Closure of the Canadian Arctic Gateways as a key prerequisite for glacial inception in Scandinavia

(in review in Nature Geoscience)

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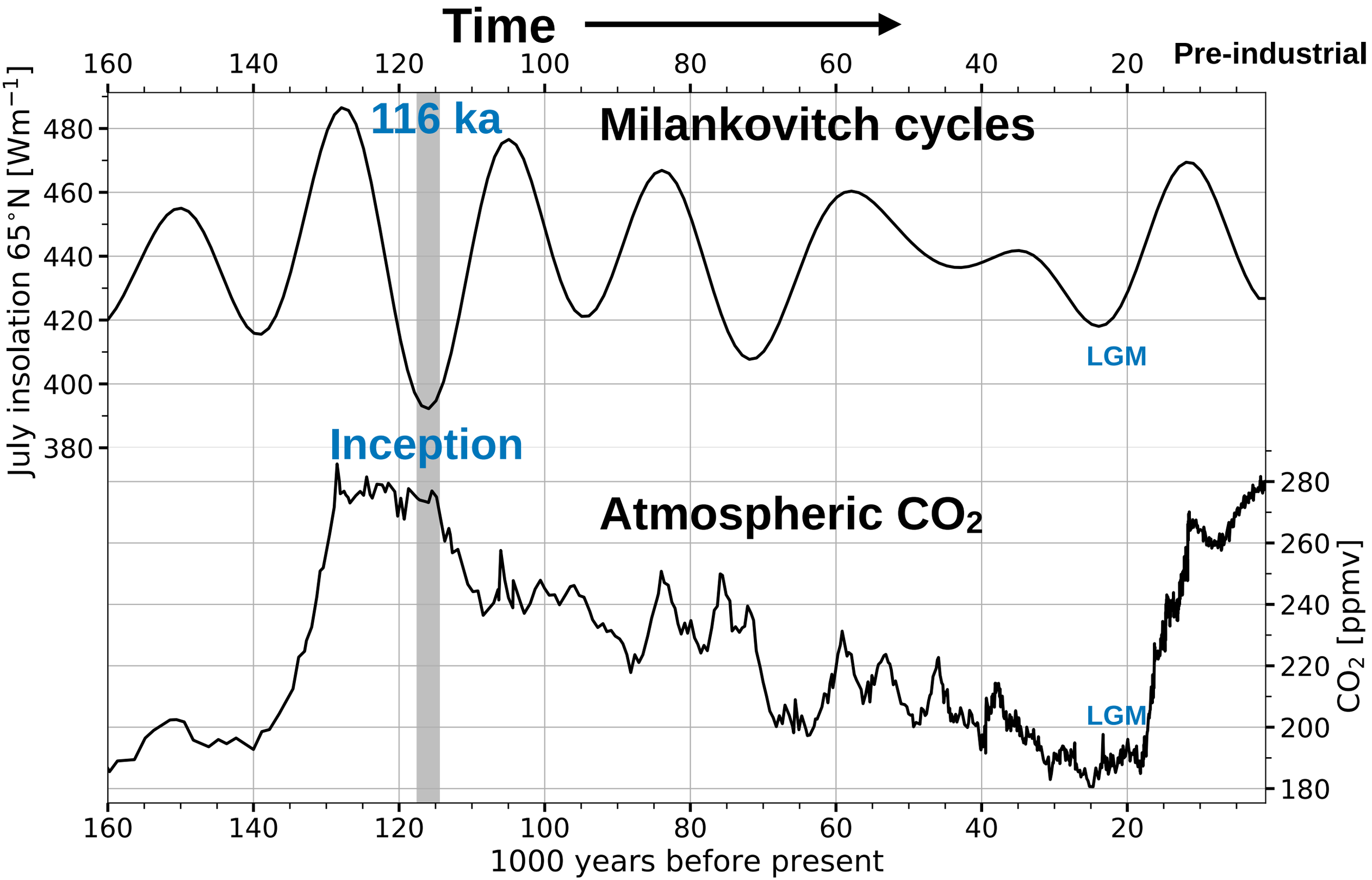
Diane Thompson: U Arizona
Esther Brady, Bette Otto-Bliesner: NCAR

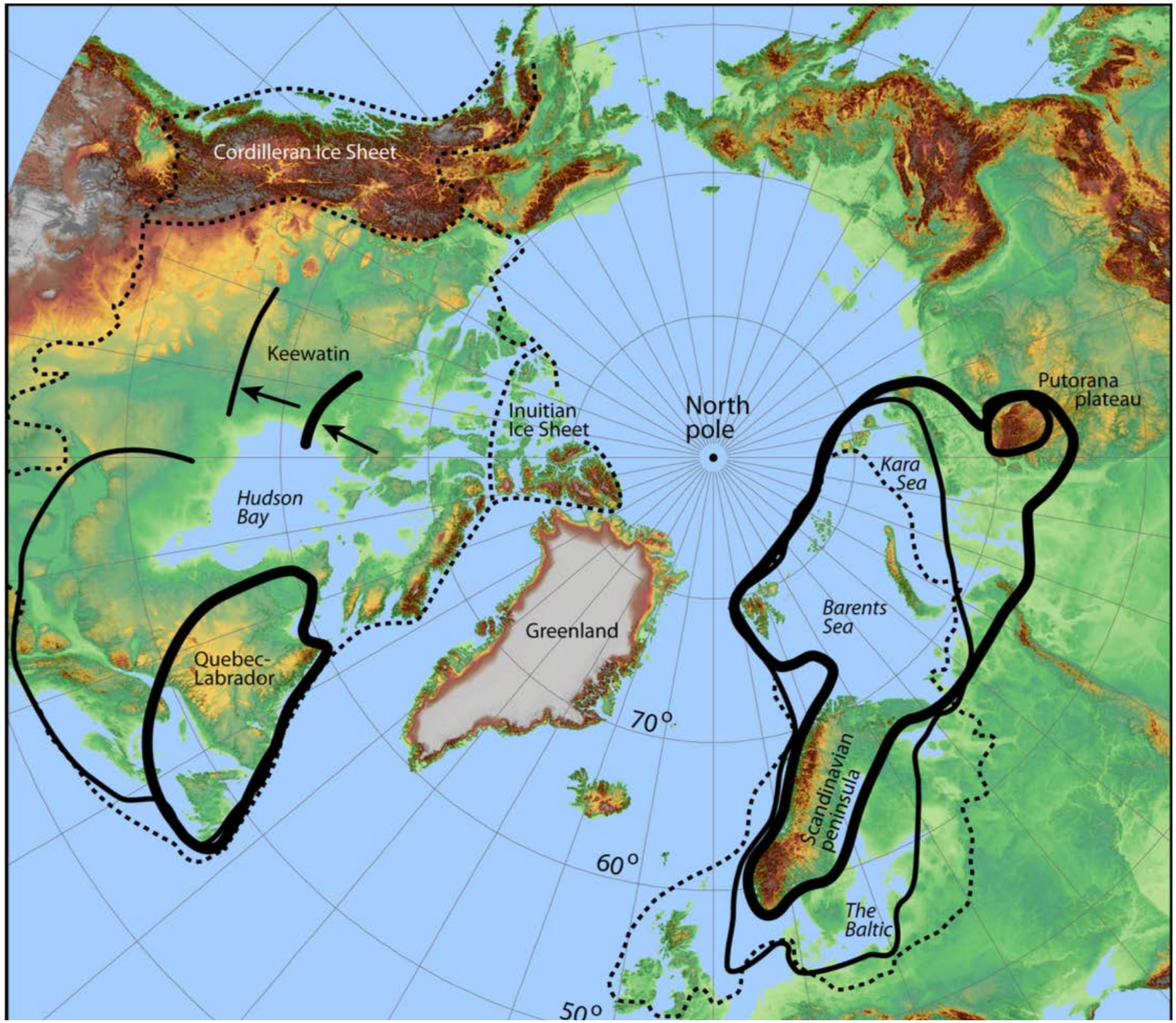
When did the inception happen?



Last glacial maximum ~21,000 years ago

https://www.quora.com/

Inception areas?

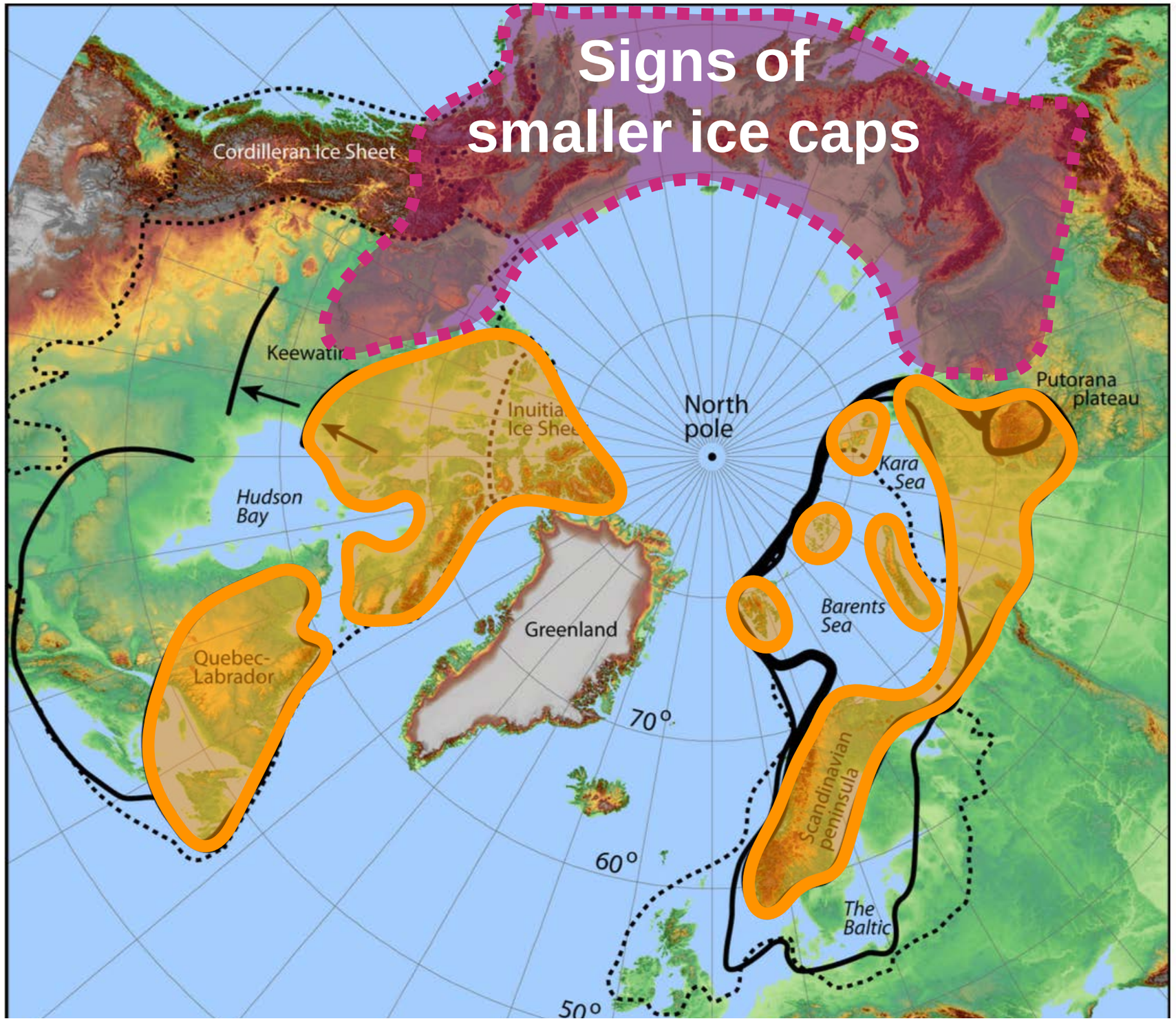


Bold lines:
Margin 10-20 kyrs after inception

Based on geological and geomorphological evidence

Kleman et al. (2013)

Inception areas?



Bold lines:
Margin 10-20 kyrs after inception

Inception (?)

No inception (?)

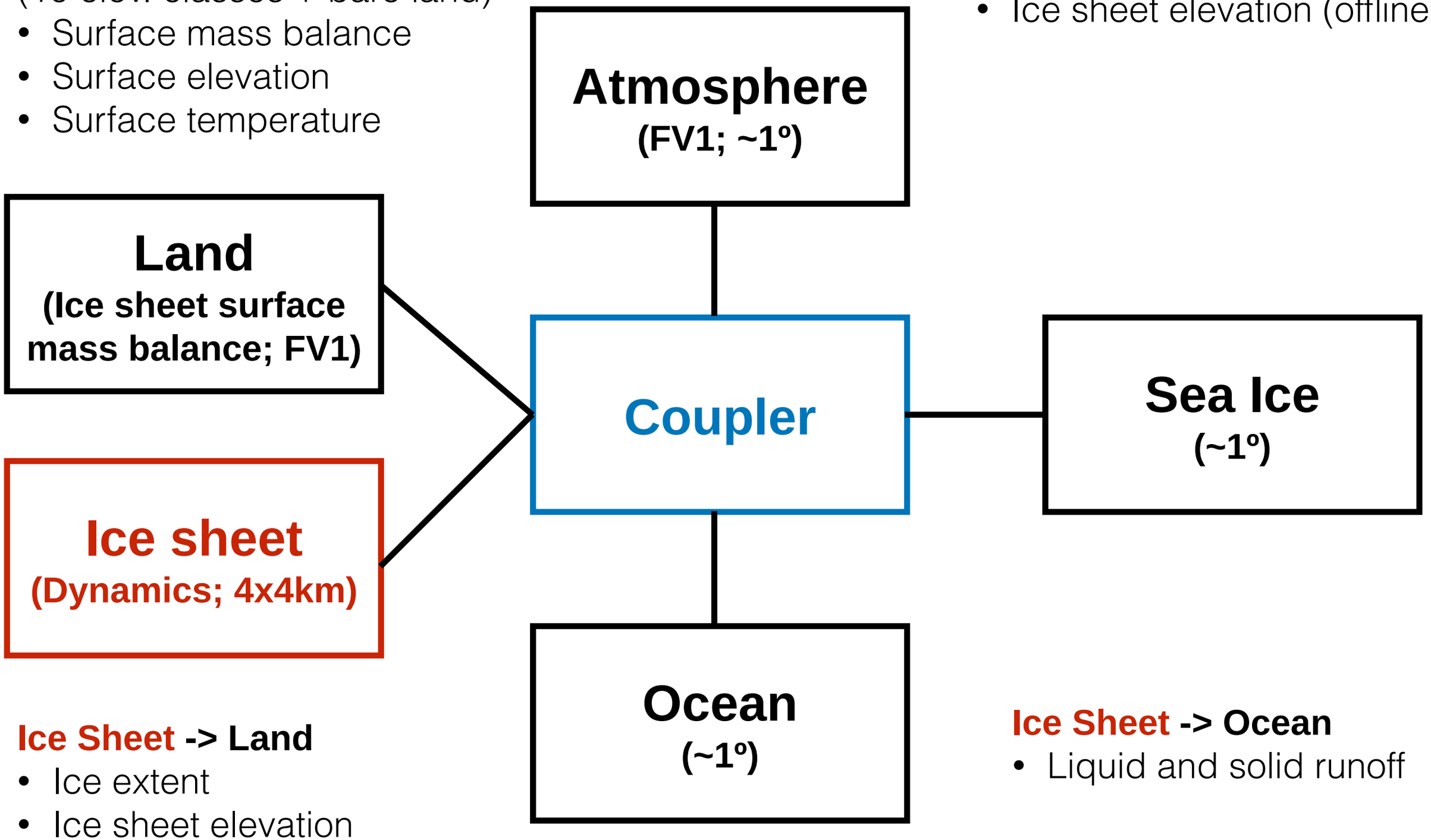
Based on geological and geomorphological evidence

Kleman et al. (2013)

Community Earth System Model 2 (CESM2)

Land -> Ice Sheet
(10 elev. classes + bare land)
- Surface mass balance
- Surface elevation
- Surface temperature

Ice Sheet -> Atmosphere
- Ice sheet elevation (offline)

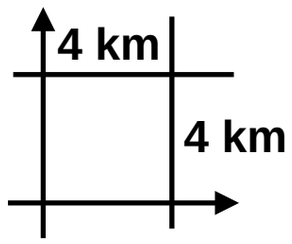


Ice Sheet -> Land
- Ice extent
- Ice sheet elevation
- SMB mask

Ice Sheet -> Ocean
- Liquid and solid runoff

Ice-sheet model grid

Greenland topography



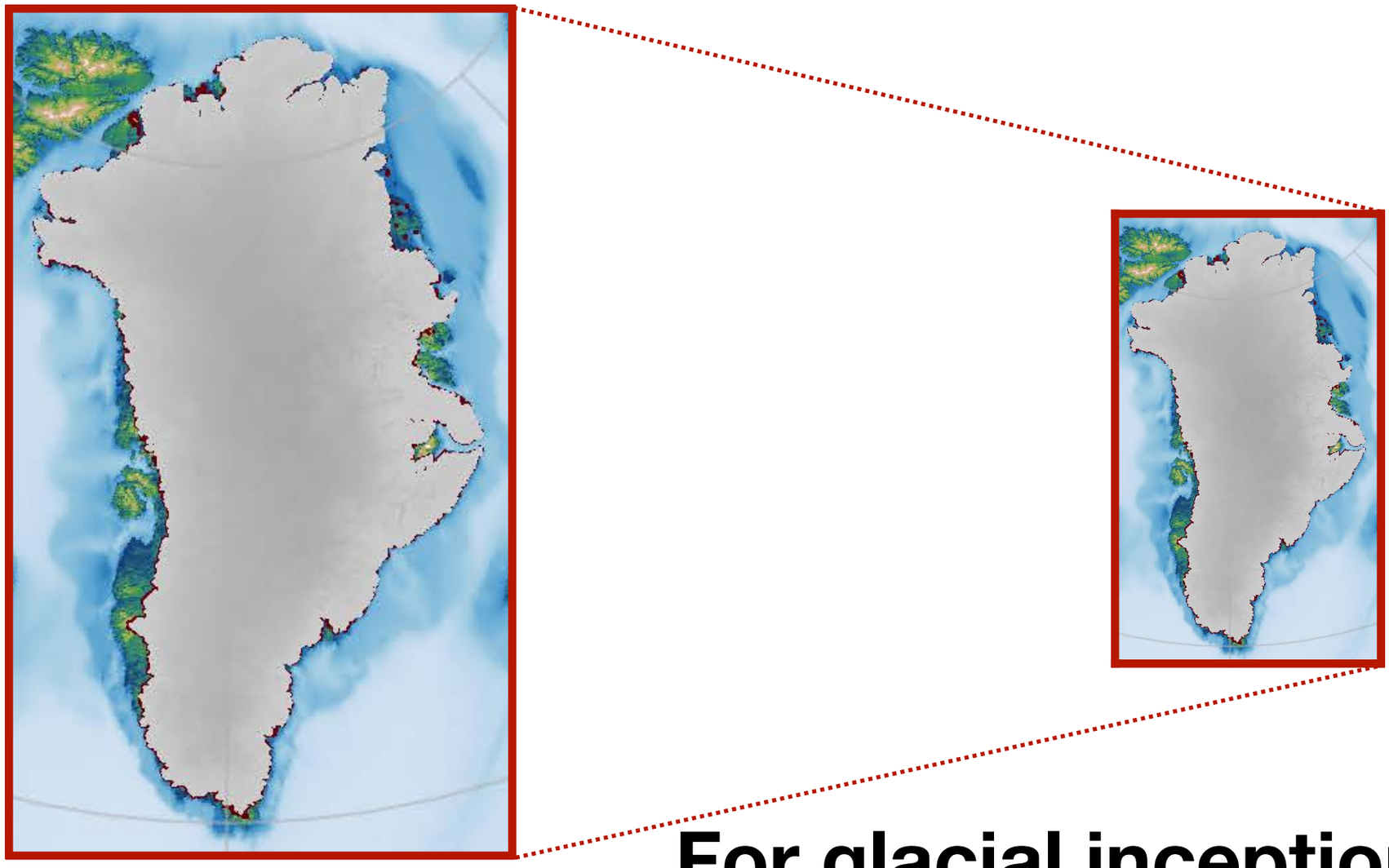
Grid spacing

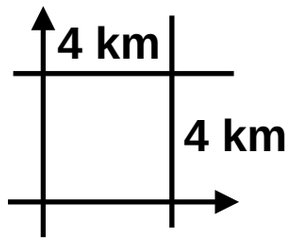
Spinup of pre-industrial climate
& Greenland ice sheet:

Lofverstrom et al. 2020, JAMES

Ice-sheet model grid

Greenland topography





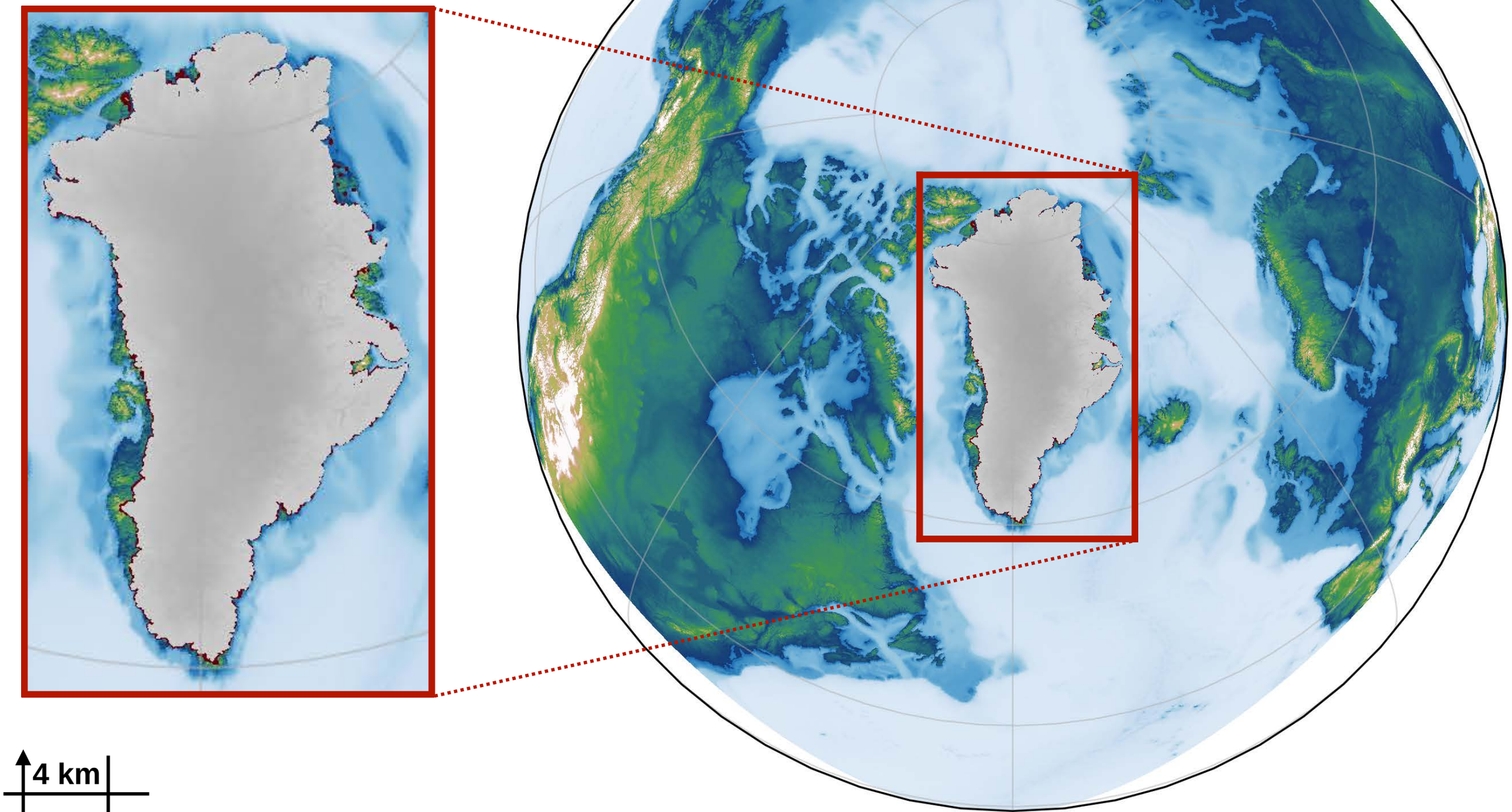
Grid spacing

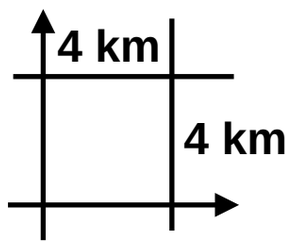
For glacial inception simulation:

- **Need a larger grid**
- **Ideally same resolution**

Ice-sheet model grid

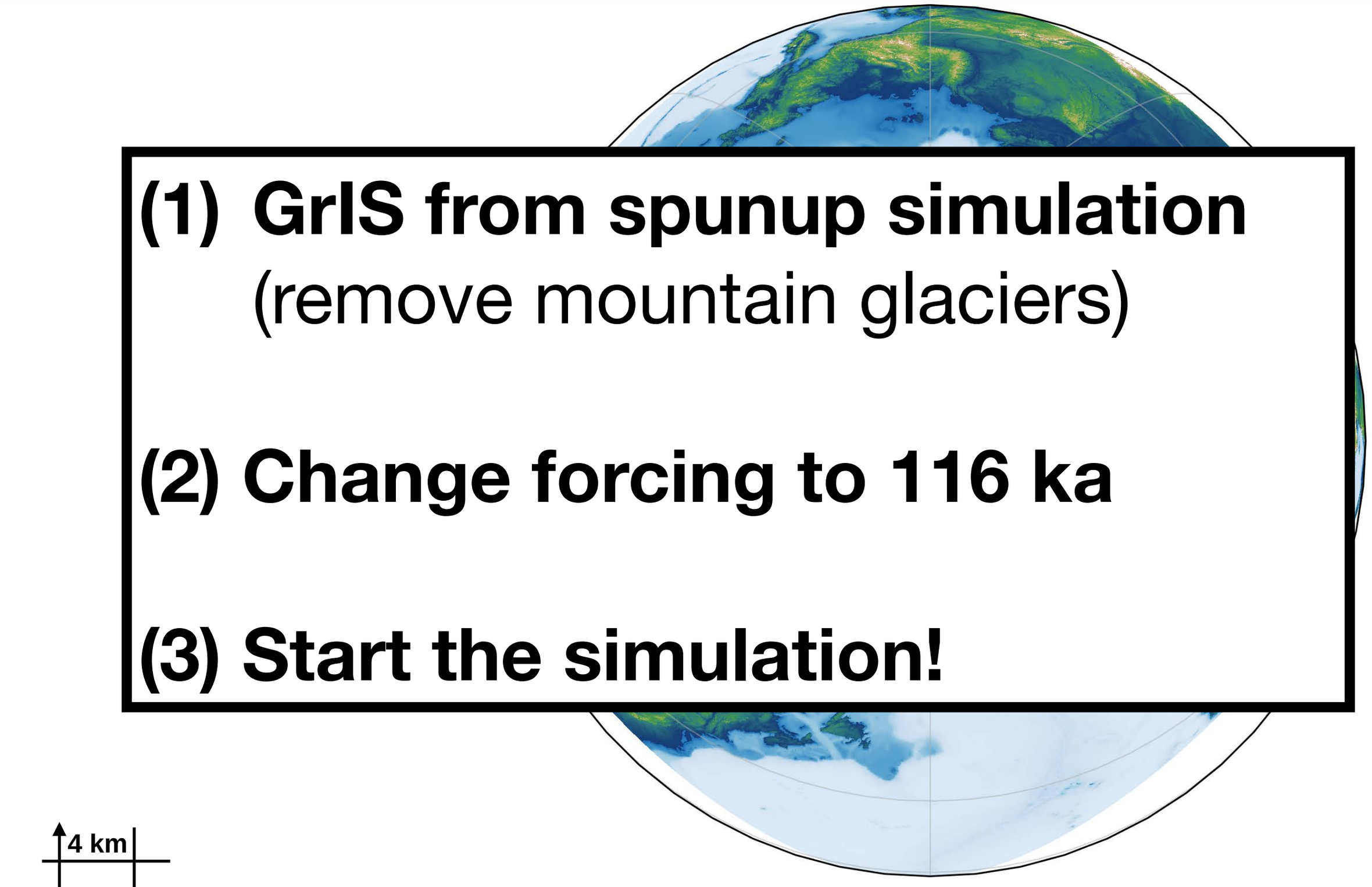
Greenland topography





Grid spacing

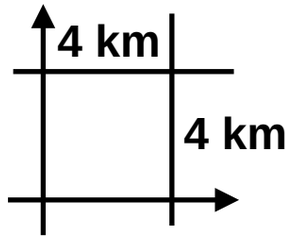
Initial condition for 116 ka simulation



(1) GrIS from spunup simulation
(remove mountain glaciers)

(2) Change forcing to 116 ka

(3) Start the simulation!

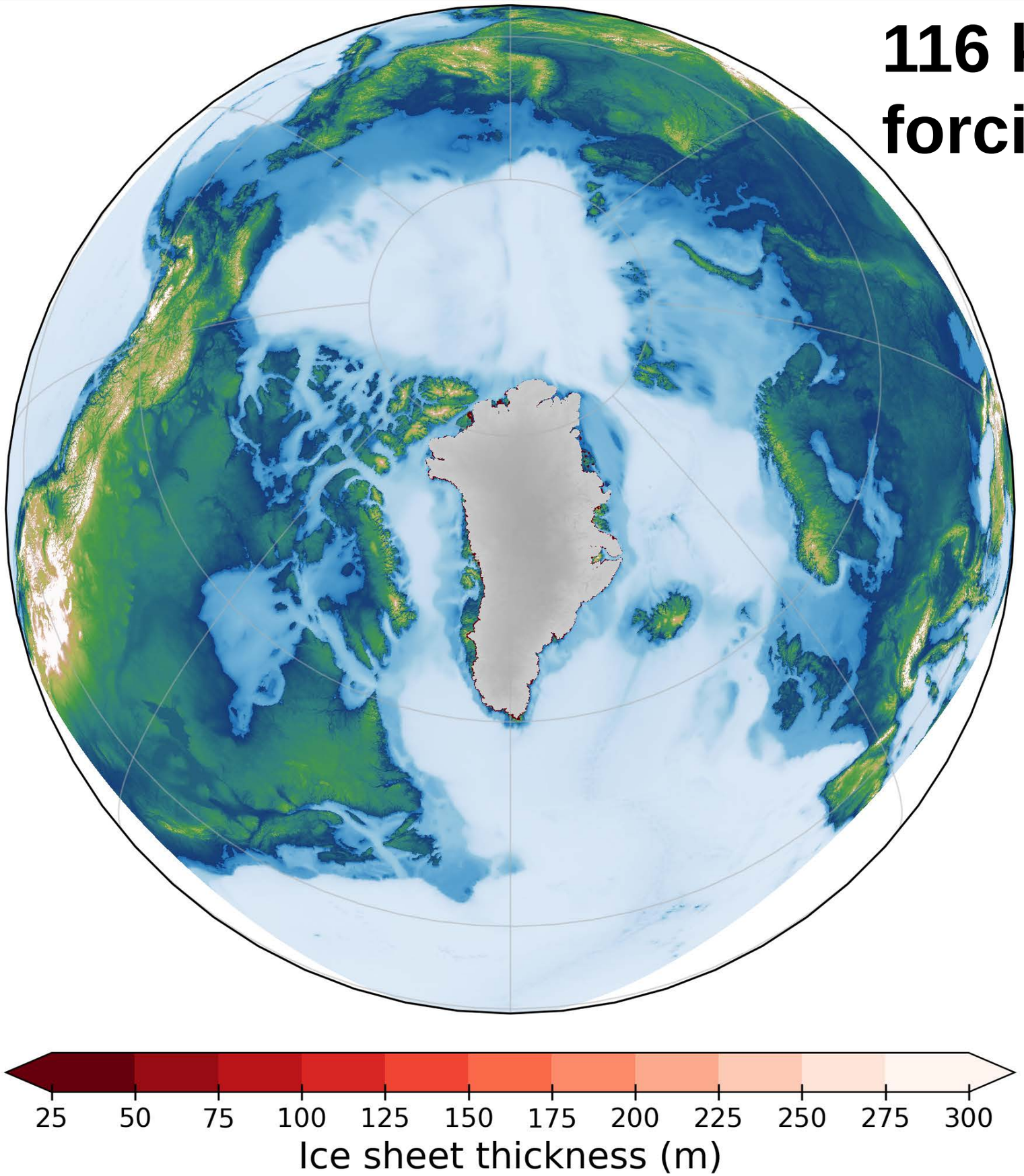


Grid spacing

0 years

Only GrIS present

116 ka forcing



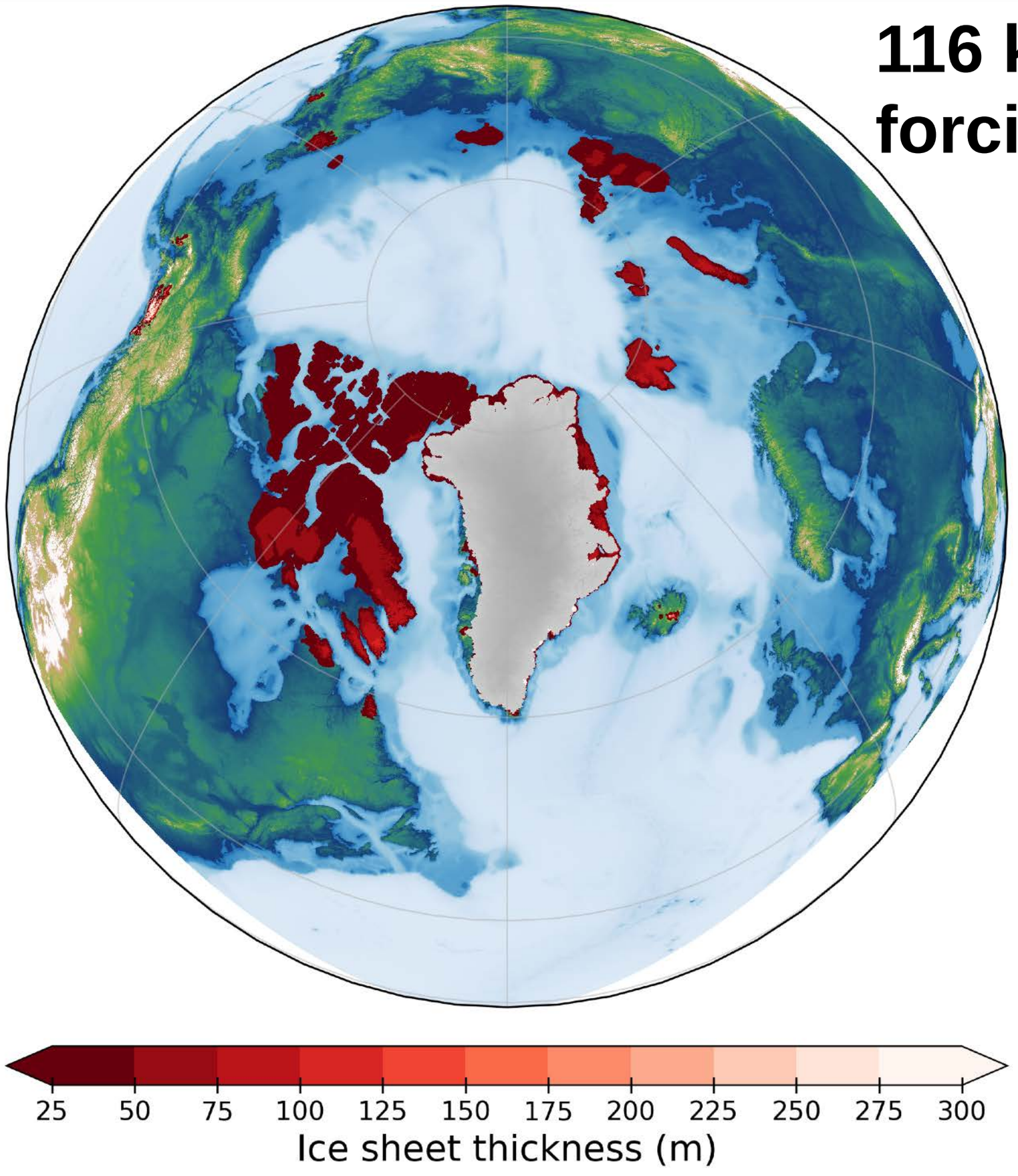
200 years

116 ka forcing

Ice sheet growing in the CAA

Ice growing on Arctic islands

Ice in highland regions of Alaska and Siberia

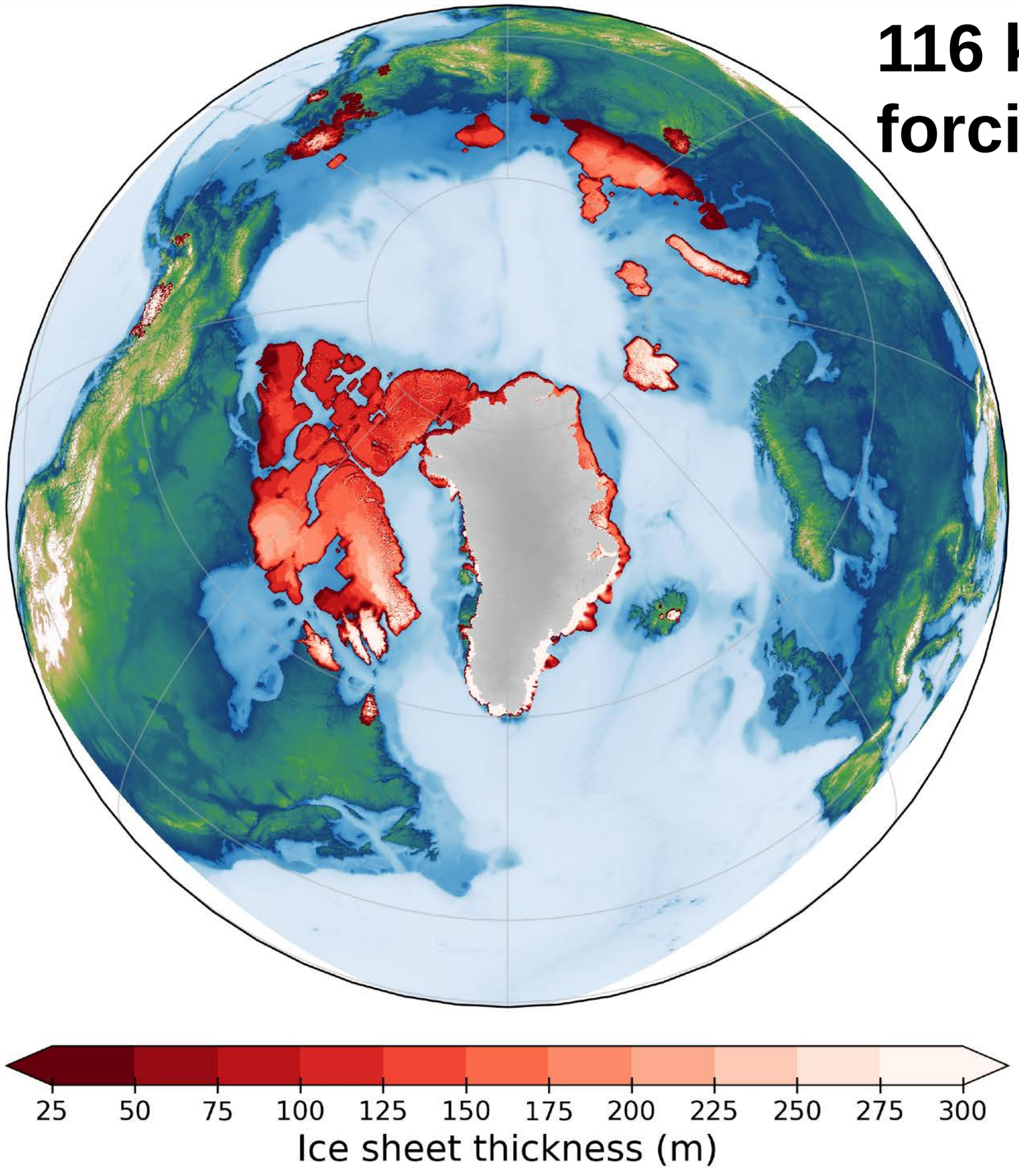


650 years

116 ka forcing

Largely the same ice distribution as before

Ice is thicker and more expansive



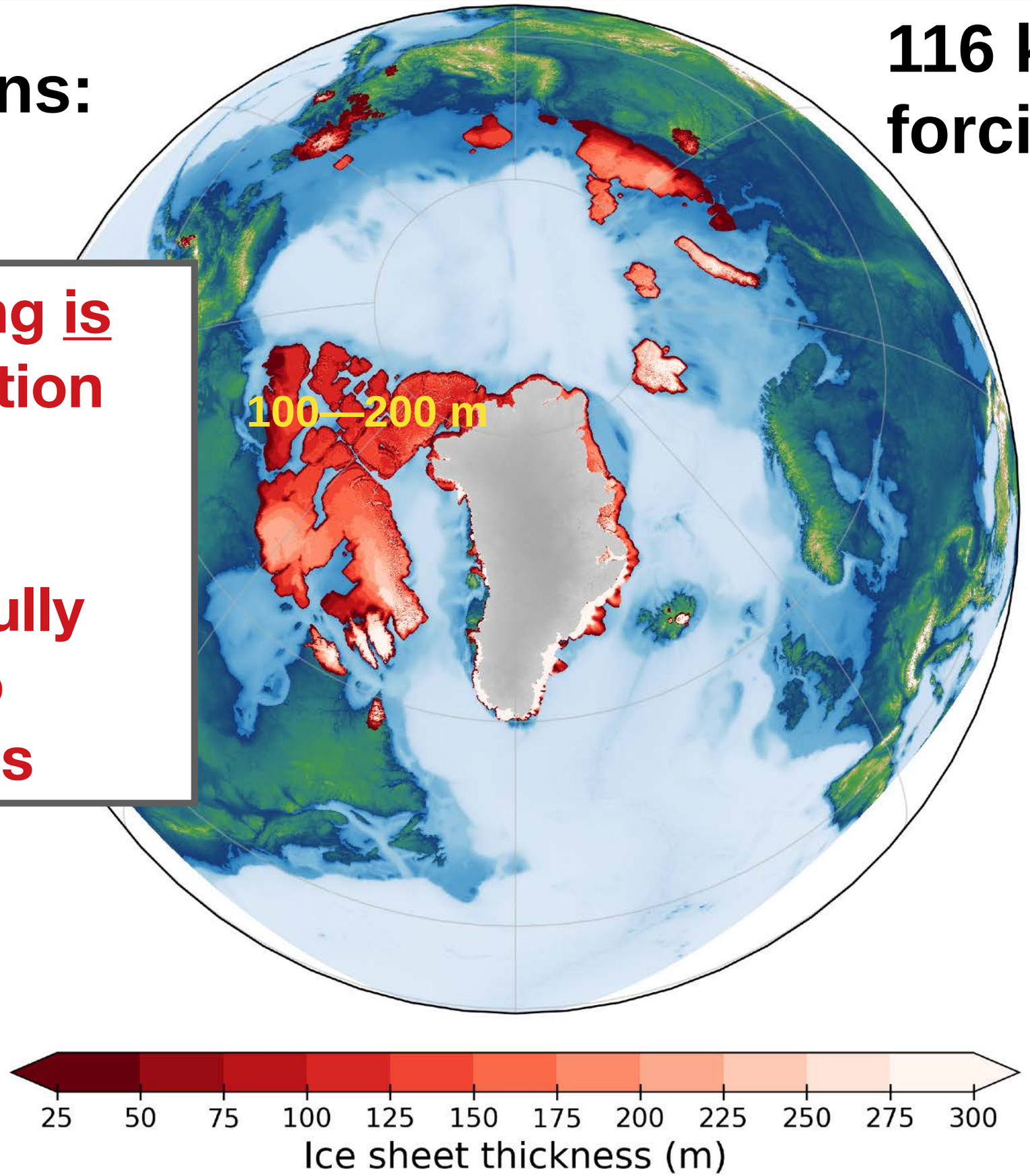
650 years

Three observations:

(1) Insolation forcing <u>is</u> sufficient for inception in Canada

(2) CAA is almost fully ice covered — also between the islands

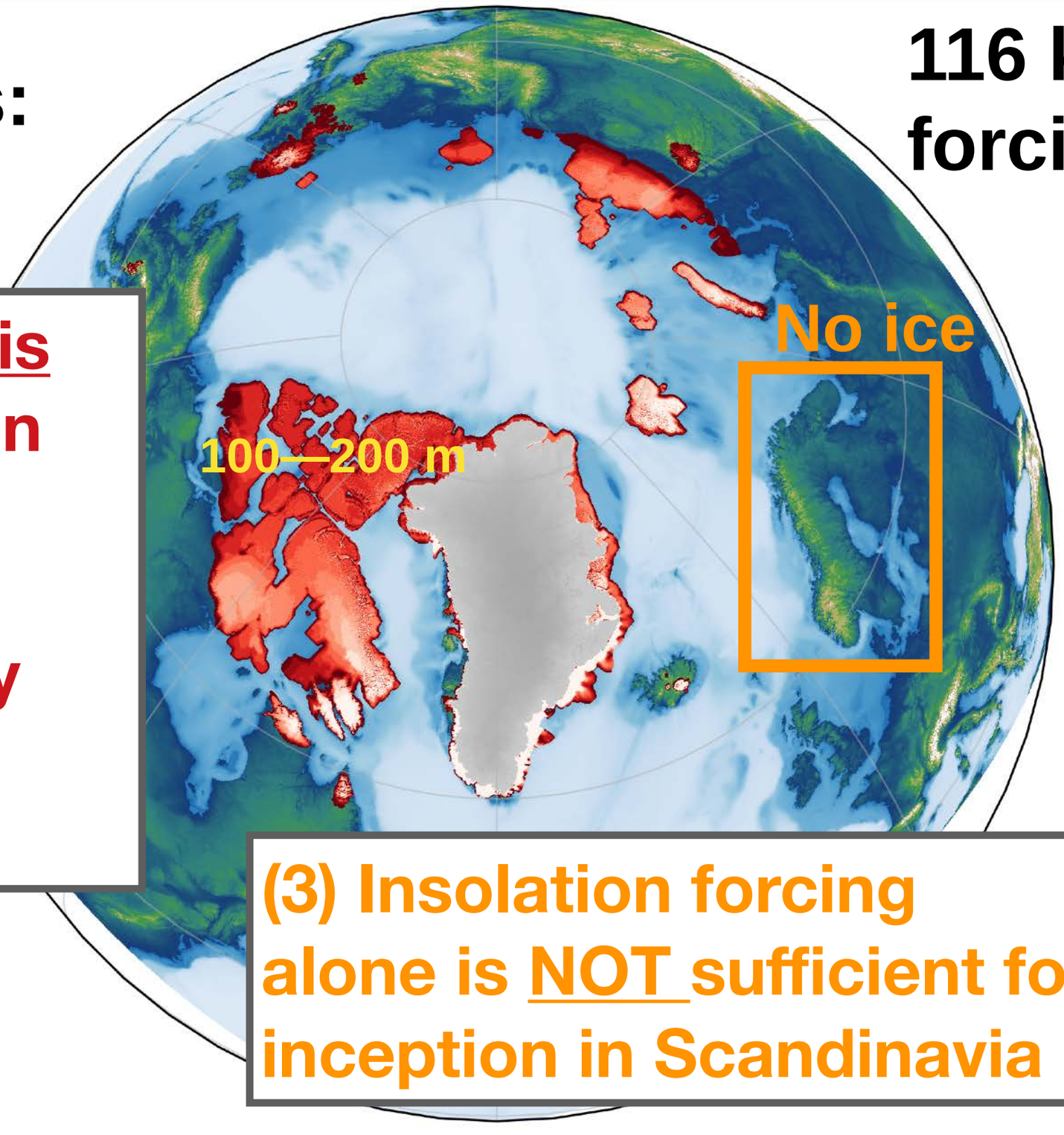
116 ka forcing



650 years

Three observations:

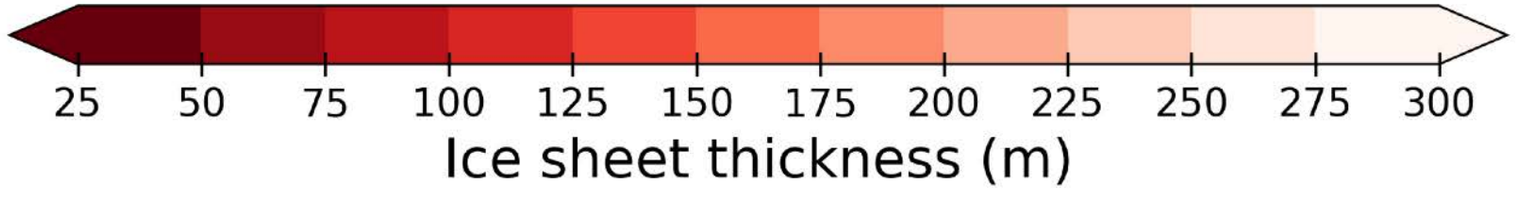
116 ka forcing



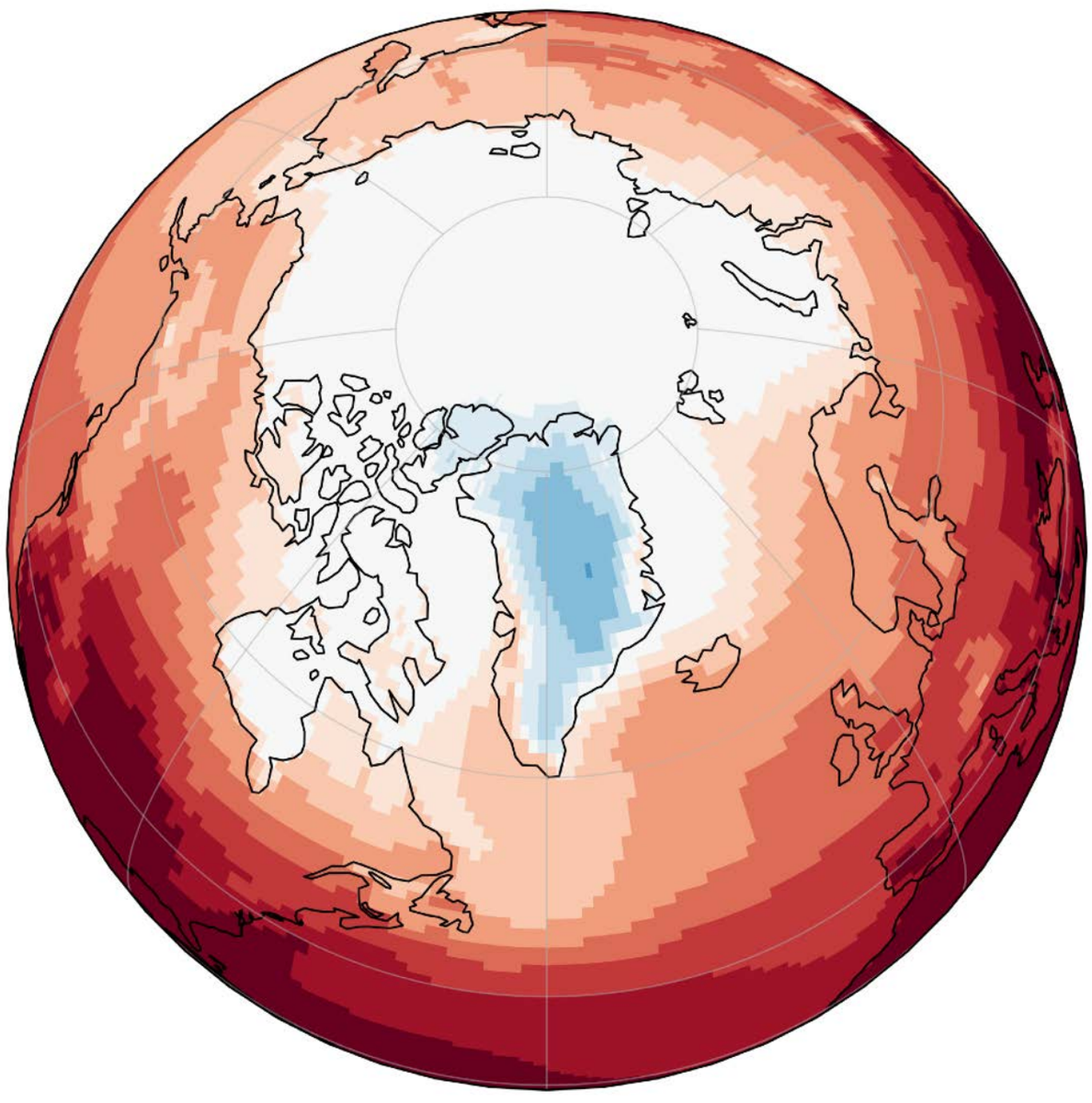
(1) Insolation forcing is sufficient for inception in Canada

(2) CAA is almost fully ice covered — also between the islands

(3) Insolation forcing alone is NOT sufficient for inception in Scandinavia



June-August surface temperature

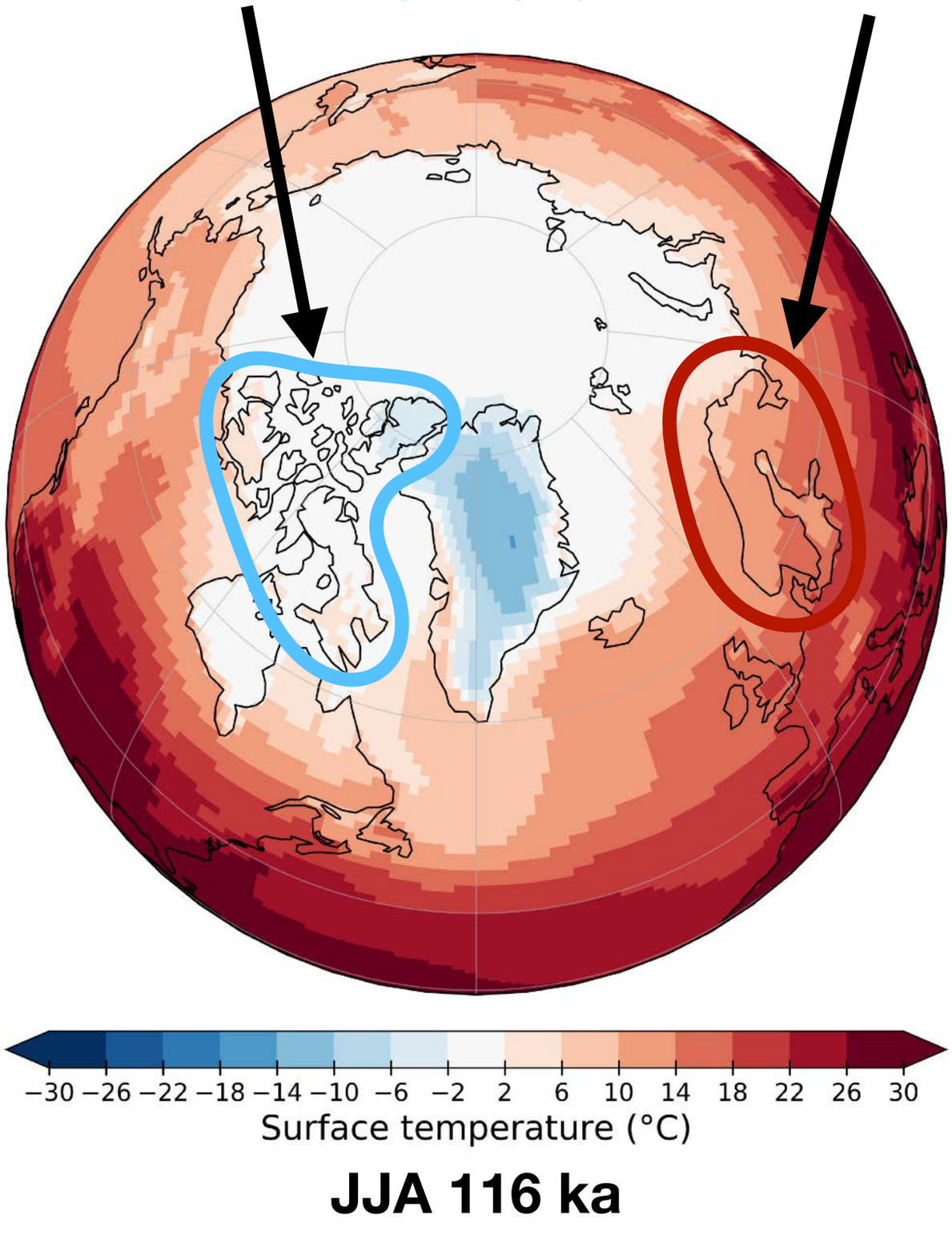


JJA 116 ka

June-August surface temperature

N. Canada is cold (favorable for inception)

Scandinavia is comp. warm! (not favorable for inception)



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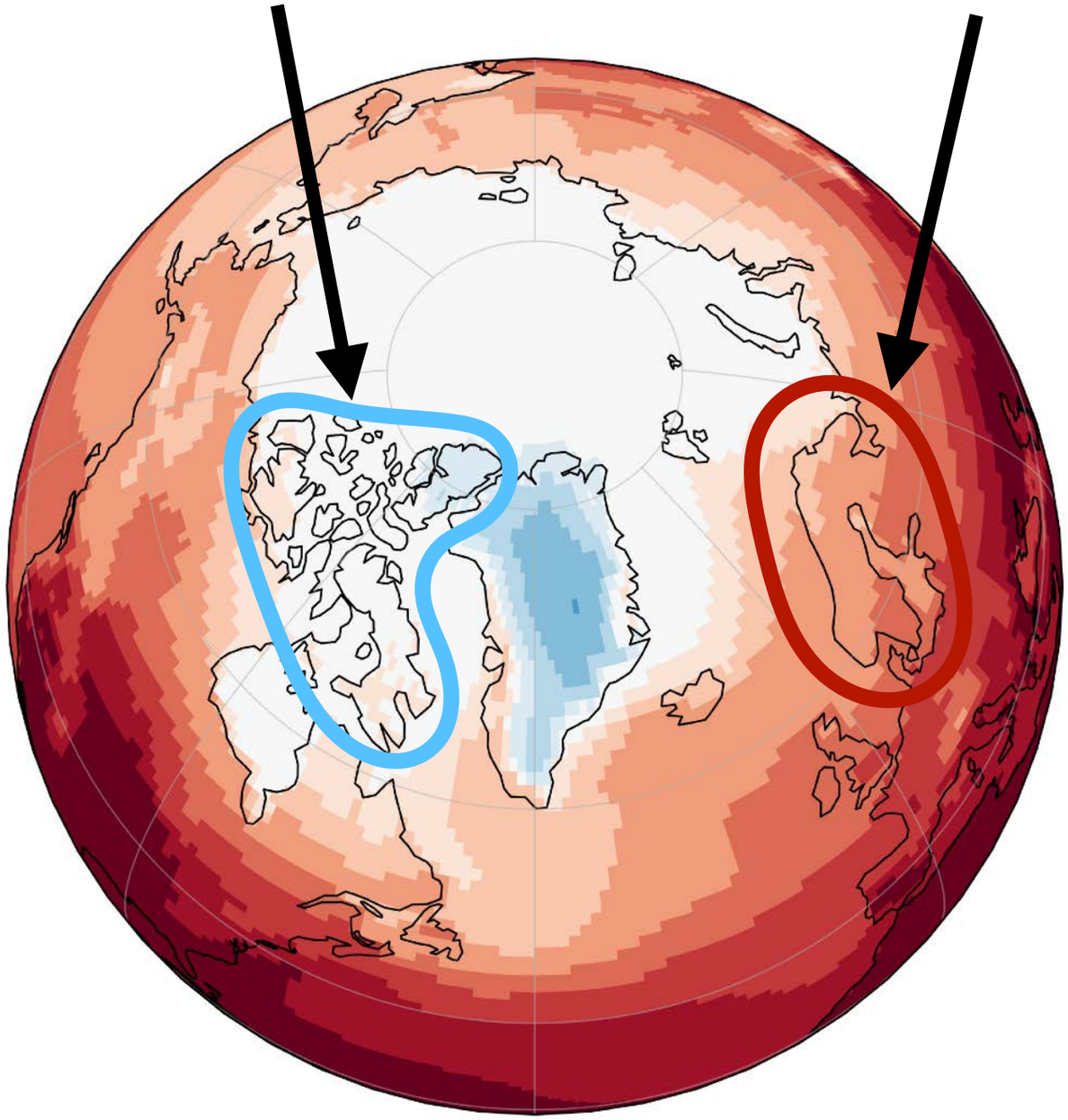
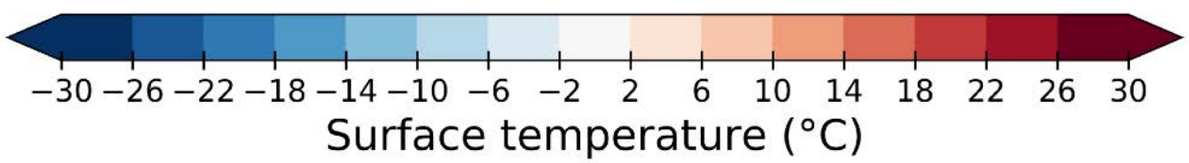
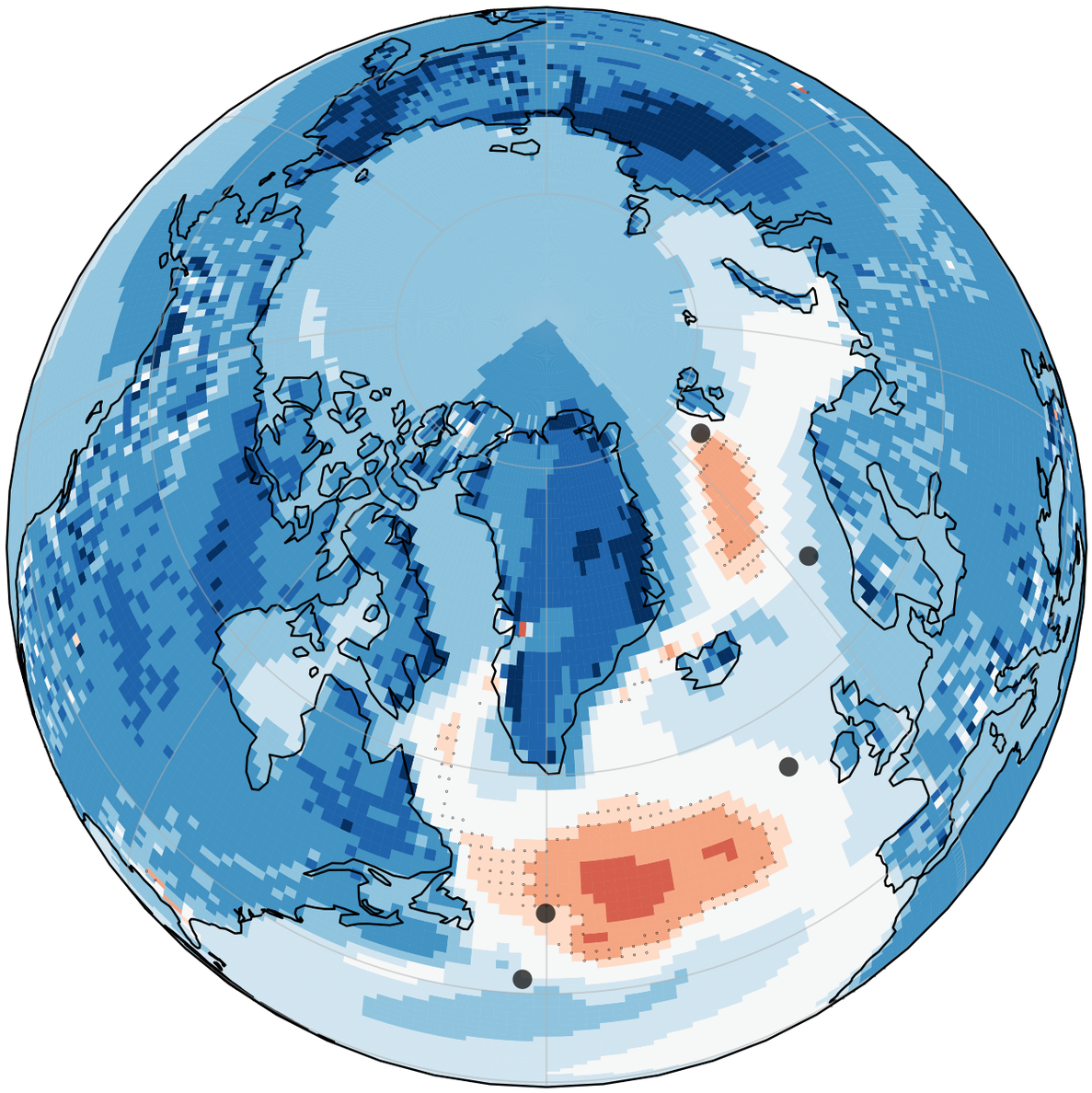
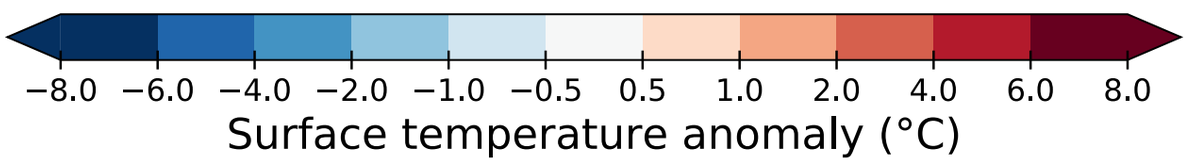




JJA 116 ka



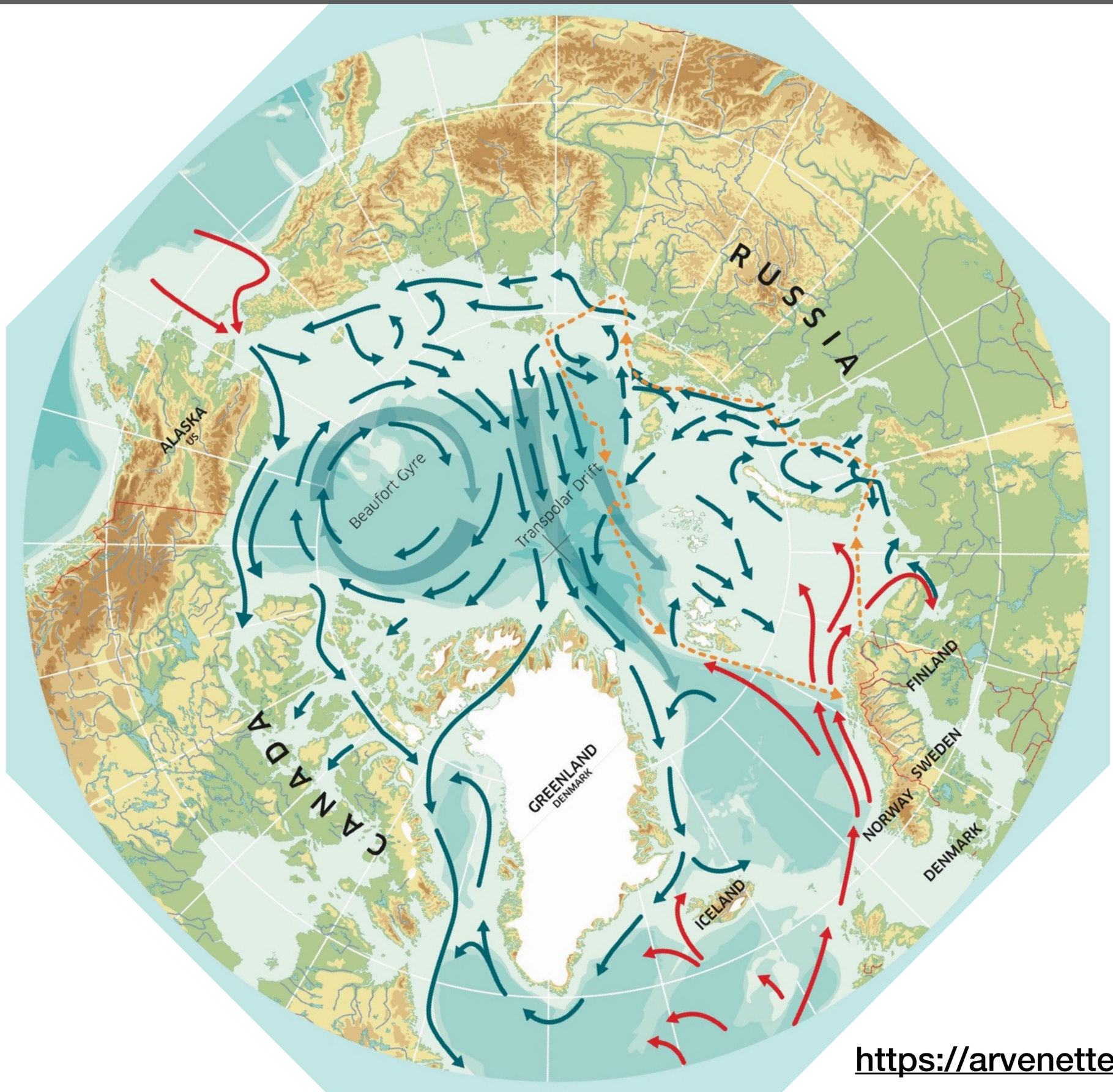


JJA 116 ka — piControl

Missing feedbacks?

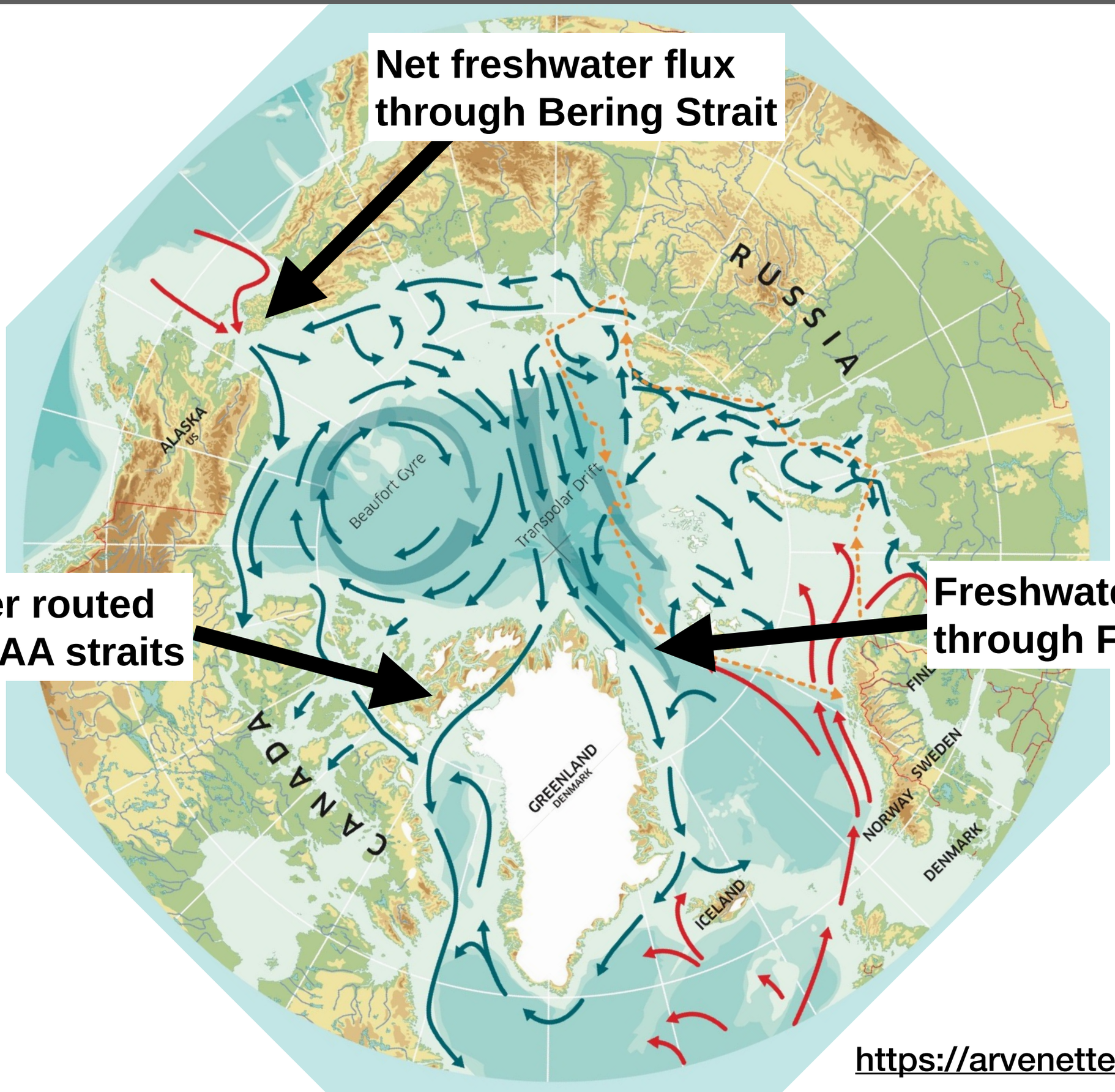
What about ocean straits in the Canadian Arctic archipelago?

Arctic currents



https://arvenetternansen.com/

Arctic currents



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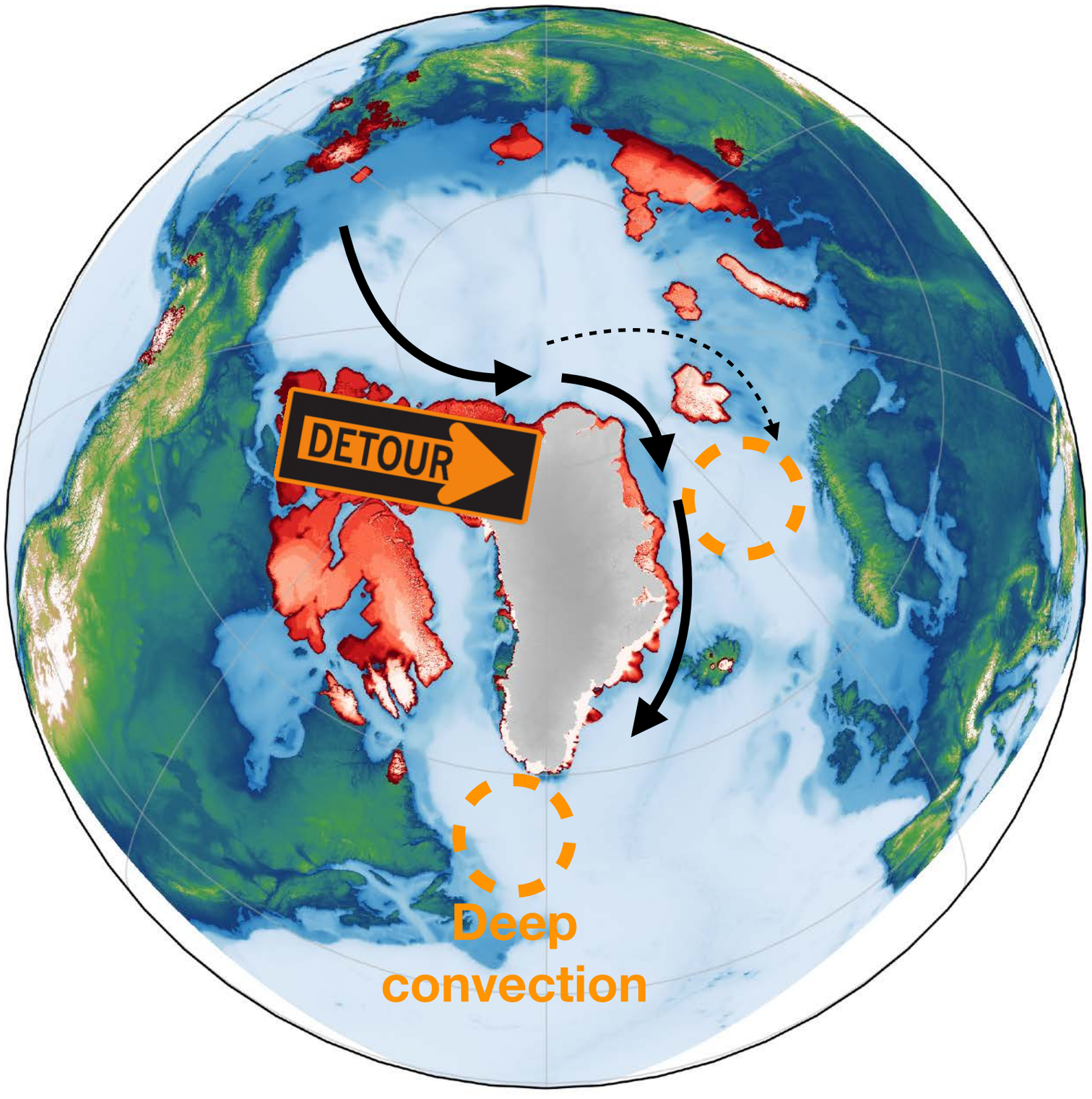
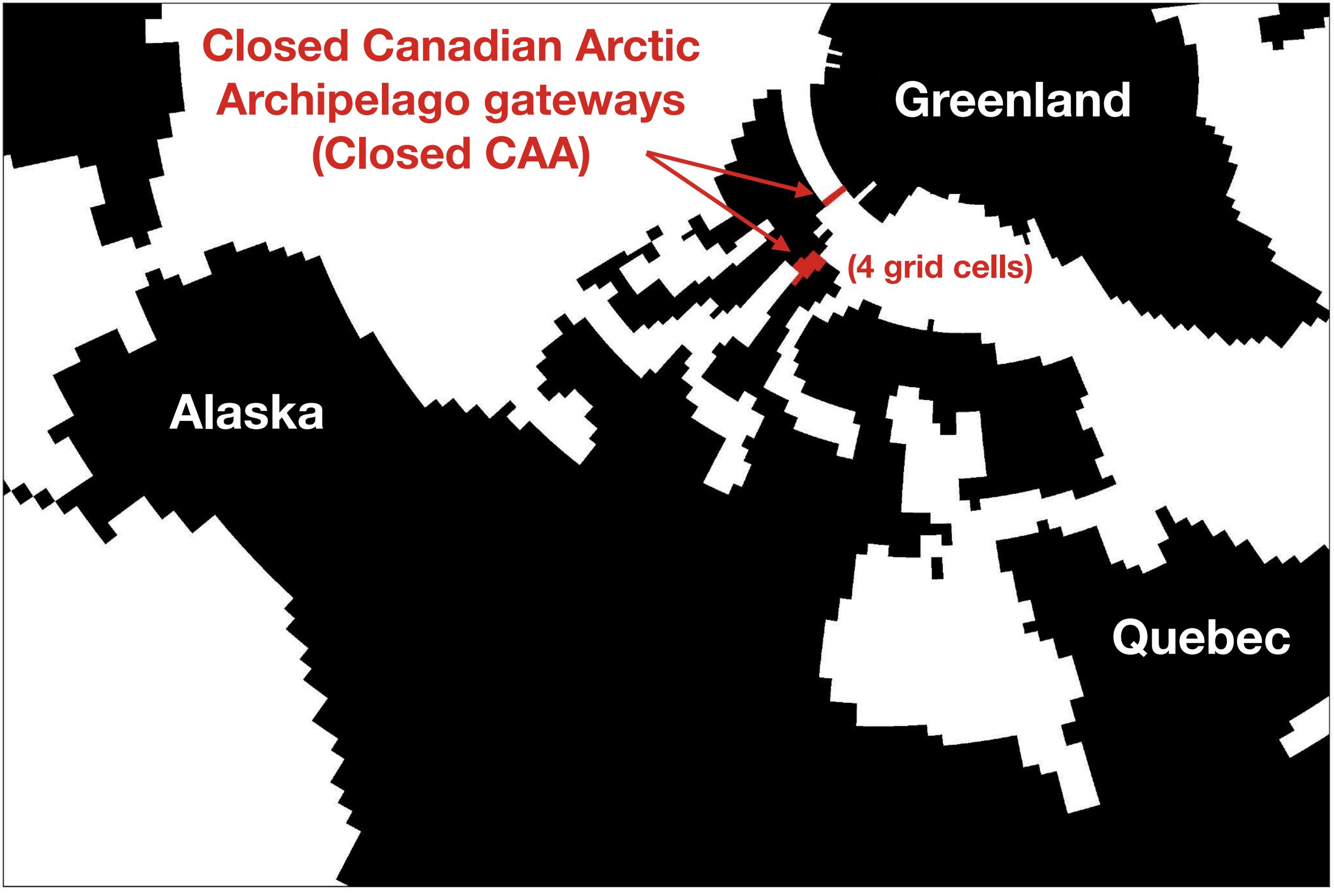
Freshwater routed east of Greenland



Canadian archipelago in the model (modified)



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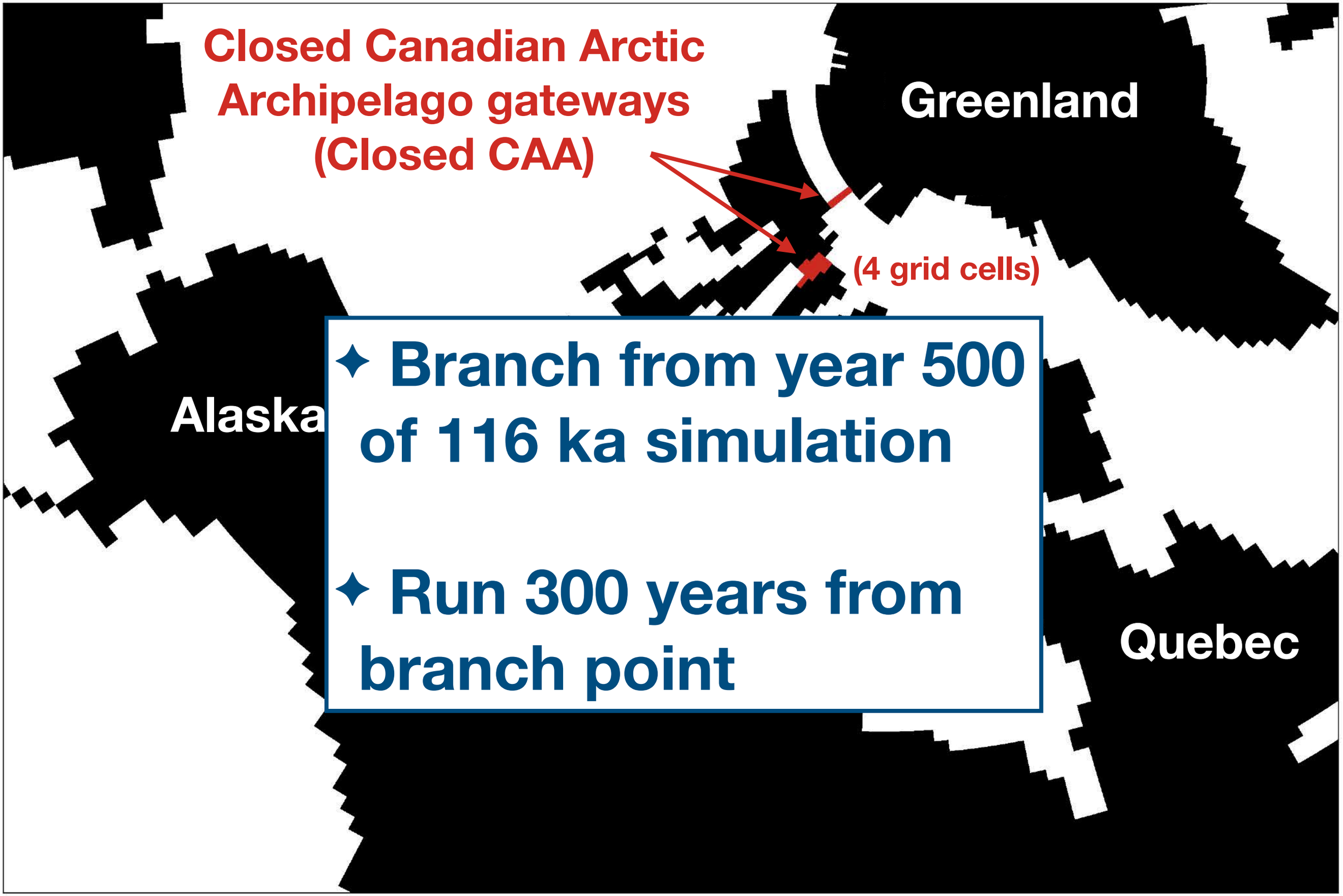
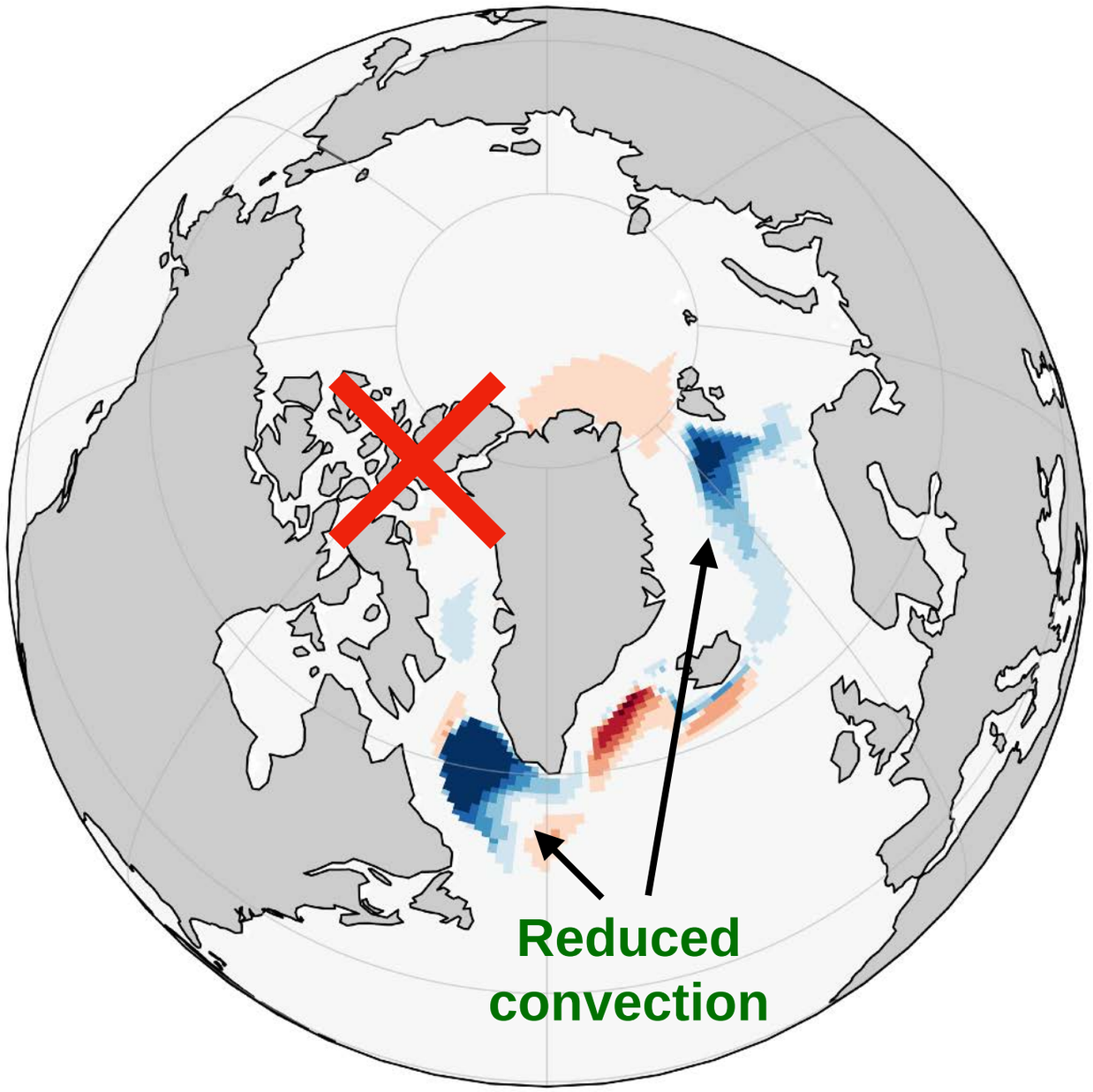
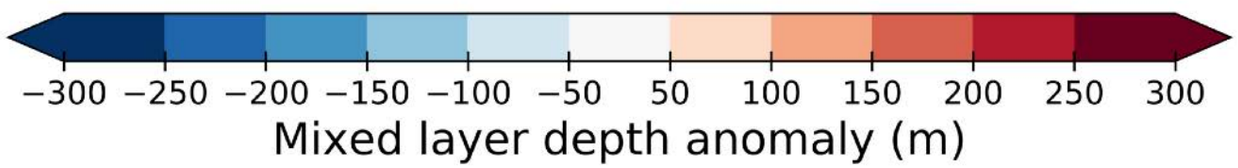


Deep convection and surface temperature

Mixed layer depth

Closed CAA —116 ka

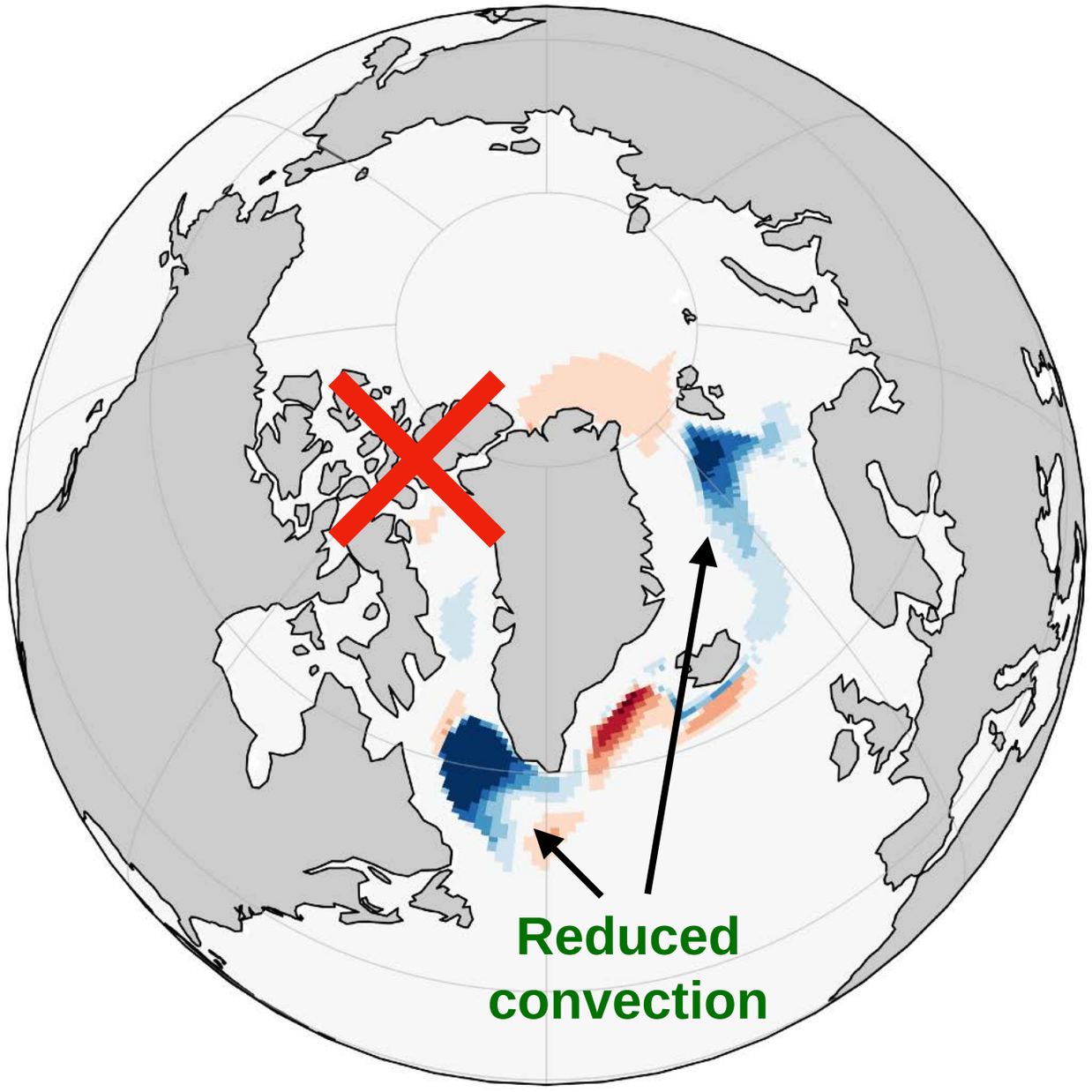




- **Weaker high-lat branch of AMOC**
- **Reduced polar heat transport**

Deep convection and surface temperature

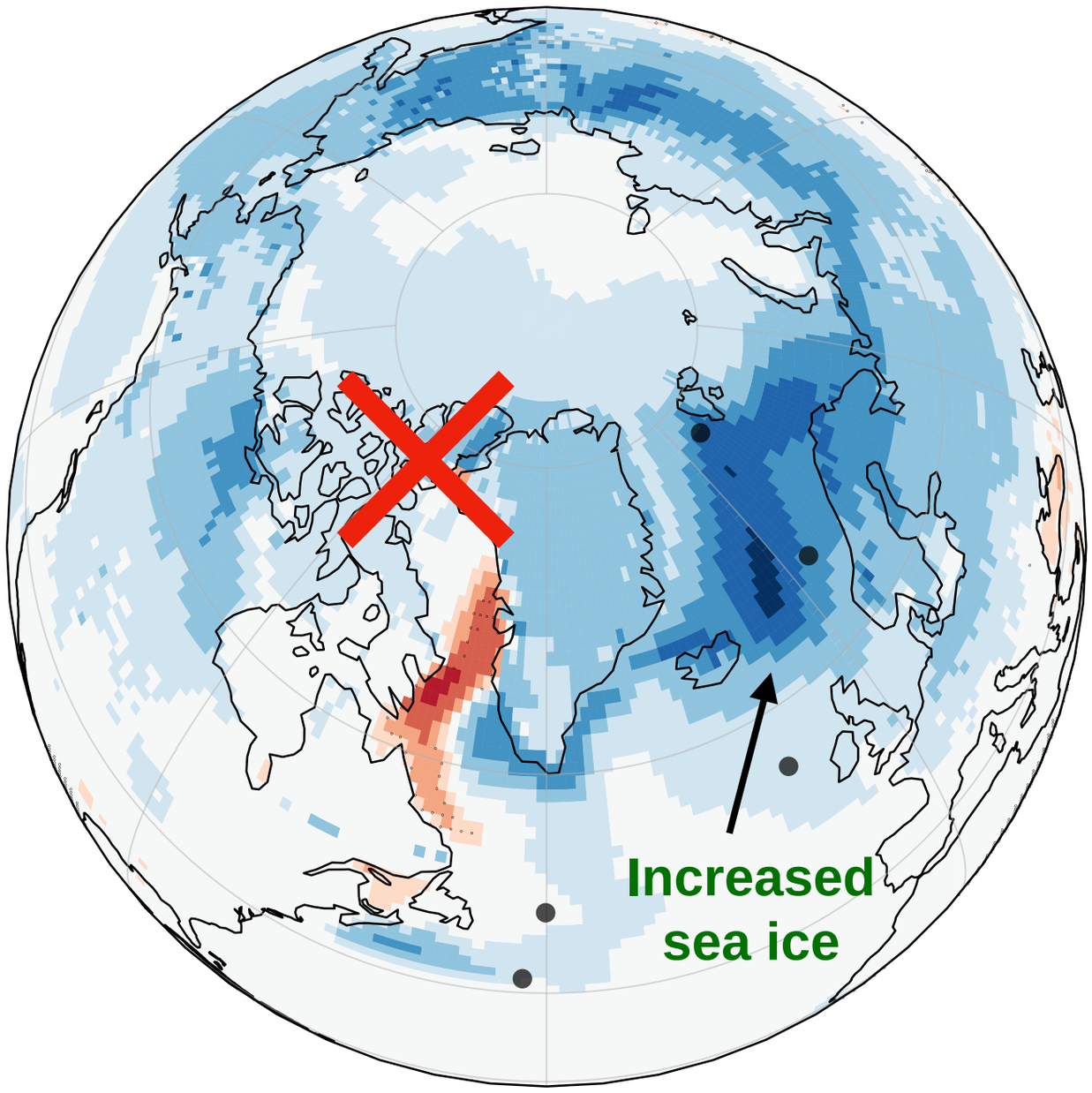
Mixed layer depth
Closed CAA —116 ka



−300 −250 −200 −150 −100 −50 50 100 150 200 250 300

Mixed layer depth anomaly (m)

JJA surface temperature
Closed CAA —116 ka

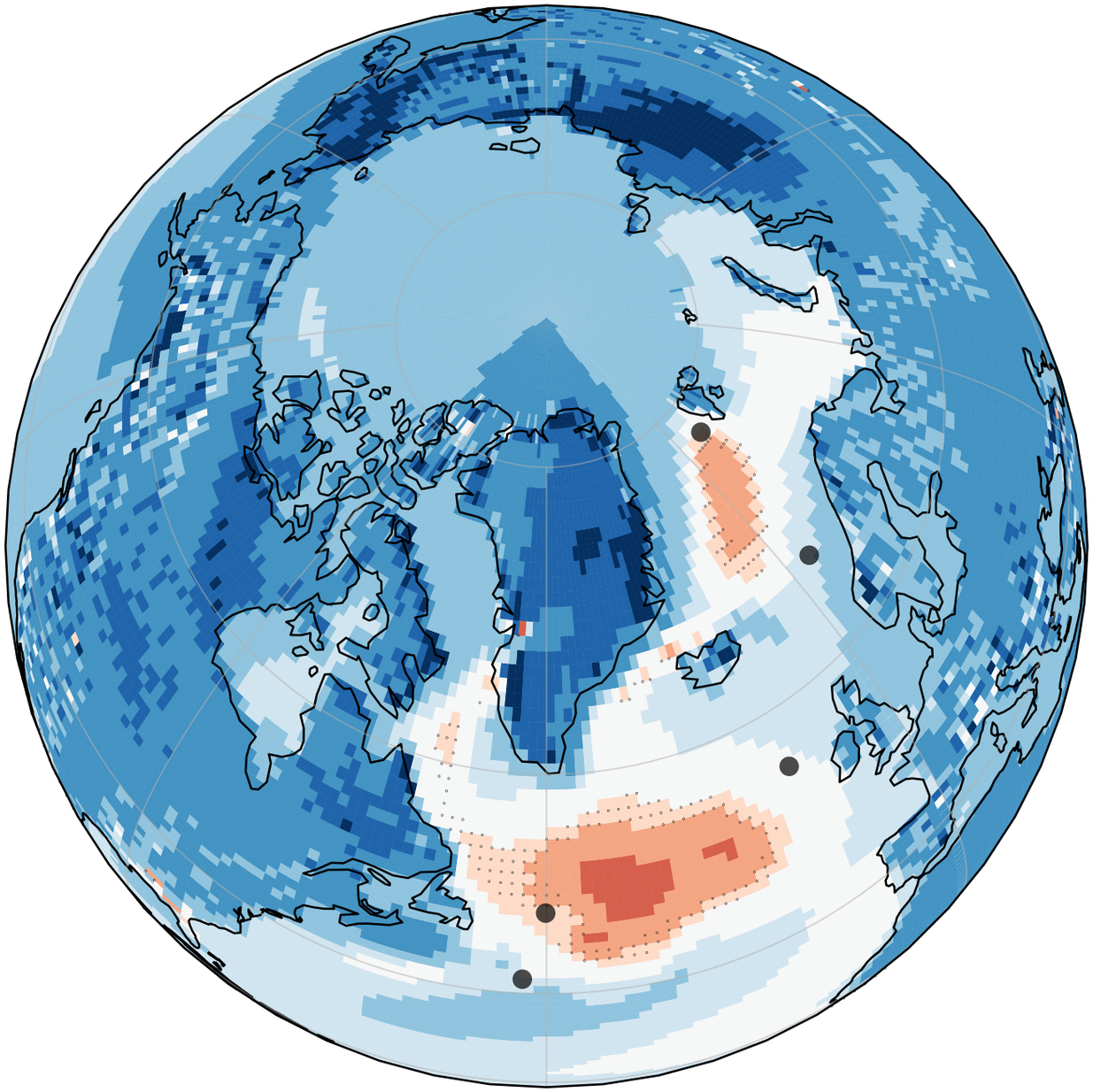


−8.0 −6.0 −4.0 −2.0 −1.0 −0.5 0.5 1.0 2.0 4.0 6.0 8.0

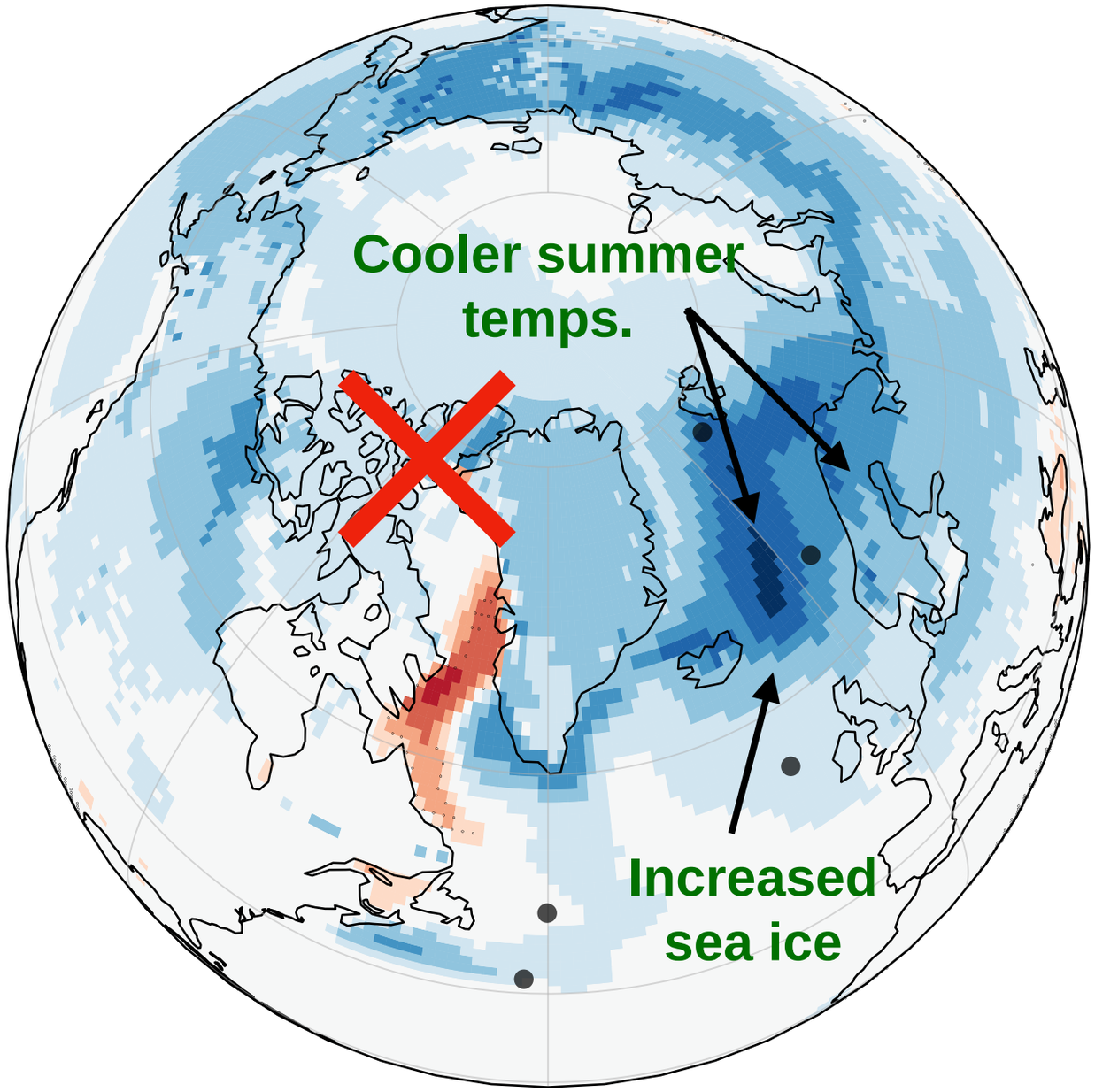
Surface temperature anomaly (°C)

Deep convection and surface temperature

JJA surface temperature
116 ka (open CAA) —piControl



JJA surface temperature
Closed CAA —116 ka



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Surface temperature anomaly (°C)

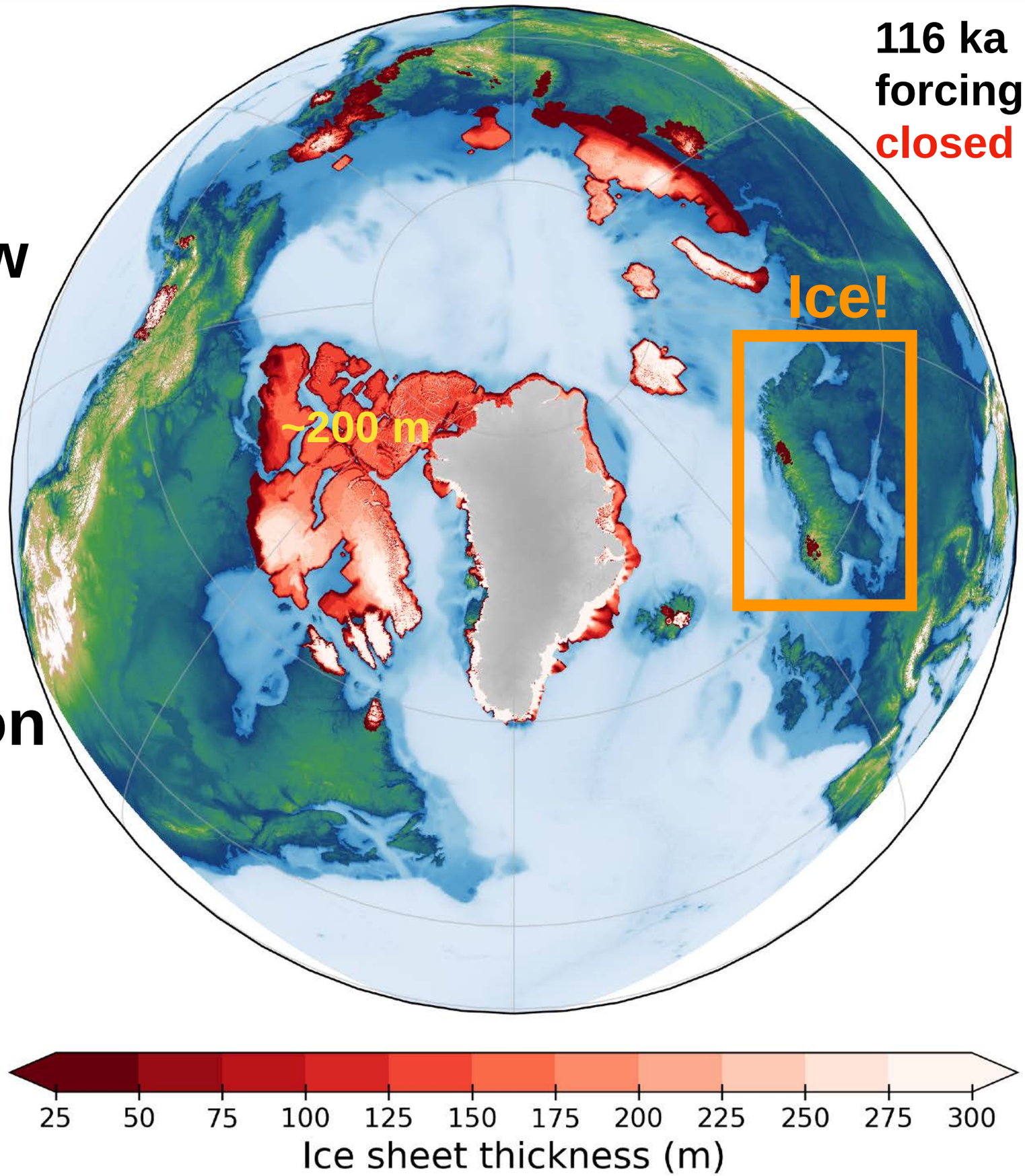
−8.0 −6.0 −4.0 −2.0 −1.0 −0.5 0.5 1.0 2.0 4.0 6.0 8.0

Surface temperature anomaly (°C)

Branch from year 500 + 315 years

Ice starting to grow in Scandinavia

Ice coverage broadly similar to 116 ka simulation

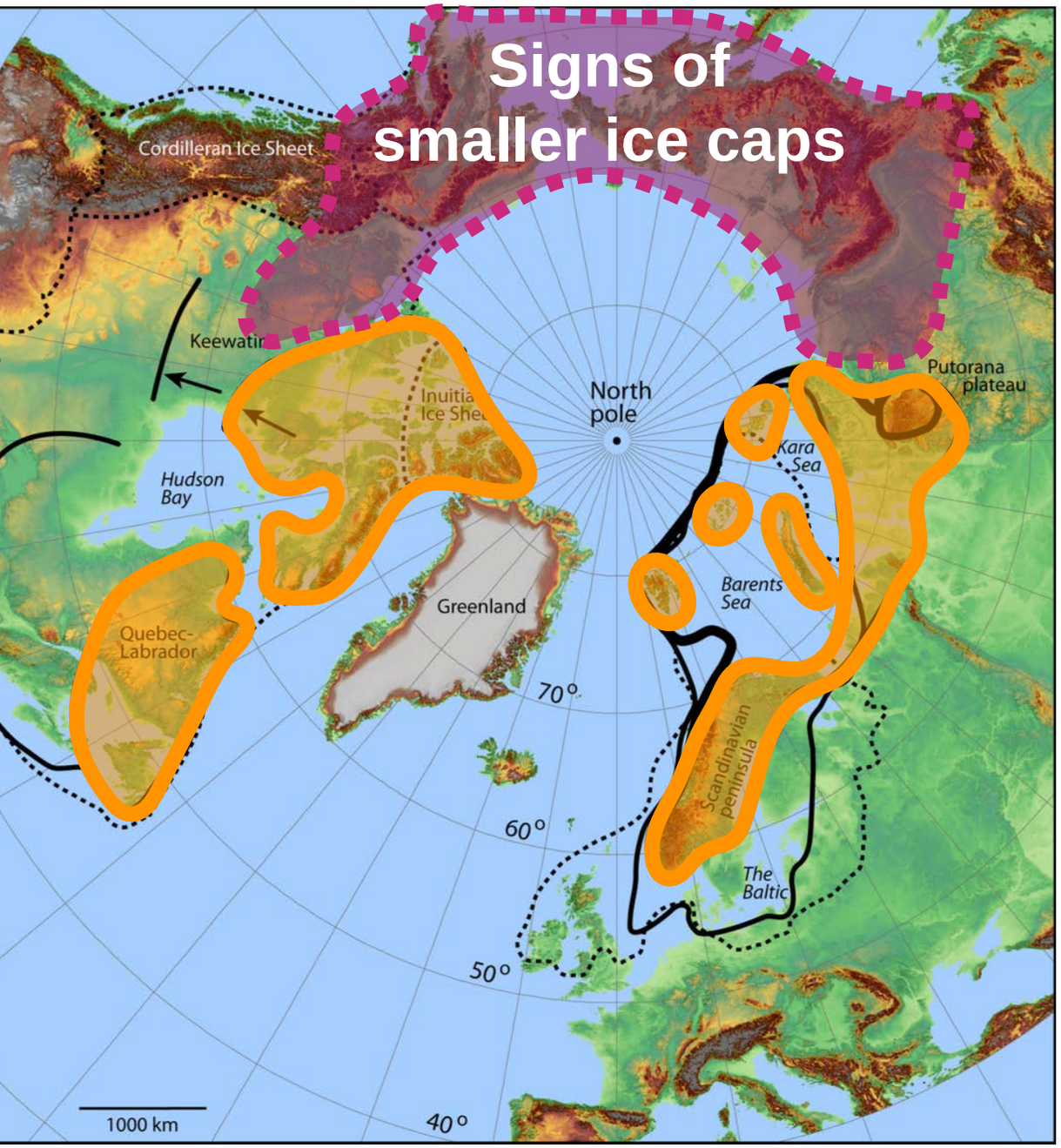


Inception areas

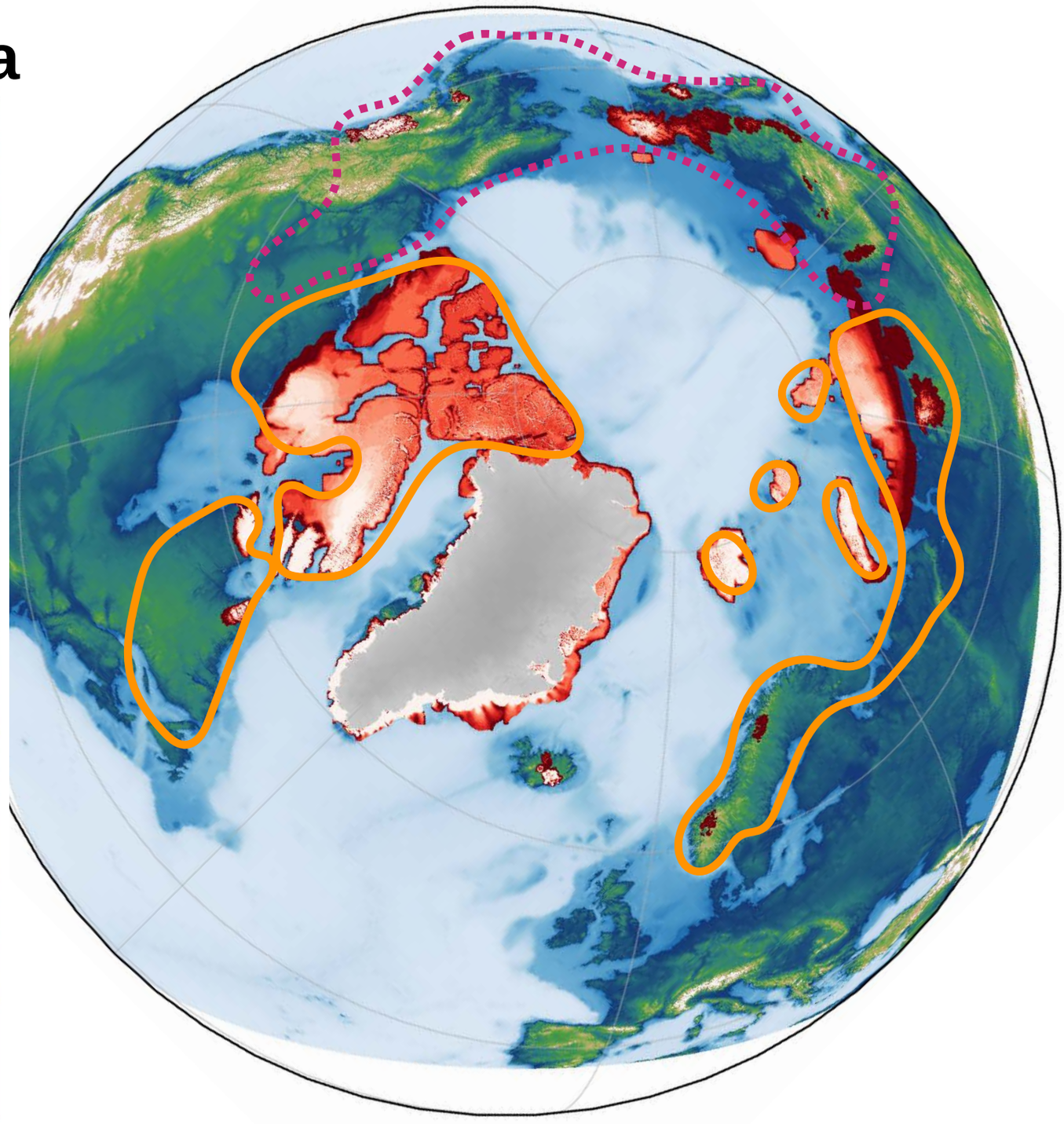
Probably no widespread inception

Probable inception areas

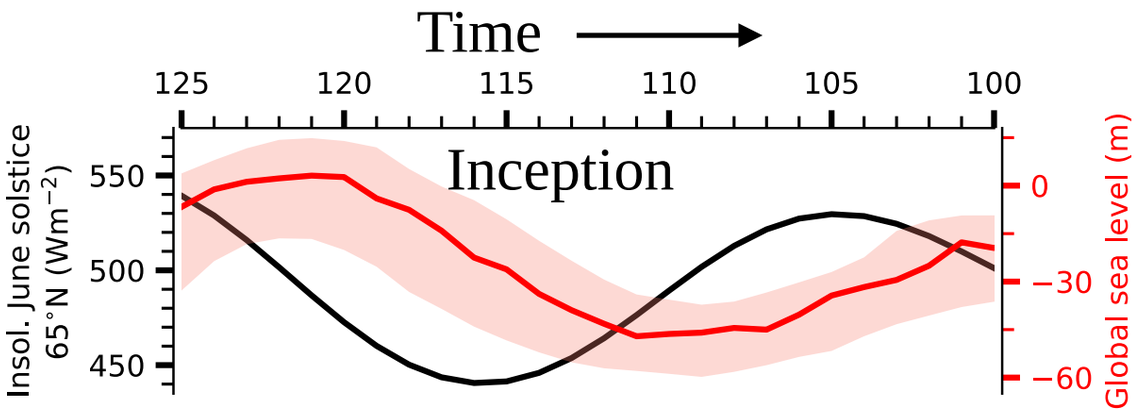
Inferred from data



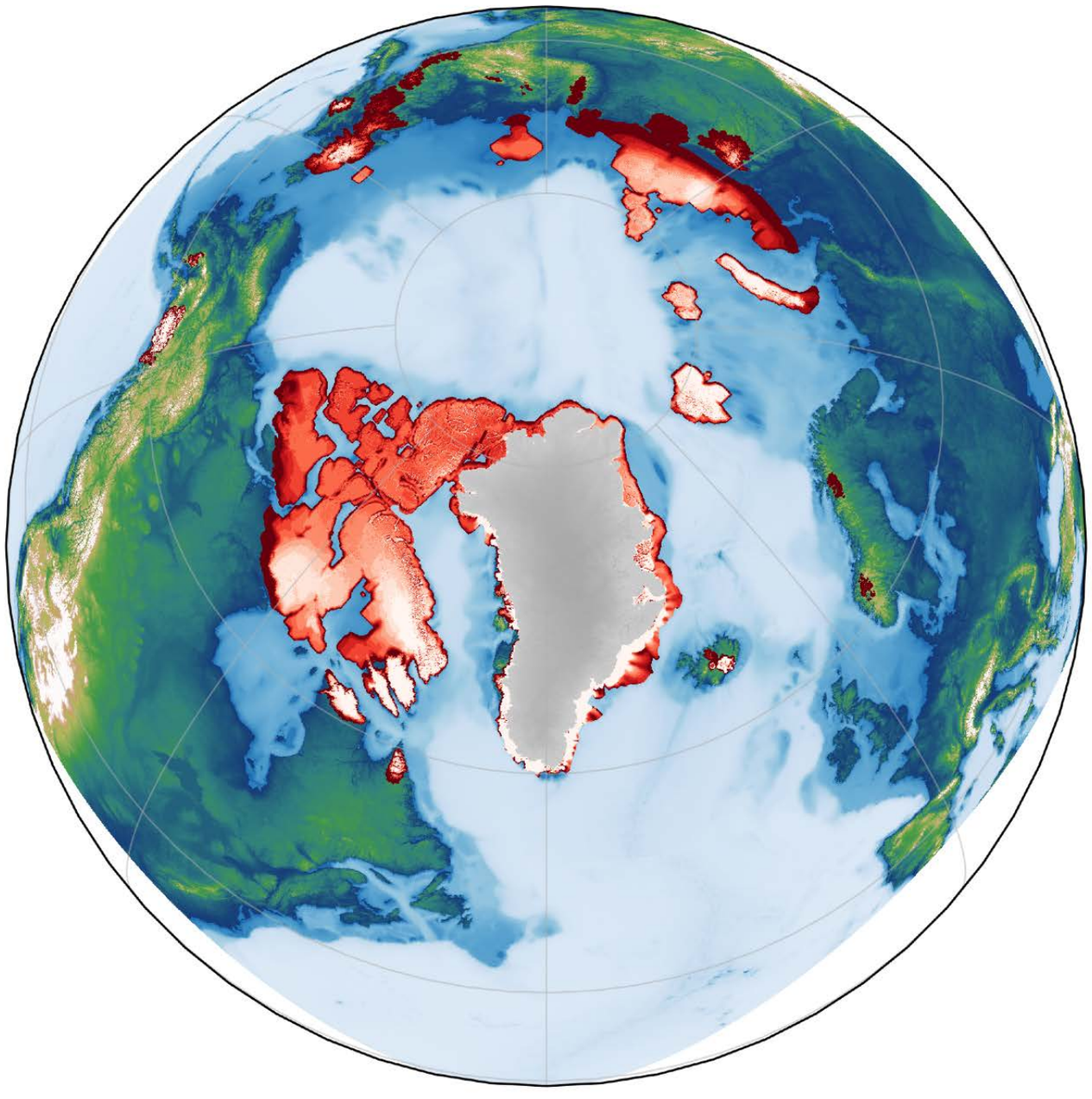
Simulated



Kleman et al. (2013)



Proxy data evidence



- **IRDs in W North Atl. before E North Atl.**
- **Time delayed IRDs in Norwegian Sea and off the British Isles**
- **Proxy data suggest that inception in Scandinavia was later than in the other locations**

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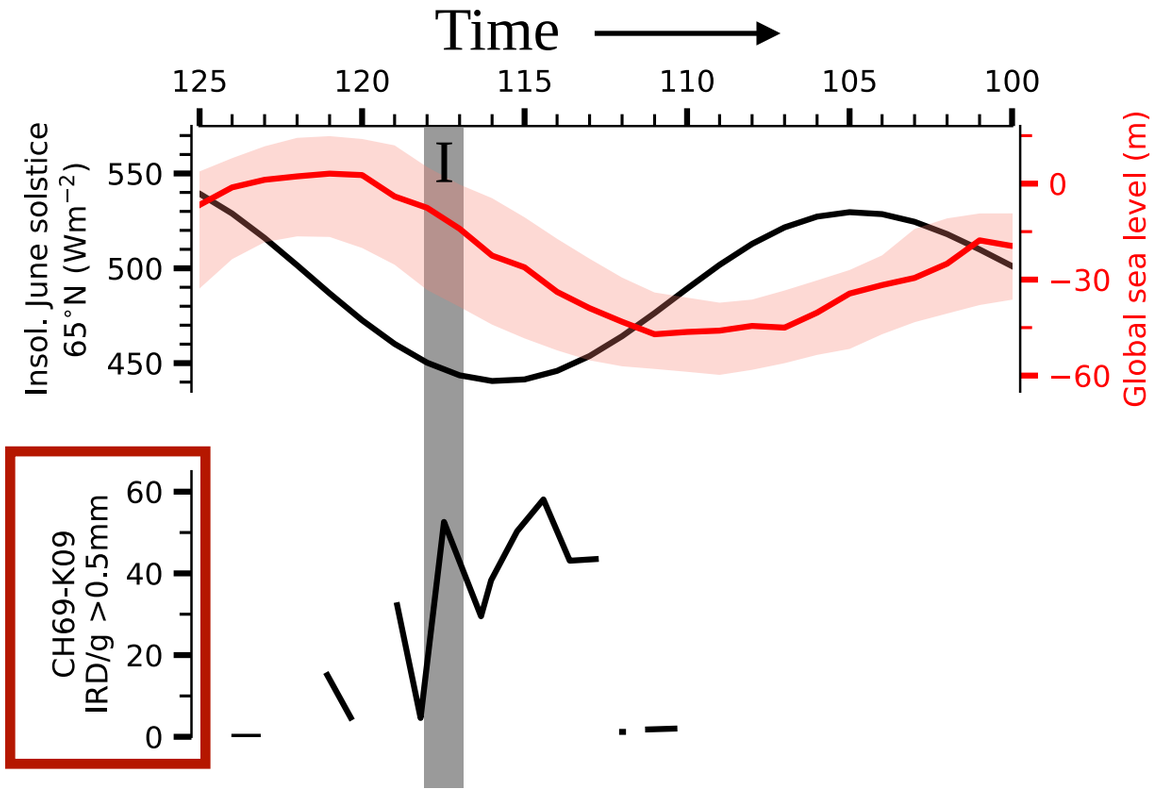

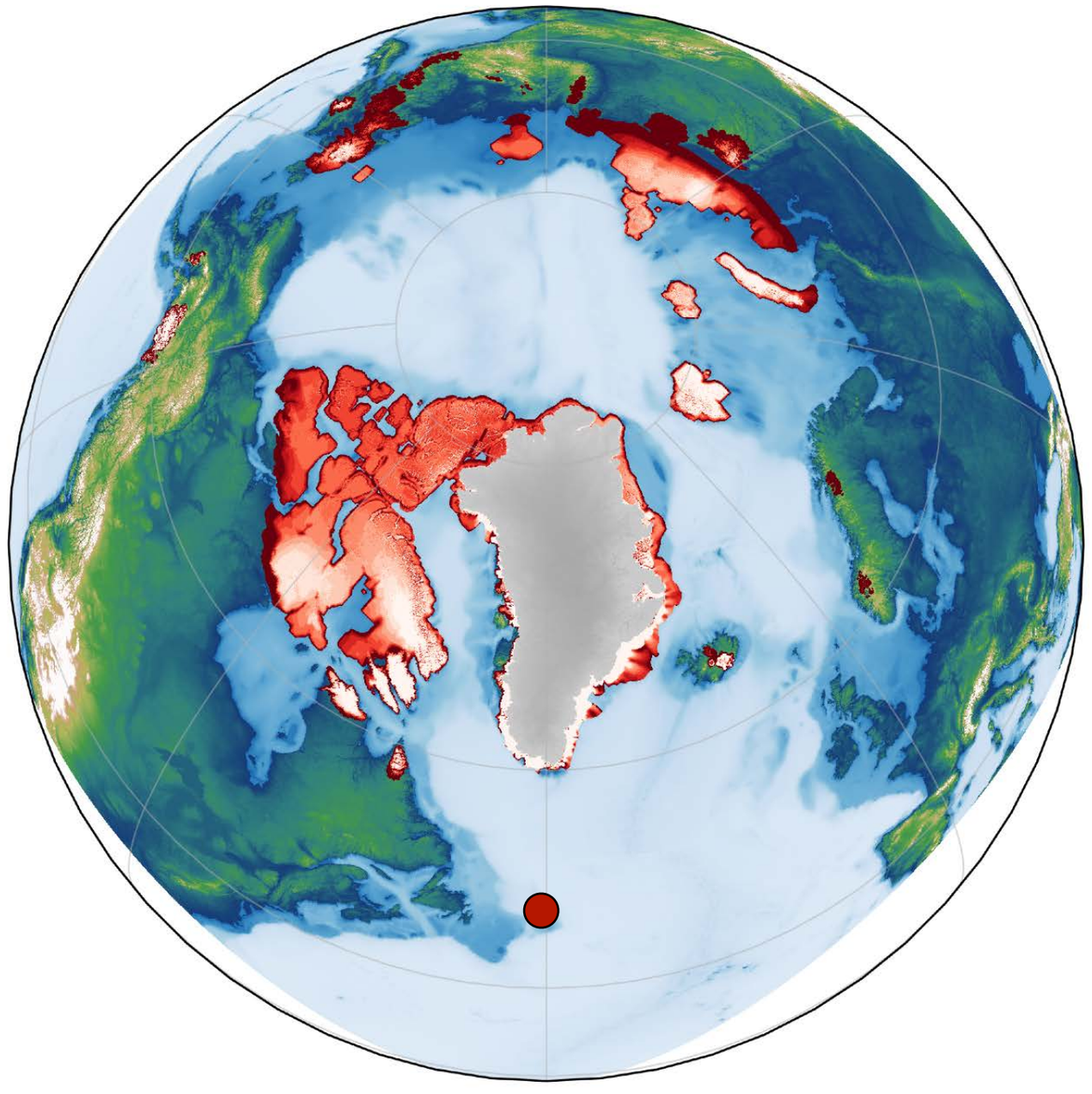

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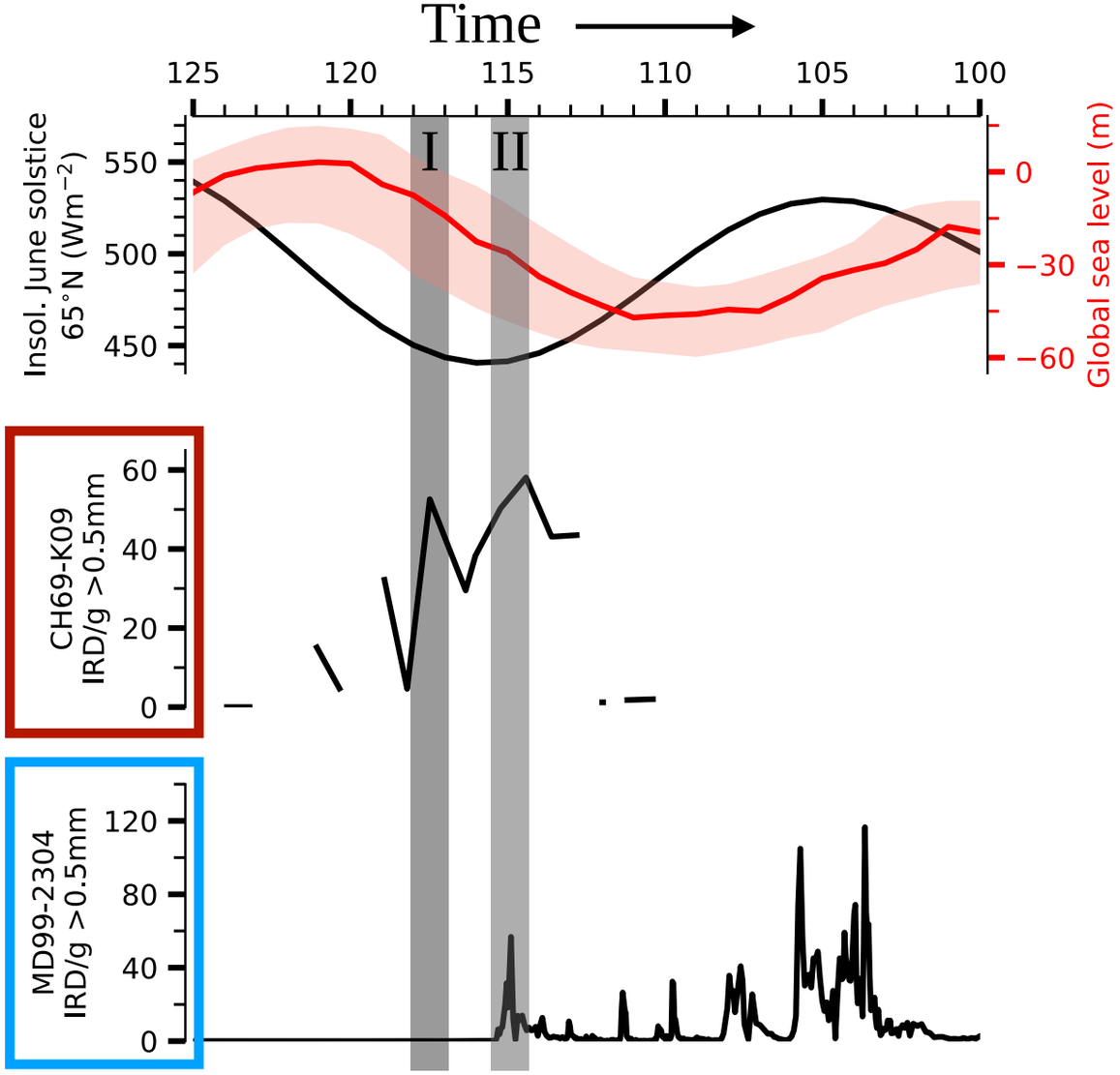

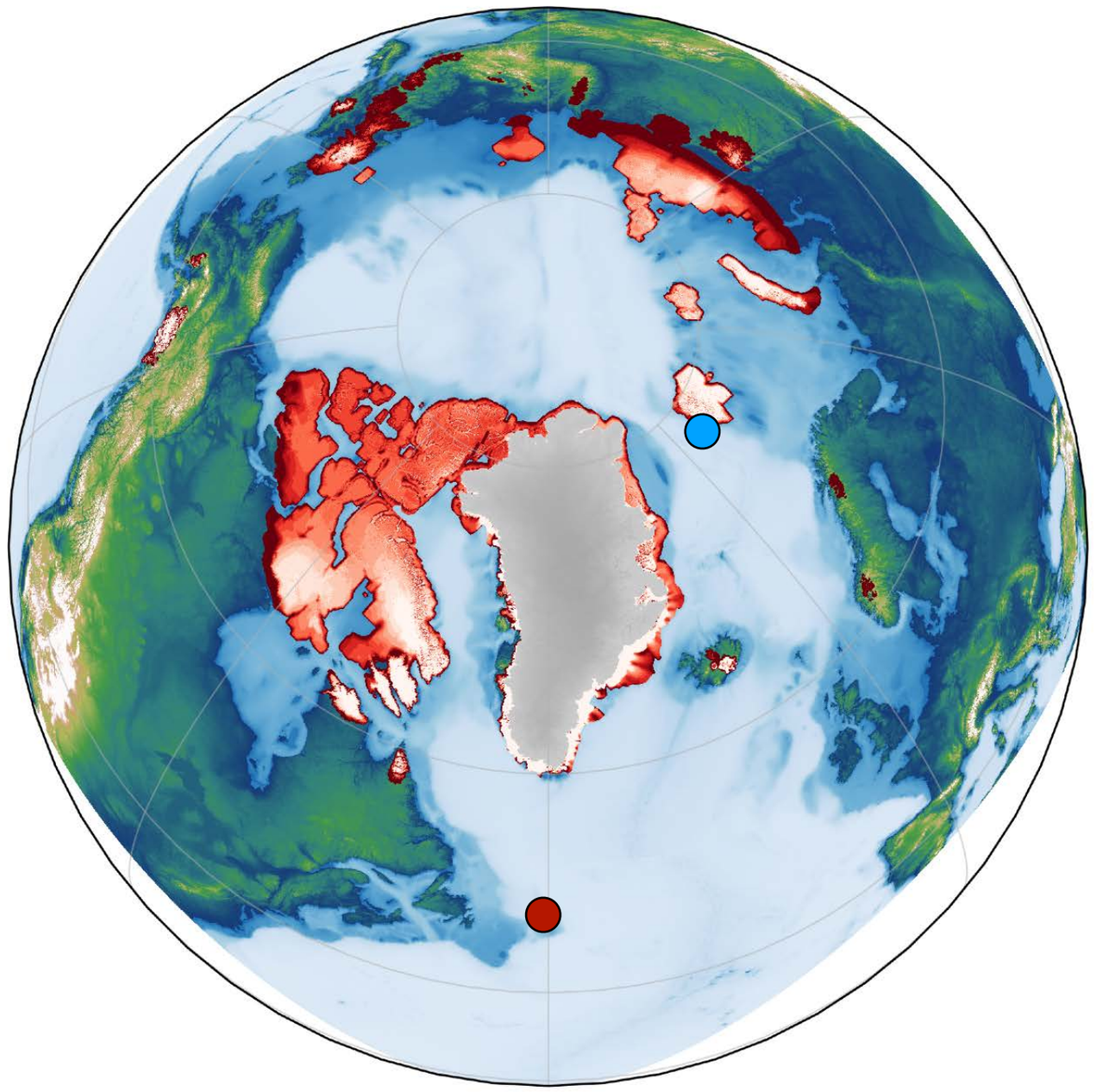

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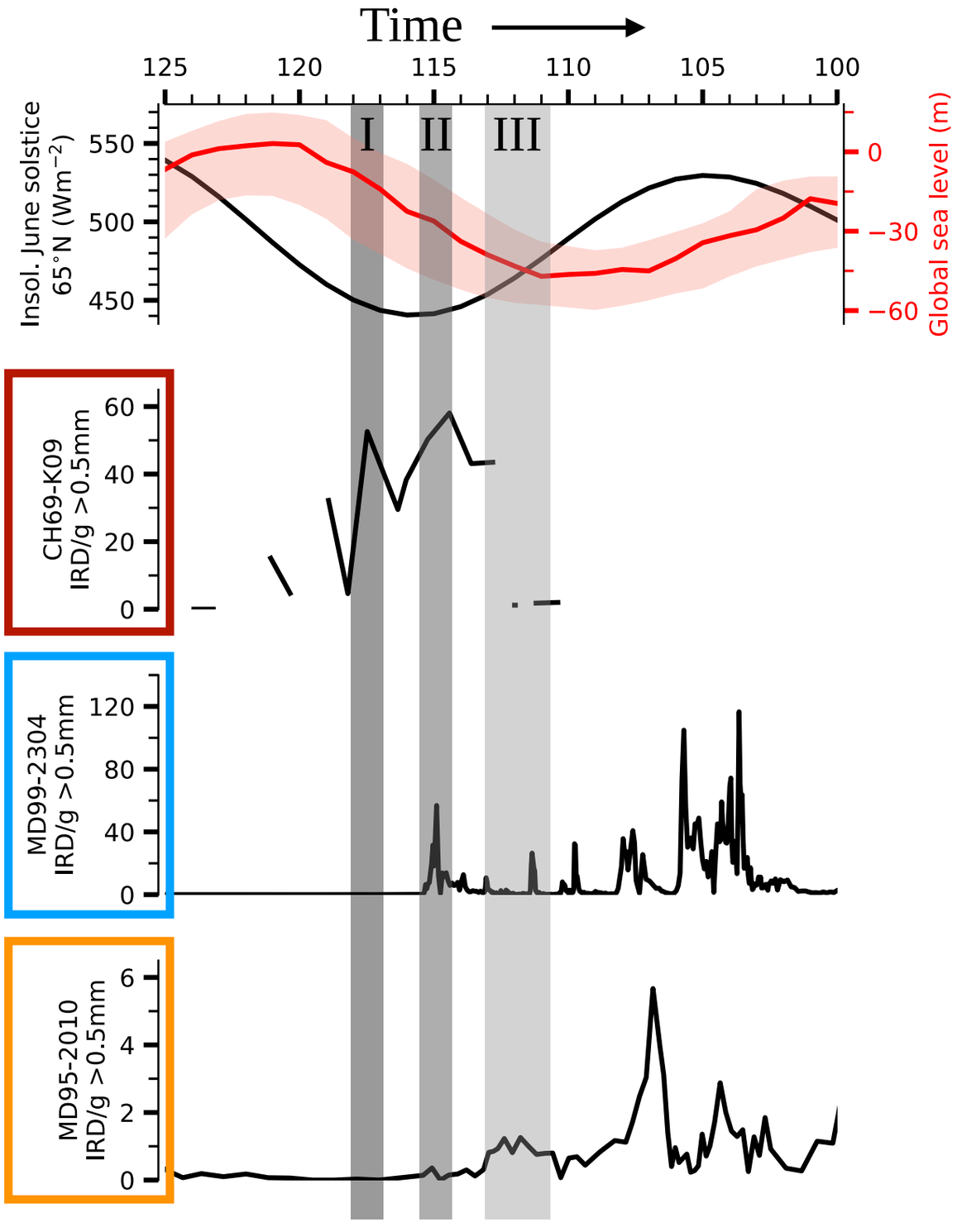

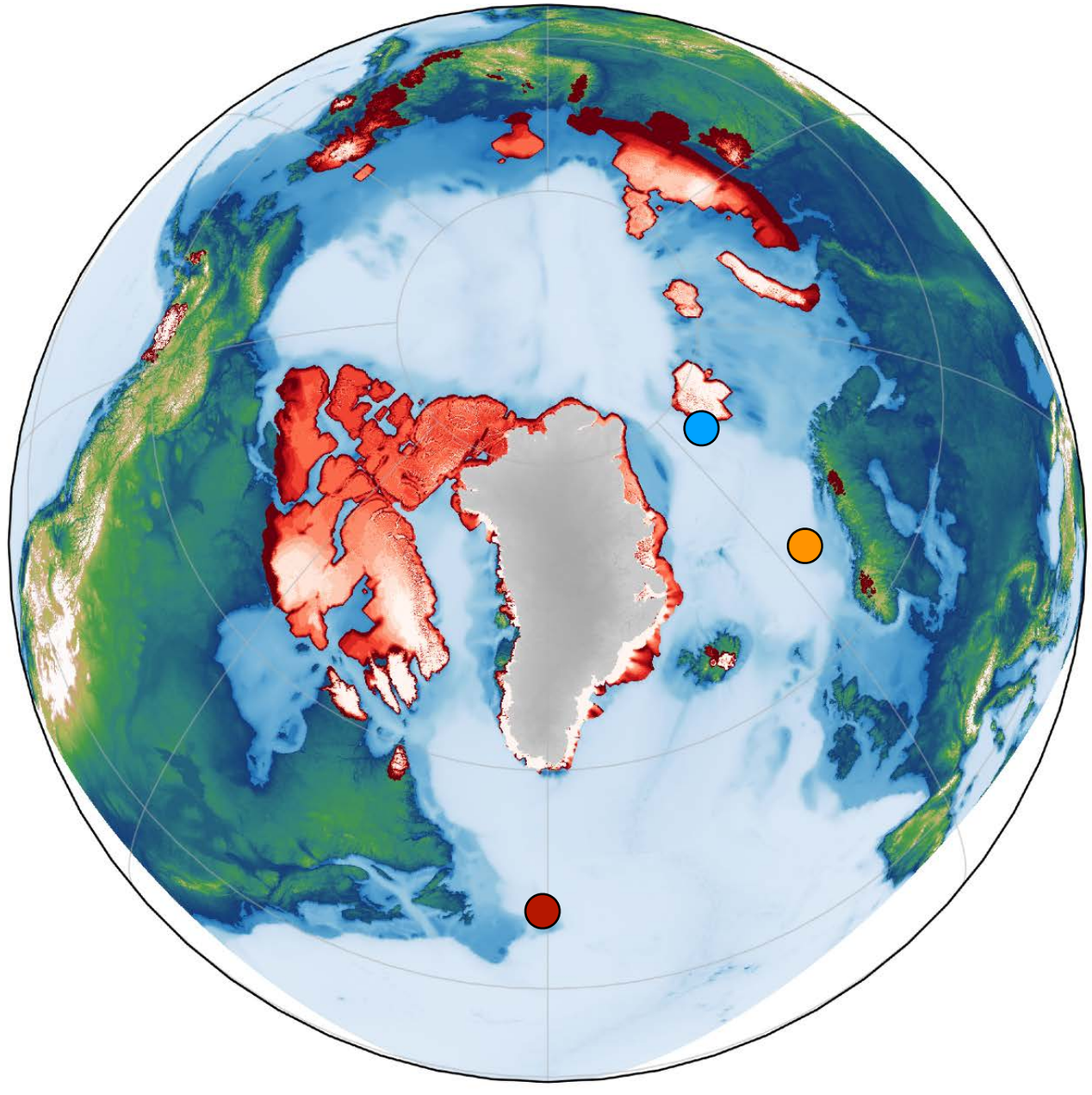

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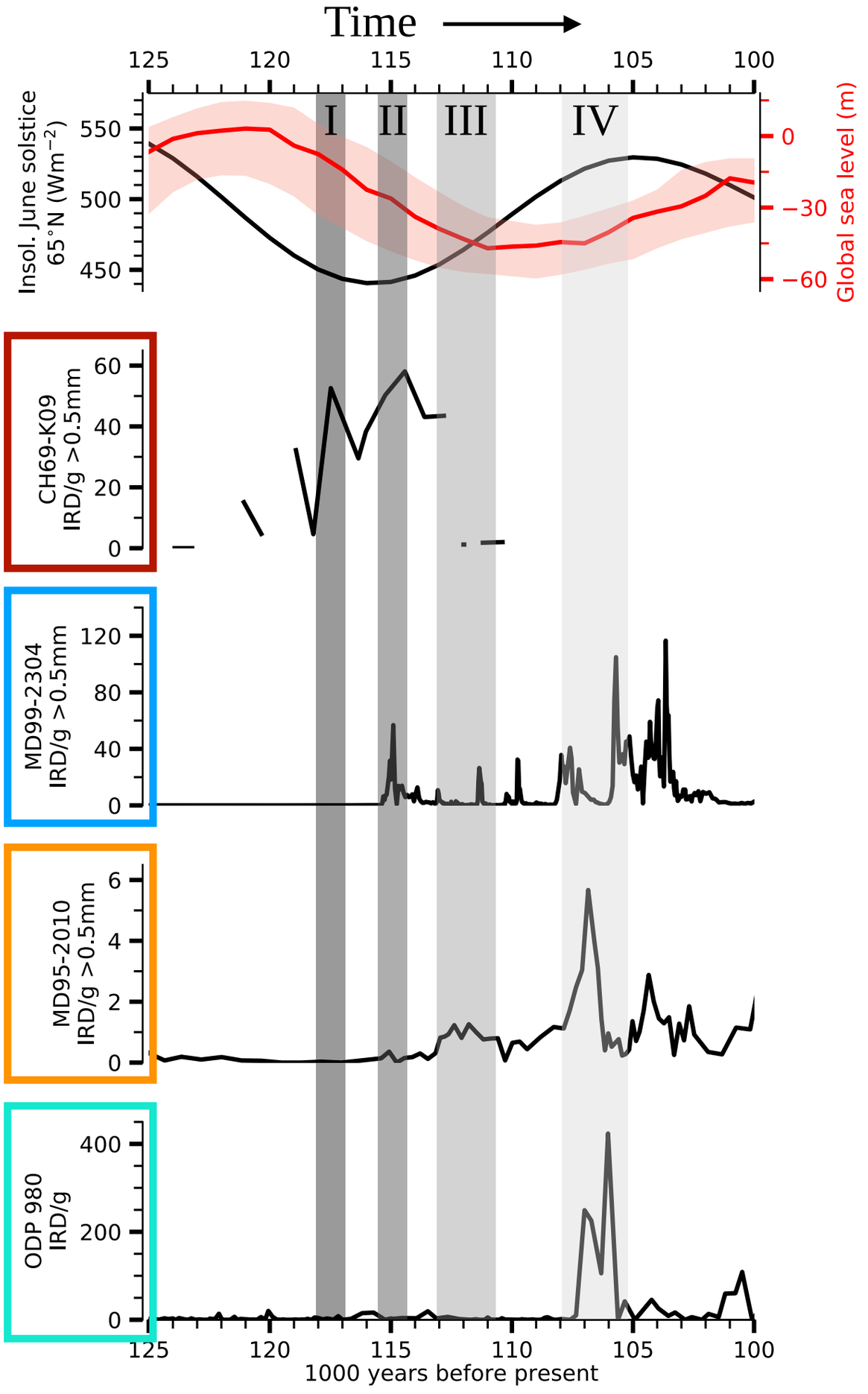

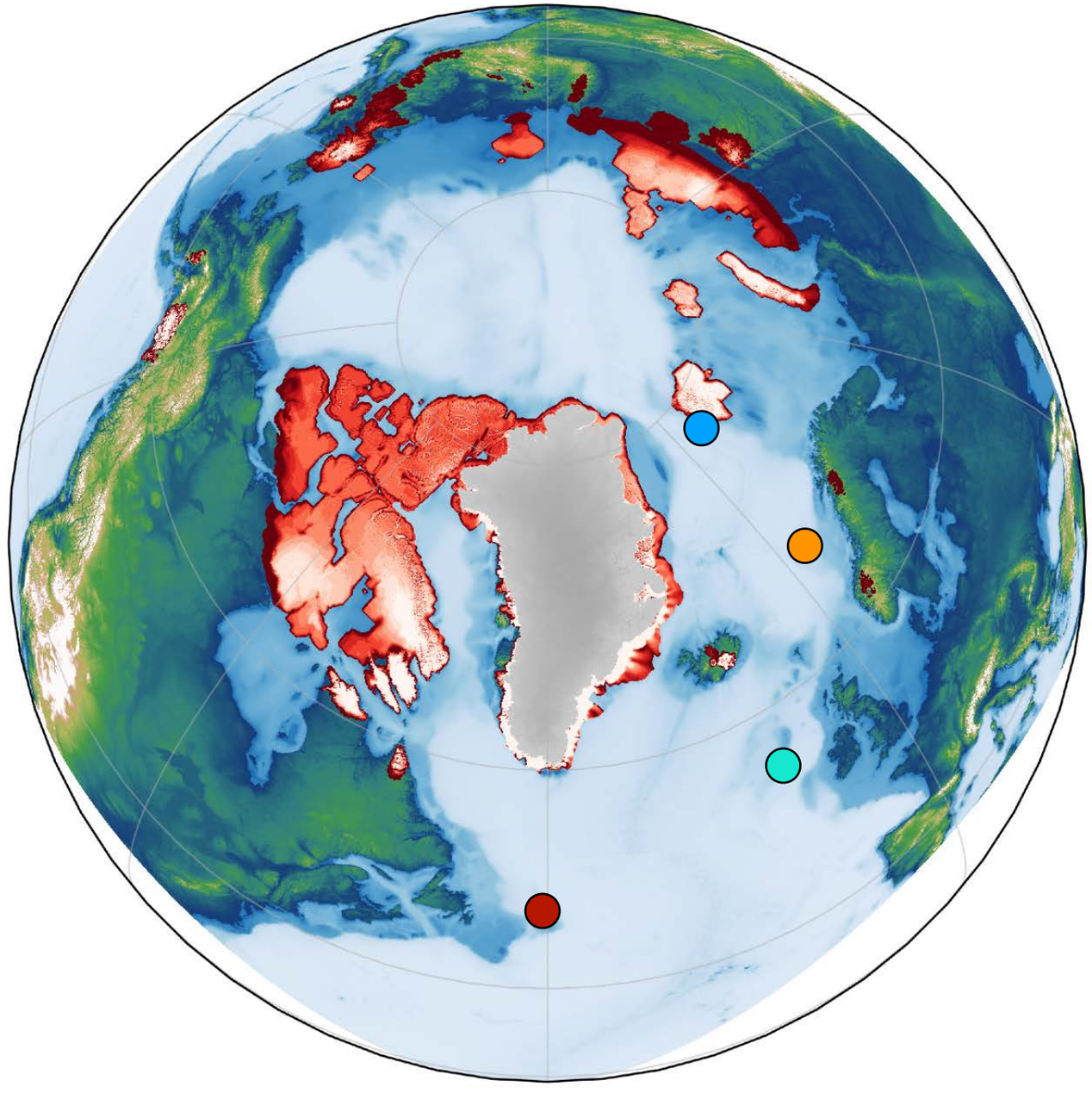

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Summary and conclusions

Canadian Arctic Archipelago (CAA) gateways:

- Strong influence on Atlantic Meridional Overturning Circulation (AMOC) and North Atlantic sea-surface temperatures (SSTs)
- Closed CAA yields weaker AMOC and colder North Atlantic SSTs and more N Atlantic sea ice

Connection to Northern Hemisphere glacial inception:

- Ice readily grows in Canadian Arctic (insolation feedback is sufficient)
- Ice sheet can “easily” close the shallow and narrow CAA straits
- Sea surface temperature feedback is imperative for inception in Scandinavia

Inception in North America may be a necessary precondition for inception in Scandinavia

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH