CESM LIWG winter meeting

Geothermal heat flow basal boundary condition during Greenland ice sheet spin up

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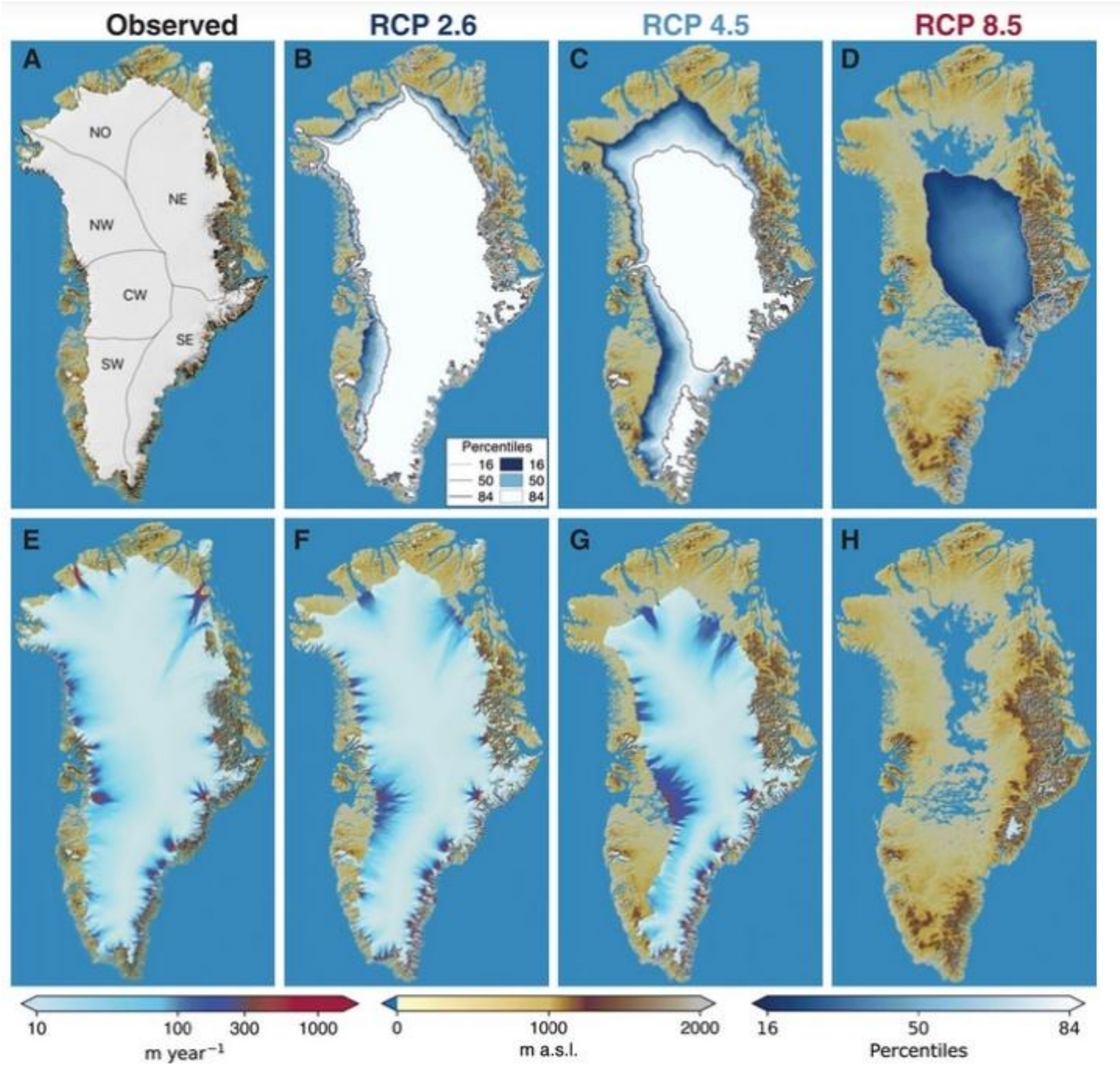
NCAR UCAR National Center for Atmospheric Research
NASA

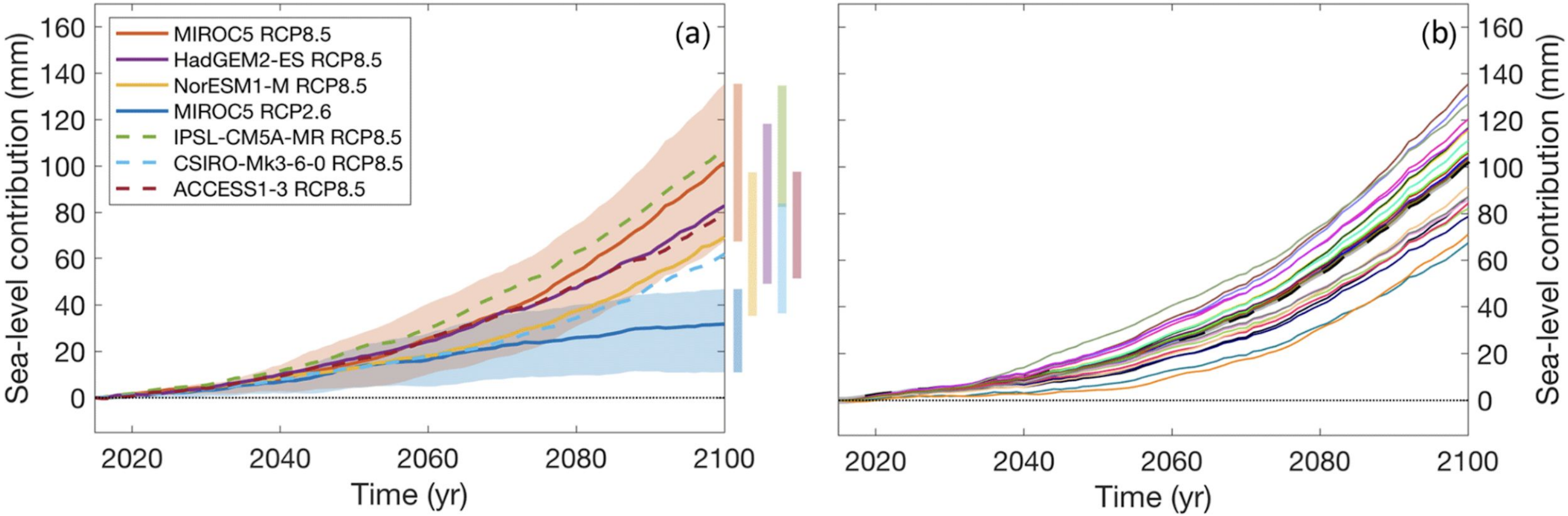


The climate community wants to model the future evolution of the Greenland Ice Sheet.

This requires using ice flow models to solve energy, mass and force balances.

(Aschwanden et al., 2019, *Sci.Adv.*)

GrIS contribution to sea level

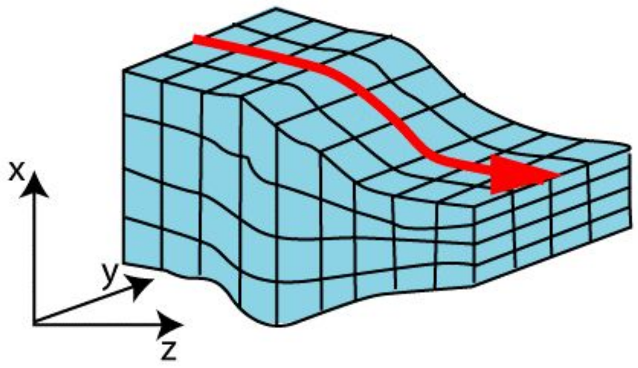


Uncertainty is still large

Goelzer et al., 2020

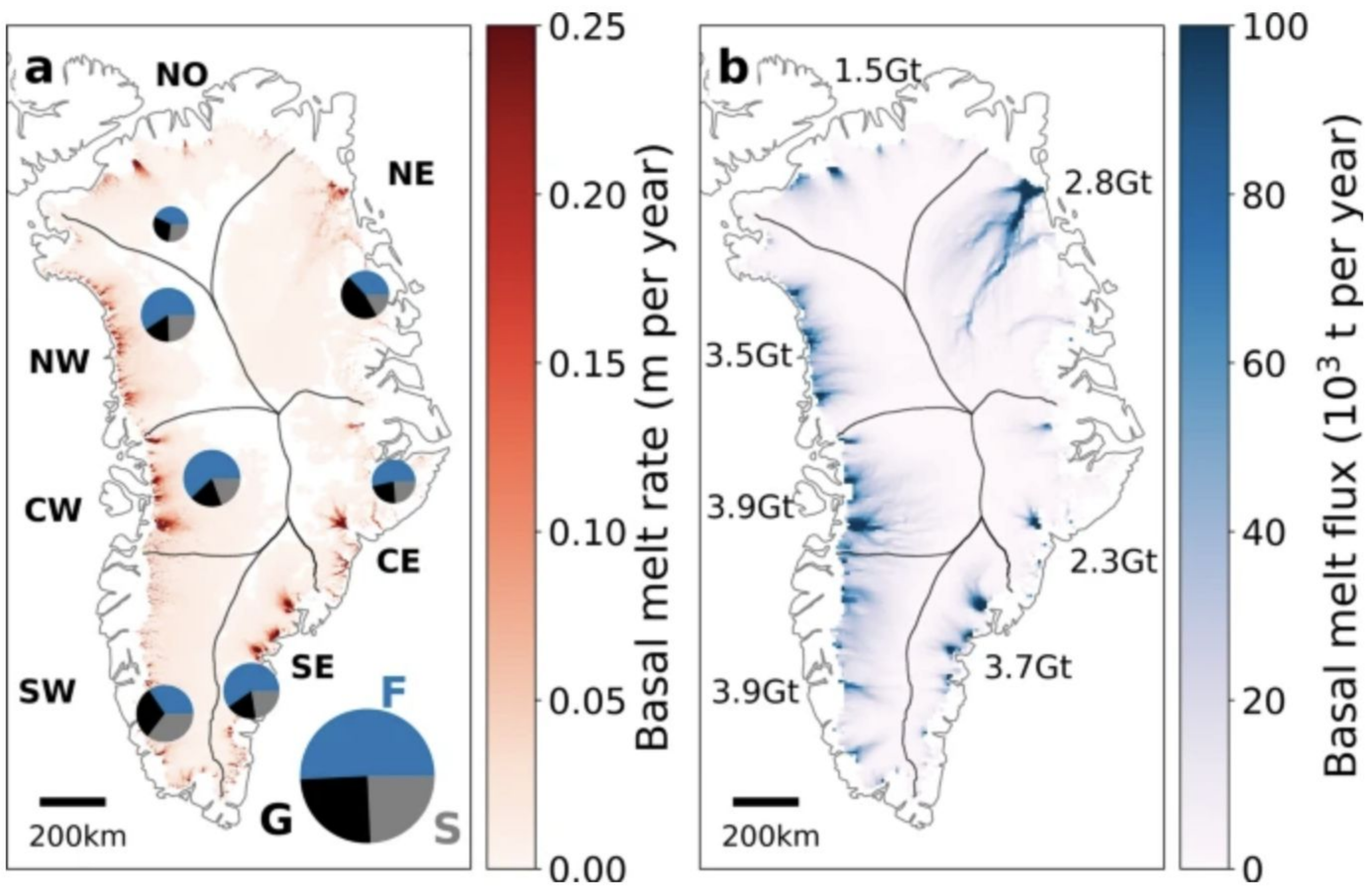
www.AntarcticGlaciers.org

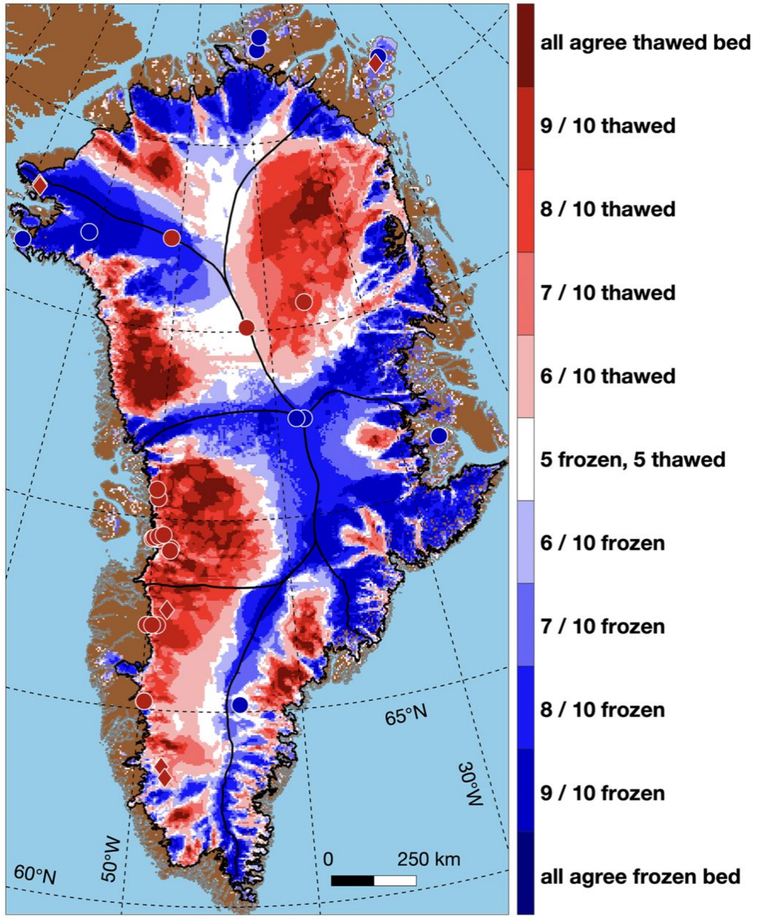
Modelling the Greenland ice sheet requires both surface and bed boundary conditions



Boundary Condition	Surface	Bed
Energy Balance • Type 1 • Type 2	• Air Temperature • Surface Energy Balance	• Bed Temperature • Geothermal Flow
Mass Balance • Type 1 • Type 2	• Surface Elevation • Surface Mass Balance	• Bed Elevation • Basal Mass Balance
Force Balance • Type 1 • Type 2	• Free Surface • Surface Velocity	• Overburden Stress • Basal Sliding

GrIS basal melt rate, dry-wet condition





Karlsson et al., 2021

frozen: ~40%, thawed: ~33%, unclear: ~28%

MacGregor et al., 2022

Duval-Lliboutry relationship

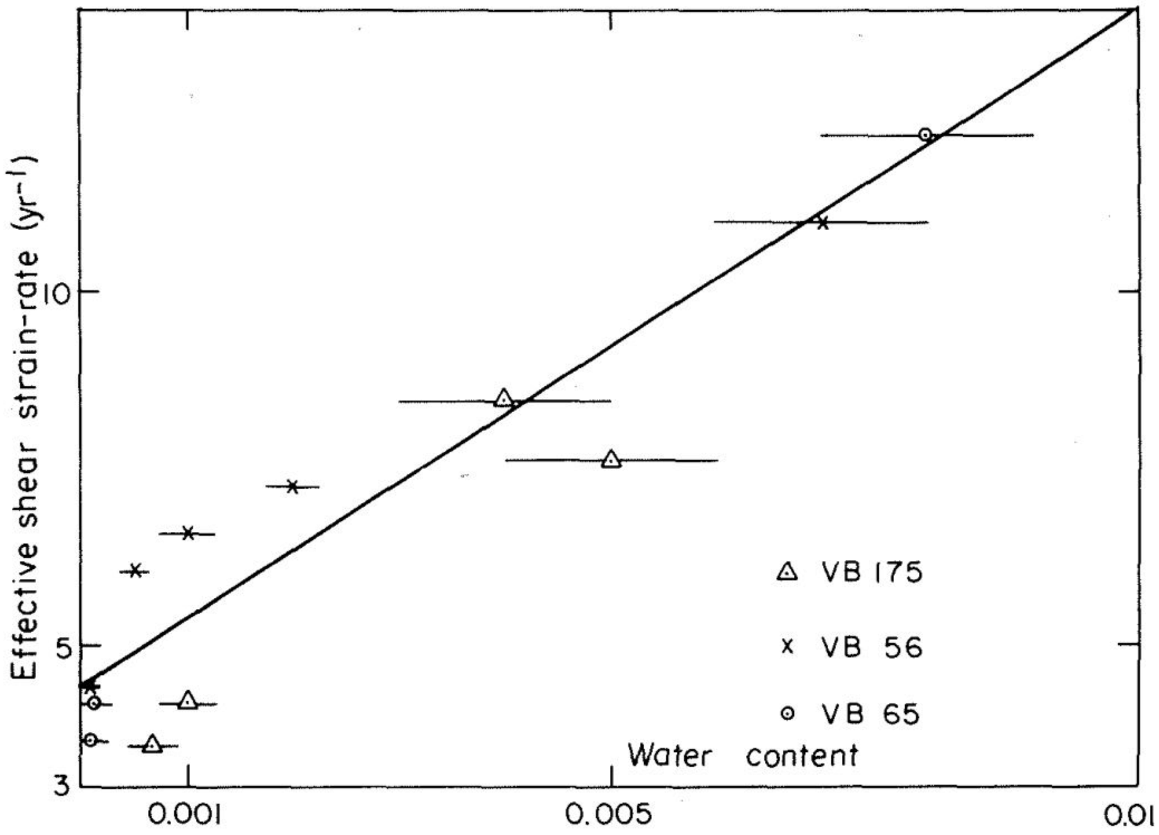


FIGURE 1. Tertiary effective shear strain rate *versus* water content. Effective shear stress $\tau = 2.90$ b.

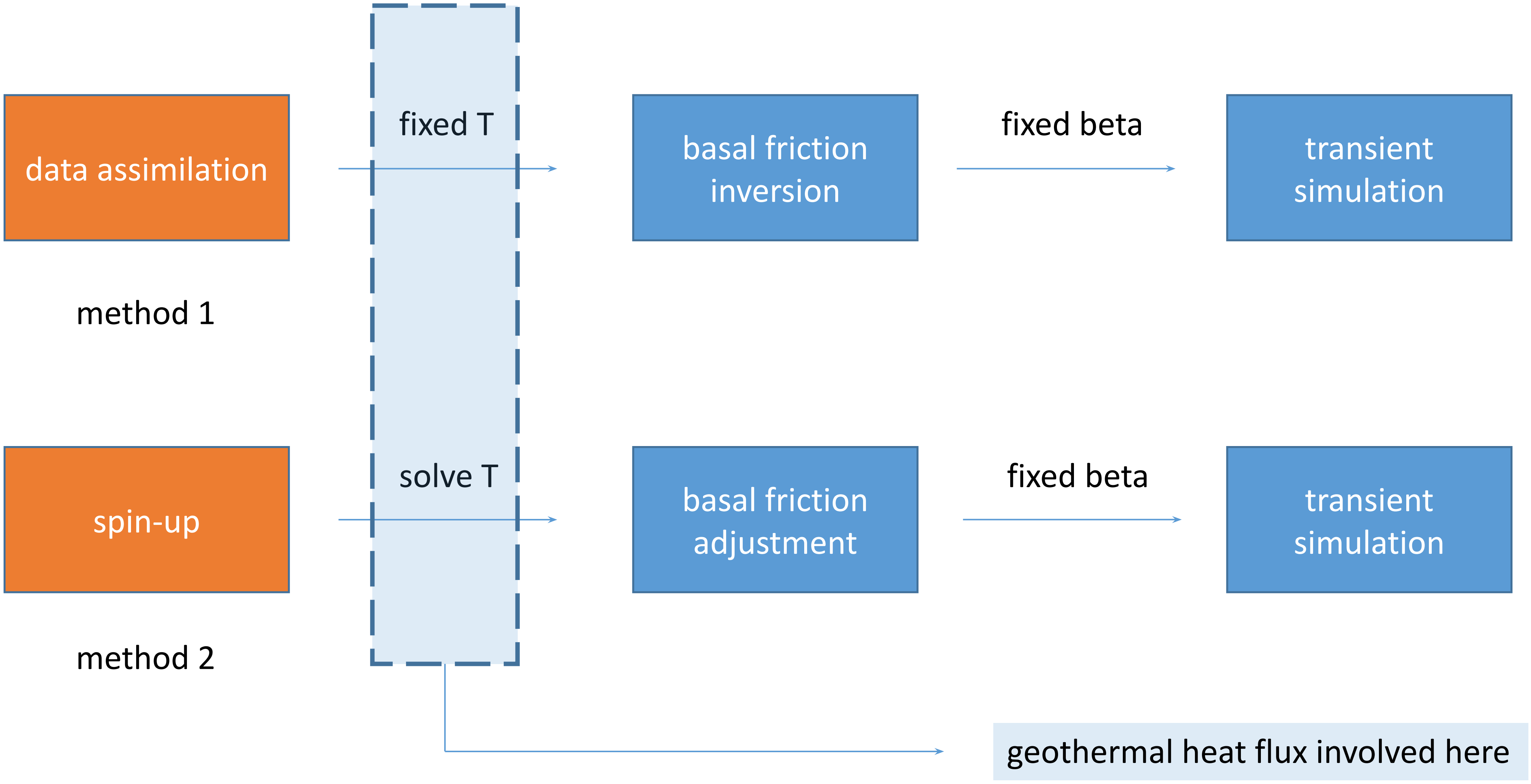
(Duval, 1977)

$A = (3.2 + 5.8\omega) \times 10^{-24}$ [s^{-1} Pa^{-3}]

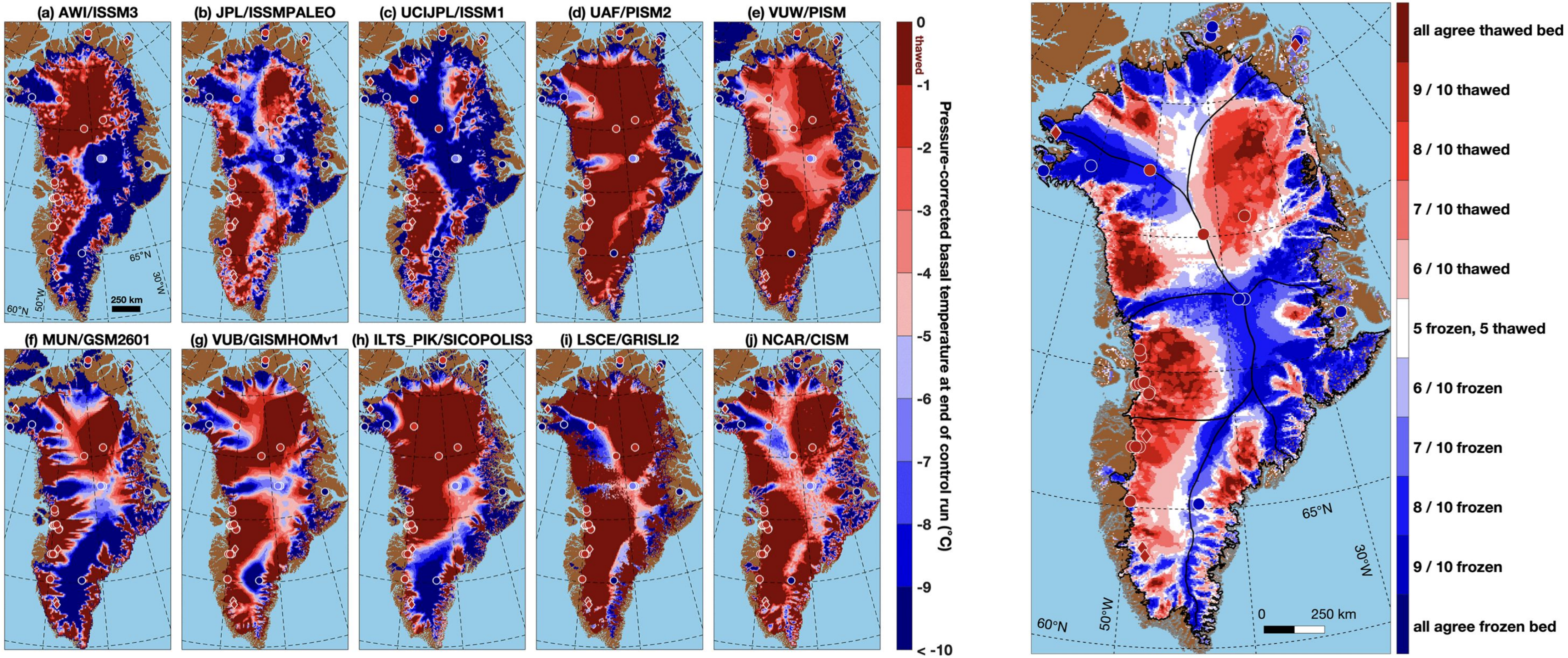
water content increases from 0 to 1.1%, the flow law rate will be 3X bigger!

this is NOT considered in most ice sheet models

ice sheet model simulation procedure



Previous study: 10 different ISMIP6 models



MacGregor et al., 2022

Can we get rid of the uncertainties raised by ice sheet models?

Study design

- single ice sheet model: CISM
- velocity solver: DIVA (depth integrated viscosity approximation)
- horizontal resolution: 4 km
- vertical layers: 10
- ice shelves: none
- geothermal datasets: 7
- spin-up years: 10 ka
- **case 1**: constrain basal friction, basal friction is nudged during spin-up
- **case 2**: do NOT constrain basal friction, apply a local till model

Model	Methodology	Geophysical datasets [unitless]	Greenland observations [unitless]	Geothermal heat flow [mW m^{-2}]	Domain coverage
Colgan et al. [2022]	Machine learning model	12	419	41.8 ± 5.3	Greenland; oceanic and continental
Rezvanbehbahani et al. [2017]	Machine learning model	20	9	54.1 ± 20.4	Greenland; continental only
Shapiro and Ritzwoller [2004]	Seismic similarity model	4	278	55.7 ± 9.4	Global; oceanic and continental
Artemieva [2019]	Thermal isostasy model	8	290	56.4 ± 12.6	Greenland; continental only
Martos et al. [2018]	Forward ~~geodynamic~~ model	5	8	60.1 ± 6.6	Greenland; continental only
Greve [2019]	Paleoclimate and ice flow model	3	8	63.3 ± 19.1	Greenland; continental only
Lucazeau [2019]	Geostatistical model	14	314	63.8 ± 7.1	Global; oceanic and continental

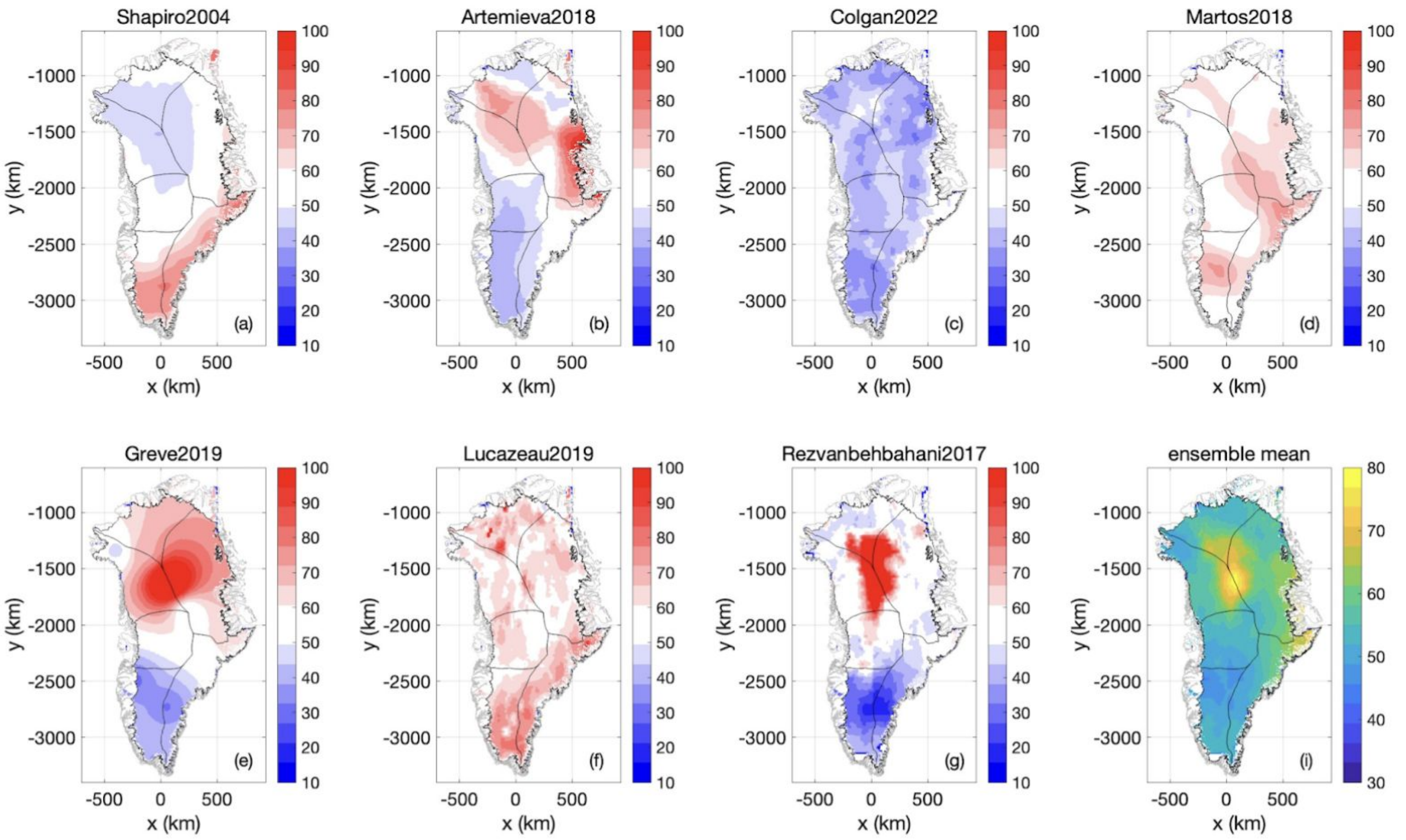
A brief description of different geothermal heat flux datasets

Colgan et al. (2022)
Rezvanbehbahani et al. (2017)
Lucazeau (2019):
machine learning/statistics

Shapiro and Ritzwoller (2004)
Martos et al. (2018)
Artemieva (2019):
mantle model

Greve (2019)
ice flow model

GrIS heat flux data



unit: mW m^{-2}

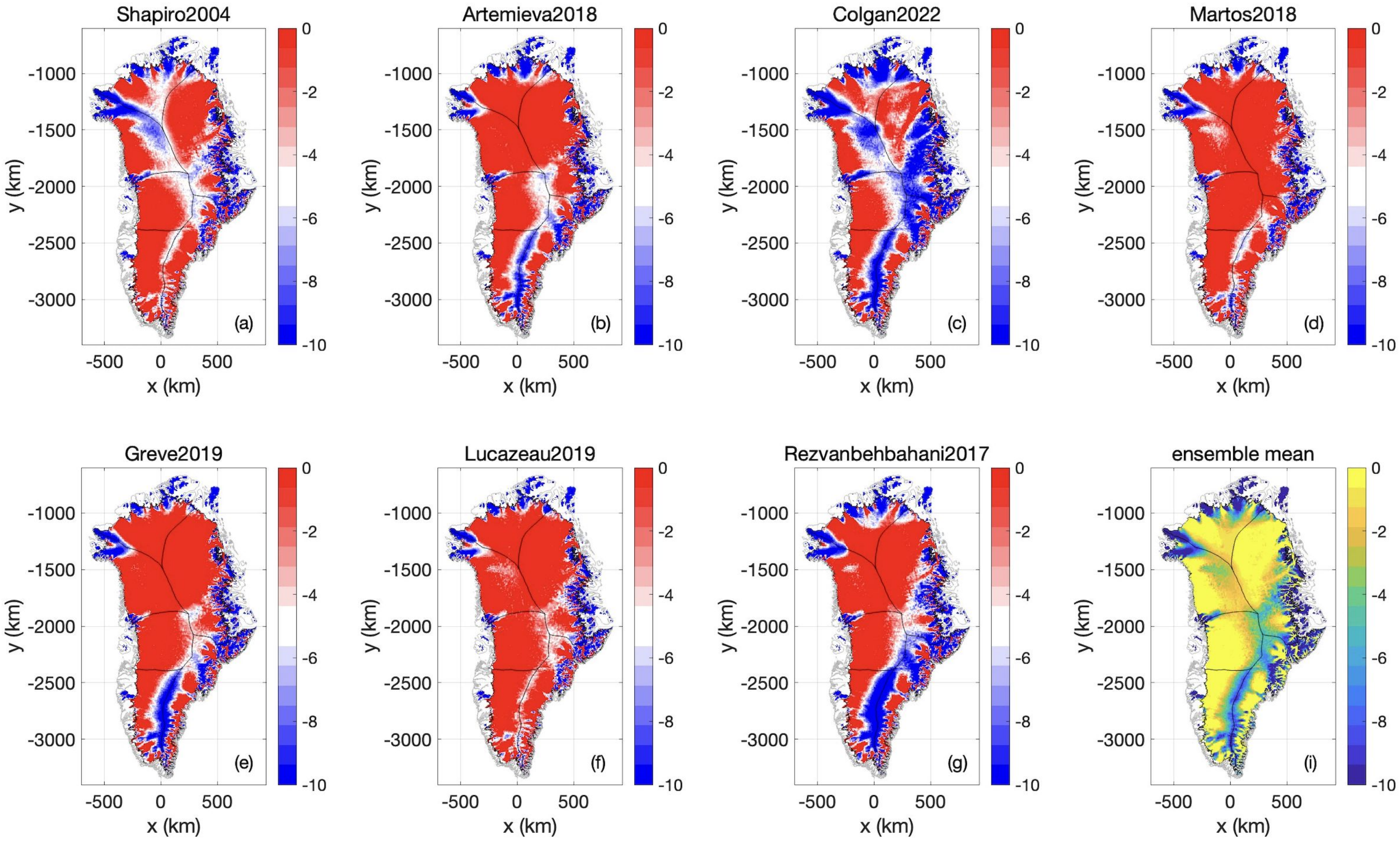
lowest mean:
Colgan et al. (2022)

largest mean:
Lucazeau et al. (2019)

lowest deviation:
Colgan et al. (2022)

largest deviation:
Rezvanbehbahani et al. (2017)

case 1: modeled basal temperature

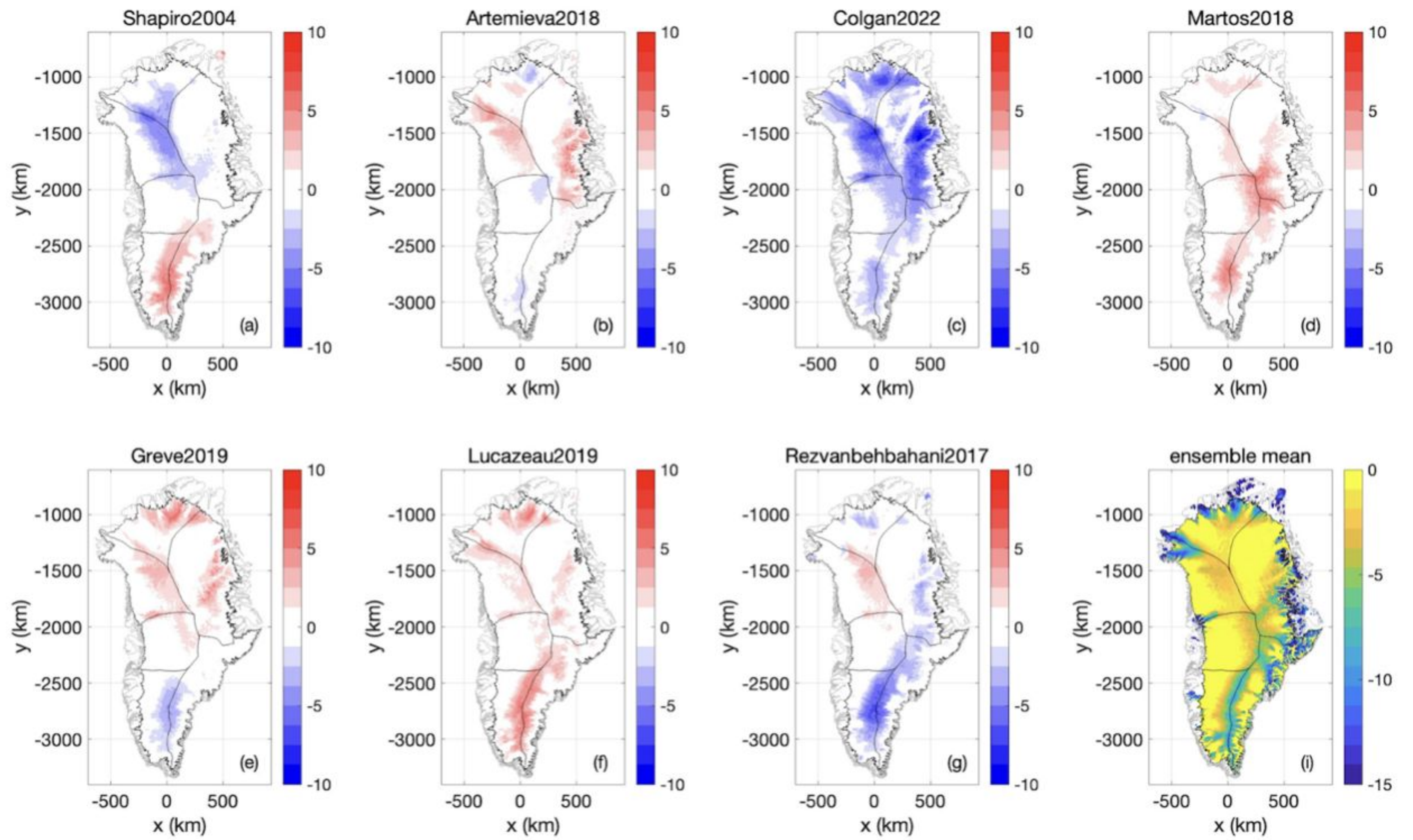


basal temperature relative to Tpmp (deg C)

largest frozen ice area:
Colgan et al. (2022)

largest thawed ice area:
Lucazeau et al. (2019)

case 1: modeled basal temperature (anomaly)

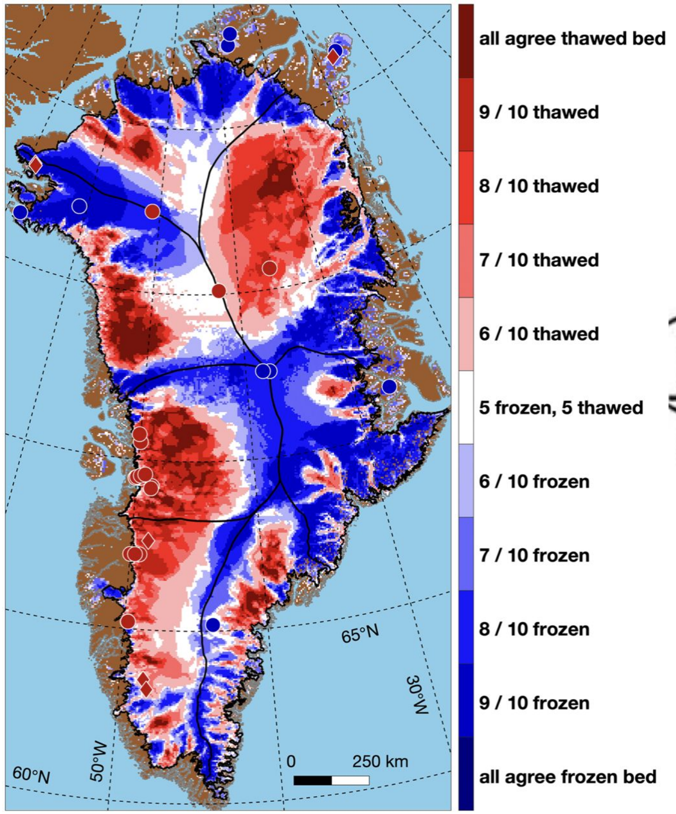


coldest basal temperature anomaly:
Colgan et al. (2022)

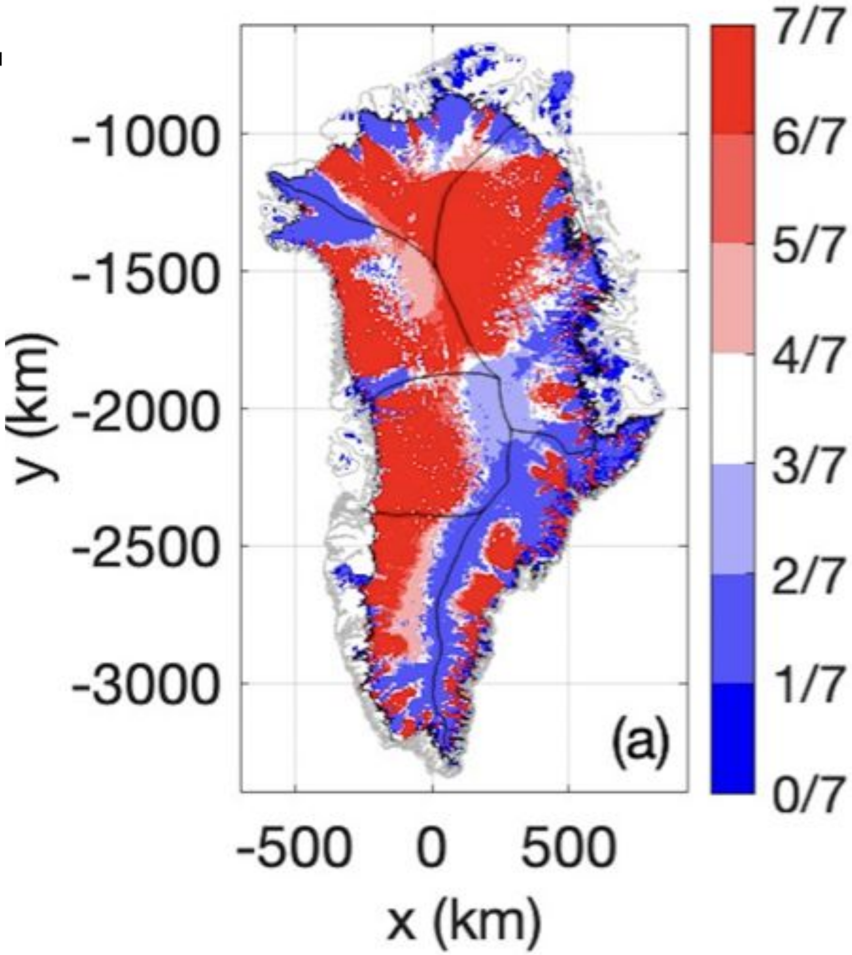
warmest basal temperature anomaly:
Lucazeau et al. (2022)

basal temperature anomaly (deg C)

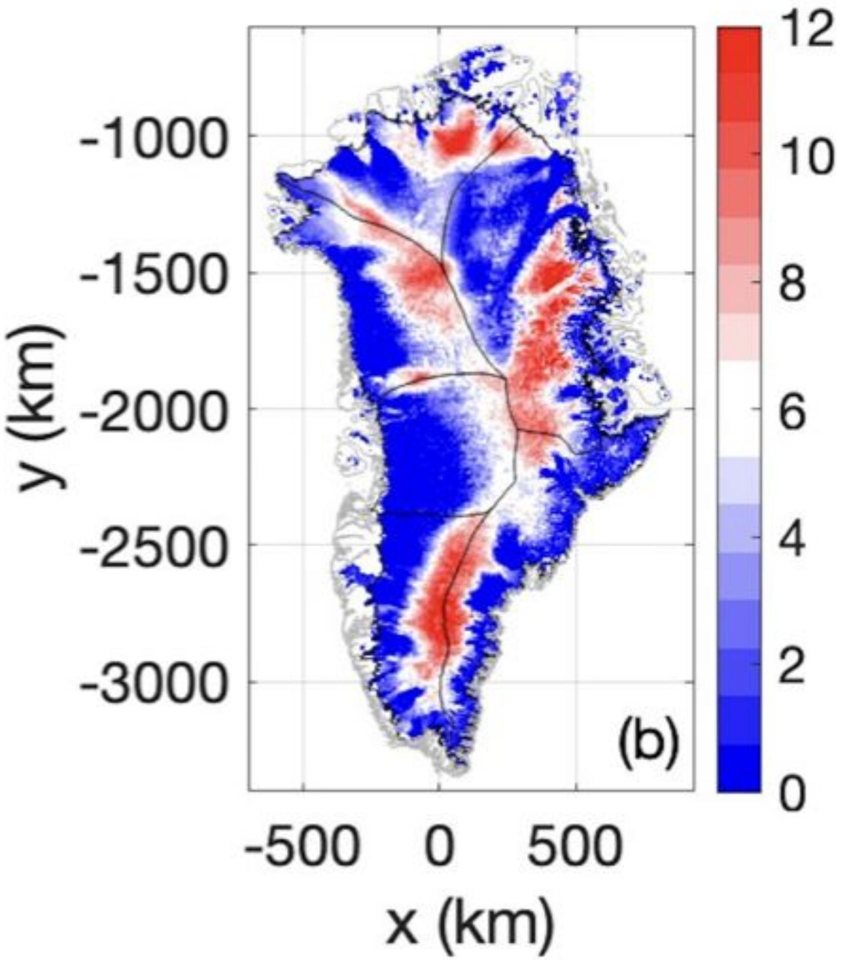
case 1: dry/wet



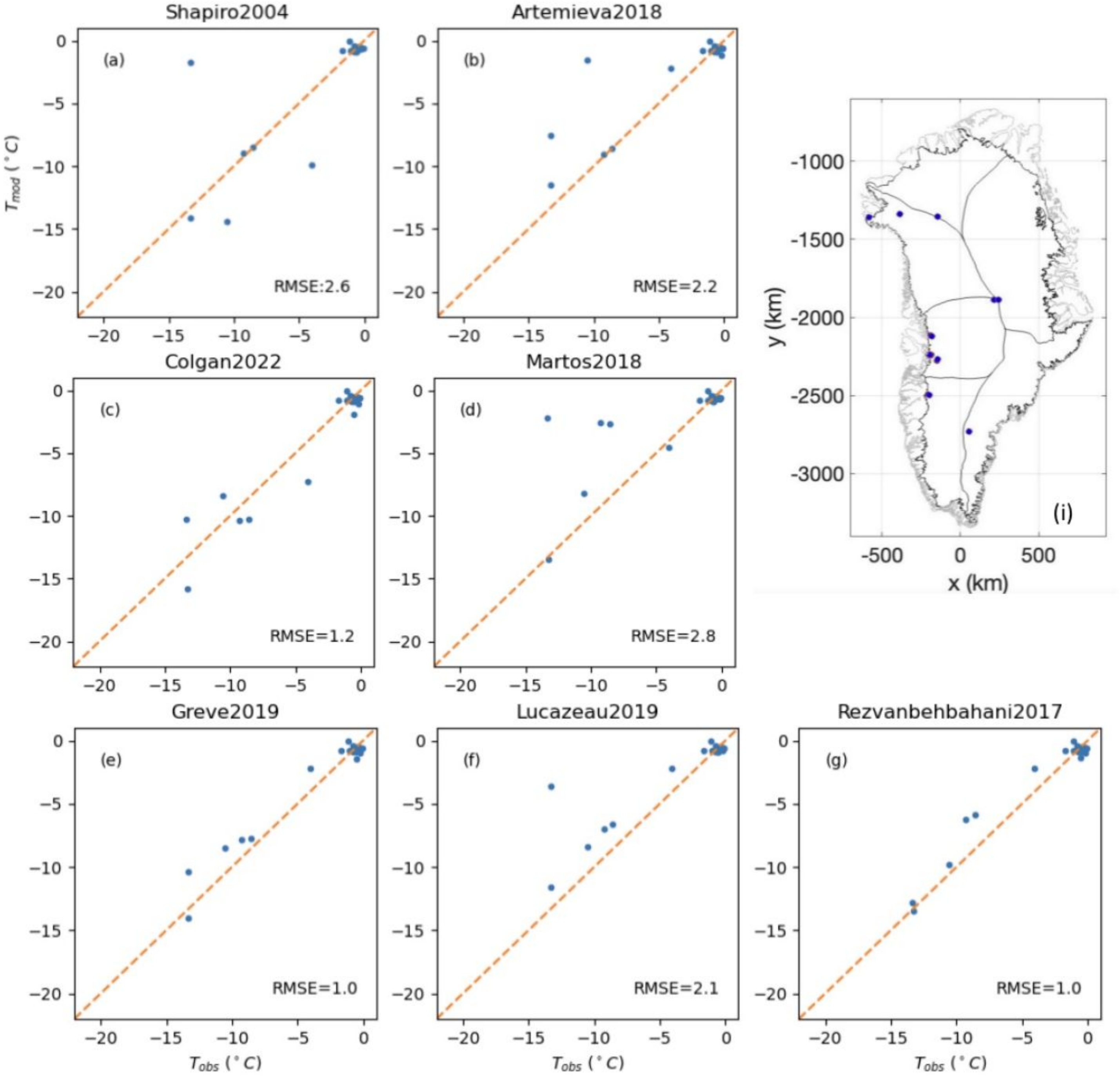
MacGregor et al. (2022)



large difference: northern GrIS



basal T ensemble spread (°C)



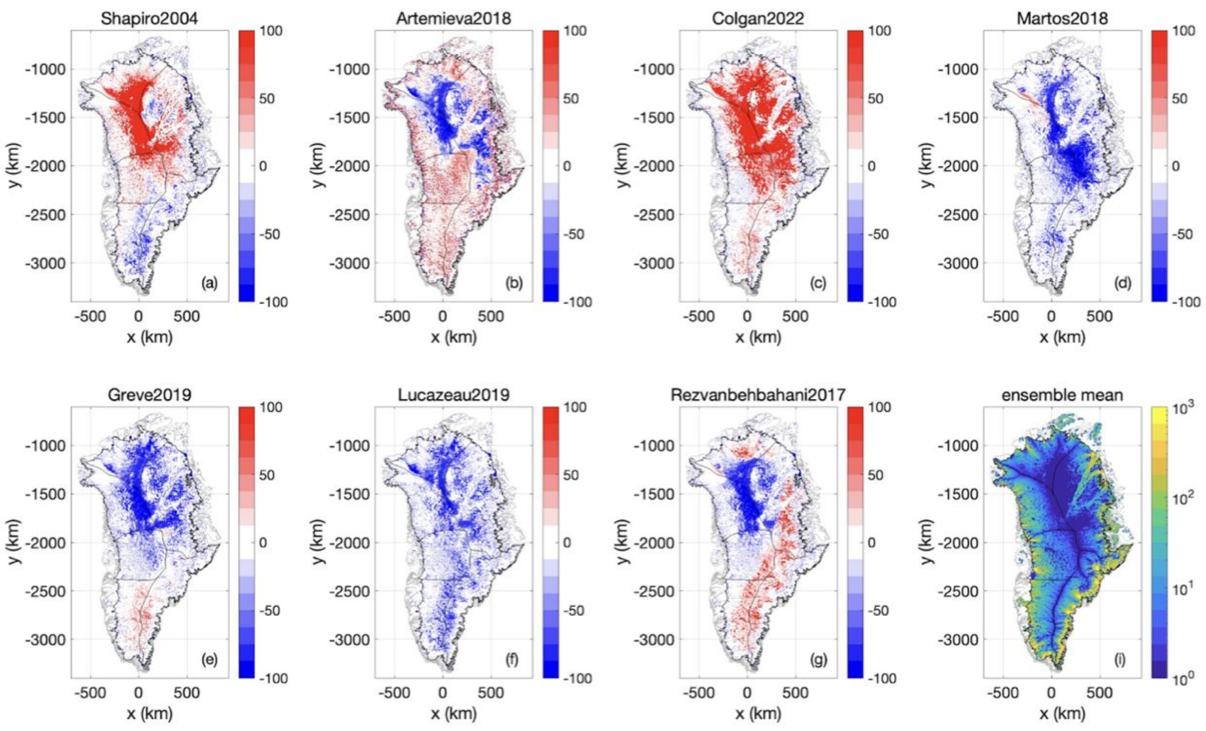
case 1:

basal T comparison with
27 ice borehole observations

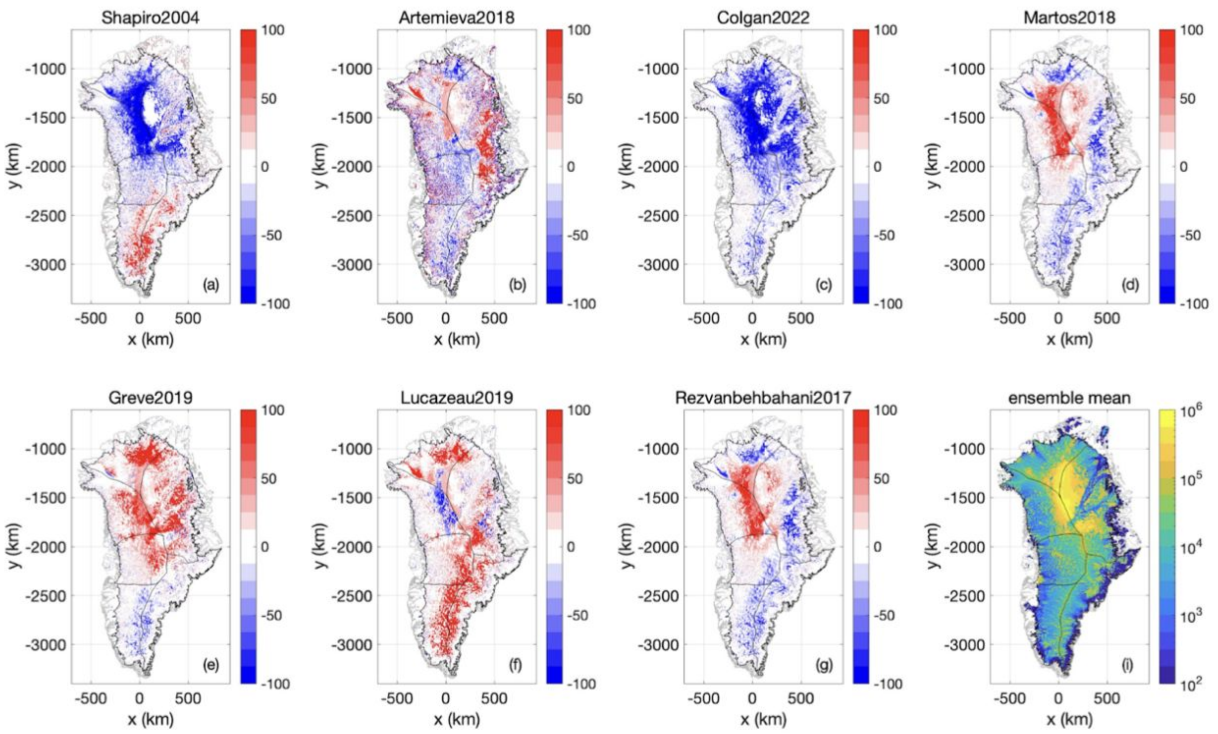
minimum RMSE:
Rezvanbehbahani et al. (2017)

largest RMSE:
Martos et al. (2018)

case 1: surface velocity and basal friction



surface velocity (m/a)

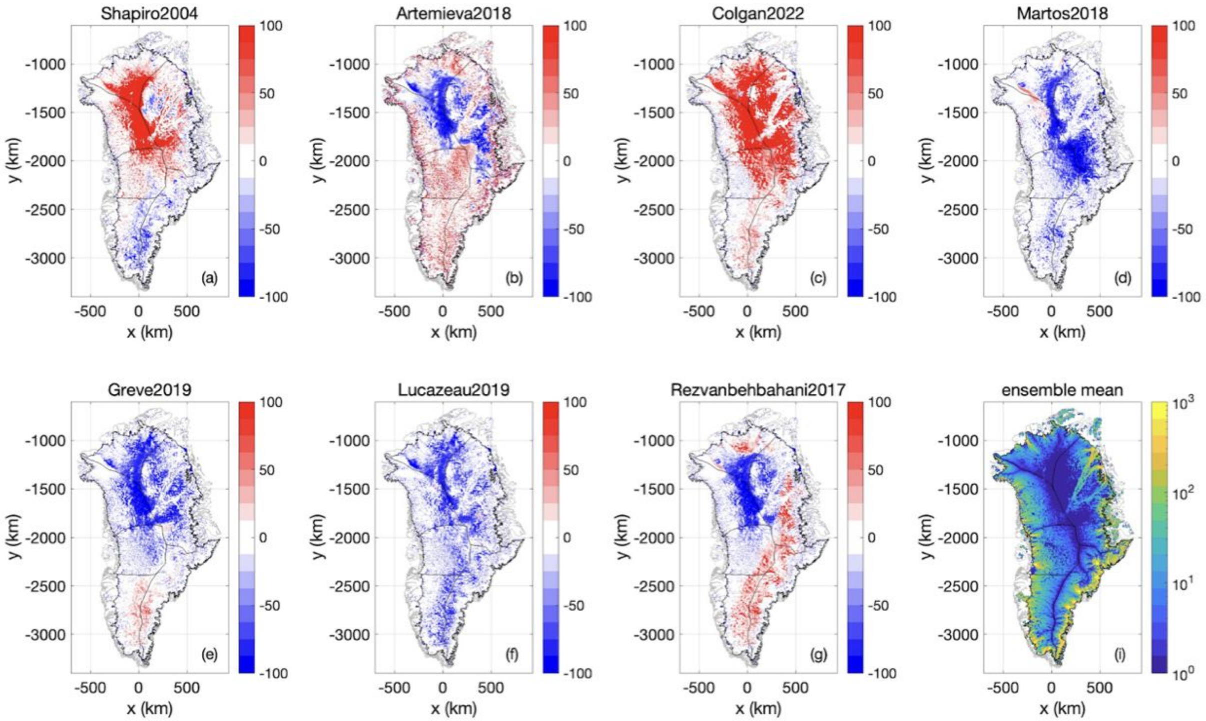


basal friction (Pa yr m^{-1})

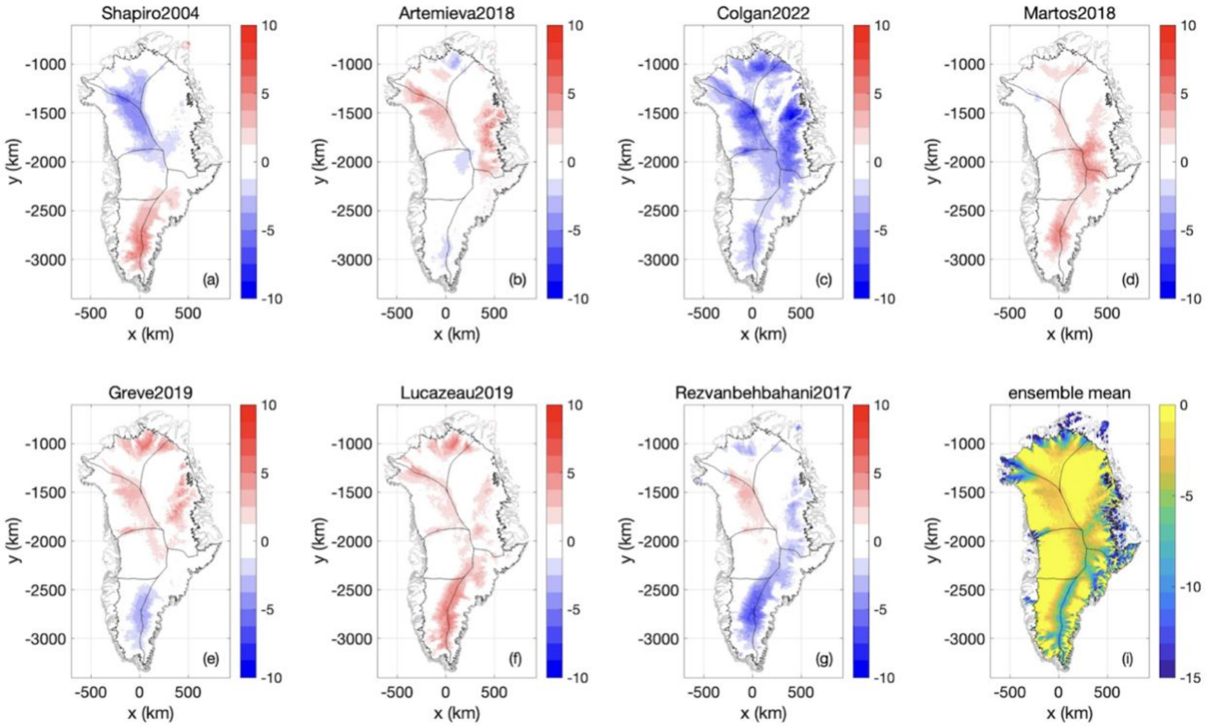
lower basal friction
larger basal friction

higher velocity
lower velocity

case 1: surface velocity and basal temperature



surface velocity (m/a)



basal temperature (° C)

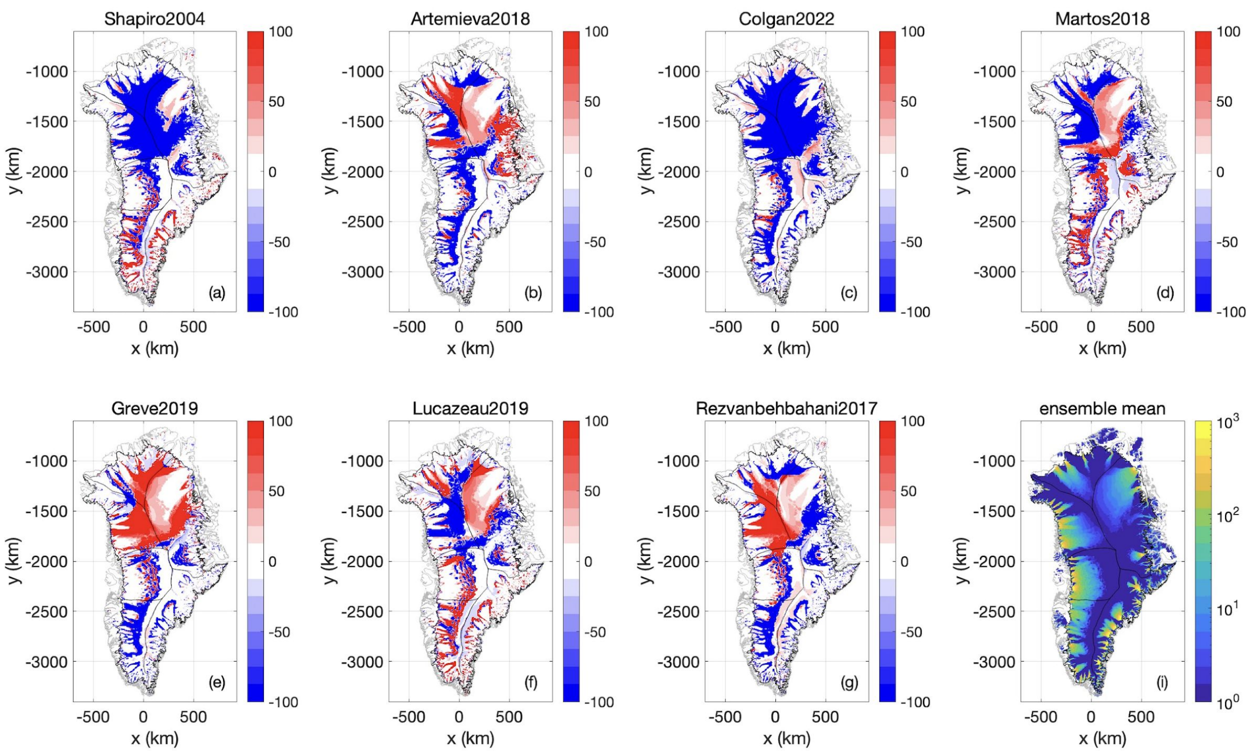
lower basal temperature
higher basal temperature

→

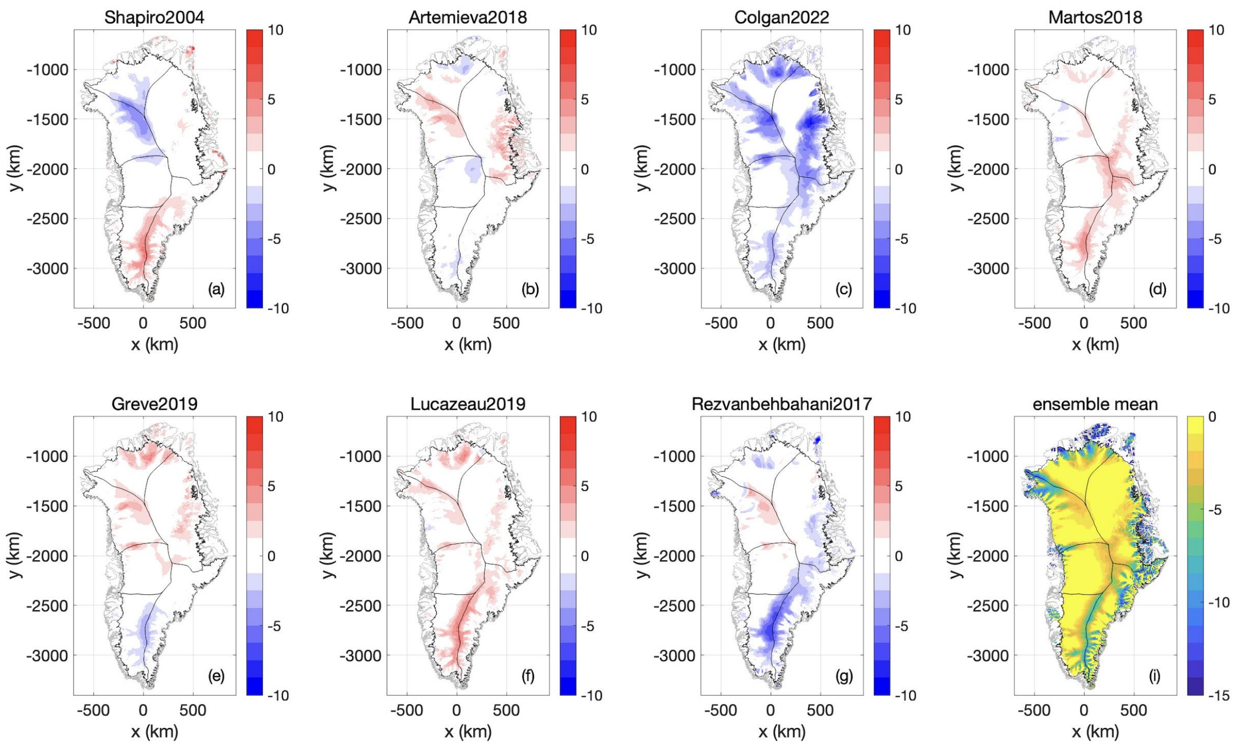
higher velocity
lower velocity

reason? basal friction nudging?
lower T --> lower friction --> higher velocity

case 2: surface velocity and basal temperature



surface velocity (m/a)



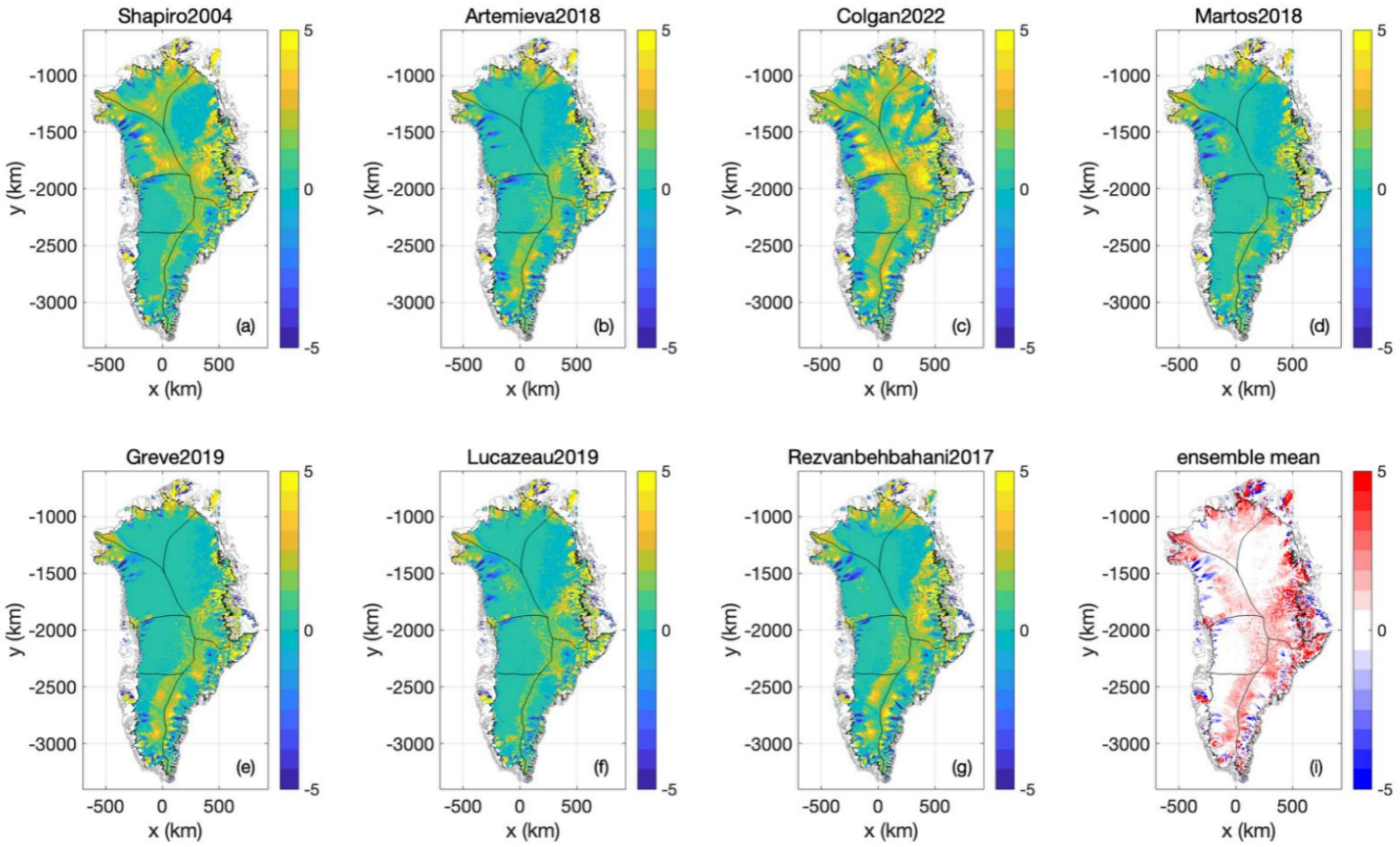
basal temperature (° C)

lower basal temperature
higher basal temperature

lower velocity
higher velocity

Things changed!

basal temperature difference $(T_{case2}-T_{case1})$

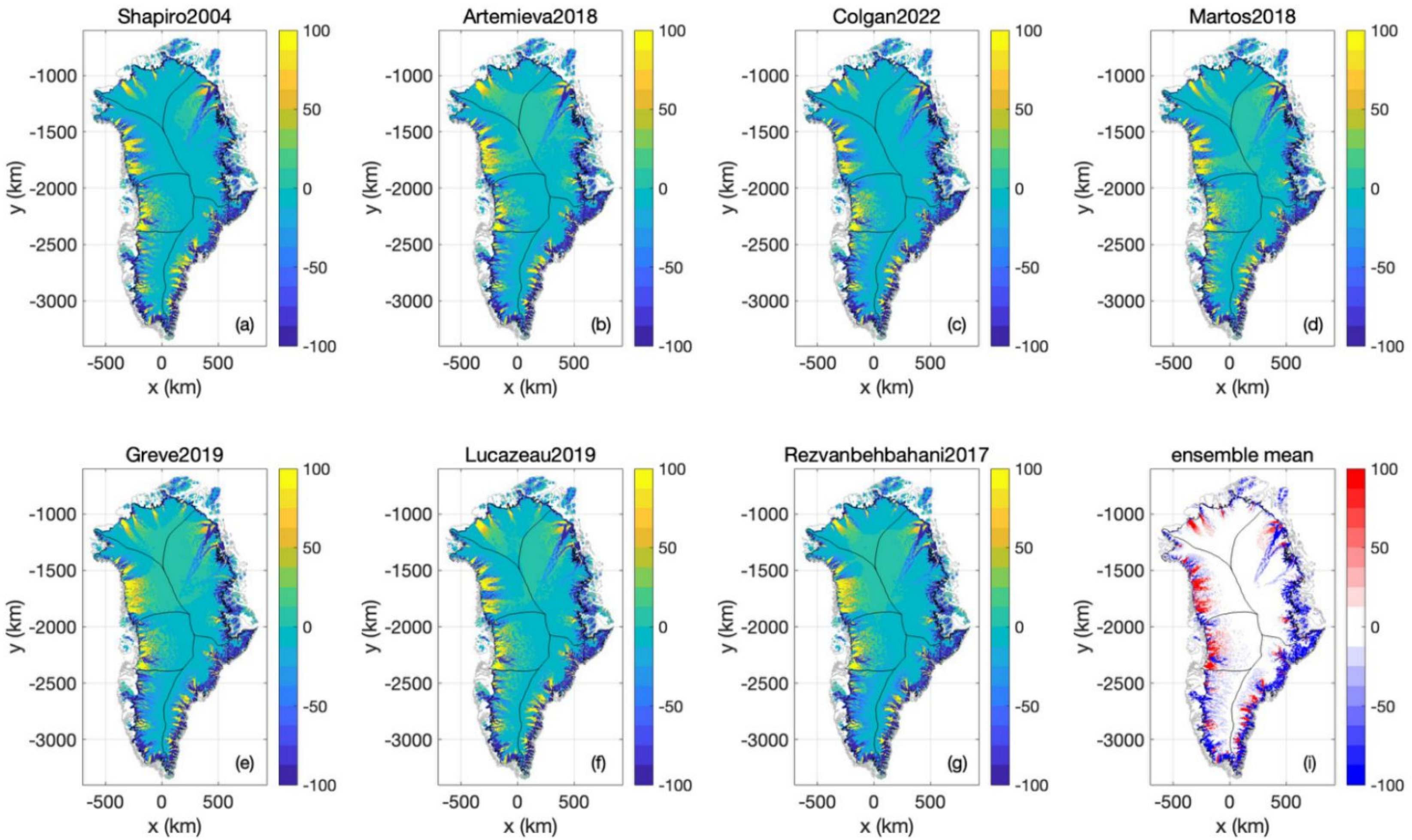


Large differences occur at cold-based region

largest difference:
Colgan et al. (2022)

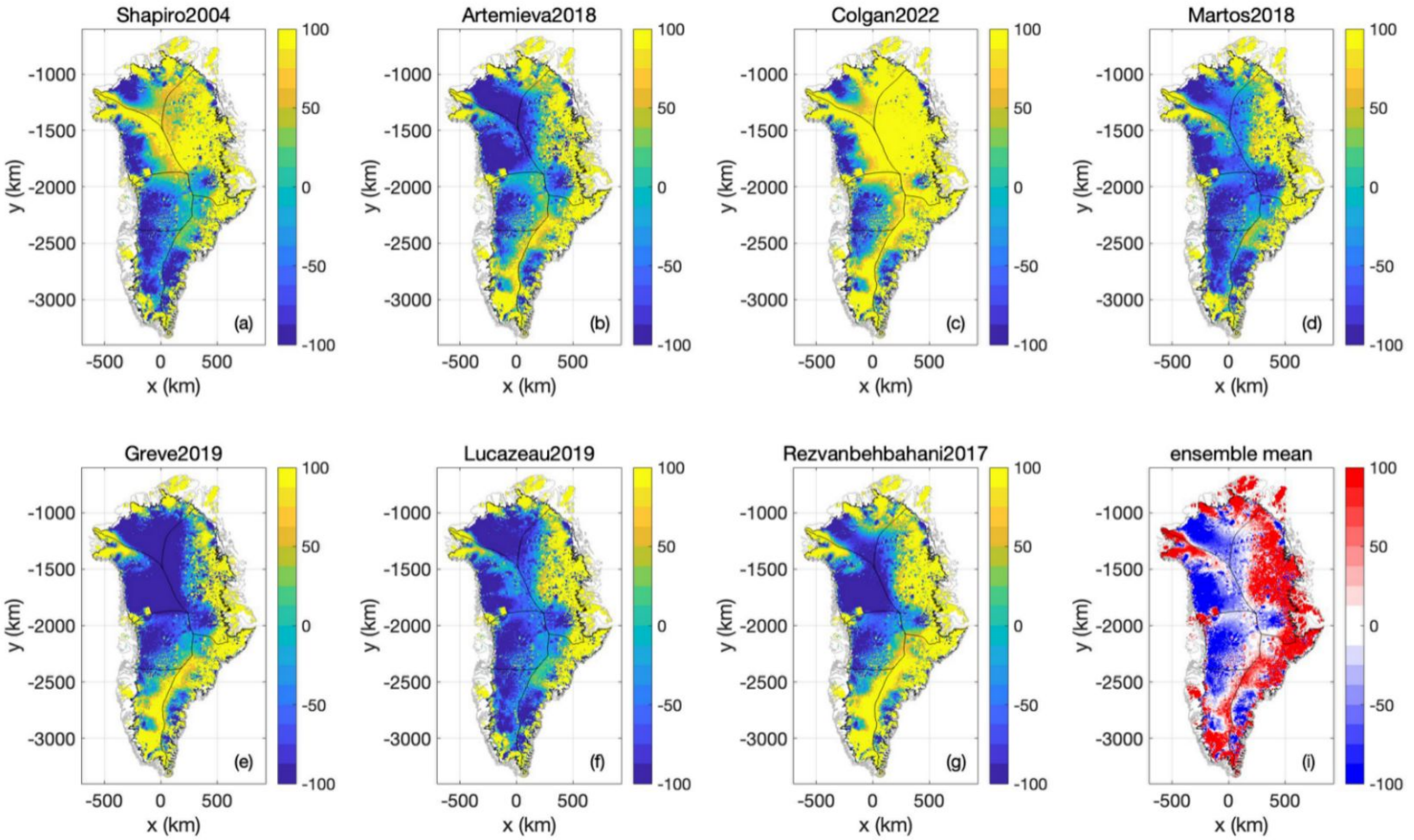
lowest difference:
Lucazeau et al. (2019)

surface velocity difference $(U_{case2}-U_{case1})$



Large differences occur
at GrIS margins / ice streams

ice thickness difference $(H_{case2}-H_{case1})$

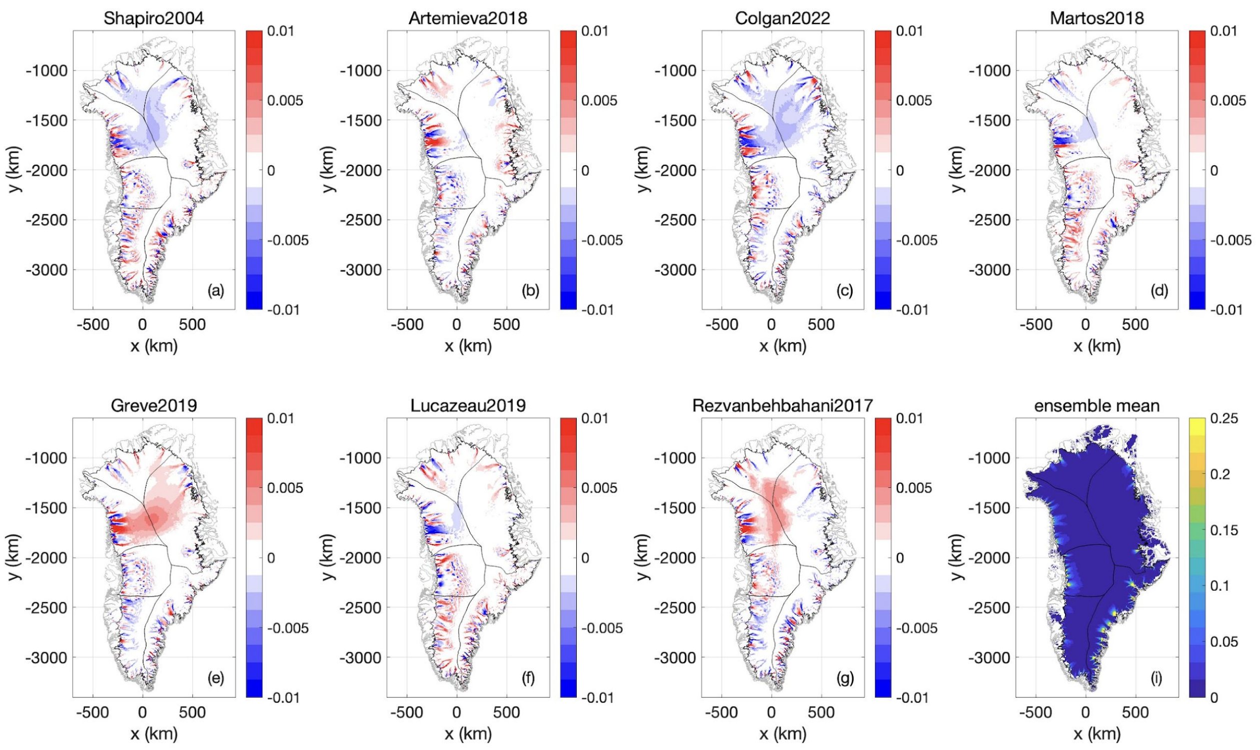


ice thickness change pattern depends on velocity changes

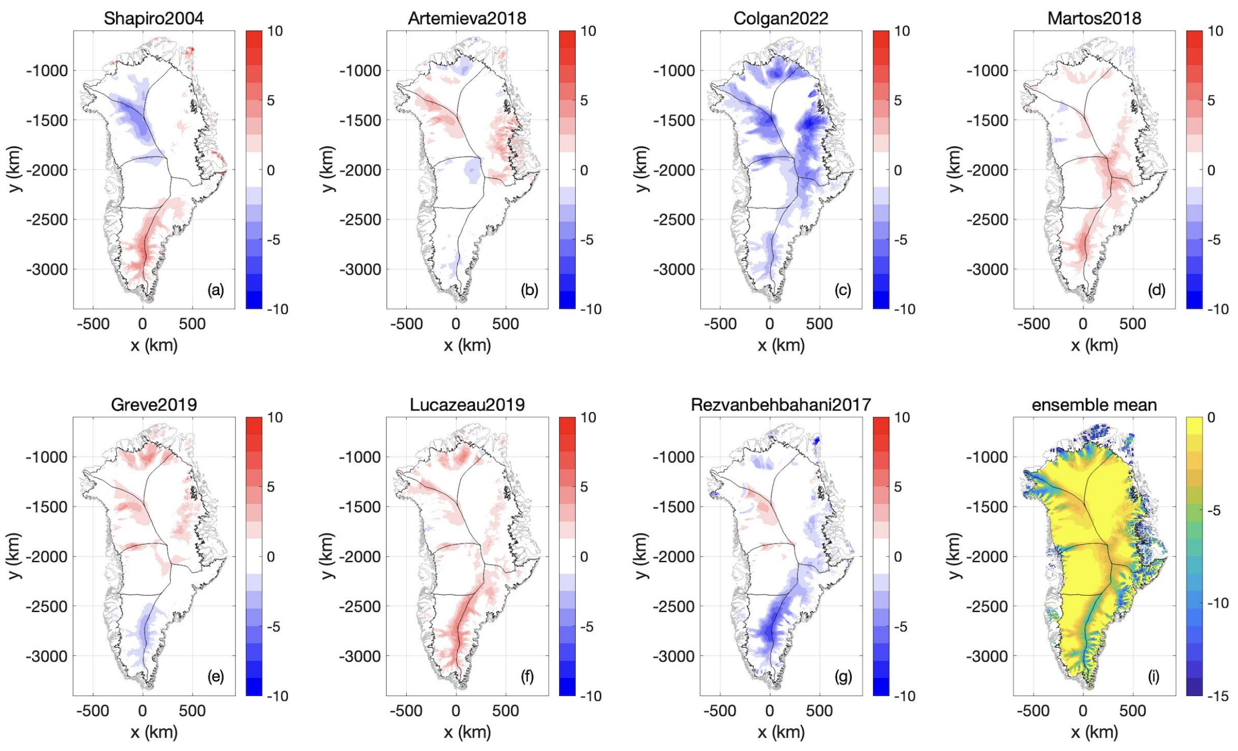
ice stream transports more ice, thickness decreases accordingly

west GrIS thinning
east GrIS thickening

case 2: basal melt rate and basal temperature



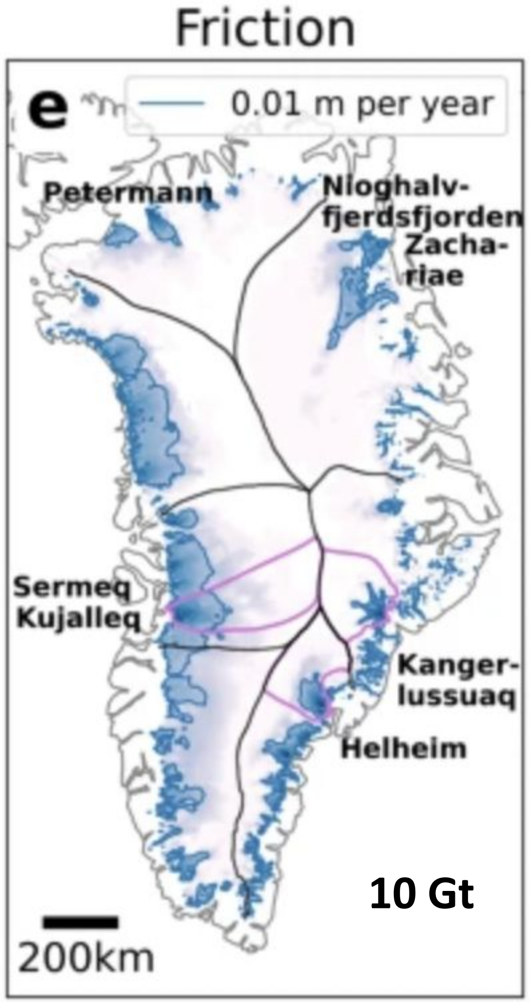
basal melt rate (m/a)



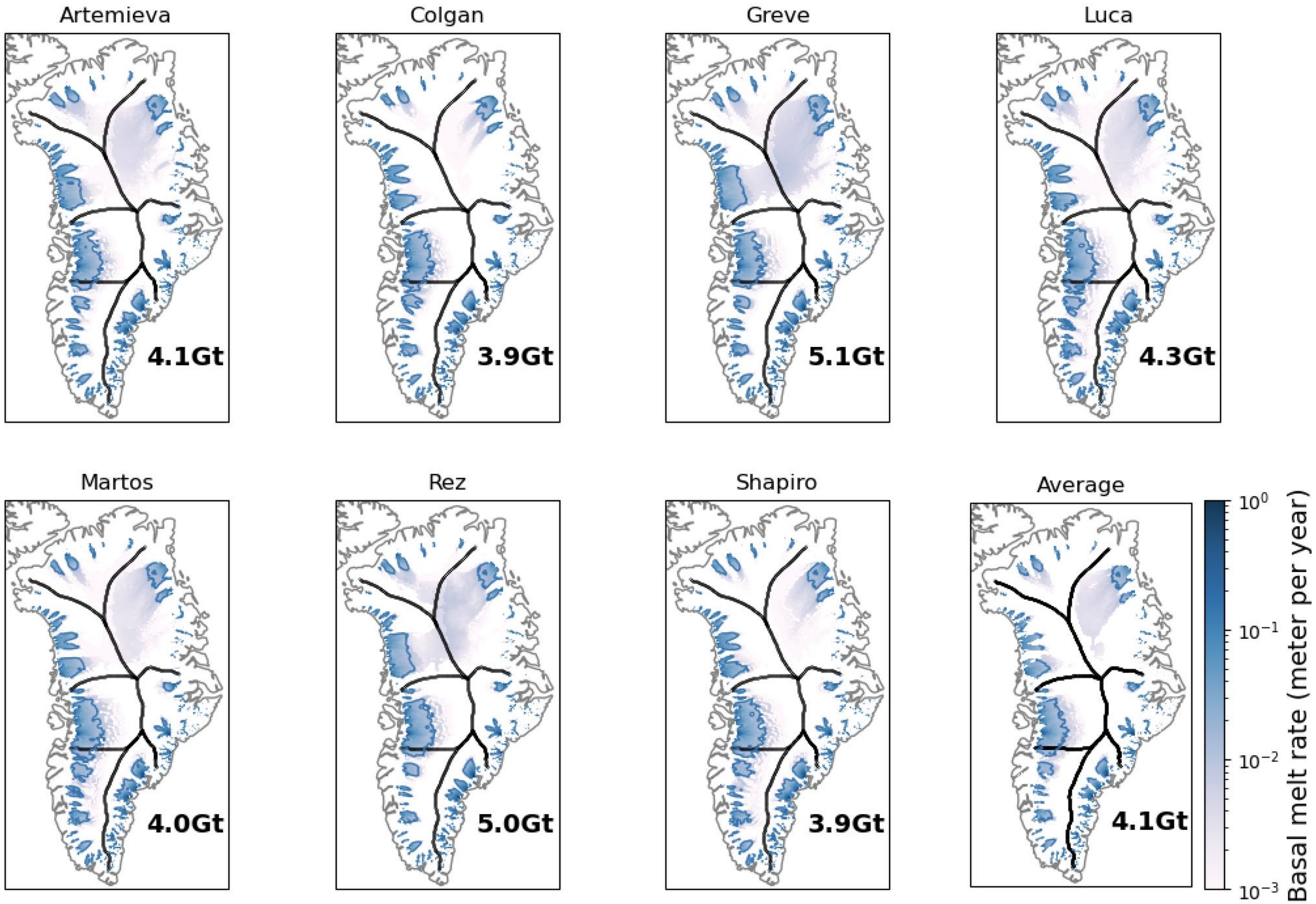
basal temperature (° C)

no very clear patten between basal melt rate and basal T

case 2: basal melt rate



Karlsson et al. (2021)



CISM results, figure made by Nanna Karlsson

CISM predicts a 50% lower basal melt than Karlsson et al. (2021)

unit: m/yr

Conclusions

- basal heat flow data has non-negligible impact on ice flows
- the choice of basal slip law (nudging or not) has significant impact
- the basal T and friction at ice streams are very important, as they can change ice geometry over the whole basins
- we do not find direct / straightforward relationships between basal temperature and basal melt rate
- Further understandings for basal melt
- analysis/writing ongoing....

Thanks!
Questions?