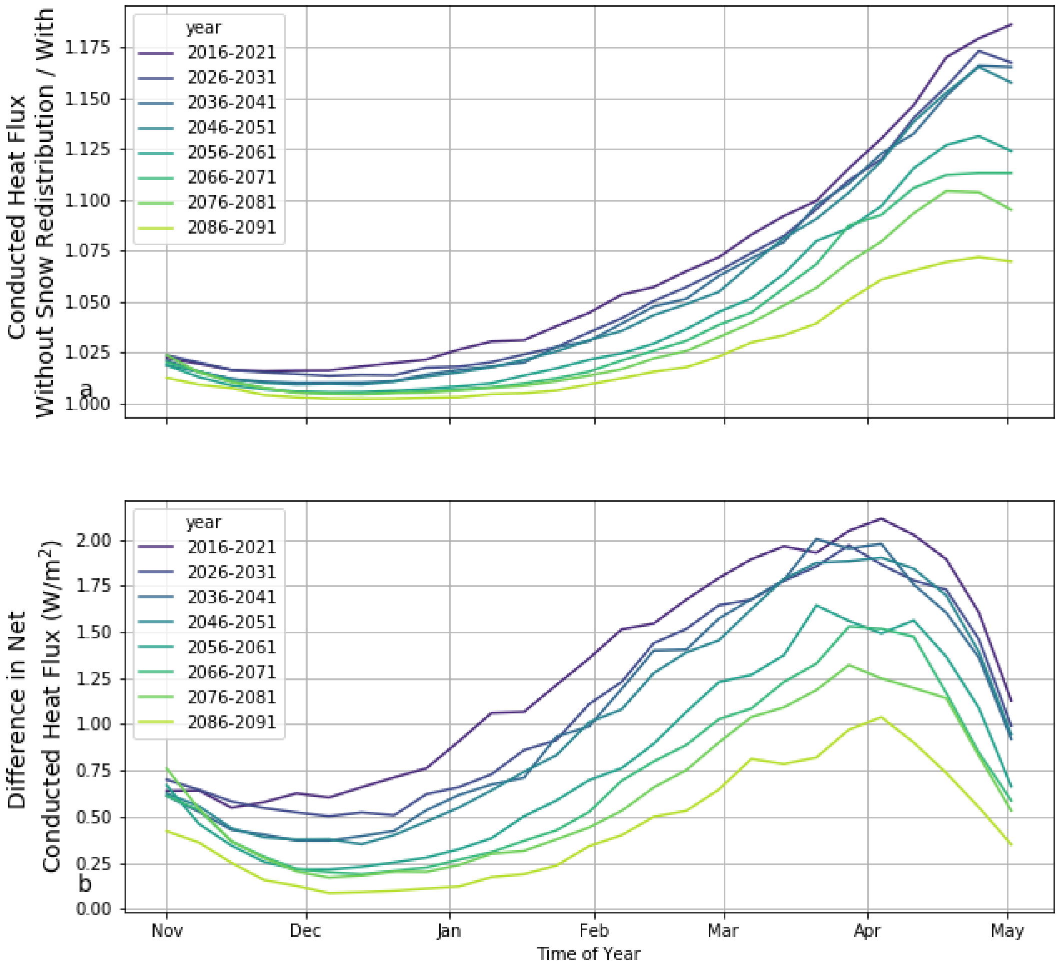
- For computation reasons, climate models cannot explicitly represent every sub grid-scale process. Instead, models often aggregate multiple processes into a single representation and tune parameter values. For example, models represent heat flux through snow on sea ice as purely vertical conduction with a single thermal conductivity (instead of explicitly representing heat transport due to air movement, lateral heat flow, etc).
- However, if the impacts of a process change in a different model setup or different climate state, then the process may need to be represented.

Impacts with More Ice Thickness Categories



- Repeated the analysis examining CESM2 output from simulations with 15 ice thickness categories
- With more categories, the snow thickness on the youngest ice is even thinner, because it's averaged over a small range of ice thicknesses.
- Thus snow redistribution onto young ice is even more important.

Impacts in Future Climate State



- Examined CESM2 21st century projections under the SSP370 scenario.
- Impacts of snow redistribution onto young ice decrease as the Arctic warms and snow and sea ice decline.
- Thus if we were to tune the model for this process under current conditions, that may not be accurate in the future climate state.

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Conclusion and Next Steps

- Field observations indicate that young Arctic sea ice preferentially accumulates between 0.025 and 0.08 m of snow from wind-driven snow redistribution.
- Offline analysis of CESM2 output suggests that neglecting this snow redistribution could lead to current climate models overestimating wintertime heat flux by 3-8% on average in the Arctic in the winter, with larger impacts in certain regions and later in the season.

- Next steps: This analysis was conducted offline on climate model outputs. Snow and heat flux impact several feedbacks in the Arctic system (that were not represented in this offline approach). Our next step is to study the sensitivity of the sea ice state to this snow redistribution onto young ice process in a fully-coupled climate model.

Contact: David.W.Clemens-Sewall.Th@dartmouth.edu

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