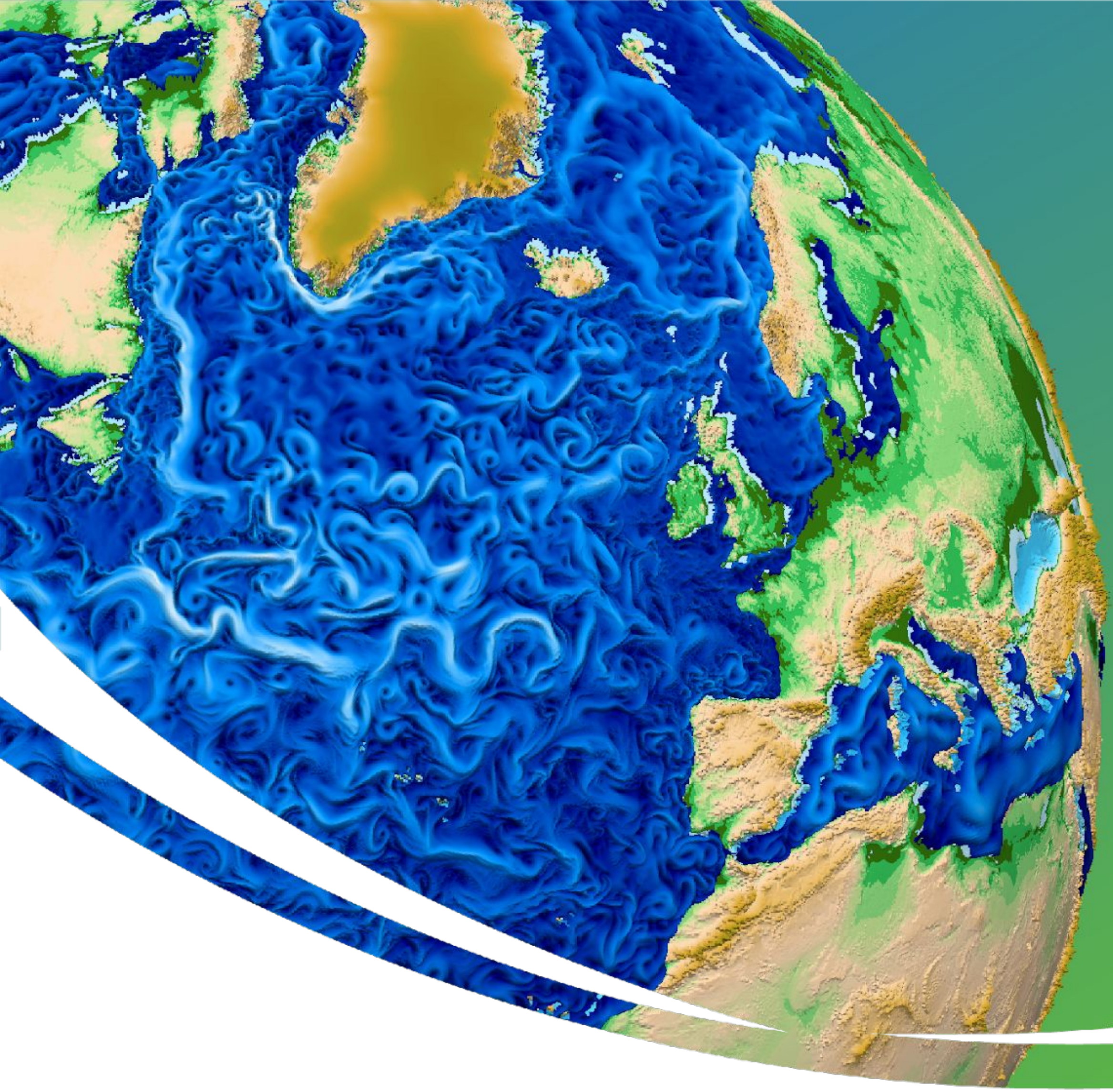

Advanced Snow Physics

Snow redistribution and metamorphism over sea ice

With Nicole Jeffery, LANL

There is MUCH more work to be done before this study is publishable

- ❑ More detailed simulation analysis including additional fields (temperature, currents, wind, etc)
- ❑ Placing these runs in the context of internal variability
- ❑ Comparison with observations
- ❑ Parameter sensitivities

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E3SM Energy Exascale Earth System Model

E3SM
Energy Exascale
Earth System Model

E3SM simulations to explore impacts and interactions of advances snow physics in Icepack

Simulation	Snow Redistribution by Wind “R”	Snow Grain Metamorphism “G”	Configurations
	• Compaction by wind • Loss to leads • Interaction with ridges • Based on Lecomte et al. 2015 • Compaction and ridge interactions only affect radiation	• Grain size evolves as function of snow temperature, gradient, density • Wet and dry processes • Based on NCAR/TN-478+STR 2019 • Use snow grain radius for radiation until ponds saturate snow	atm/lnd: ne30pg2 ocn/ice: IcoswISC30E3r5
G+R	✓	✓	Fully coupled (B) 1850-2014 Ice + slab ocean (QC) 5 years Column (Icepack) 10 years
Redist	✓		
Grain		✓	
Off			

G+R is an E3SM v3 historical run.
The other runs use the same restart file.
QC applies the same atmospheric forcing for all simulations.

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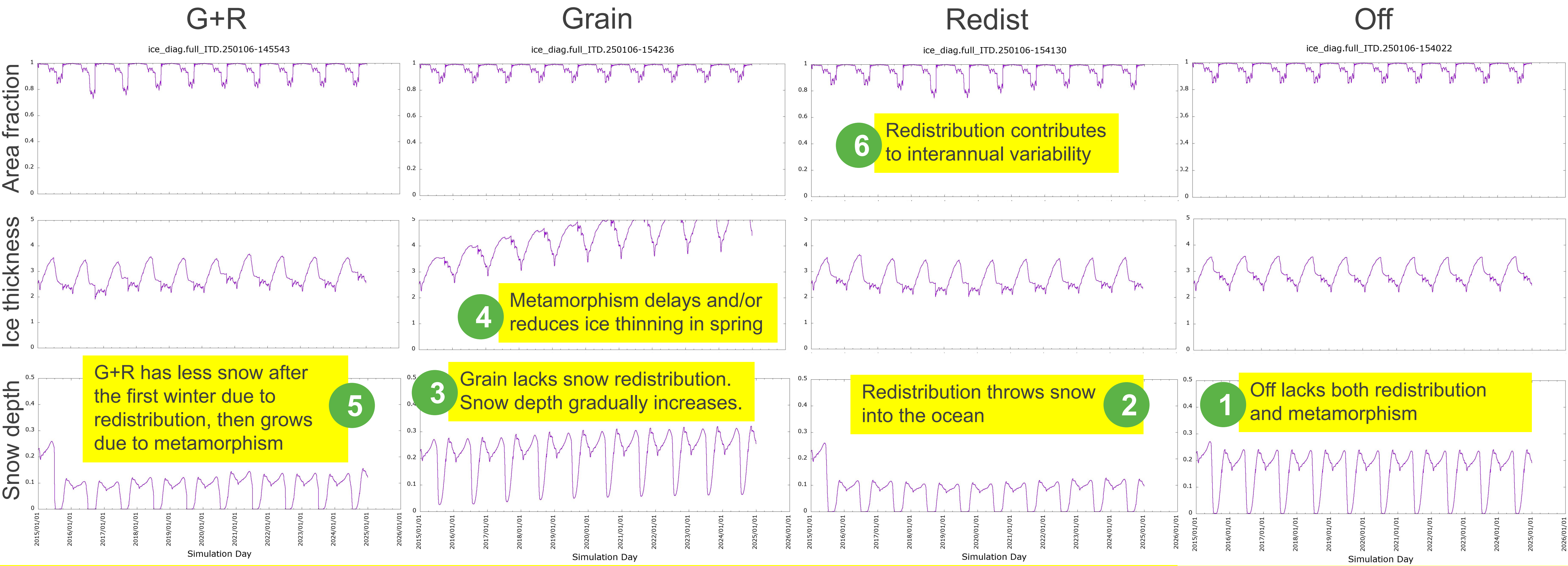
Physical principles

- Snow is insulating, reducing ice growth and melt
- Snow redistribution reduces snow on sea ice by throwing it into the ocean
  - enhances ice growth and melt
  - reduces albedo
- Snow albedo effects will be small in winter / low light periods
- Snow-ice formation converts snow to ice
- Ridging throws snow into the ocean
- Ridging enhances thermodynamic growth and ice thickening in freezing conditions

E3SM Energy Exascale Earth System Model

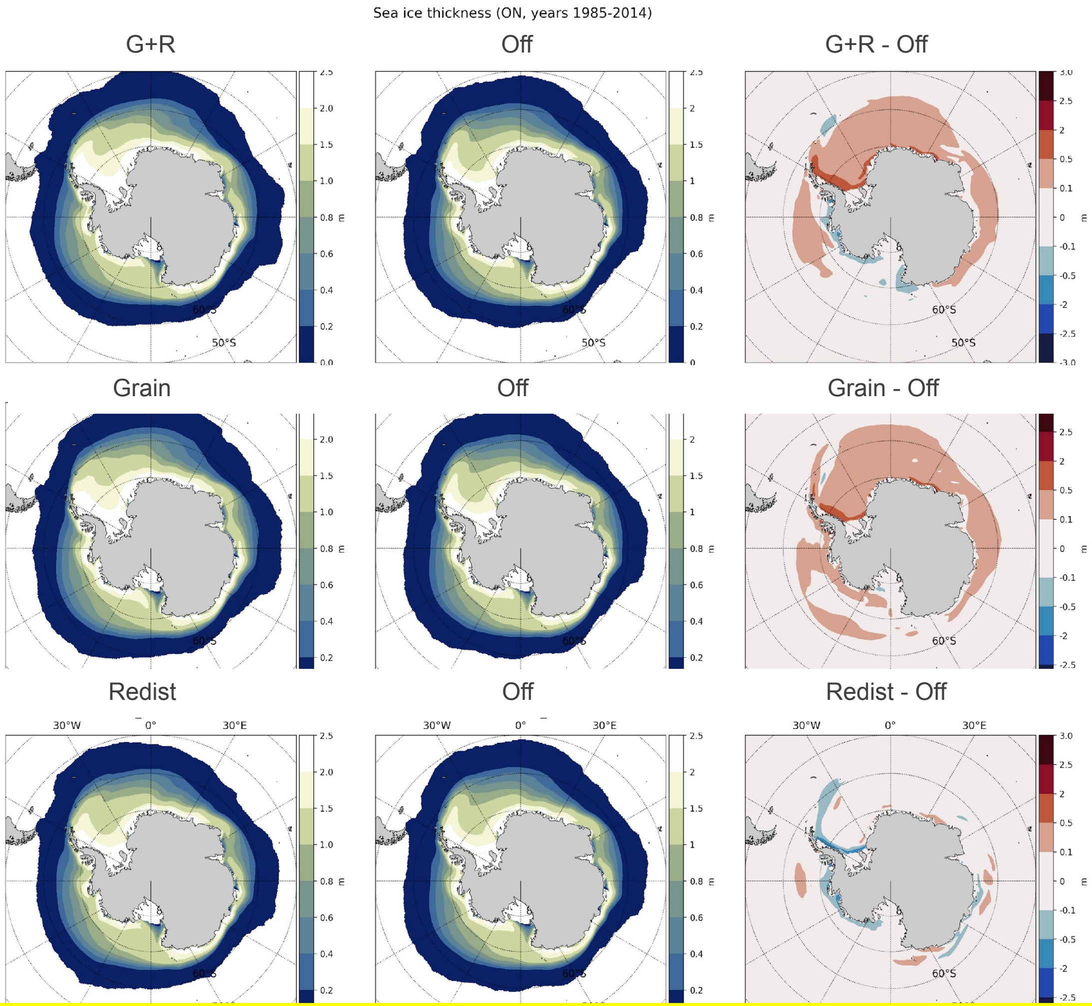
Icepack 10-year column simulations

Configured as in MPAS-seaice, with snicar and thermo ocean mixed layer on



Redistribution sets the baseline snow amount and offsets Metamorphism's tendency to reduce ice thinning.

SH 1985-2014: Ice thickness



SON

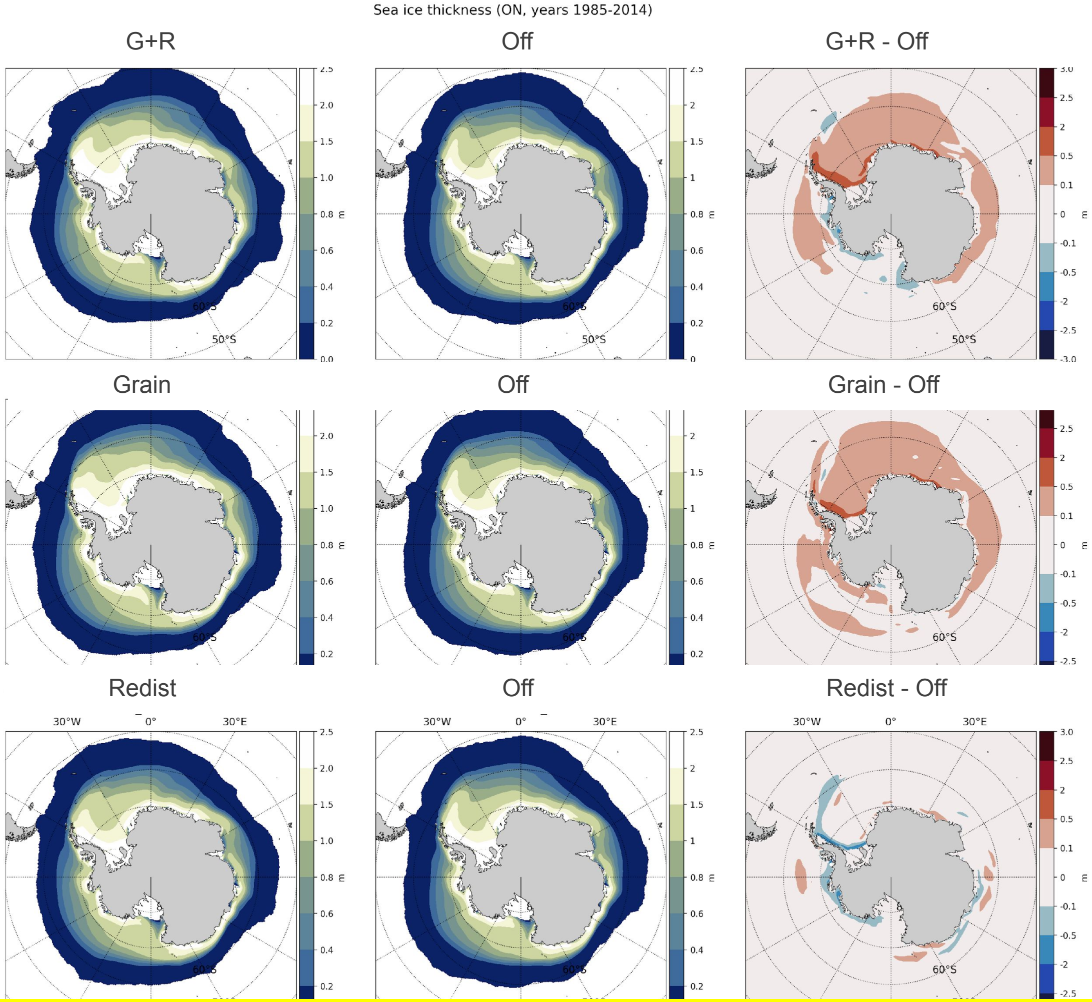
Metamorphism
+
Redistribution

Without redistribution
Metamorphism tends to *thicken* the ice

Without metamorphism
Redistribution tends to *thin* the ice

Metamorphism drives thickness changes in the Weddell Sea, and Redistribution drives them on the other side.

SH 1985-2014: Ice thickness



SON

Metamorphism
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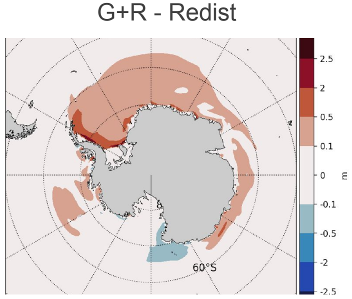
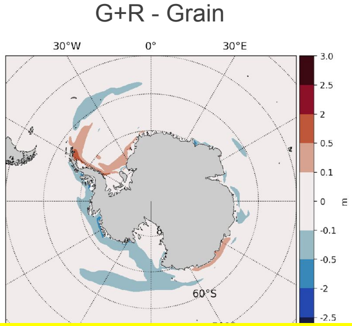
Redistribution

Without redistribution
Metamorphism
tends to *thicken*
the ice

Without metamorphism
Redistribution
tends to *thin* the
ice



In the presence of Redistribution, the ice may thicken even more



In the presence of Metamorphism, the ice may thin even more

Their relative behavior is different when metamorphism and redistribution interact.

Snow processes

Process	Effect on snow and ice	Relative effect on redistribution physics *	Relative effect on metamorphism physics	
Snow-ice formation	Thins snow, thickens ice	Enhances	Counters	Ridging is more difficult but ridges are larger
Snow loss during ridging	Thins snow	Enhances	Counters	
Albedo changes due to redistribution on ridges *	Reduces albedo on level ice (especially ponds), increases albedo on deformed ice	Depends on level and ridged ice fractions	Depends on level and ridged ice fractions	Less important than snow loss to leads

* Most of my analysis assumes that the primary impact of snow redistribution is loss to the ocean through leads.

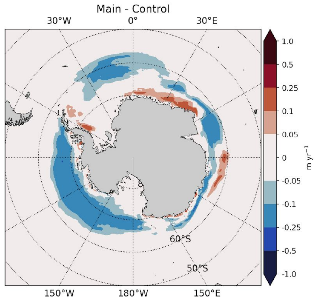
- Snow-ice and snow loss enhance the impacts of wind redistribution over level ice, countering growth due to metamorphism.
- Ridging is also an important process with respect to snow.

SH 1985-2014: Interactions between Metamorphism and Redistribution

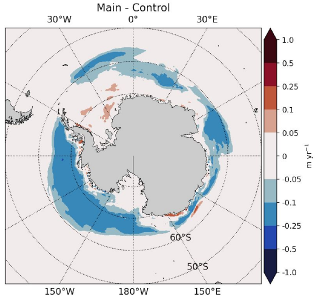
ANN

Snow-ice formation rate

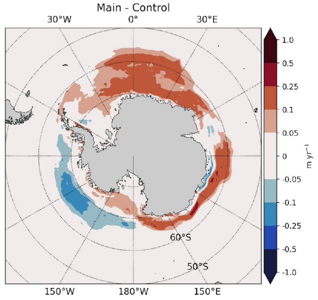
Without metamorphism
Redist – Off



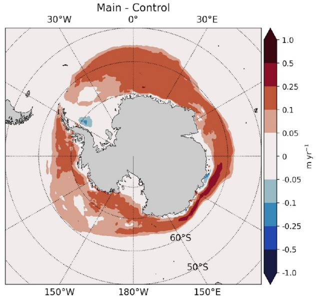
With metamorphism
G+R – Grain



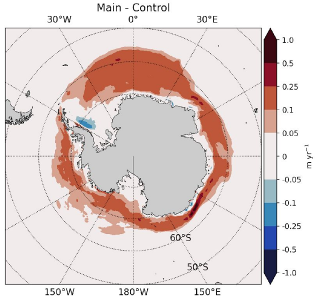
G+R - Off



Without redistribution
Grain – Off



With redistribution
G+R – Redist



1 Snow-ice enhances spatial differences.

2 Snow-ice counters spatial differences.

E3SM Energy Exascale Earth System Model

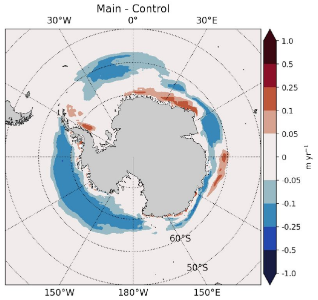
B

SH 1985-2014: Interactions between Metamorphism and Redistribution

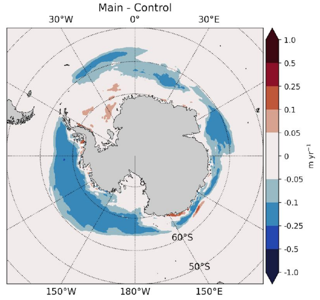
ANN

Snow-ice formation rate

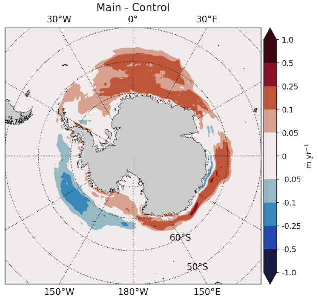
Without metamorphism
Redist – Off



With metamorphism
G+R – Grain

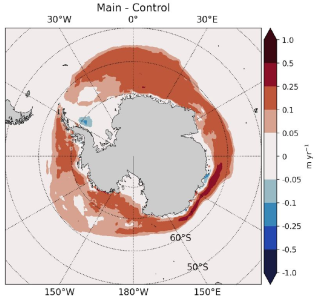


G+R - Off

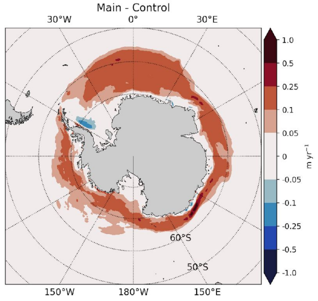


1 Snow-ice enhances spatial differences.

Without redistribution
Grain – Off



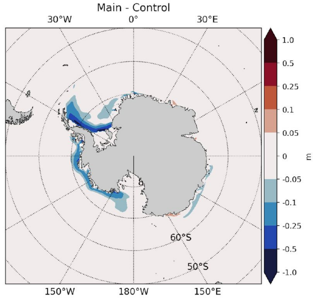
With redistribution
G+R – Redist



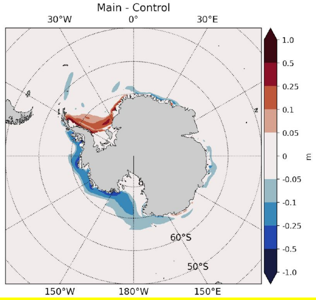
2 Snow-ice counters spatial differences.

Ridged ice thickness

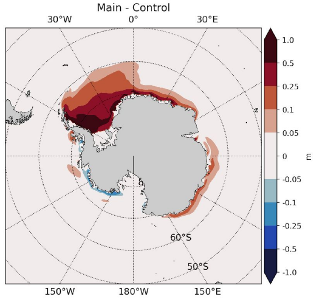
Without metamorphism
Redist – Off



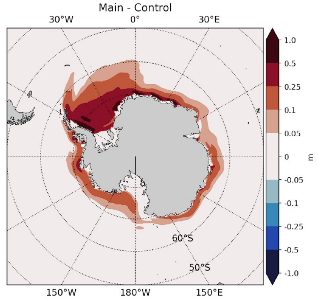
With metamorphism
G+R – Grain



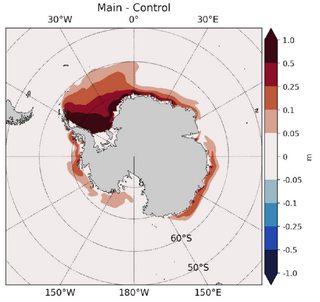
G+R - Off



Without redistribution
Grain – Off



With redistribution
G+R – Redist



3 Redistribution tends to reduce ridged ice

Metamorphism dominates in the Weddell Sea but enhances thinning elsewhere.
Is ridging enhancing the contrast? ? 5

4 Metamorphosis increases ridged ice everywhere

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SH Year 5: Interactions between Metamorphism and Redistribution

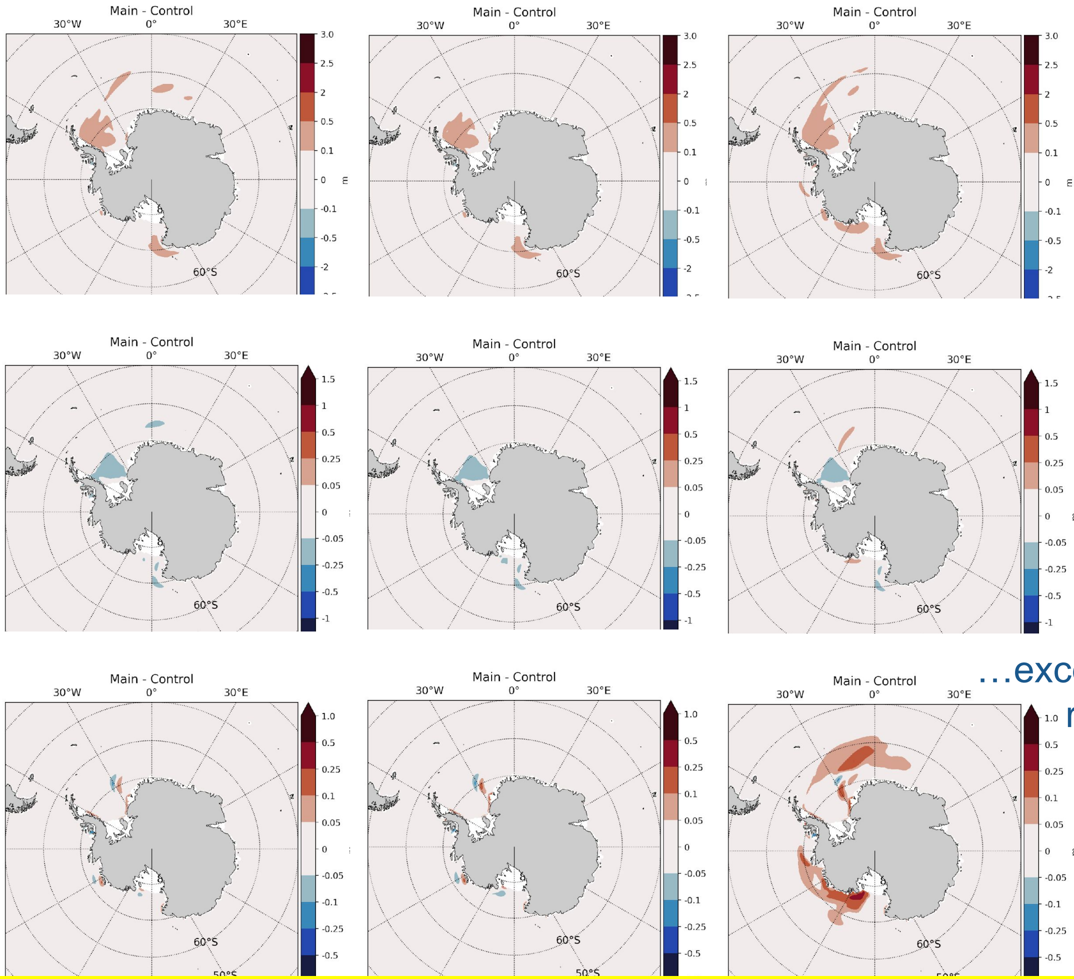
Redistribution dominates SON differences (and JJA)

Redist – Off | G+R – Grain | G+R - Off

Ice thickness

Snow depth

Ridged ice thickness



…except for ridging

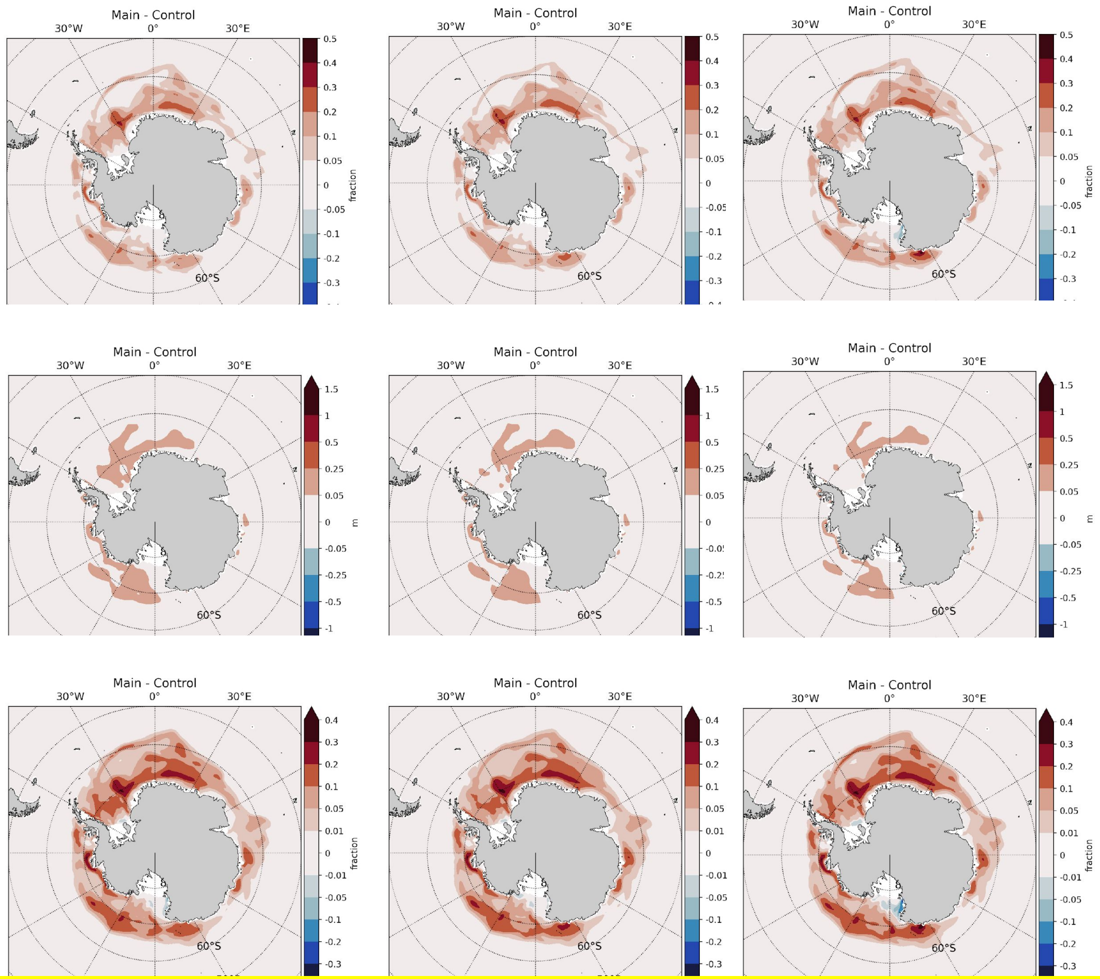
Metamorphosis dominates DJF differences (and MAM)

Grain – Off | G+R – Redist | G+R - Off

ice concentration

Snow depth

Albedo



Relative importance of R and especially G varies seasonally. Except ridging, differences are similar so interactions are small in QC.

Antarctic Coastal Current

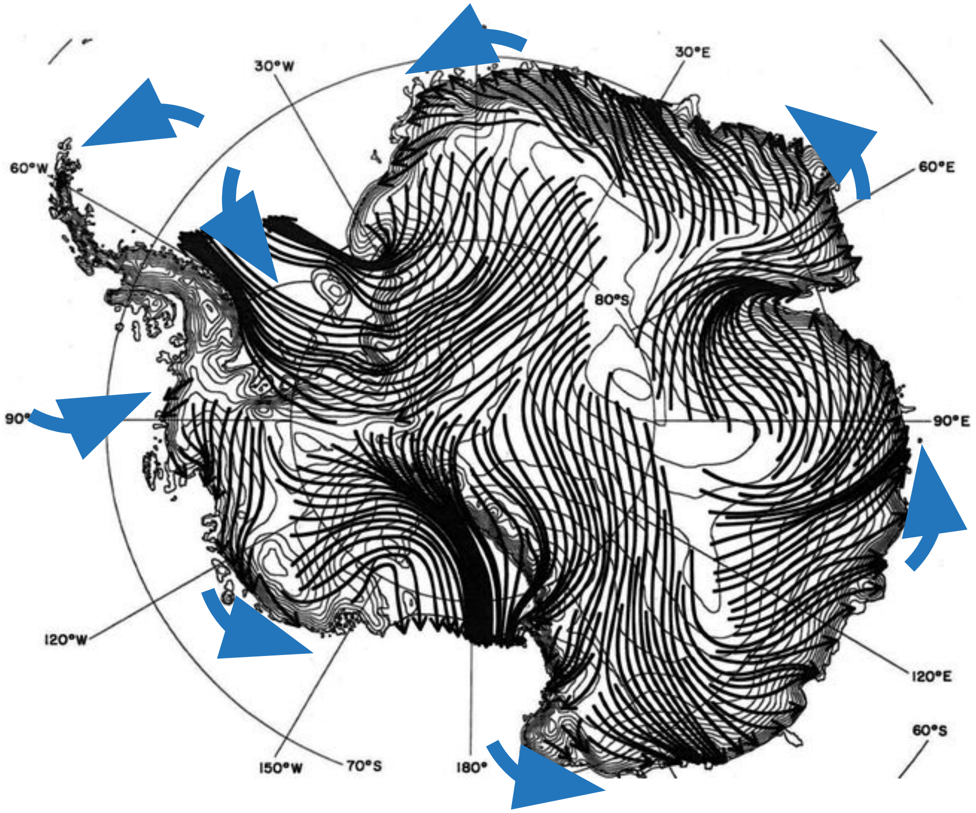
Coastal processes depend on balance of wind and Coriolis force:

- Katabatic winds push ice away from the coast (divergence).
- Coriolis turns ice in the counter current toward the coast (convergence), increasing ridging.

Both processes increase ice production.

Snow processes modify their effects. E.g.,

- Snow-ice formation
- Snow loss during ridging
- Albedo changes due to redistribution on ridges
- Albedo changes due to melt ponds on non-ridged ice (snow melt; ponds hide under snow)



Katabatic wind figure:

Fig. 3. Mean streamlines at σ = 0.9983 over Antarctica from the June 2003–May 2004 AMPS archive.

From: Parish TR, Bromwich DH. Reexamination of the Near-Surface Airflow over the Antarctic Continent and Implications on Atmospheric Circulations at High Southern Latitudes. *Mon. Wea. Rev.. 2007;135(5):1961-1973. doi:10.1175/MWR3374.1*

SH coastal dynamics seem to be the most interesting physical aspect for the entire study.

- Strong spatial differences
- Nonlinear
- Coupled
- Counterintuitive

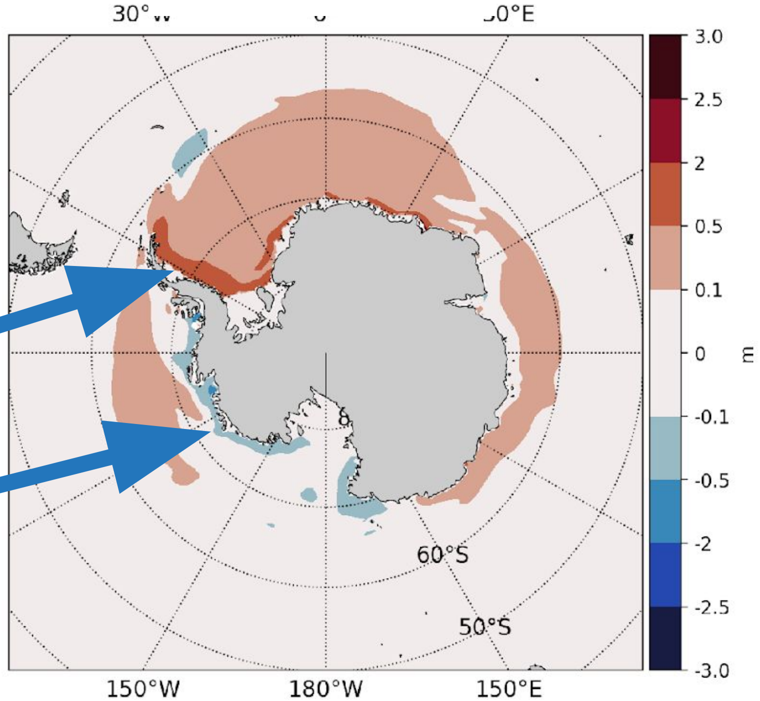
Metamorphism tends to *thicken* the ice.

Redistribution tends to *thin* the ice.

Driven by Metamorphism
Enhanced by Redistribution

Driven by Redistribution
Enhanced by Metamorphism

SON Ice thickness
G+R – Off



There is MUCH more work to be done before this study is publishable

- ❑ More detailed simulation analysis including additional fields (temperature, currents, wind, etc)
- ❑ Placing these runs in the context of internal variability
- ❑ Comparison with observations
- ❑ Parameter sensitivities

Hypotheses:

- Thermodynamic feedbacks associated with ice production in coastal areas set the stage, and ridging amplifies the differences near the coasts over time.
- The balance of katabatic wind (and large-scale pressure systems) versus Coriolis force in the coastal current determines the degree to which sea ice diverges from the coast and associated ridging / ice production.

e3sm.org

Configuration of E3SM v3 LR historical ensemble

casename = v3.LR.historical_0051 and on
compset = WCYCL20TR, extended beyond 2014 with SSP245
resolution = ne30pg2_r05_IcoswISC30E3r5

- ne30pg2: atmosphere (ne30 dynamics grid, pg2 physics grid)
- r05: land and river on ½ deg lat/lon grid (commonly referred to as "tri-grid")
- IcoswISC30E3r5: ocean and sea-ice on **Icos**ahedral **30 km** mesh with ice shelves cavities (**wISC**), E3SMv3 (**E3**) revision **r5**.

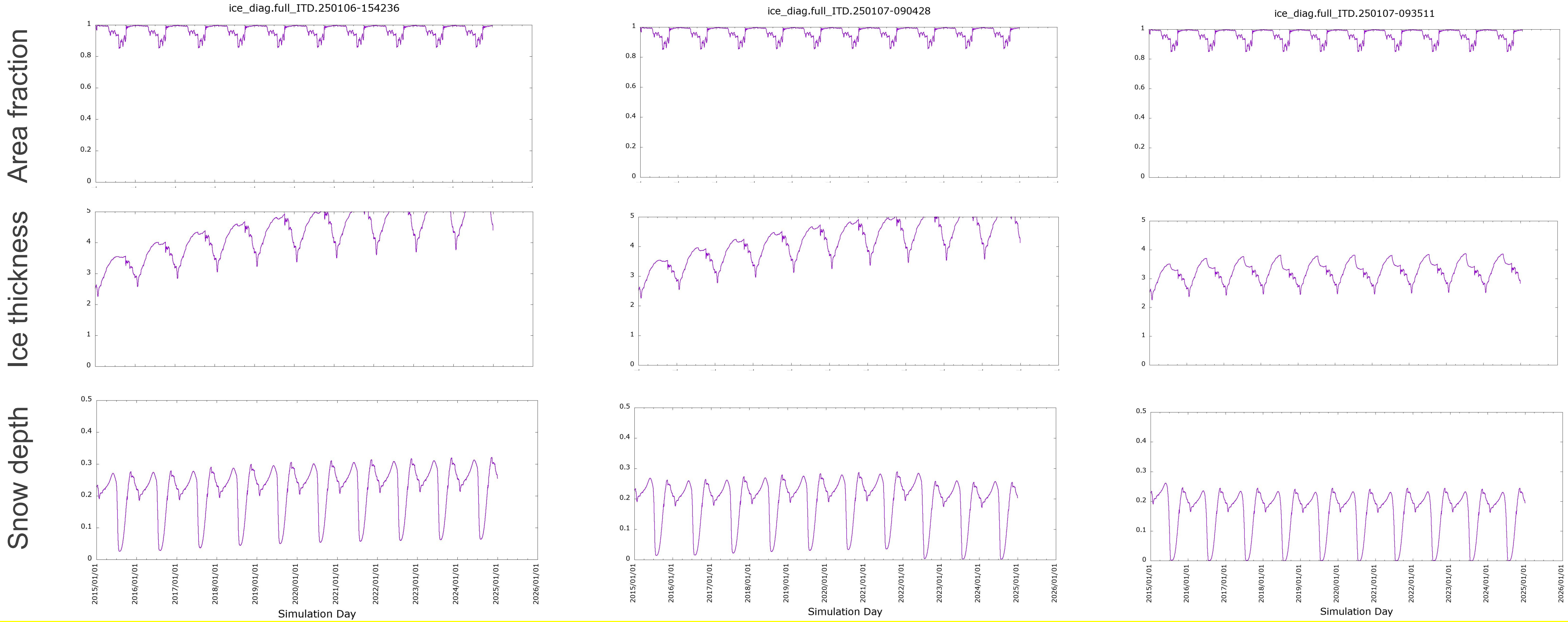
model_start_type = hybrid from v3.LR.piControl starting **0051-01-01, every 10 years through at least 0331-01-01**
start_date = 1850-01-01

special note: replace default landuse.timeseries with landuse.timeseries_0.5x0.5_hist_simyr1850-2015_c240308.nc (created after 3.0.0 tag)

Icepack sensitivity to snowfall radius

Configured as in MPAS-seaice, with snicar and thermo ocean mixed layer on

Grain, rsnw_fall = 54.526 µm | Grain, rsnw_fall = 100.0 µm | Grain, rsnw_fall = 300.0 µm

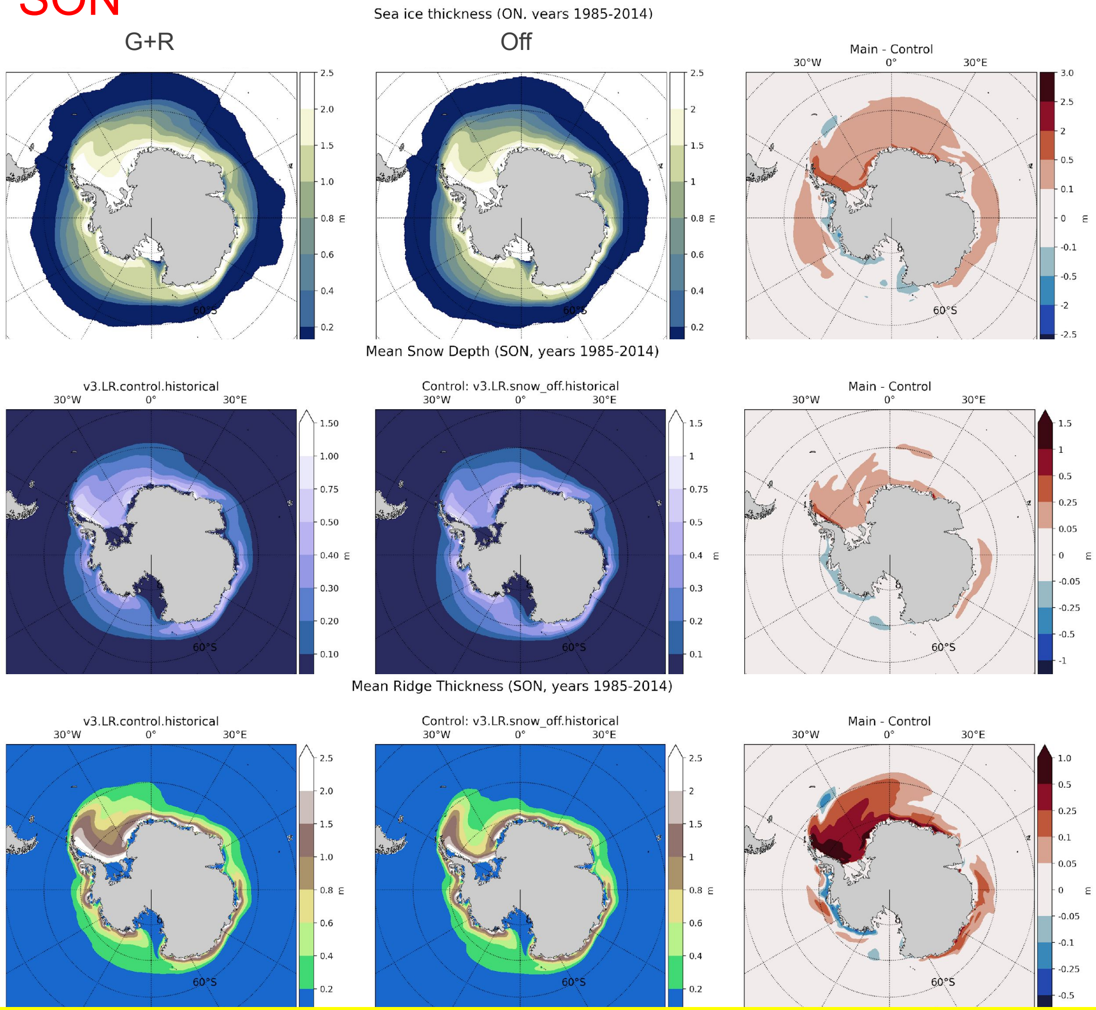


rsnw_tmax (maximum dry snow radius) didn't make much difference.

Radius of freshly fallen snow controls ice thickness.
Metamorphosis leads to shorter melt seasons and colder winter temperatures.

SH 1985-2014: G+R > Off except near some coasts

SON



Thicker ice except AB/Ross Seas

More snow in winter except AB/Ross Seas

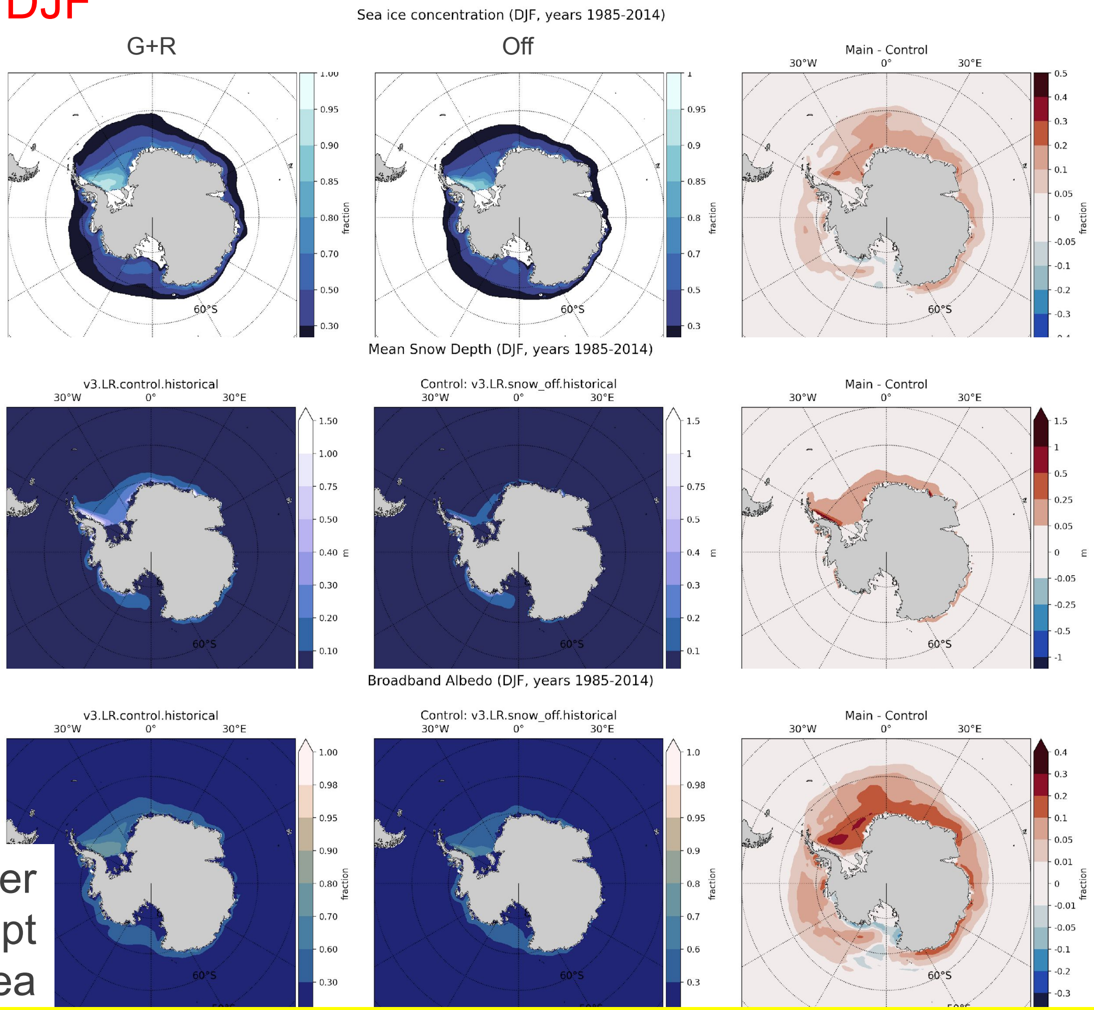
More ridged ice except on AB coast

DJF

Higher concentration

More snow

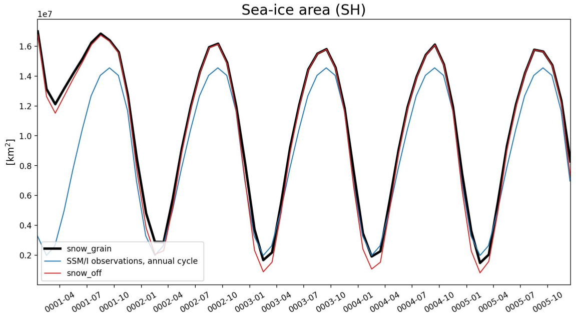
Brighter pack except in Ross Sea

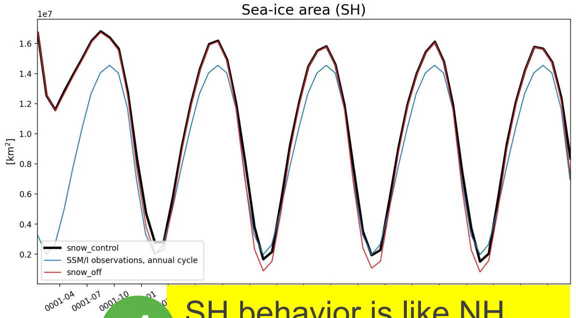


B simulations show a distinct pattern of differences in the Weddell and AB/Ross Seas.

SH Grain-G+R Grain-Off G+R-Off Redist-Off

Ice Area

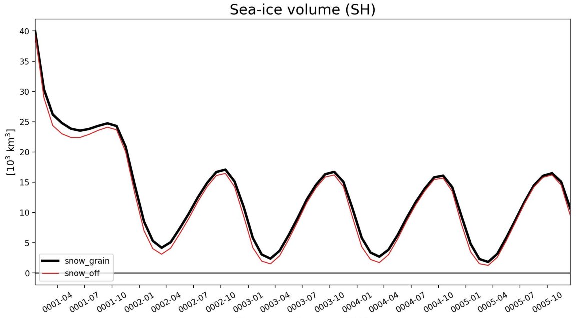




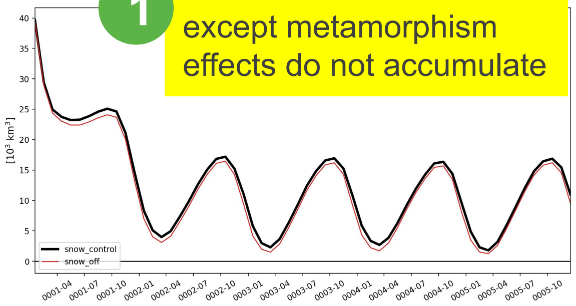
Ice Volume

Grain lacks redistribution, so has more insulating snow in winter

Winter Grain < G+R



1 SH behavior is like NH except metamorphism effects do not accumulate

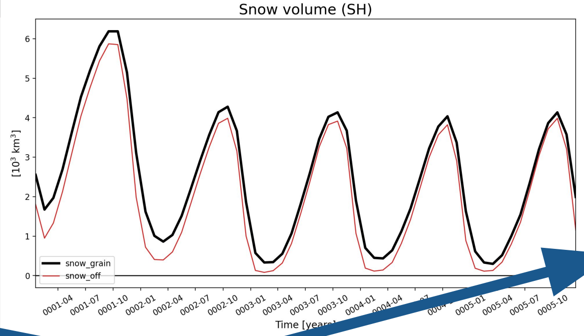


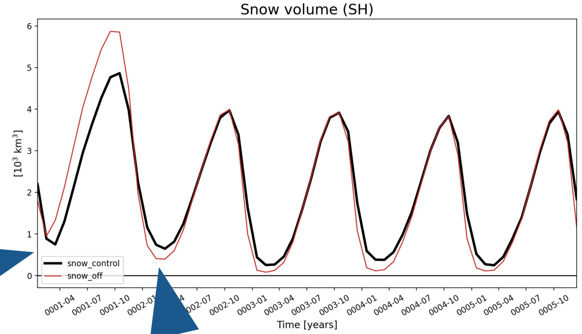
Off lacks redistribution, so has more insulating snow in winter

Winter Redist > Off

2 Redistribution differences are magnified in winter

Snow Volume





G+R has less snow initially

Metamorphism quickly becomes more important than redistribution in the summer

QC Experiment
QC G+R / Off
Observations

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