

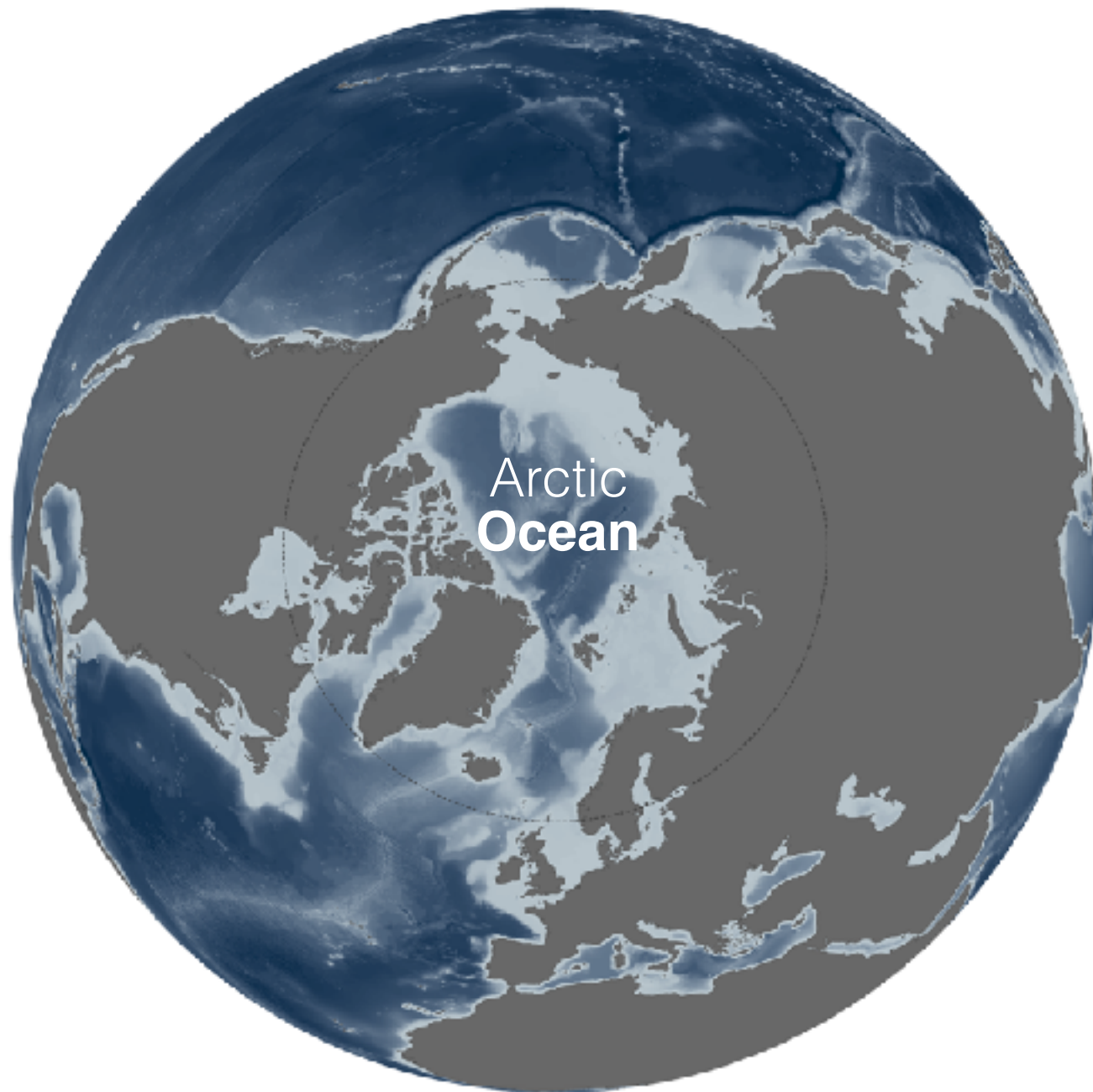
How icebergs traveled from North America to Morocco during the last ice age

Postdoc: Till Wagner

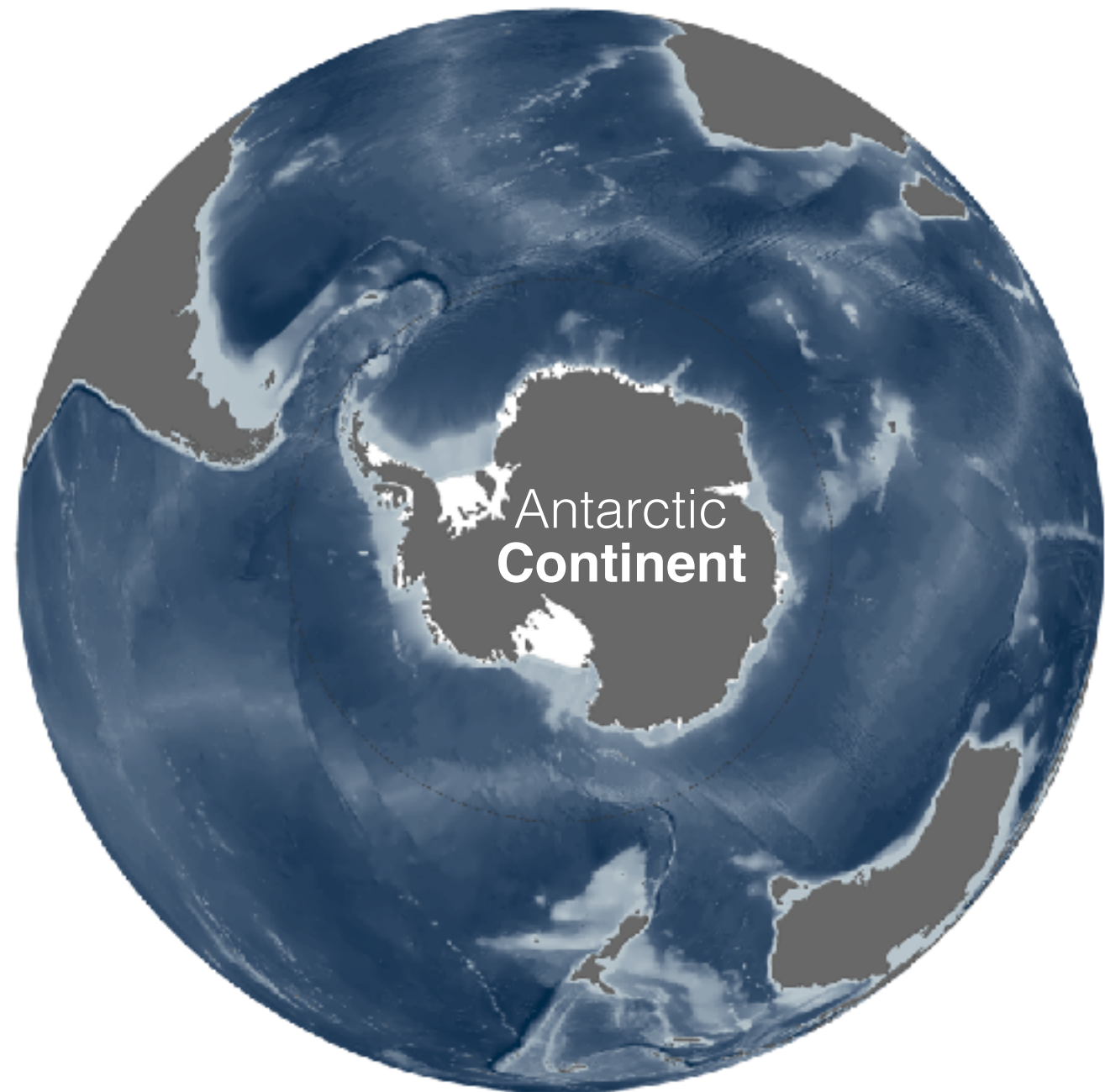
Mentor: Ian Eisenman, SIO
Co-Mentor: Pietro Cicotti, SDSC

October 31, 2017

Cryosphere 101

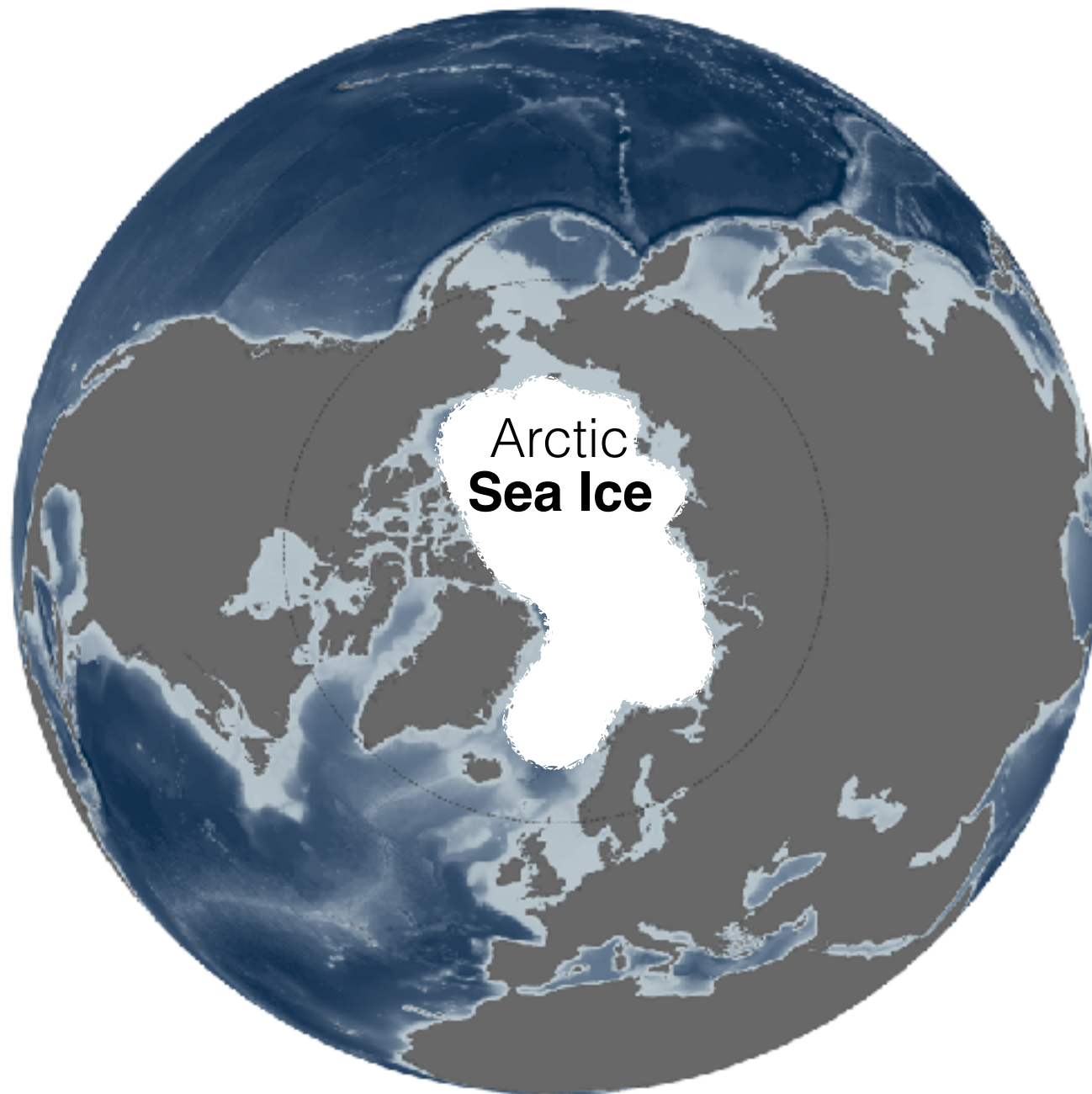


NOAA Climate.gov

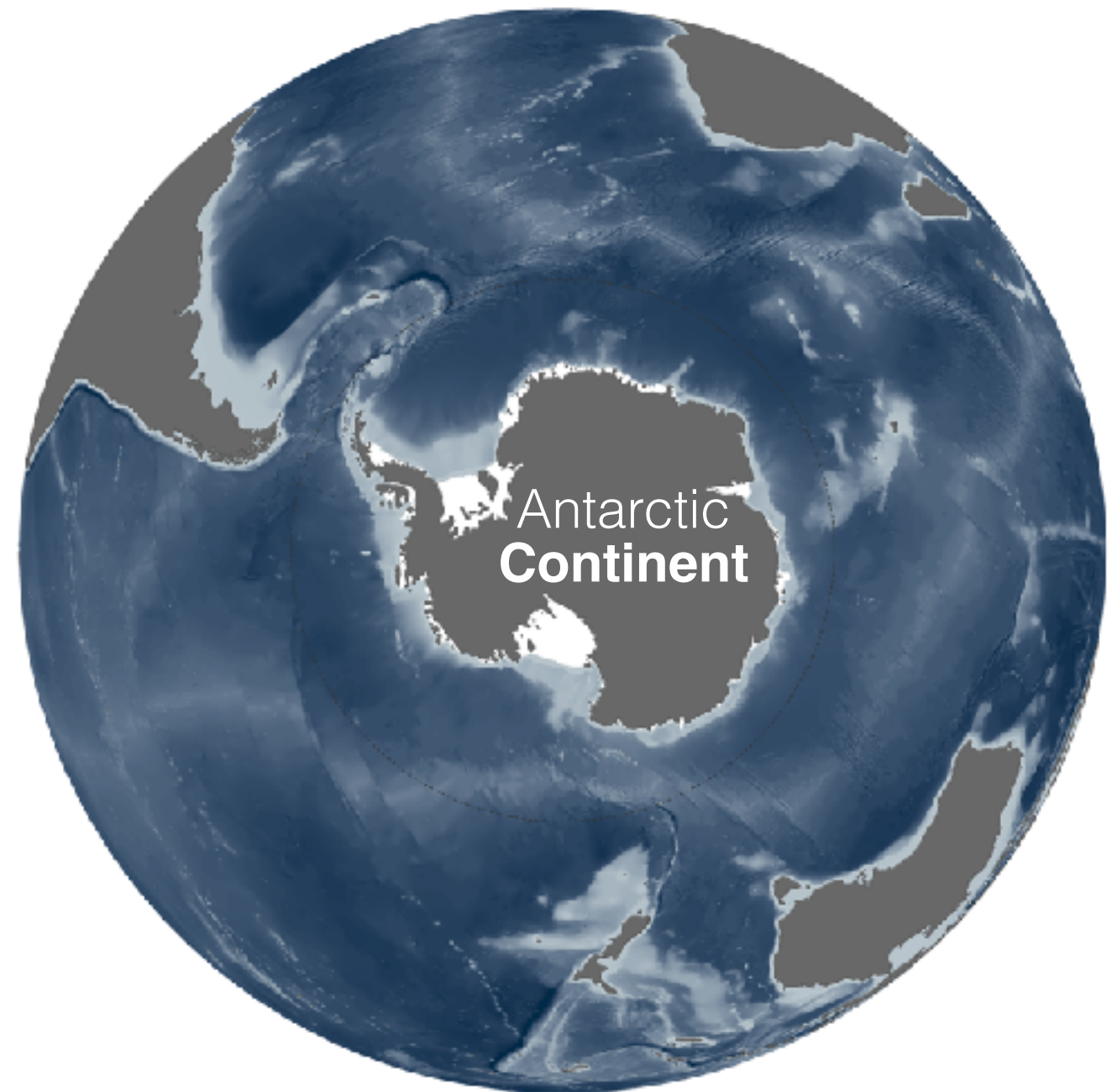


NOAA Climate.gov

Cryosphere 101

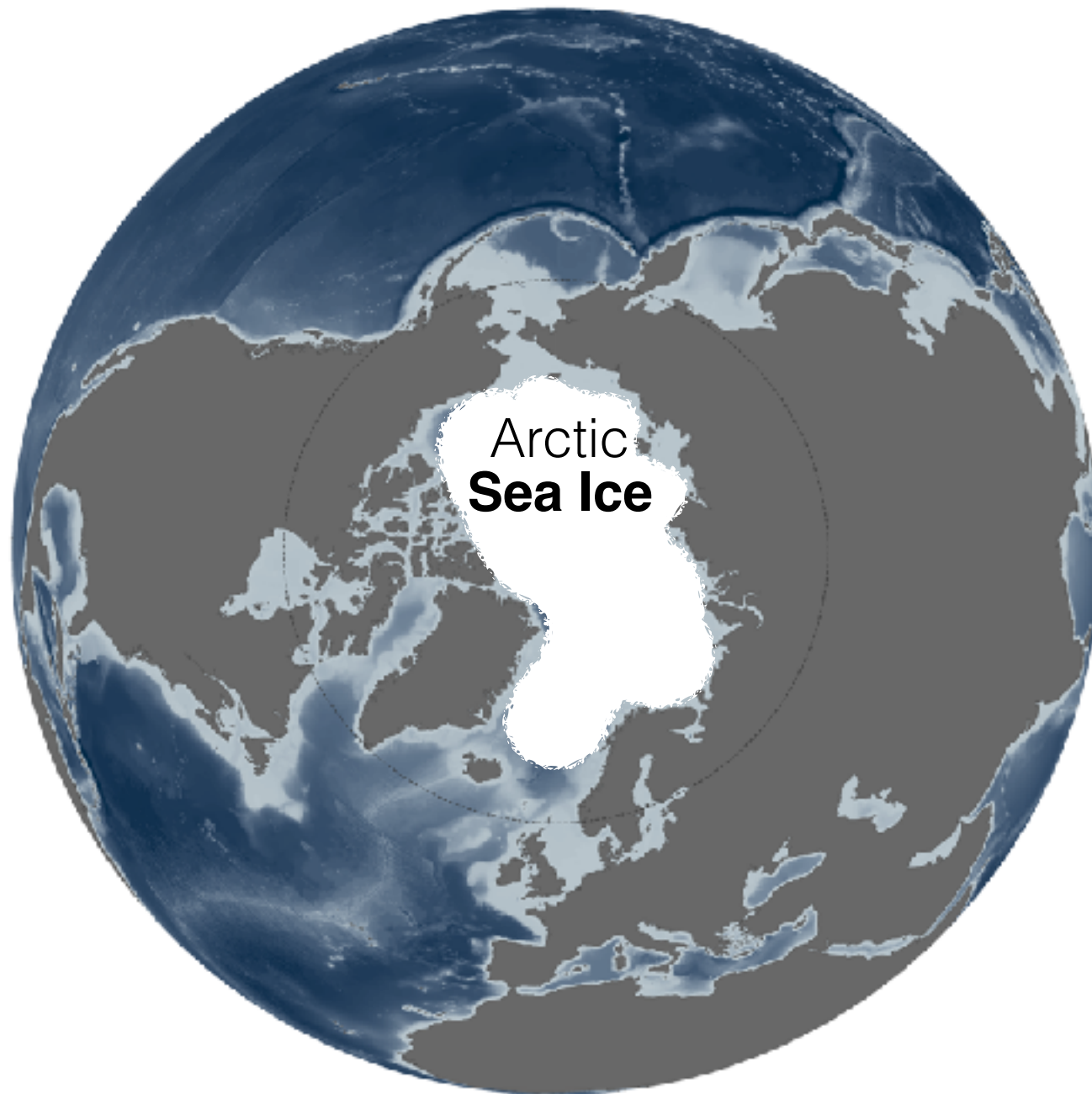


NOAA Climate.gov

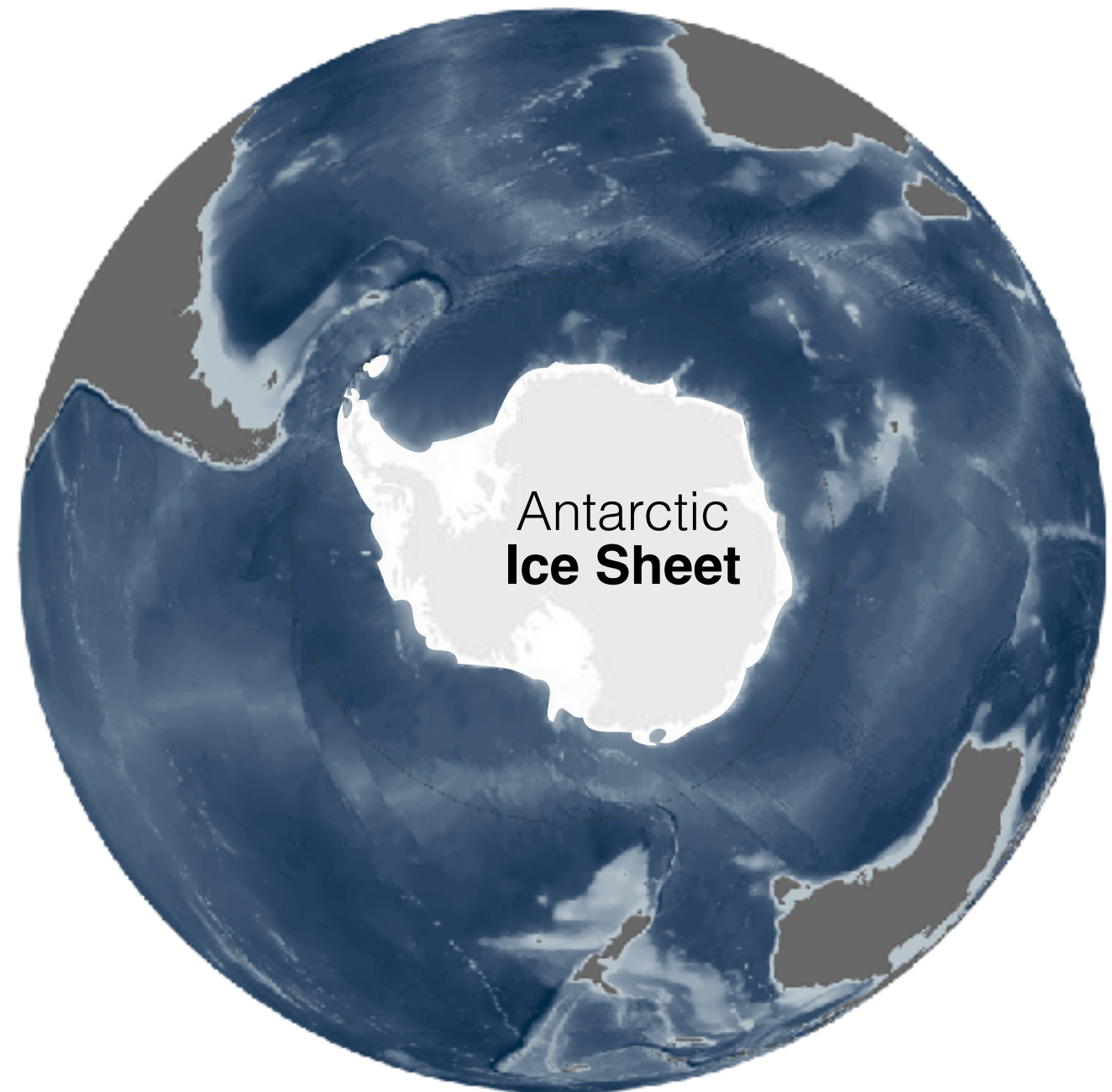


NOAA Climate.gov

Cryosphere 101

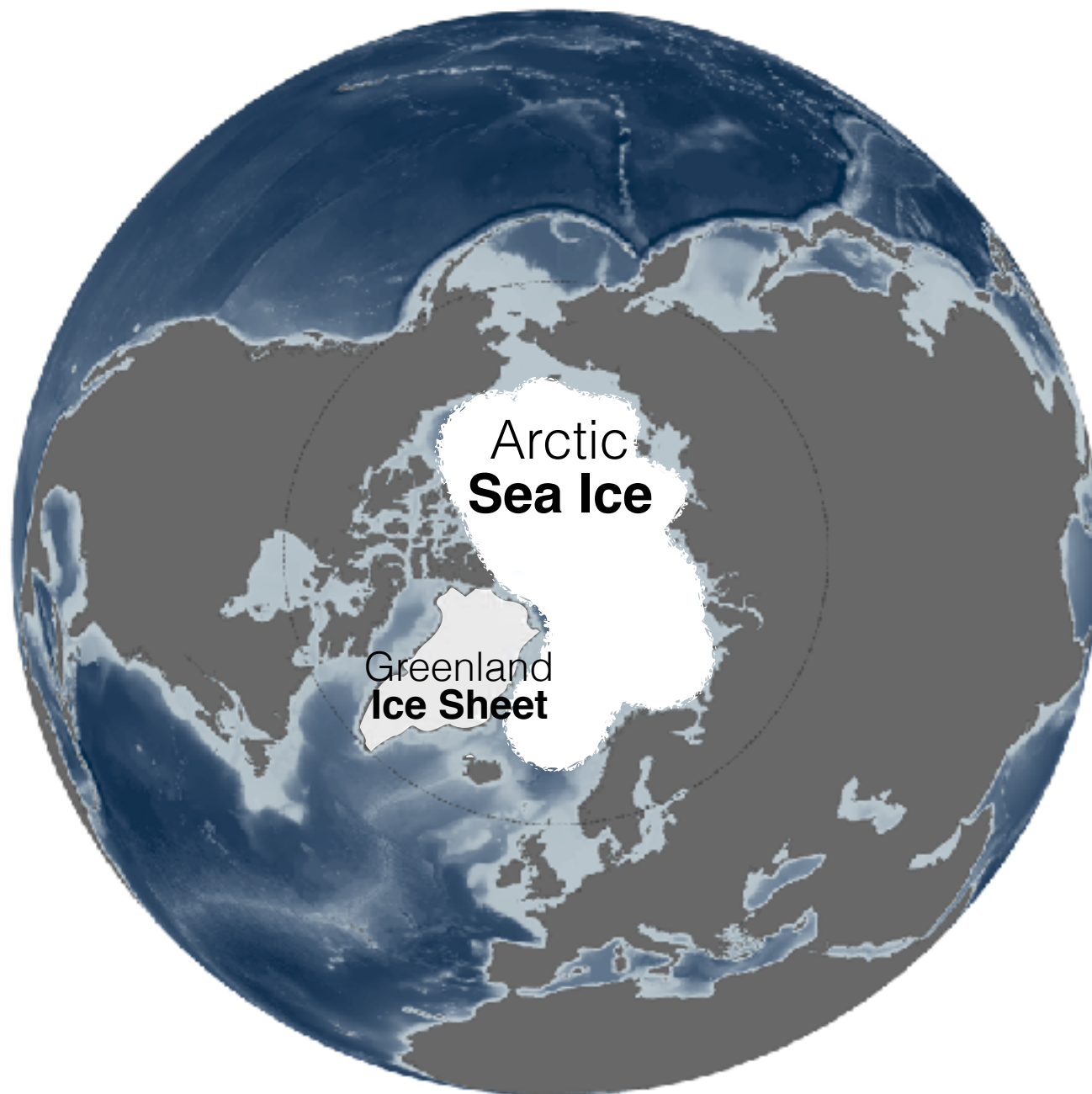


NOAA Climate.gov

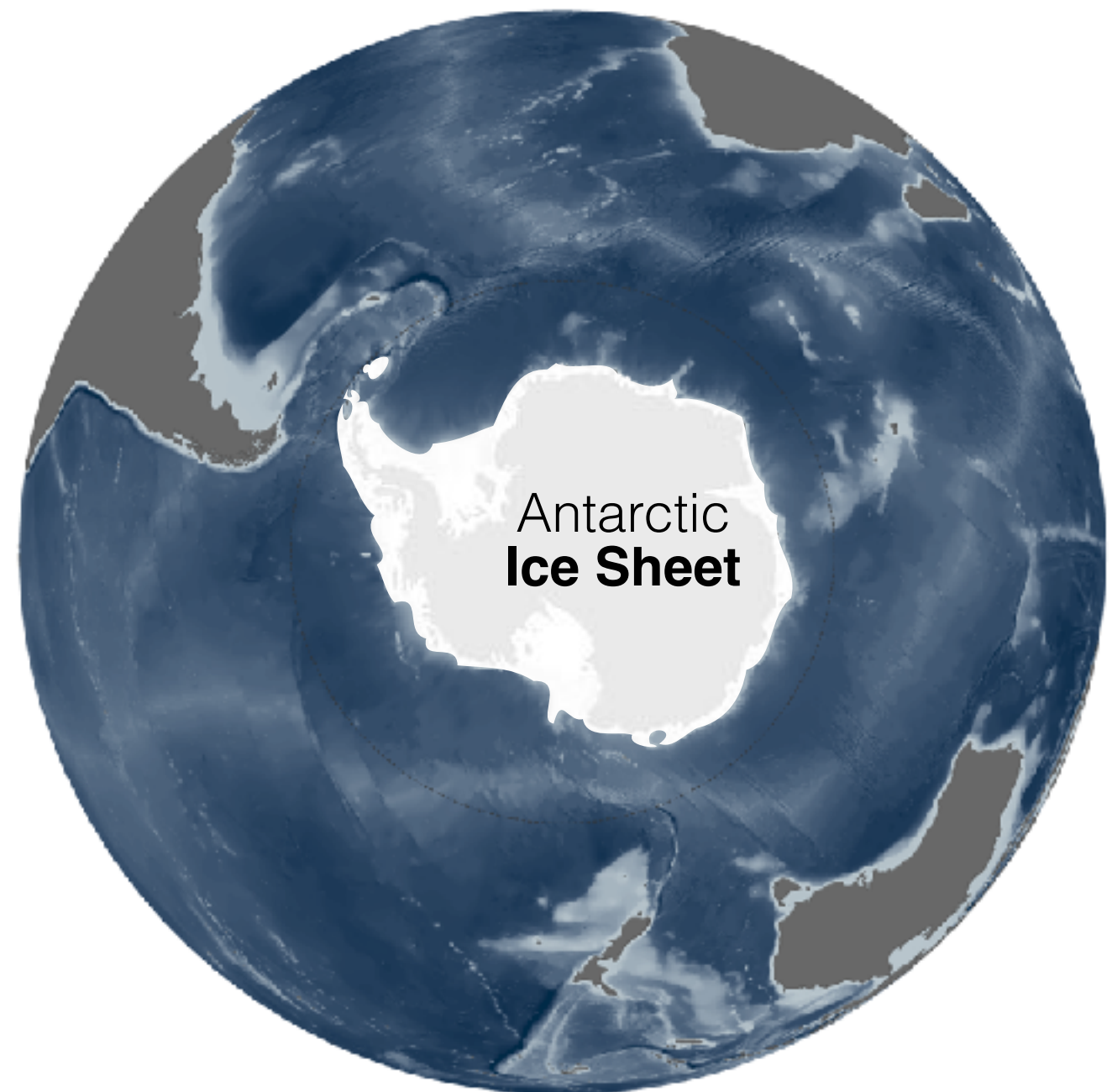


NOAA Climate.gov

Cryosphere 101



NOAA Climate.gov



NOAA Climate.gov

Arctic Sea Ice



Arctic Sea Ice



↓ ~1-4m
↑

Arctic Sea Ice

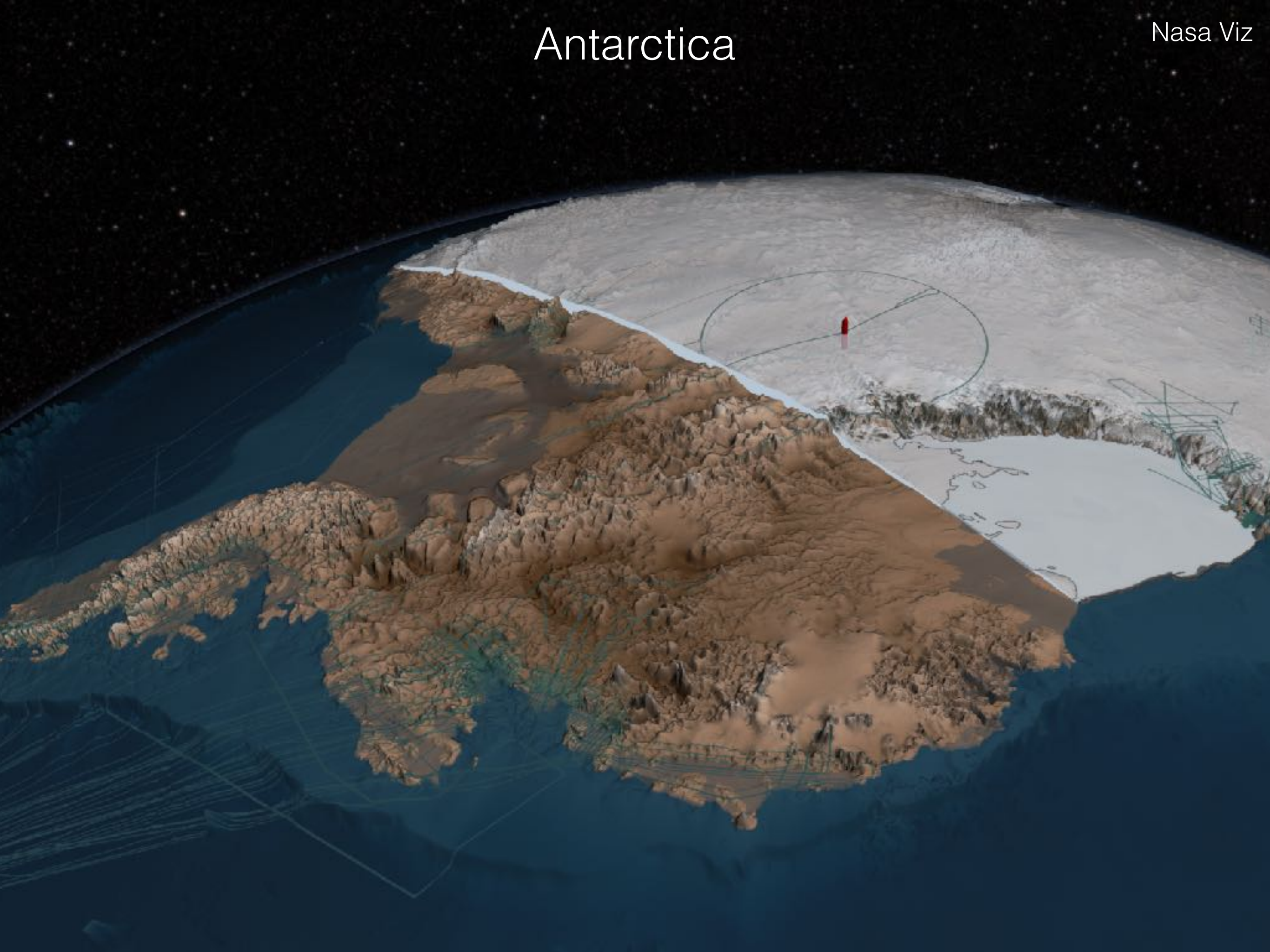


↓ ~1-4m
↑

Does not contribute
to sea level rise.

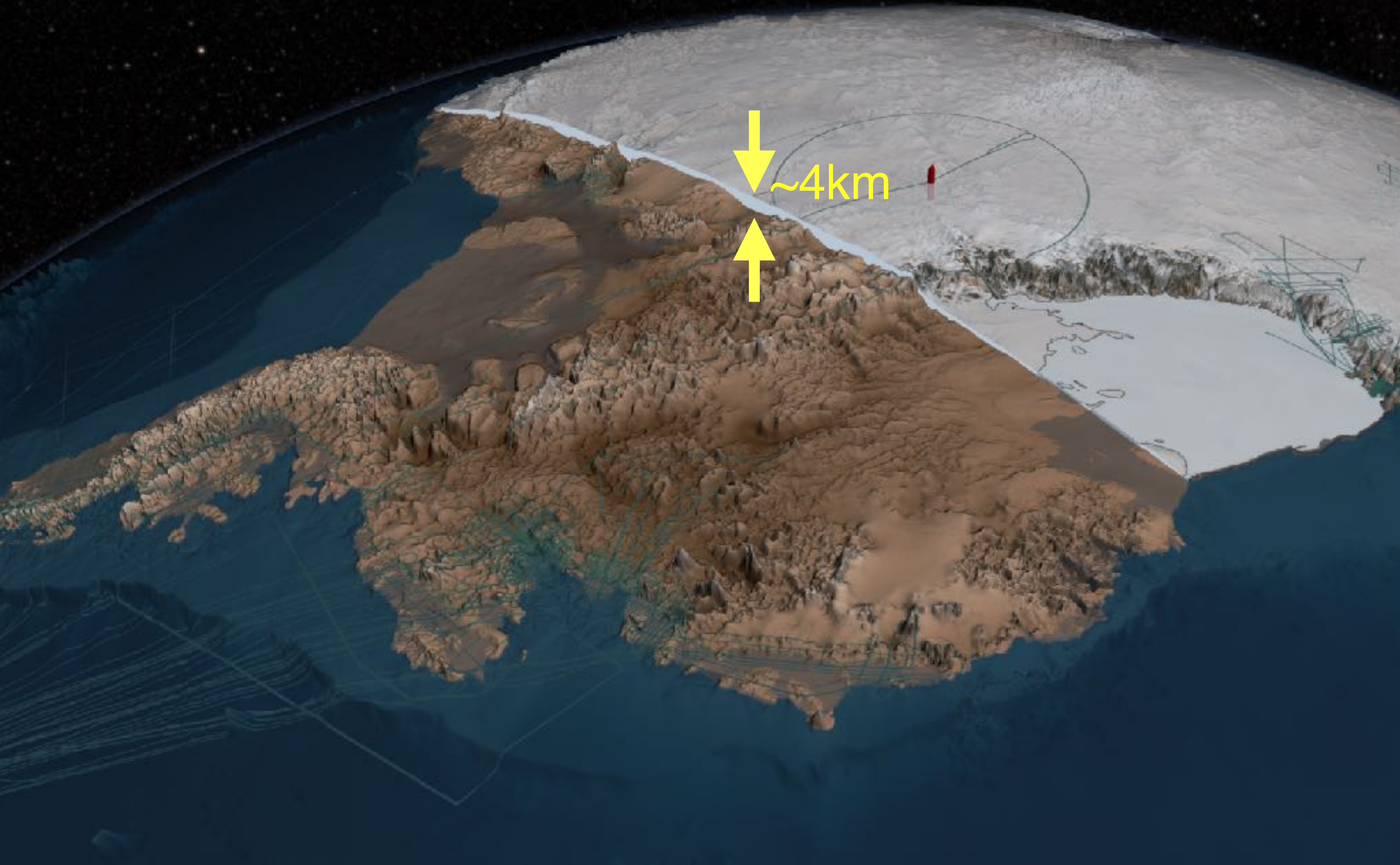
Antarctica

Nasa Viz



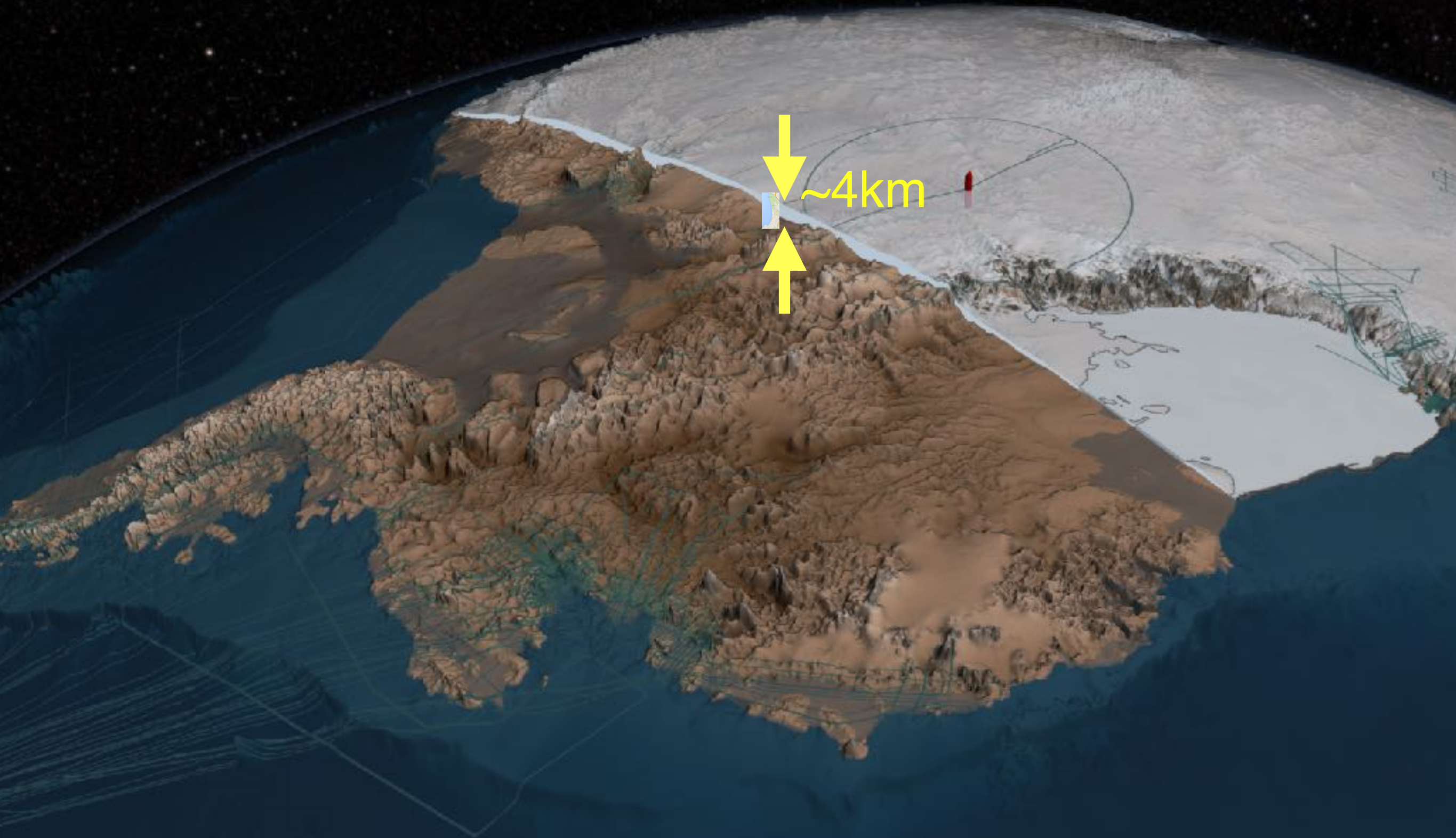
Antarctica

Nasa Viz



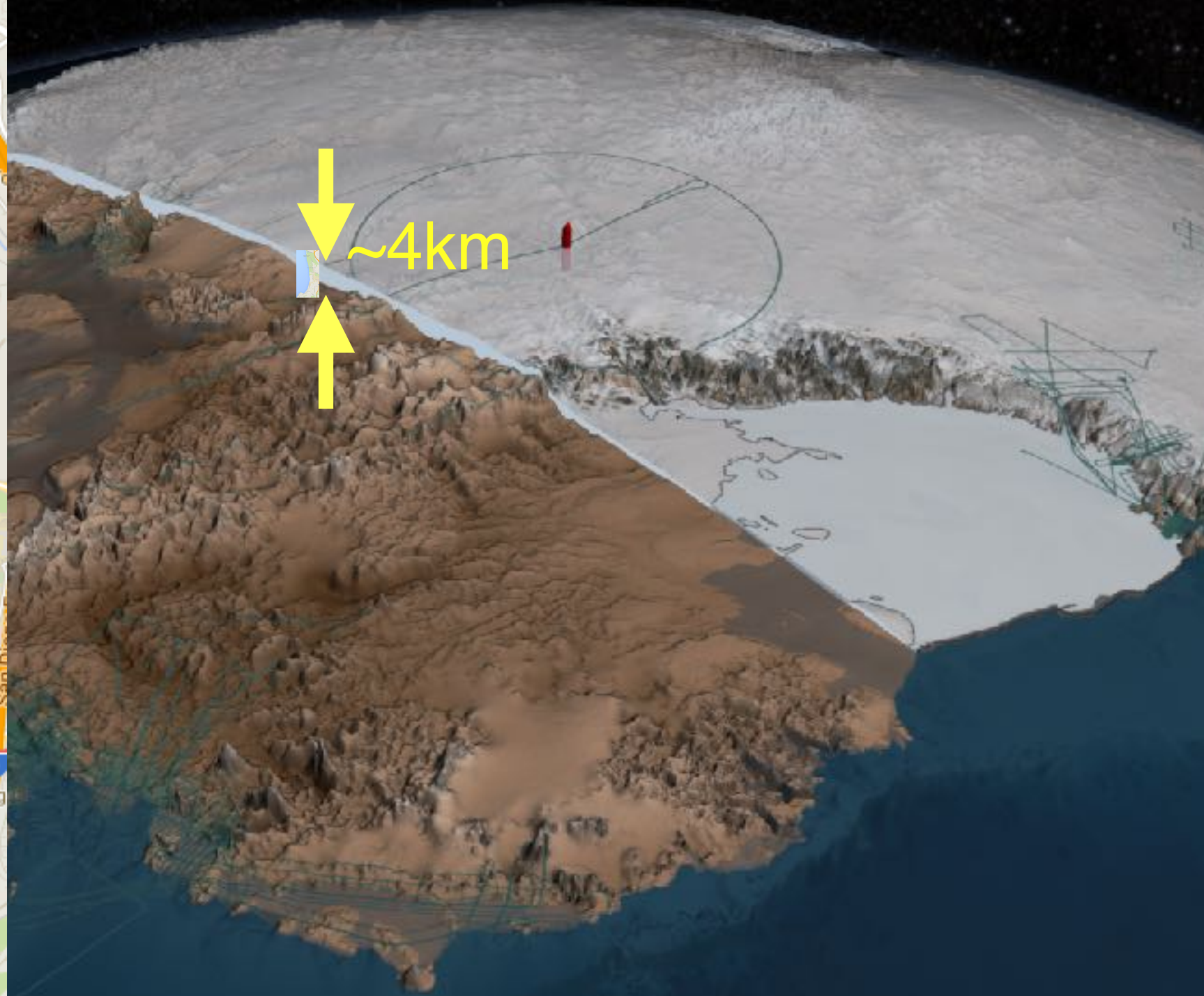
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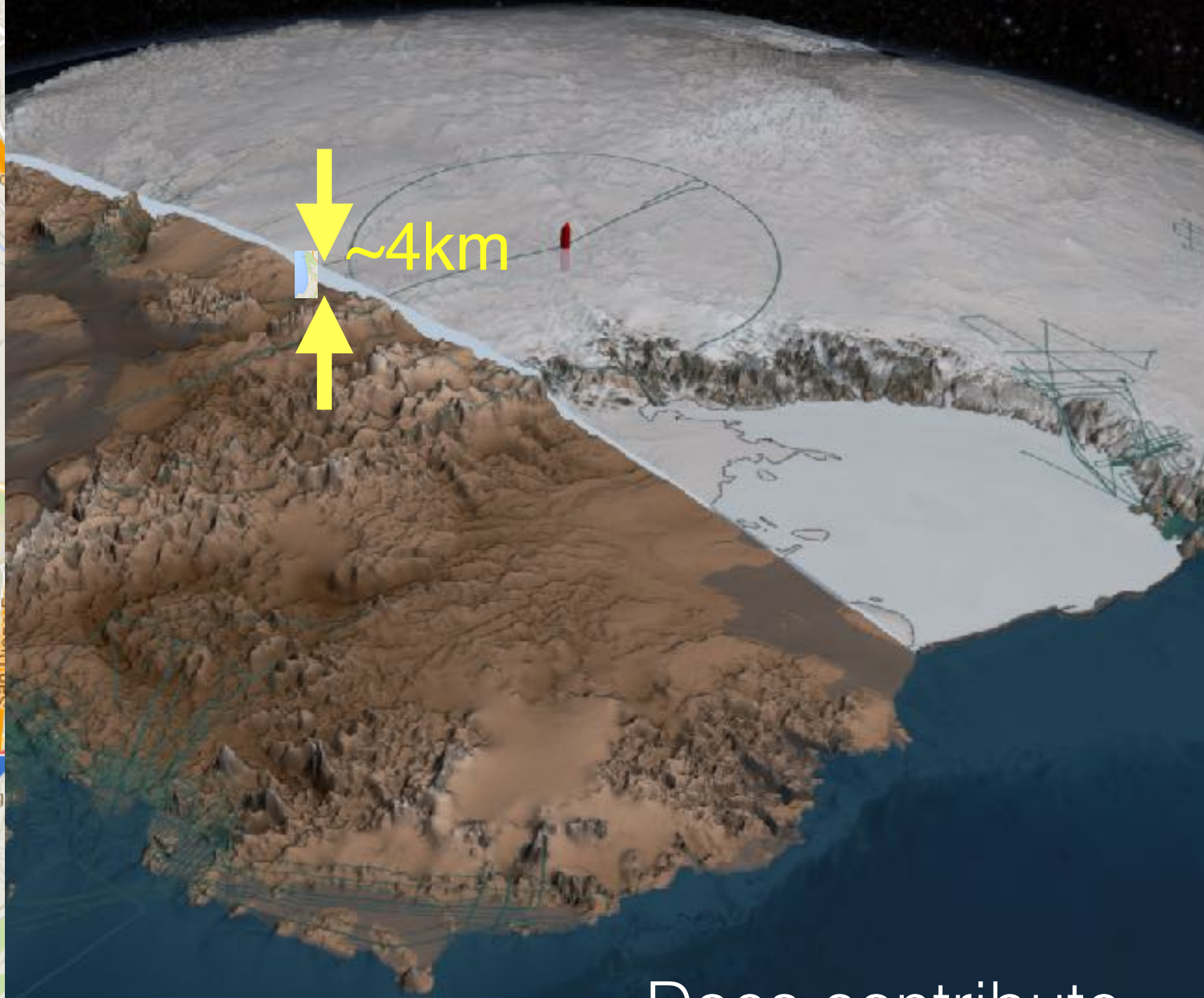
Antarctica

Nasa Viz



Antarctica

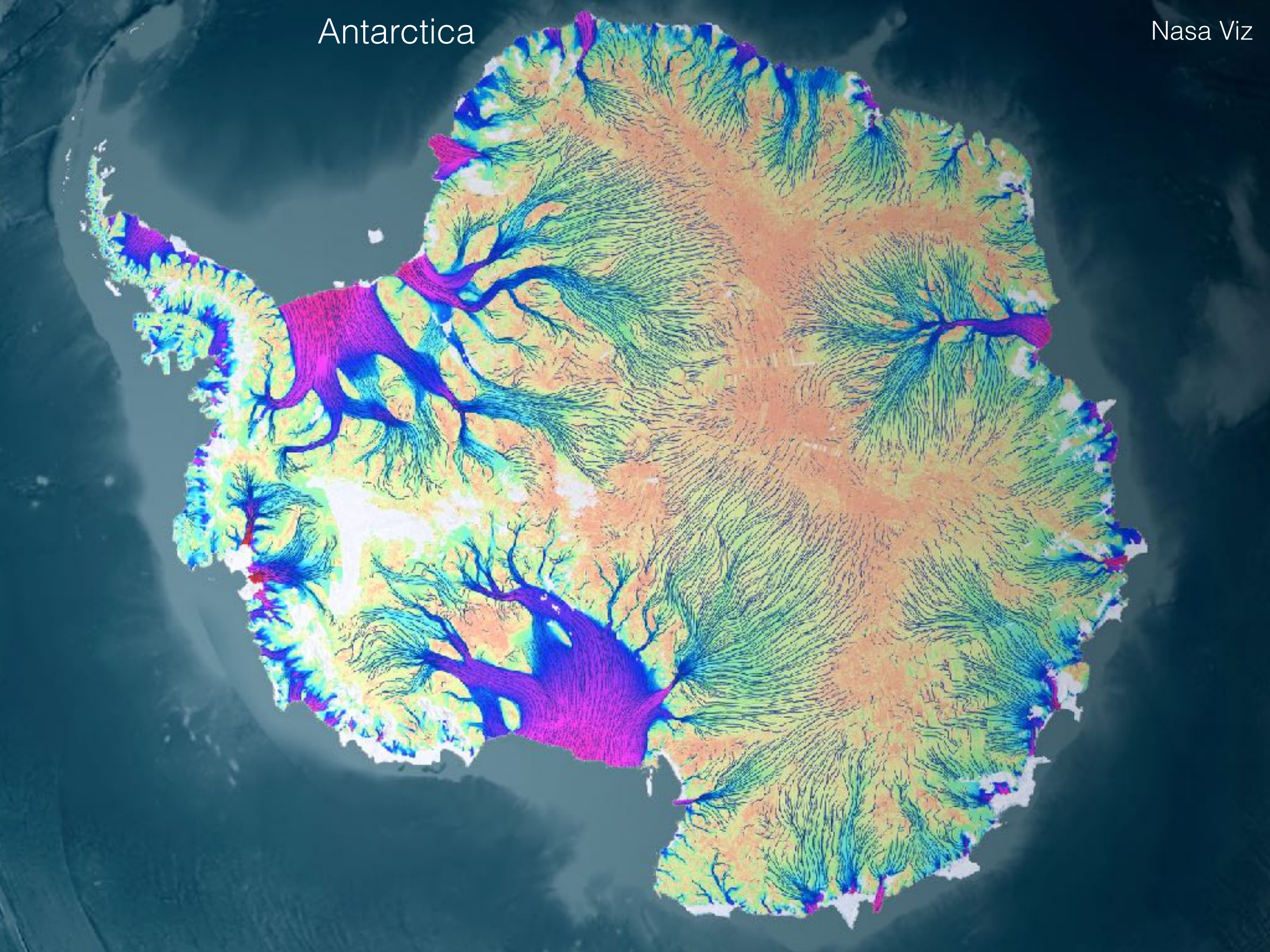
Nasa Viz



Does contribute
to sea level rise.

Antarctica

Nasa Viz

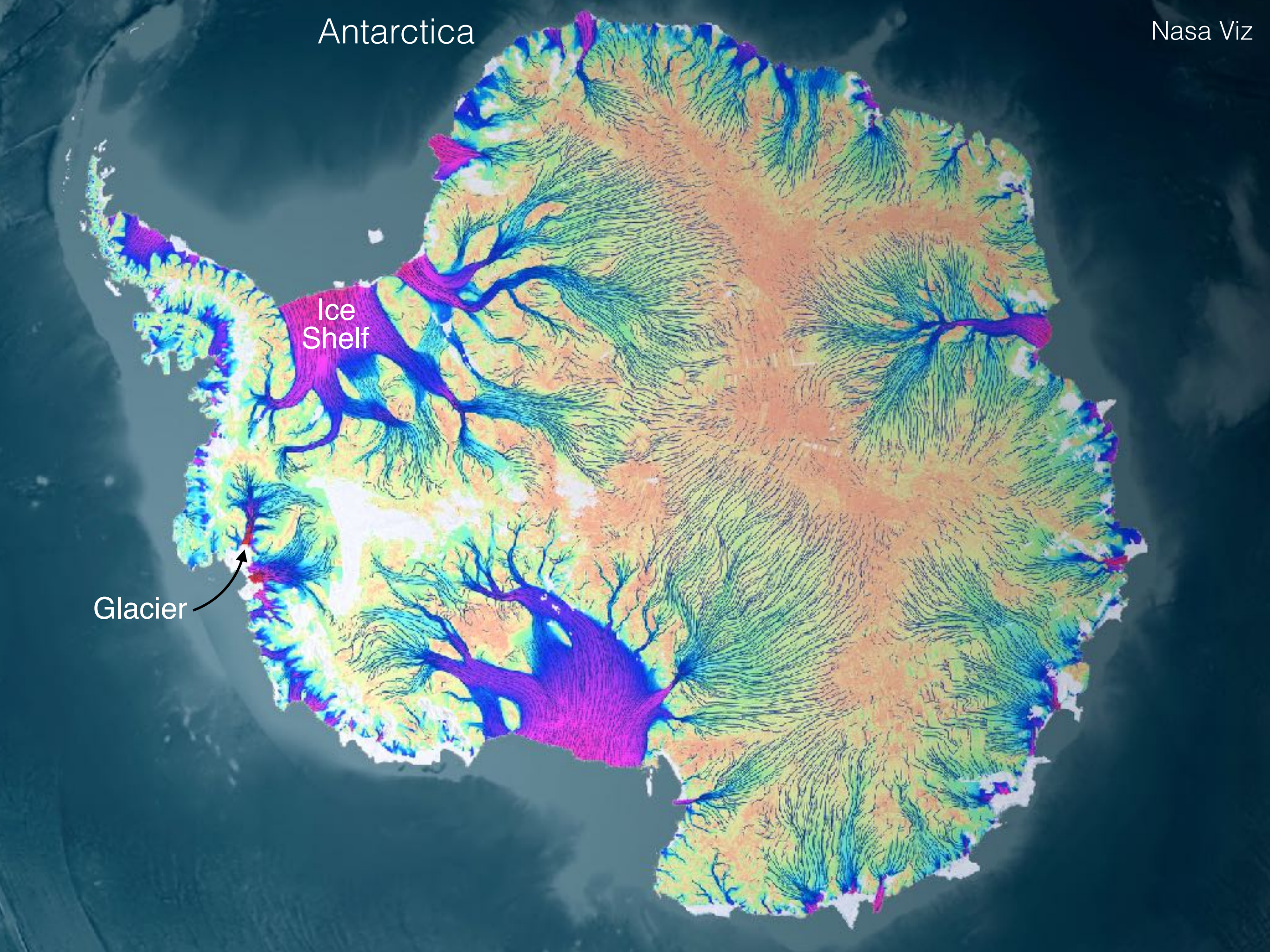


Antarctica

Nasa Viz

Ice
Shelf

Glacier



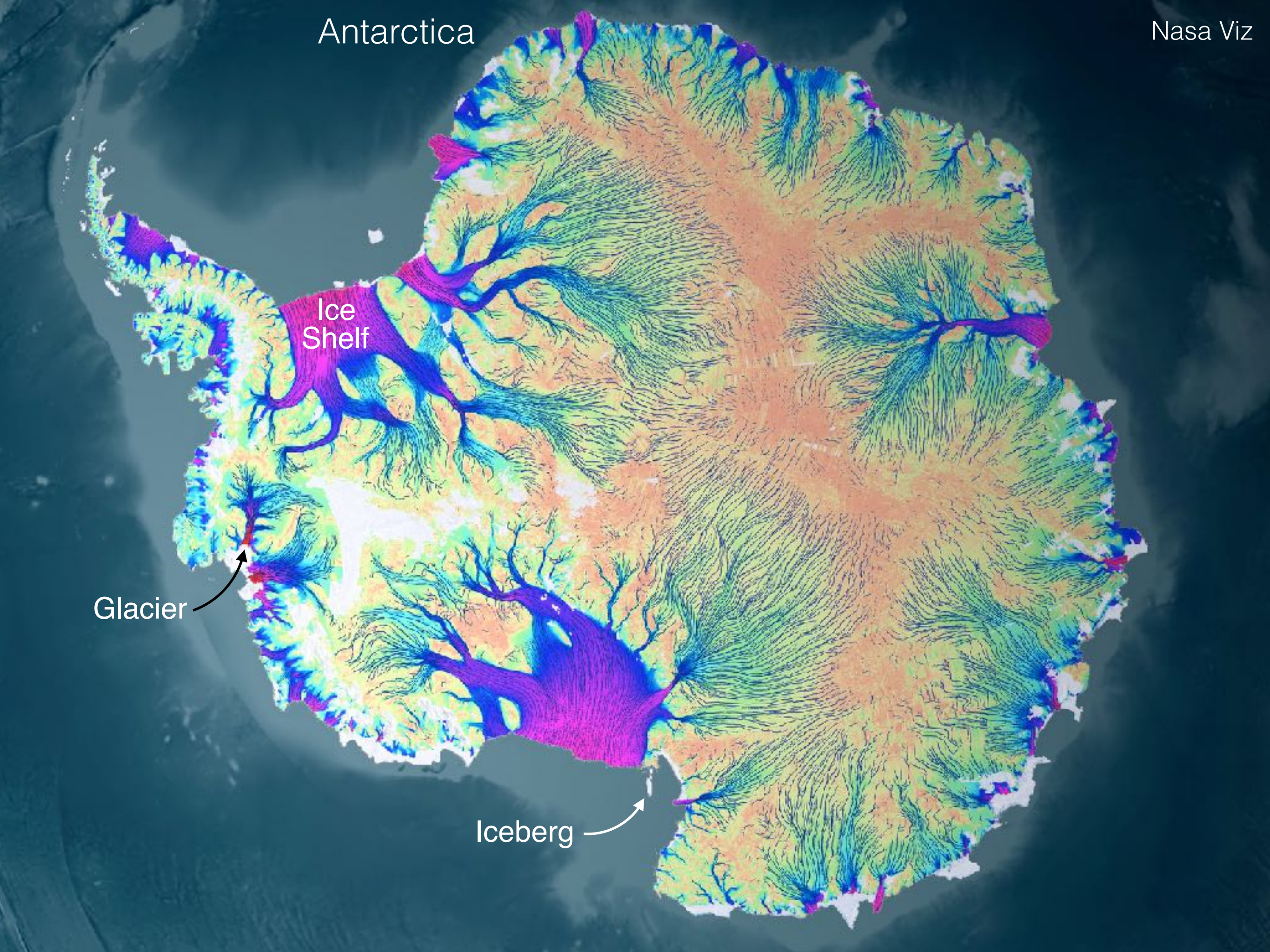
Antarctica

Nasa Viz

Ice
Shelf

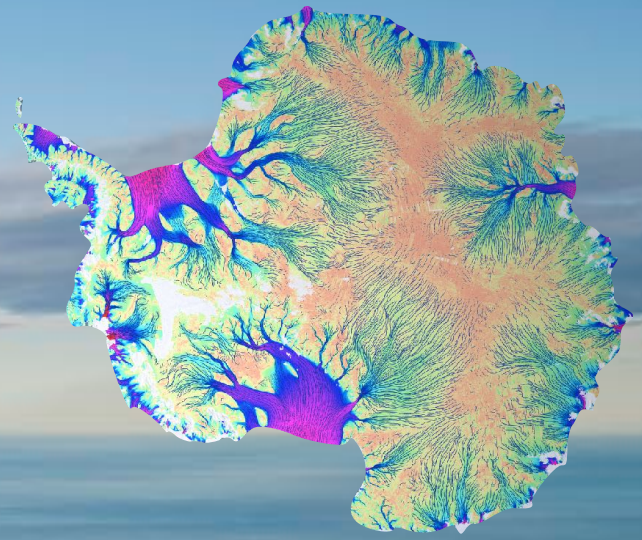
Glacier

Iceberg

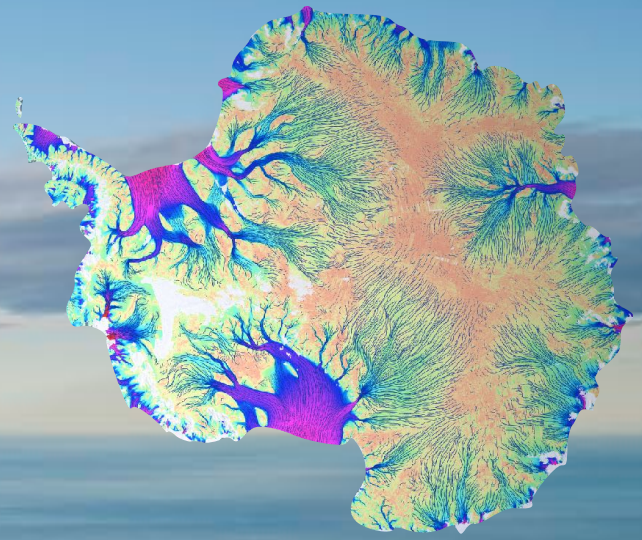




Tabular iceberg



Tabular iceberg

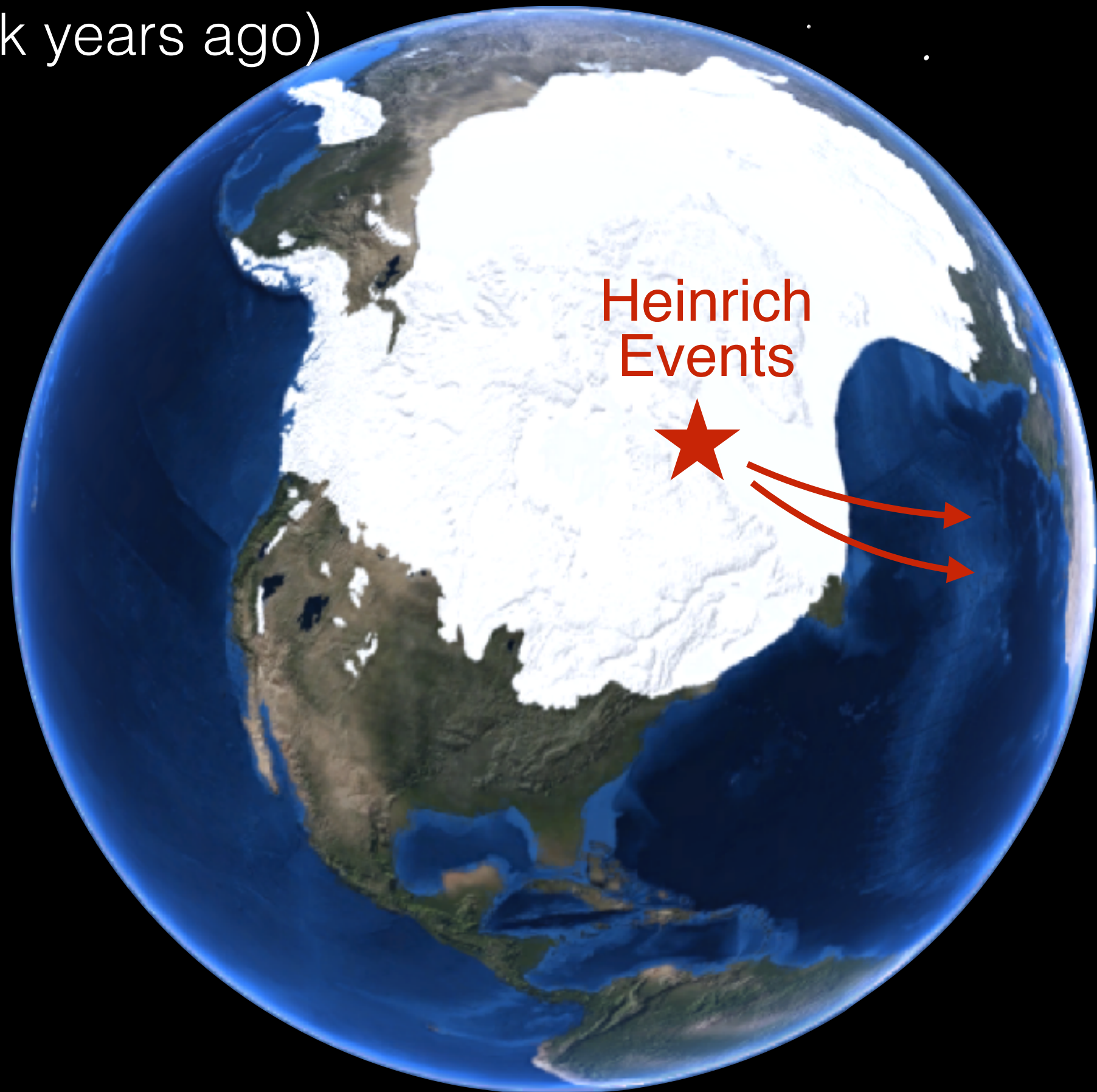


Ship

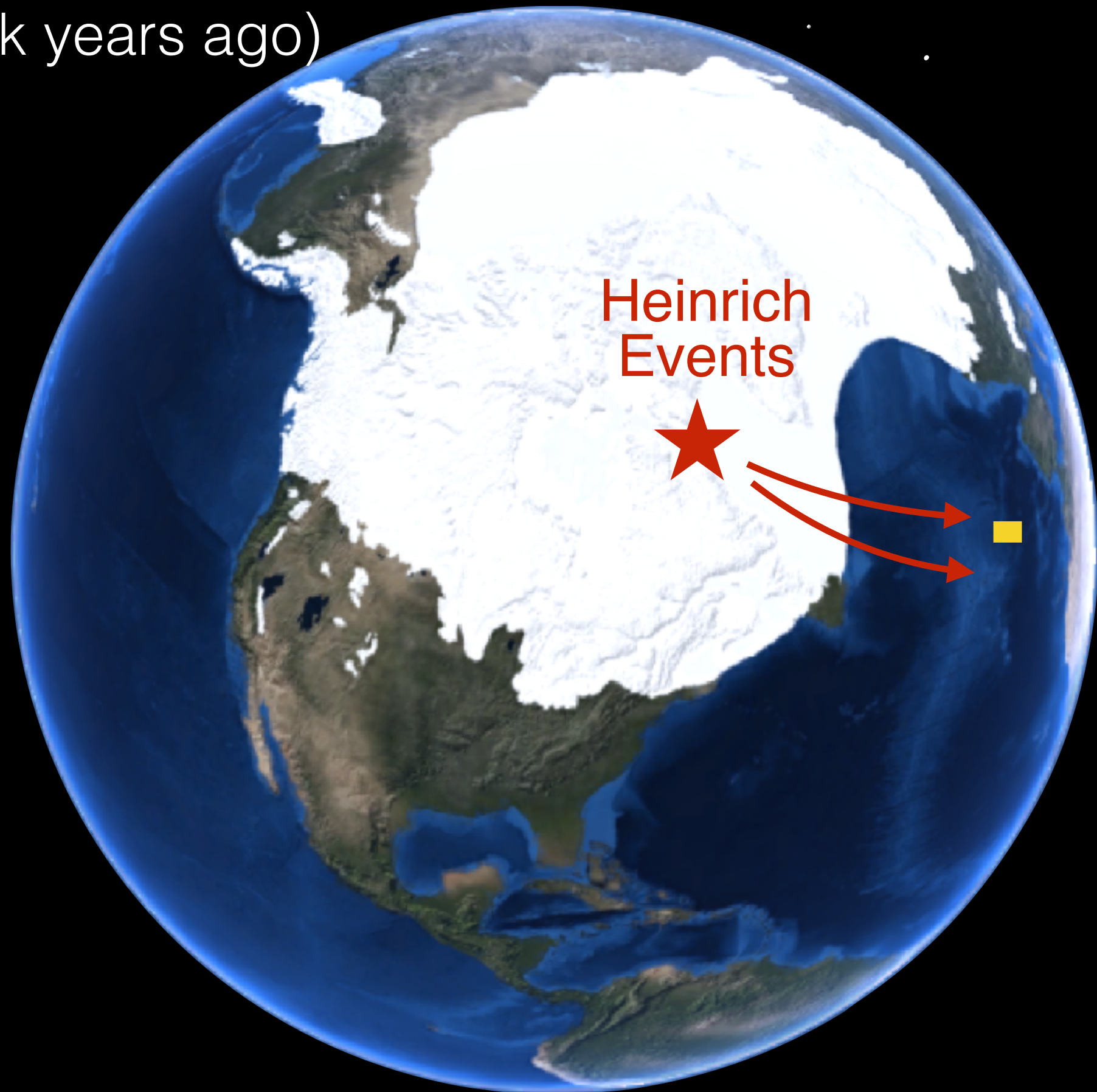
Laurentide ice sheet during last glacial period
(100k - 20k years ago)



Laurentide ice sheet during last glacial period
(100k - 20k years ago)

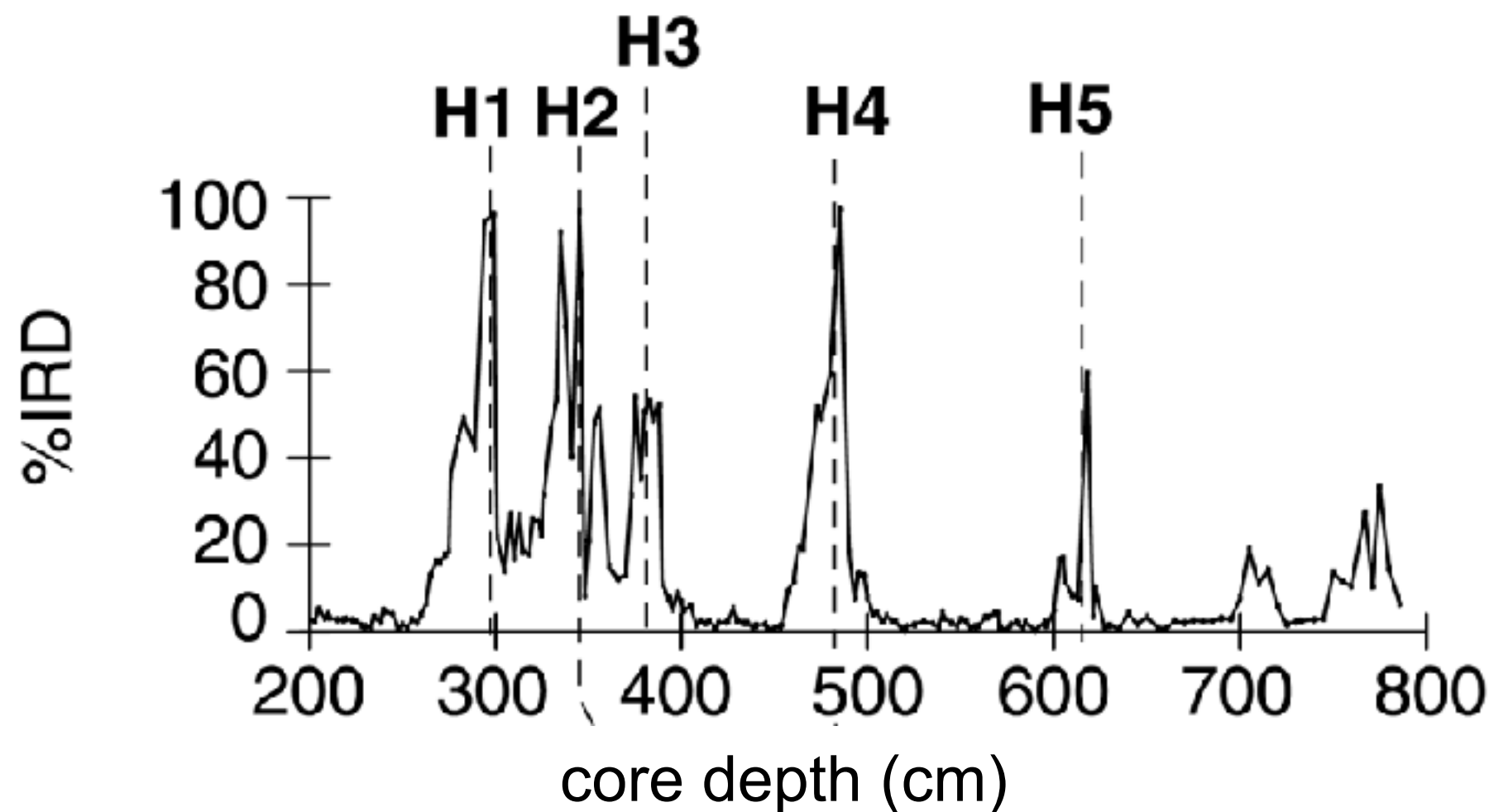


Laurentide ice sheet during last glacial period
(100k - 20k years ago)



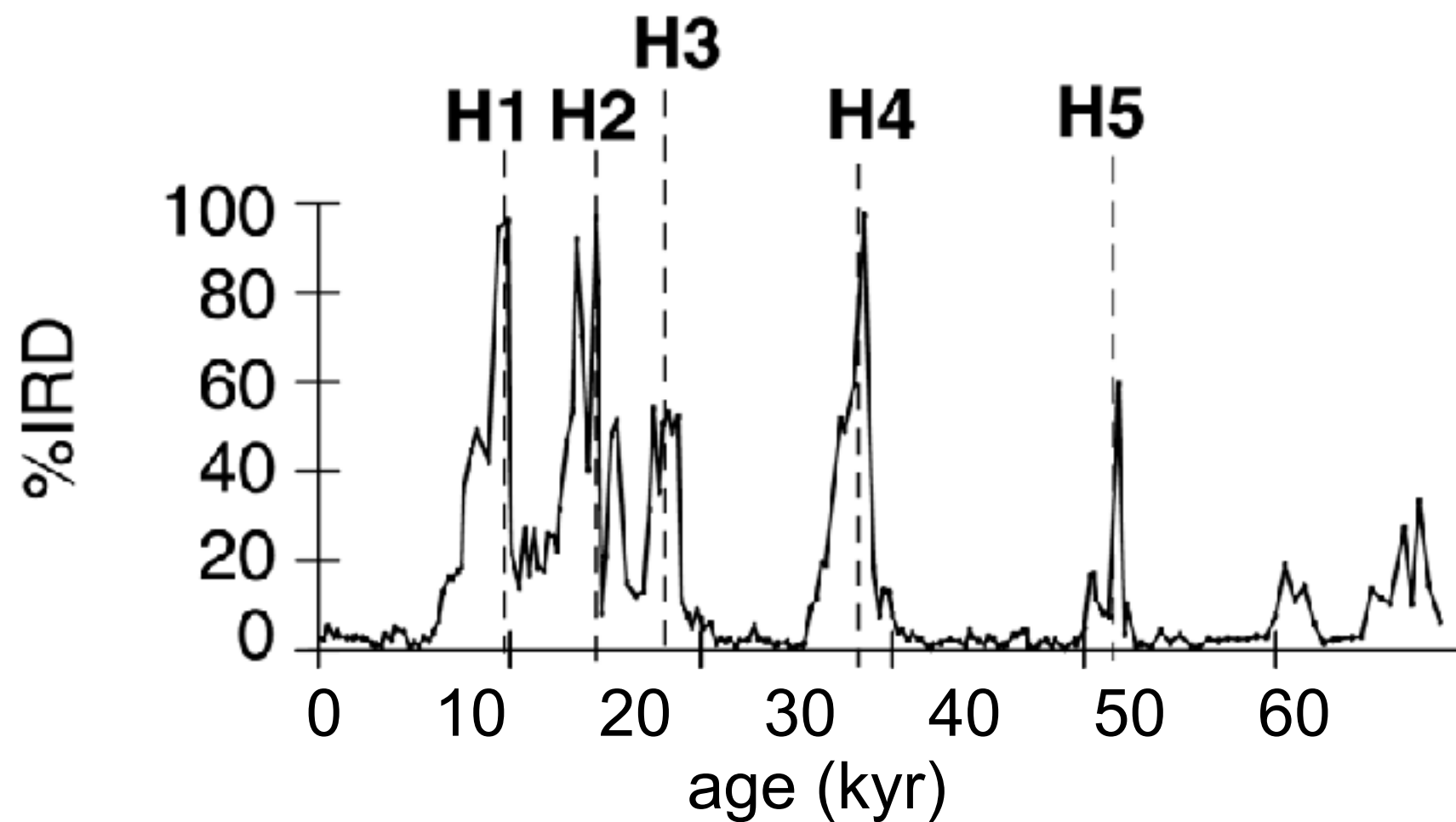
Laurentide ice sheet during last glacial period (100k - 20k years ago)

Heinrich
Events



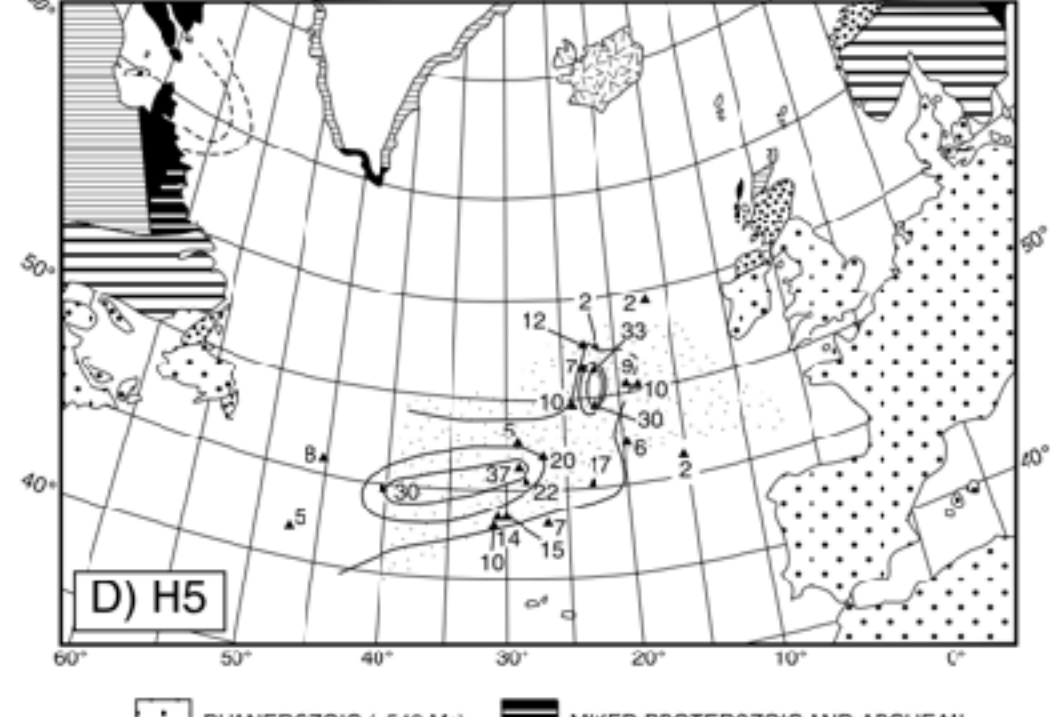
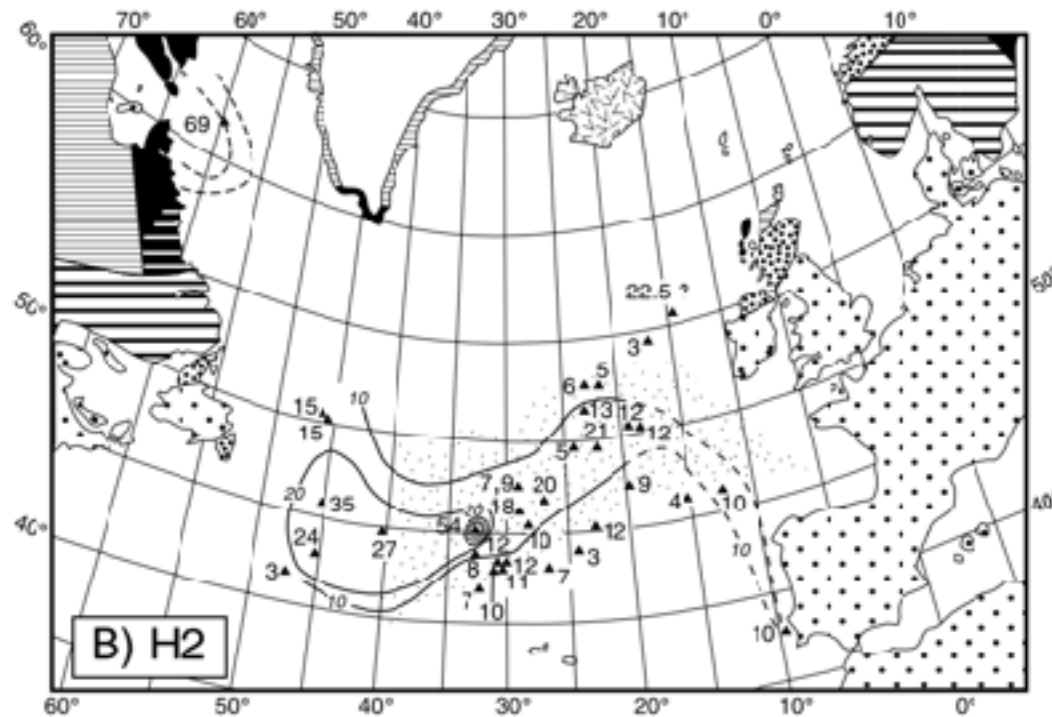
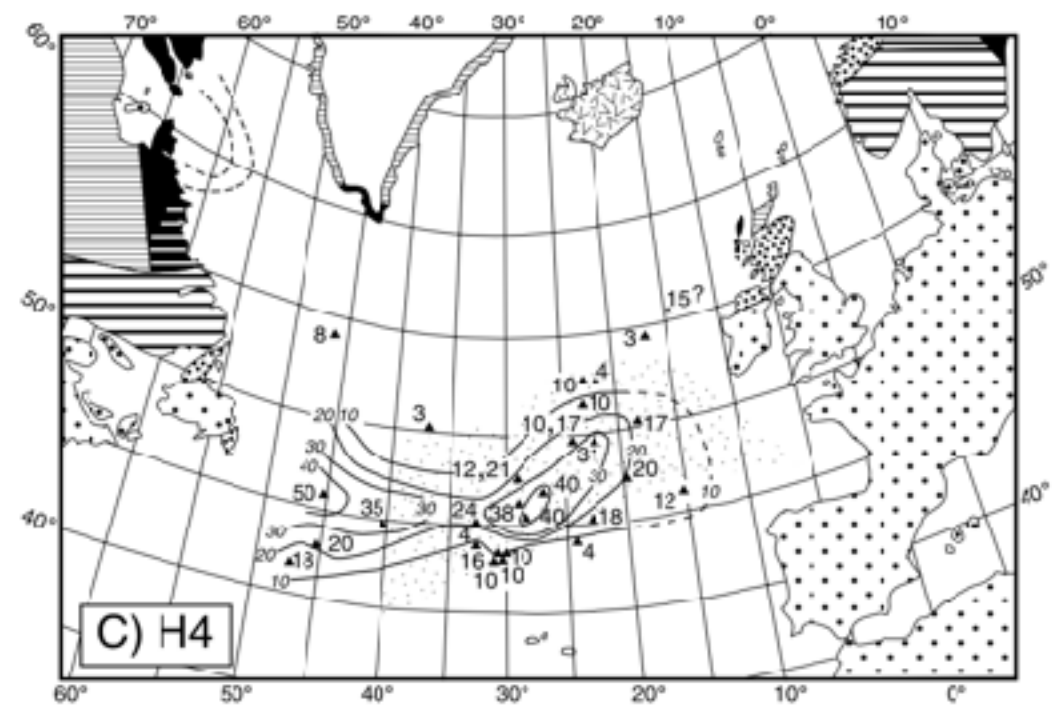
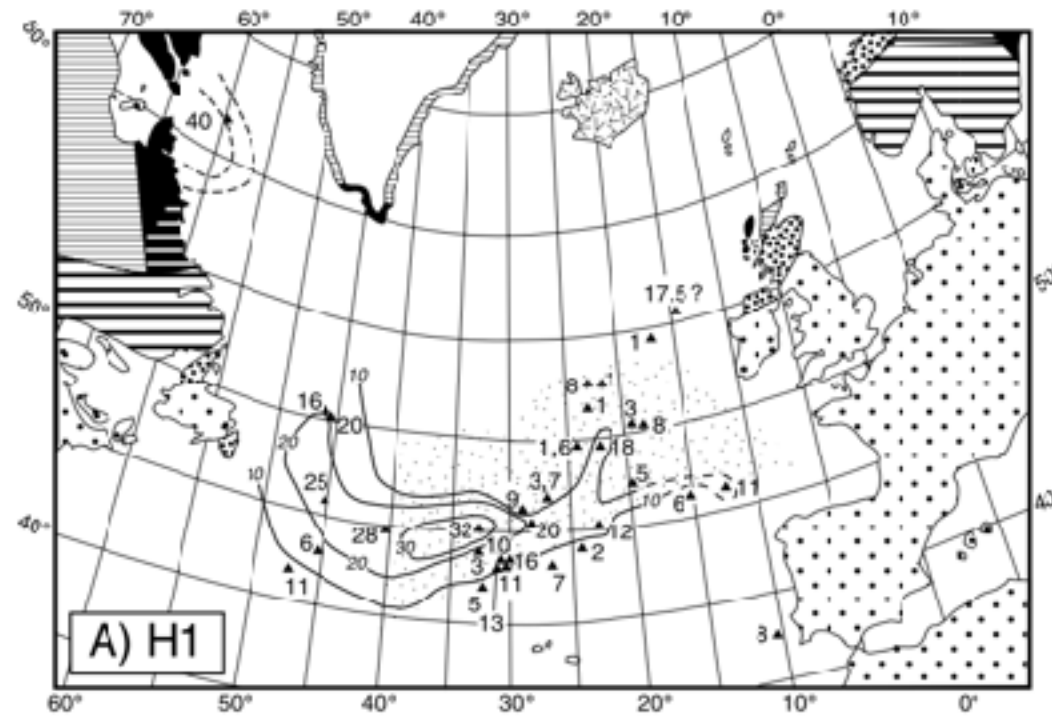
Laurentide ice sheet during last glacial period (100k - 20k years ago)

Heinrich
Events



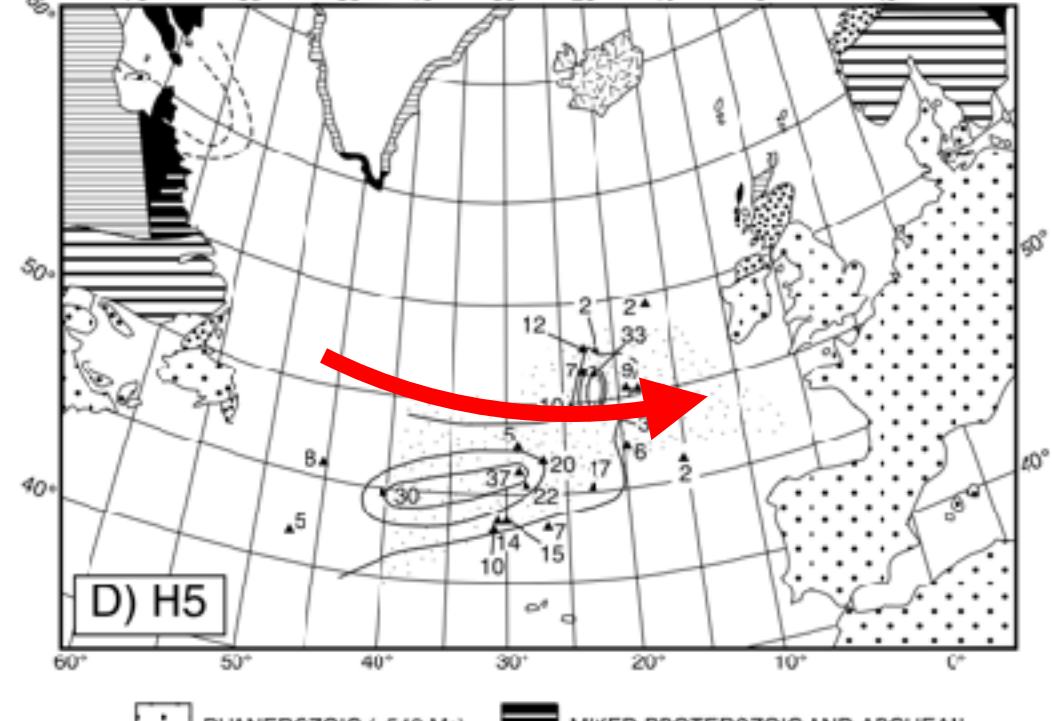
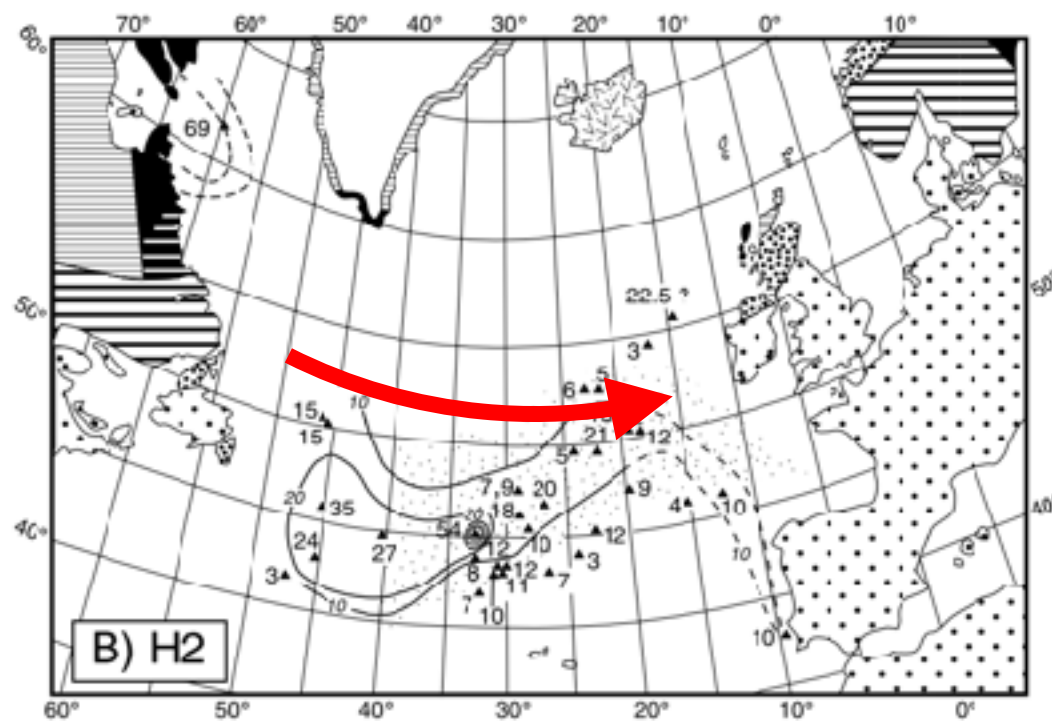
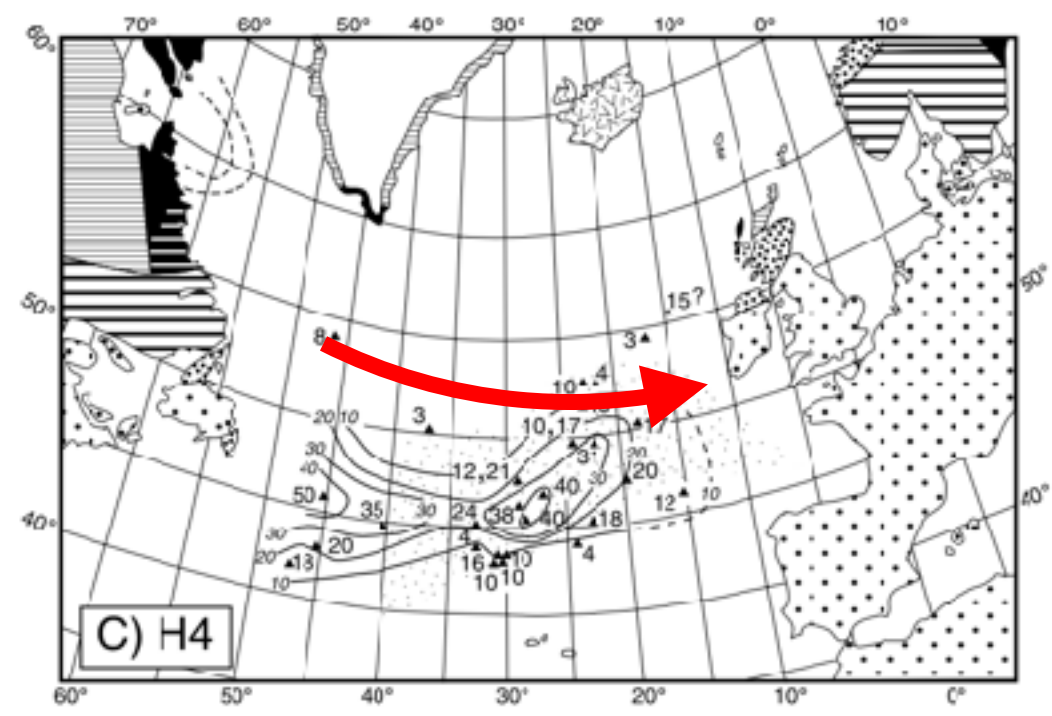
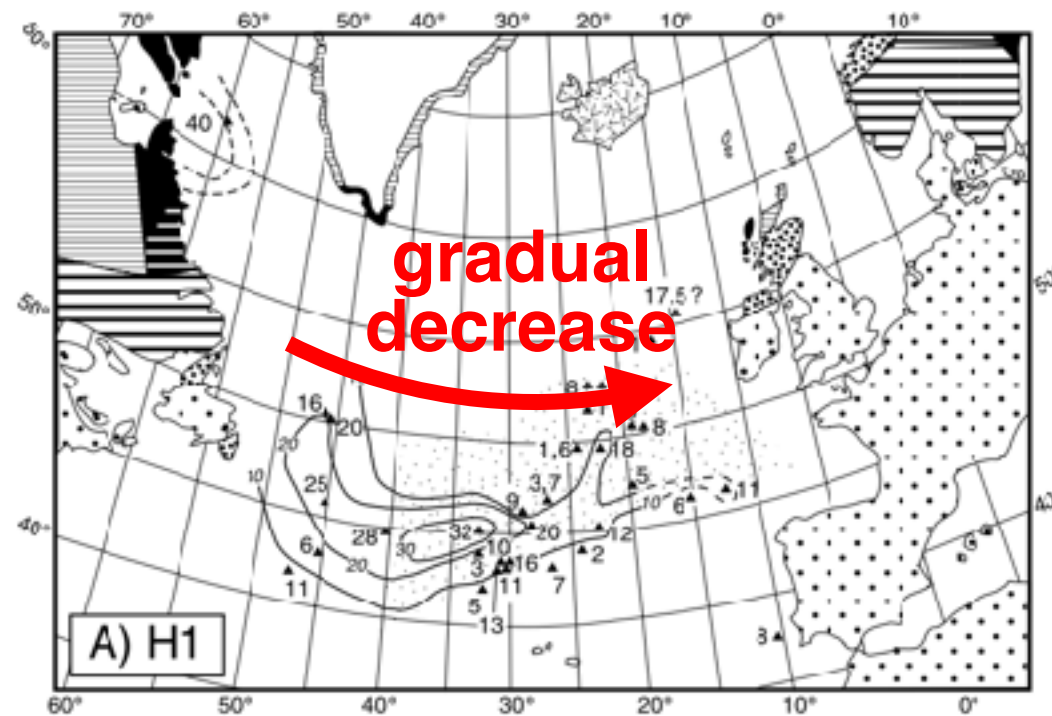
How does simulated iceberg melt compare to ice-rafted debris layers of Heinrich Events?

How does simulated iceberg melt compare to ice-rafted debris layers of Heinrich Events?



Hemming (2004)

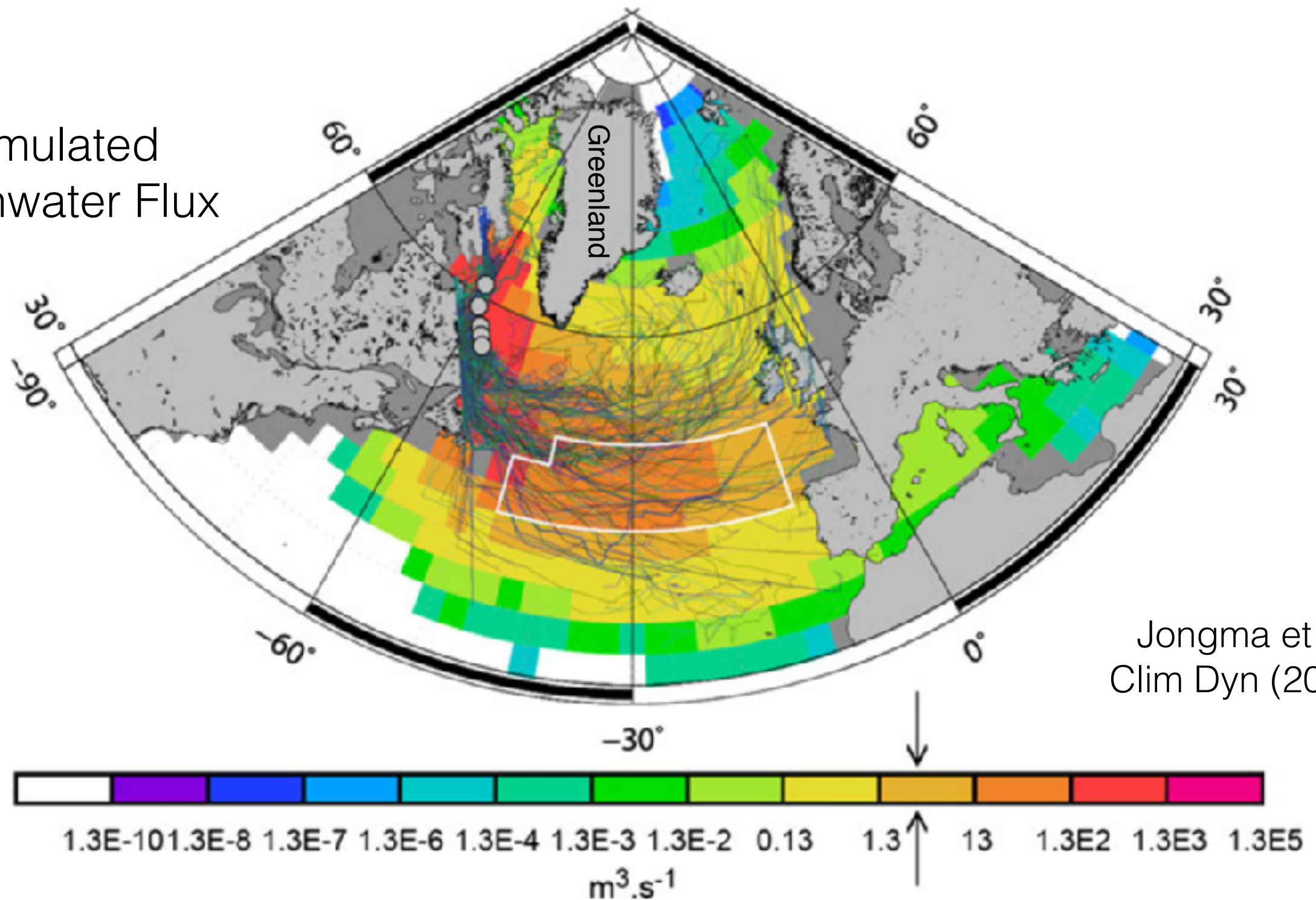
How does simulated iceberg melt compare to ice-rafted debris layers of Heinrich Events?



Hemming (2004)

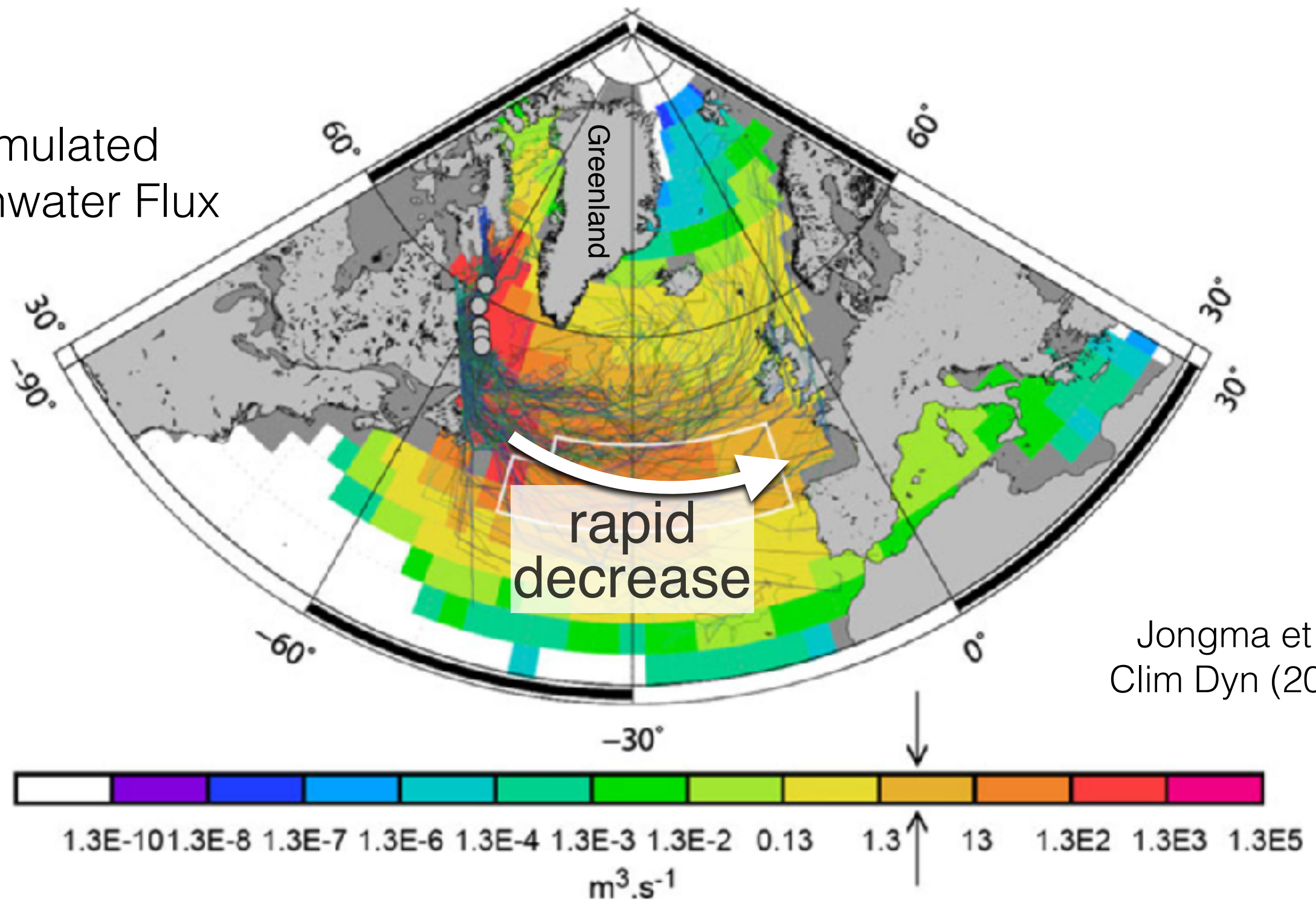
How does simulated iceberg melt compare to Ice-Rafted Debris Layers of Heinrich Events?

Simulated
Freshwater Flux



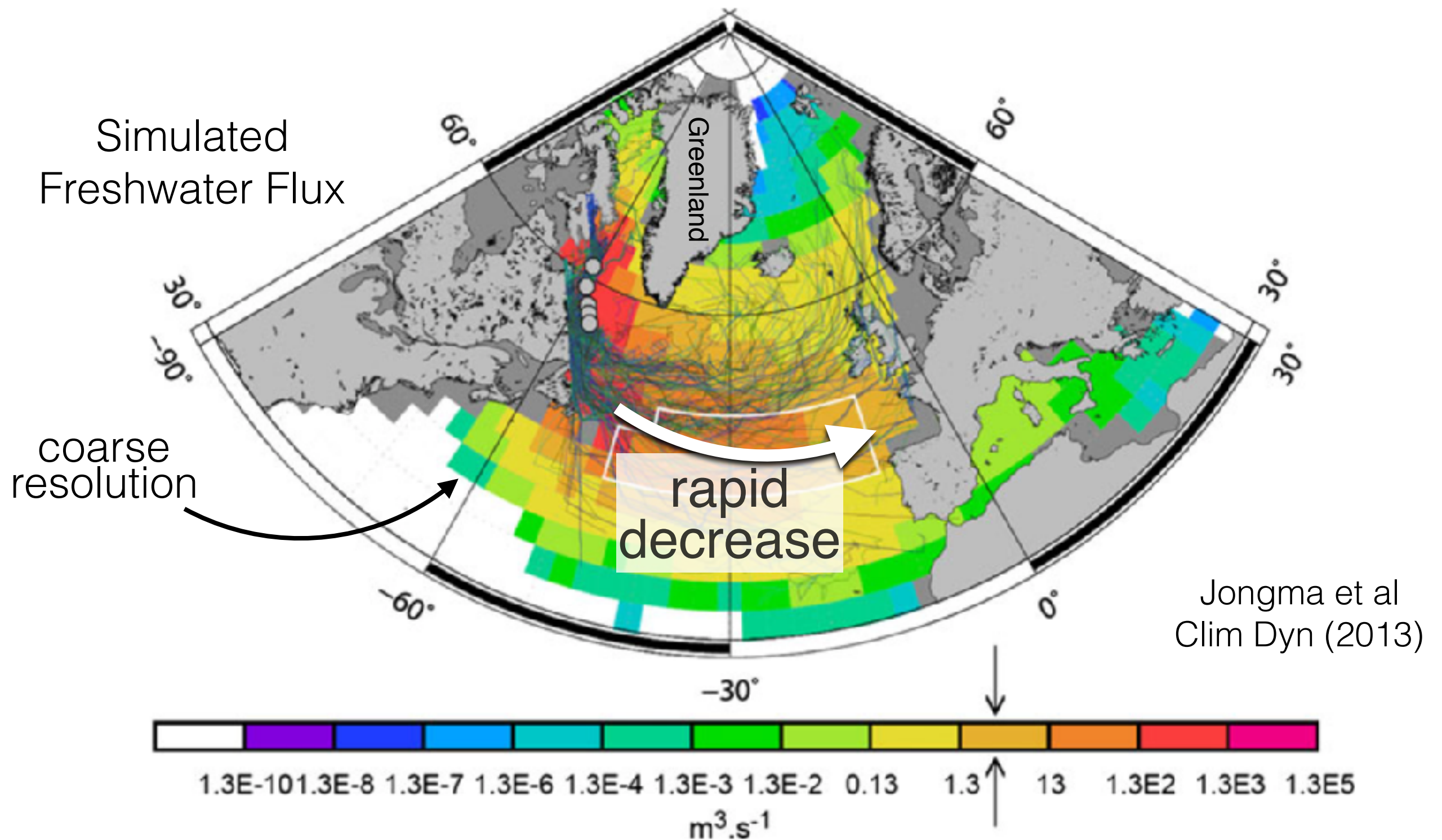
How does simulated iceberg melt compare to Ice-Rafted Debris Layers of Heinrich Events?

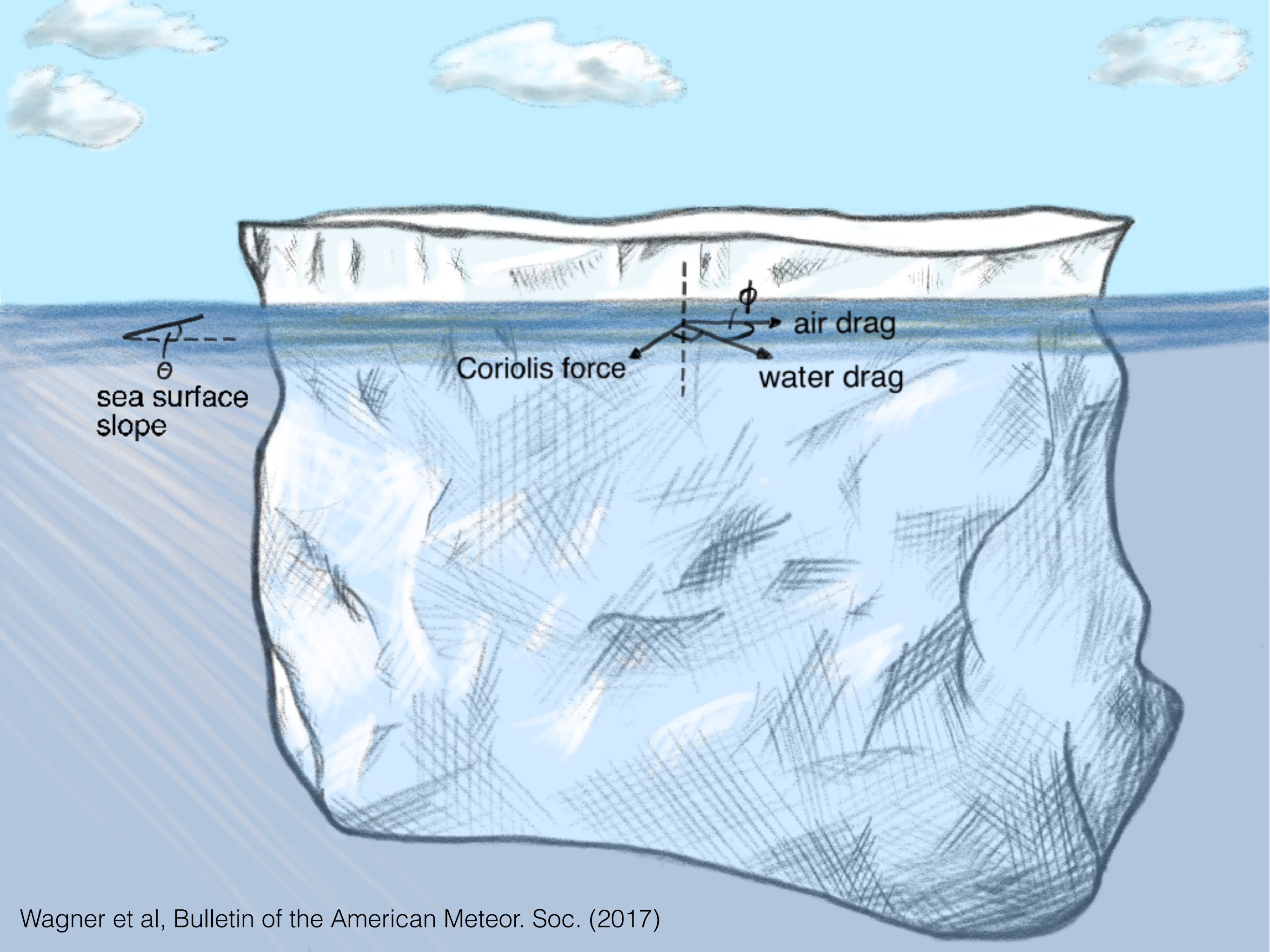
Simulated
Freshwater Flux



Jongma et al
Clim Dyn (2013)

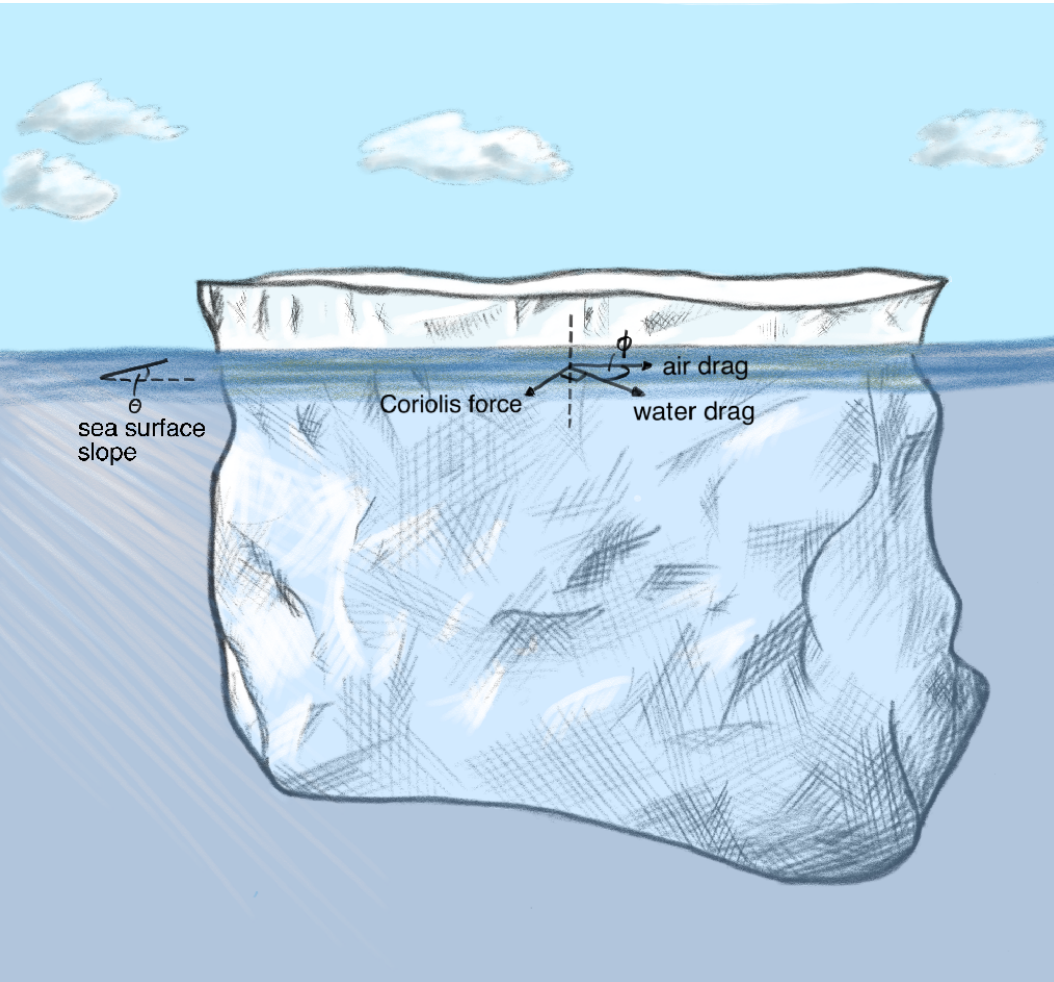
How does simulated iceberg melt compare to Ice-Rafted Debris Layers of Heinrich Events?





An Analytical Model for Iceberg Drift

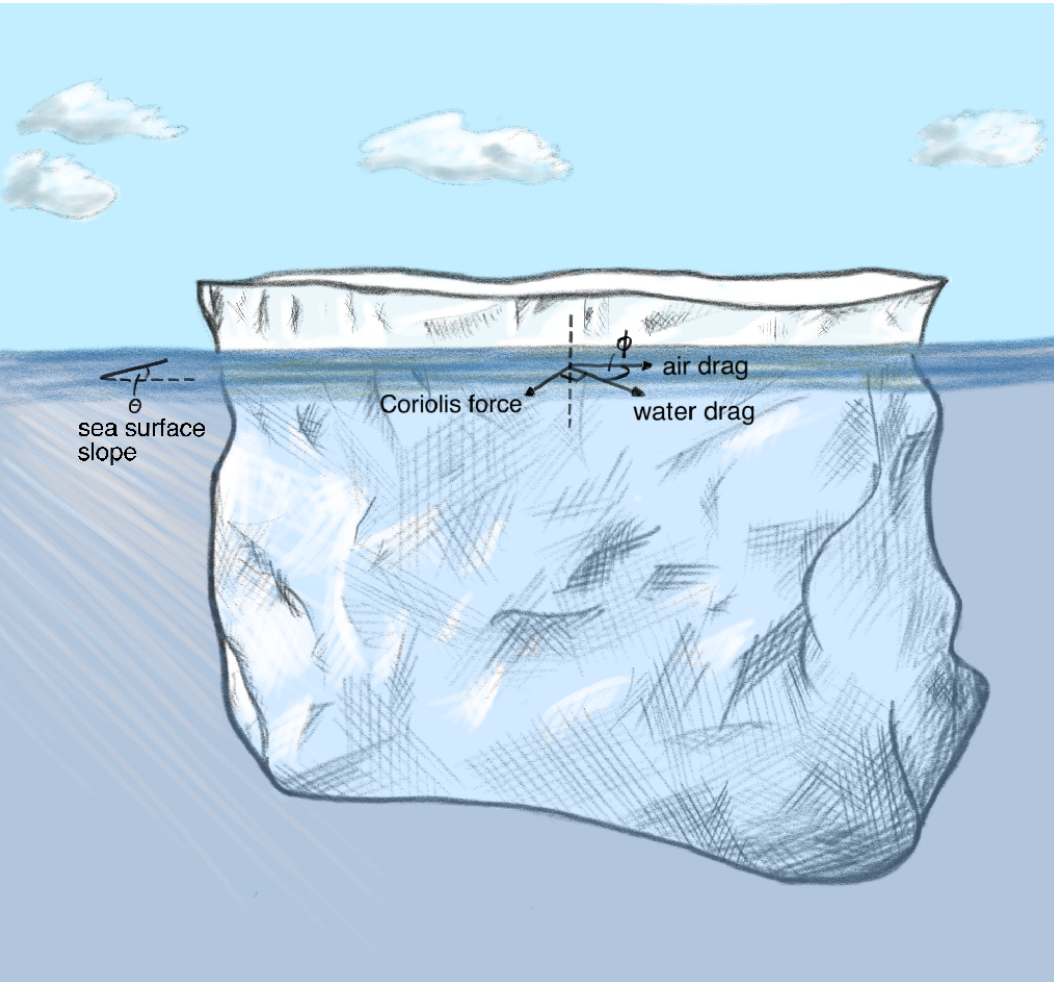
Wagner et al, J. Phys. Oceanogr., (2017)



$$\vec{V}_i = \vec{V}_w + C(\alpha \hat{k} \times \vec{v}_a + \beta \vec{v}_a)$$

An Analytical Model for Iceberg Drift

Wagner et al, J. Phys. Oceanogr., (2017)

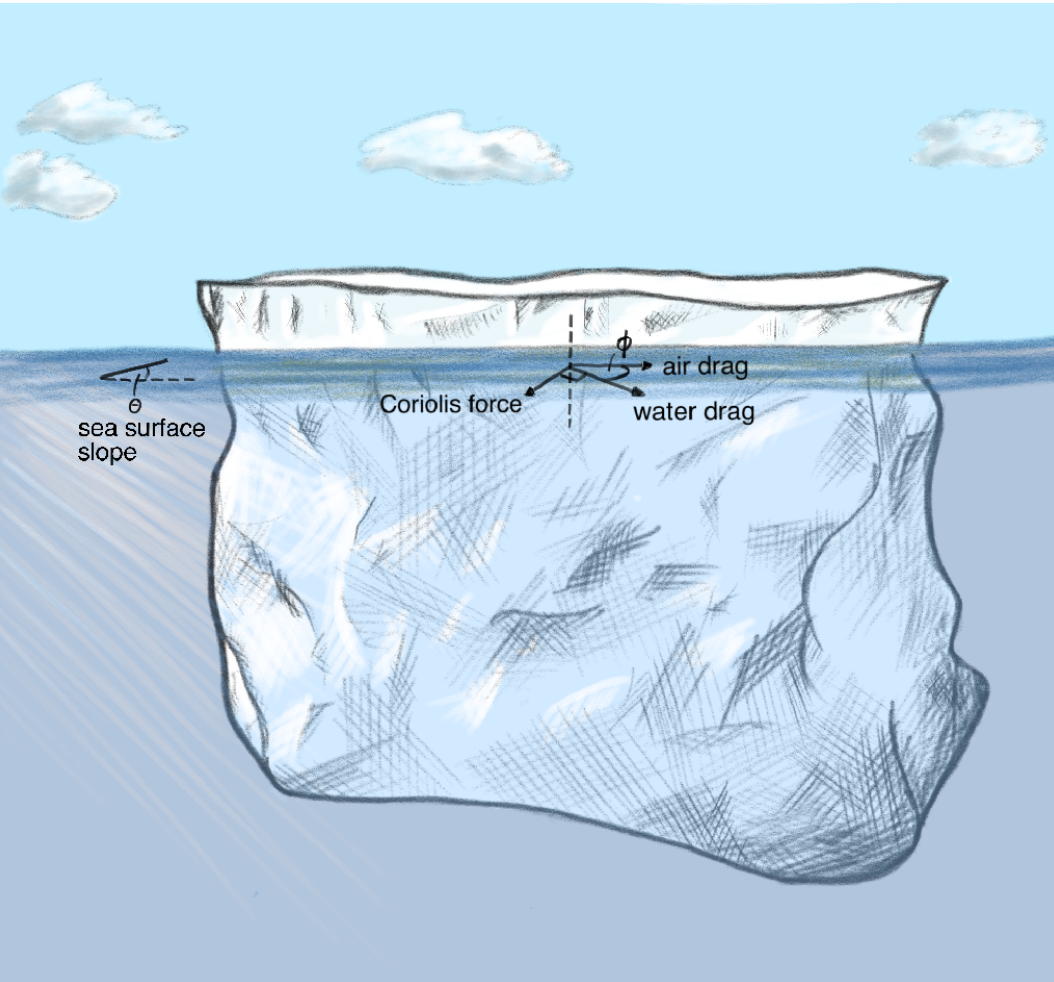


$$\vec{V}_i = \vec{V}_w + C(\alpha \hat{k} \times \vec{v}_a + \beta \vec{v}_a)$$

ice
velocity

An Analytical Model for Iceberg Drift

Wagner et al, J. Phys. Oceanogr., (2017)



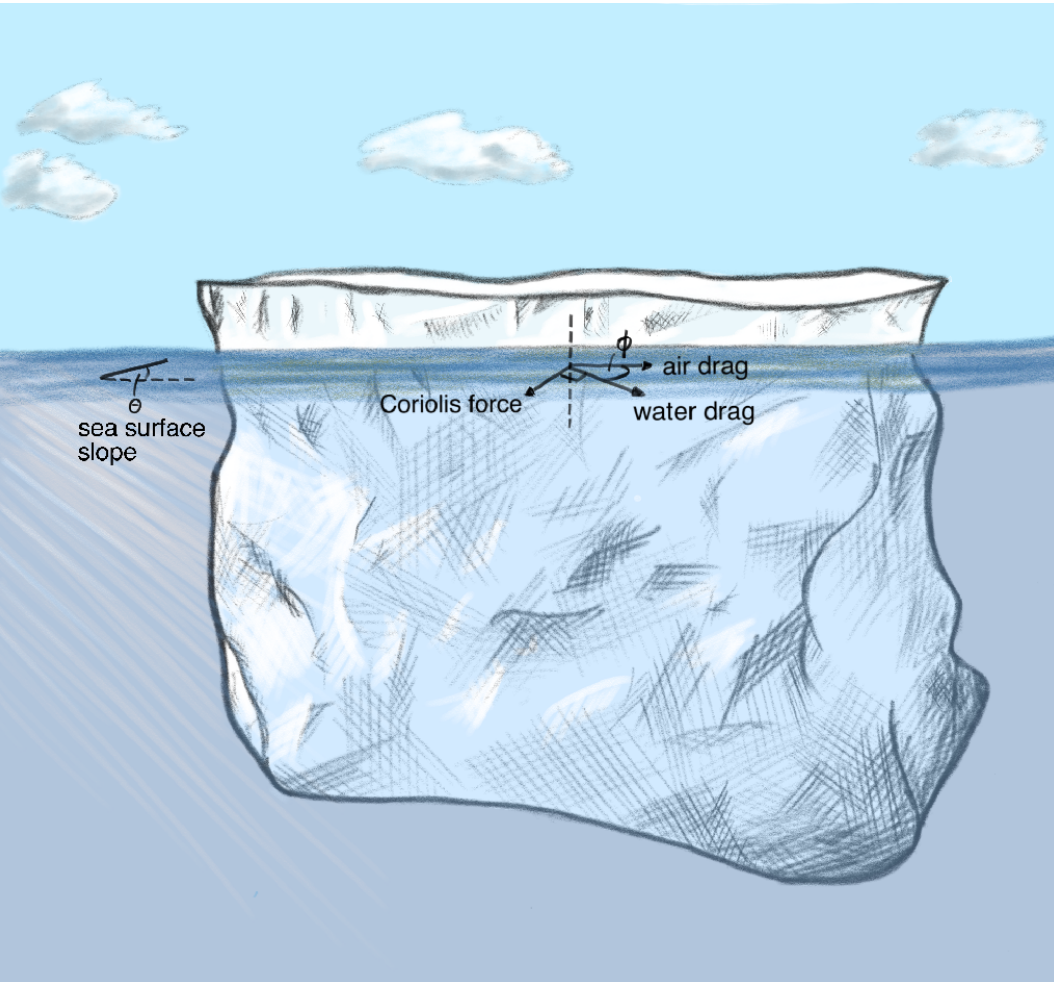
water velocity

$$\vec{V}_i = \vec{V}_w + C(\alpha \hat{k} \times \vec{v}_a + \beta \vec{v}_a)$$

ice velocity

An Analytical Model for Iceberg Drift

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water velocity

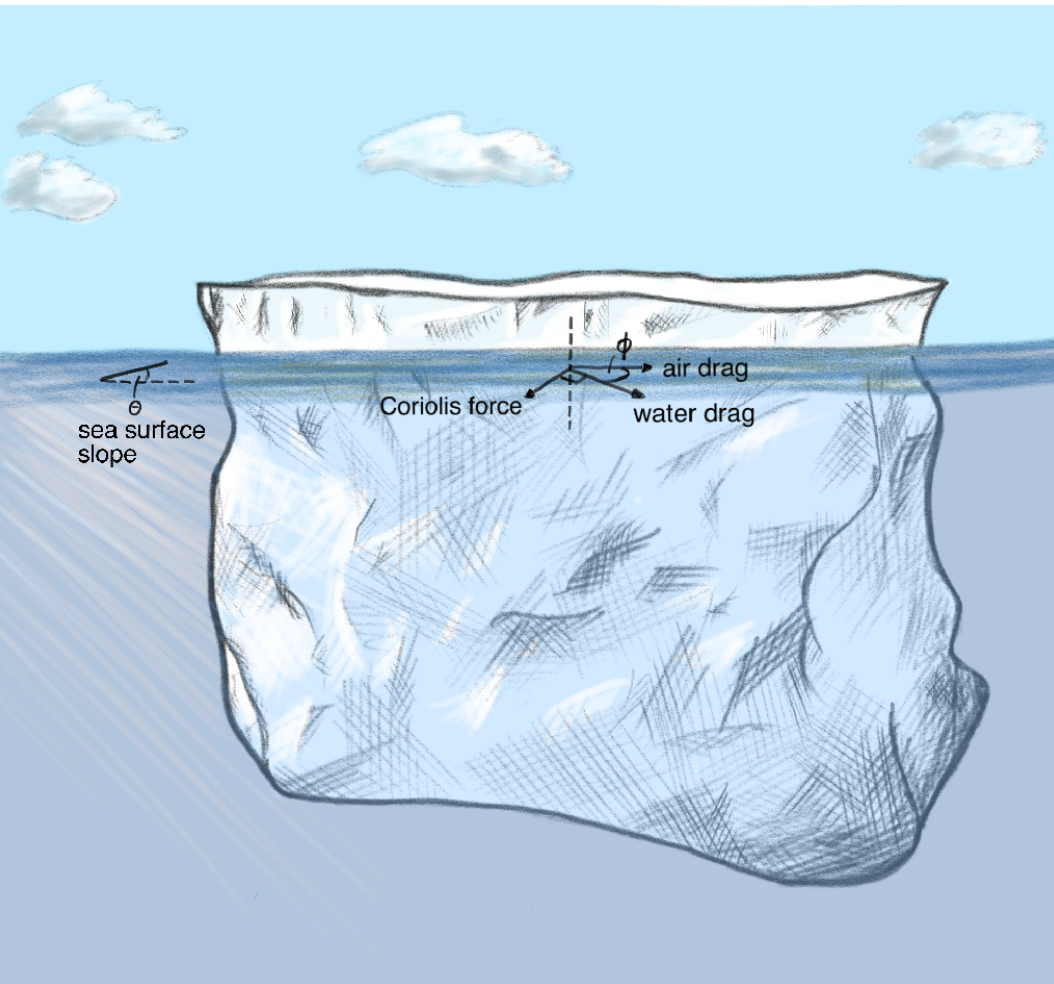
$$\vec{V}_i = \vec{V}_w + C(\alpha \hat{k} \times \vec{v}_a + \beta \vec{v}_a)$$

ice velocity

across-wind air velocity

An Analytical Model for Iceberg Drift

Wagner et al, J. Phys. Oceanogr., (2017)



water velocity

along-wind air velocity

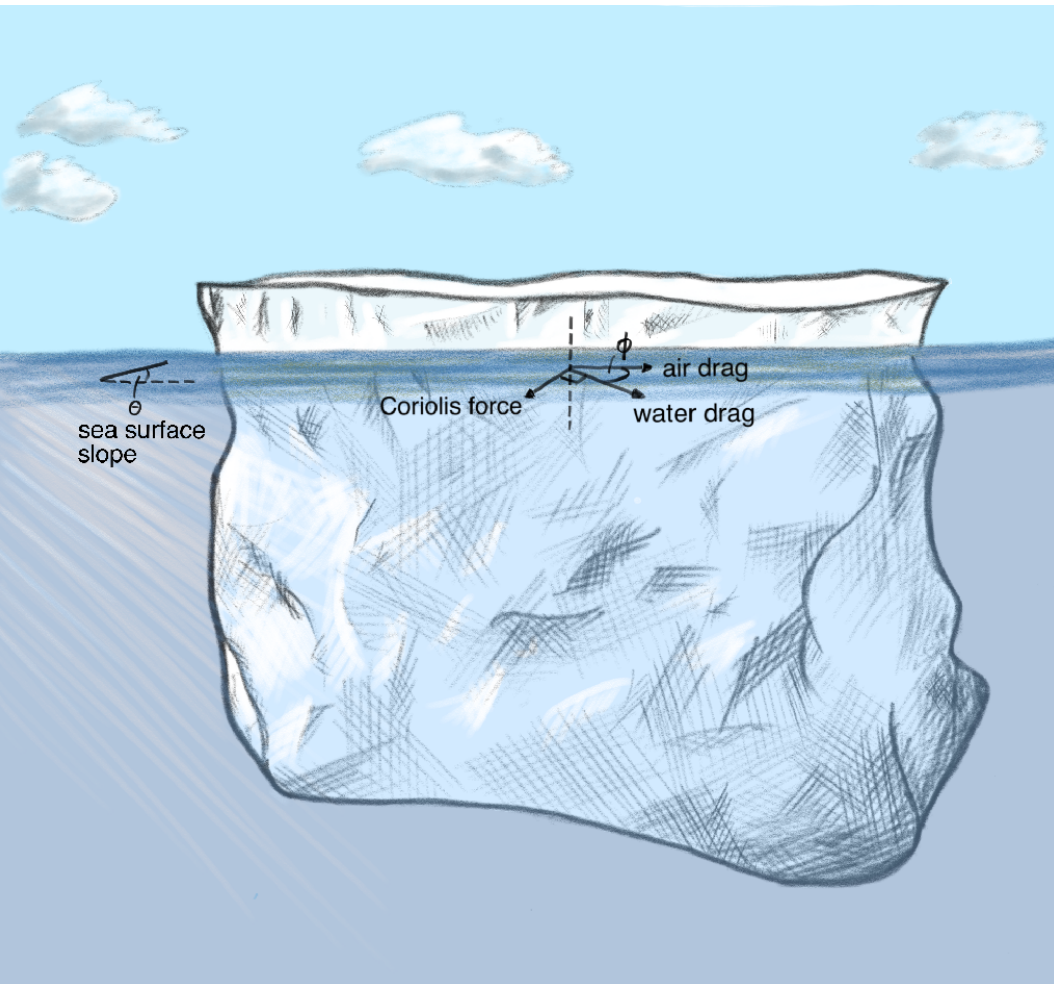
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ice velocity

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across-wind air velocity

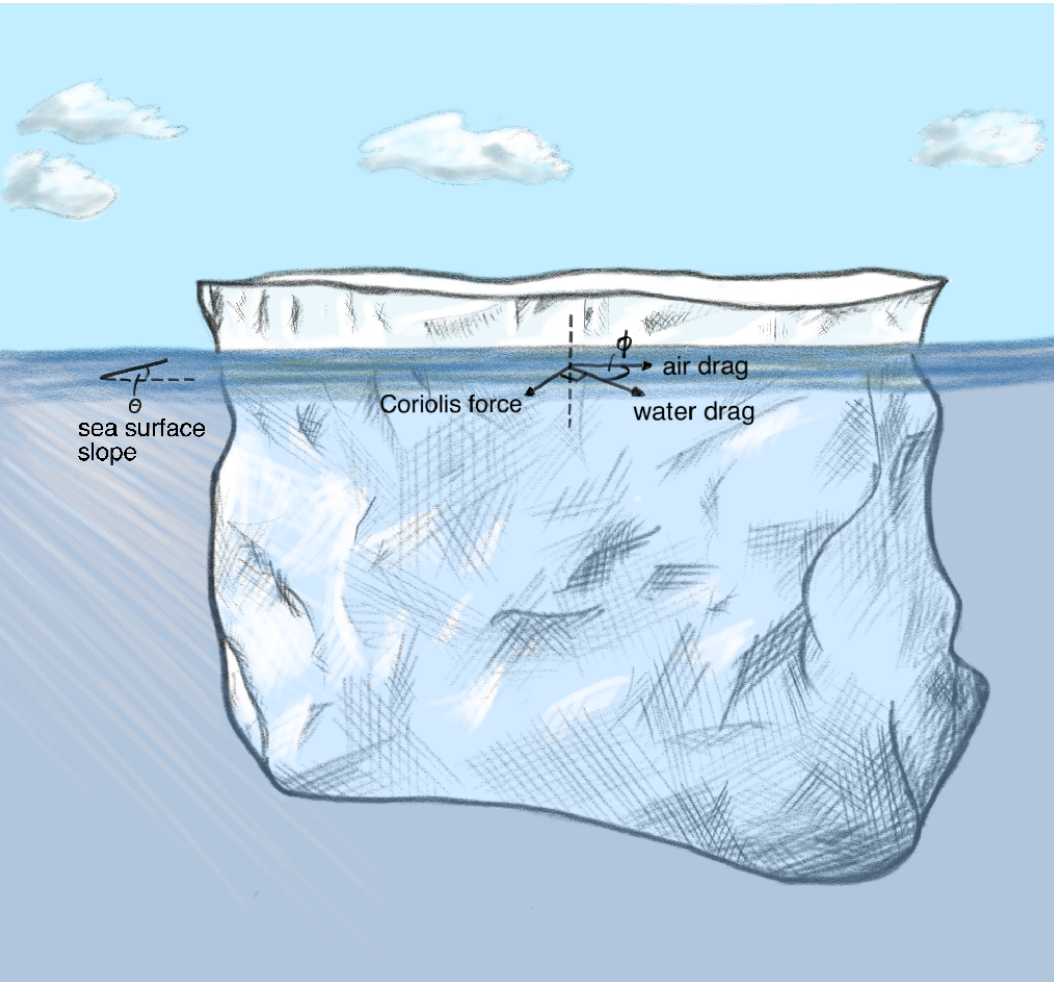
along-wind air velocity

$\beta = \beta(L, |\vec{v}_a|)$

$\alpha = \alpha(L, |\vec{v}_a|)$

An Analytical Model for Iceberg Drift

Wagner et al, J. Phys. Oceanogr., (2017)



$$\vec{V}_i = \vec{V}_w + C(\alpha \hat{k} \times \vec{v}_a + \beta \vec{v}_a)$$

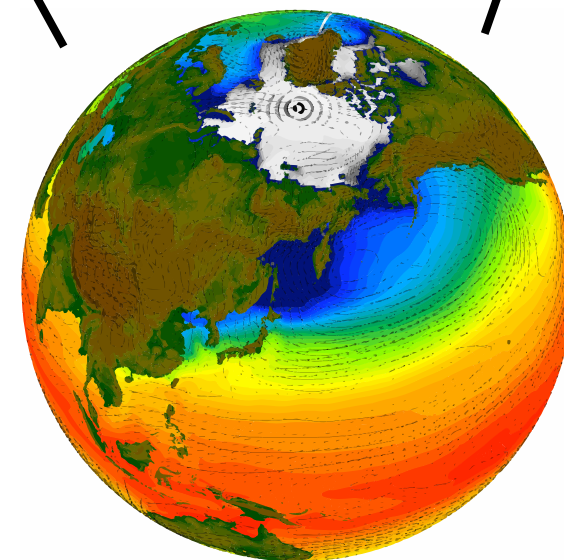
Labels for the equation components:

- $\vec{V}_i$: ice velocity
- $\vec{V}_w$: water velocity
- $\alpha \hat{k} \times \vec{v}_a$: across-wind air velocity
- $\beta \vec{v}_a$: along-wind air velocity

Parameter definitions:

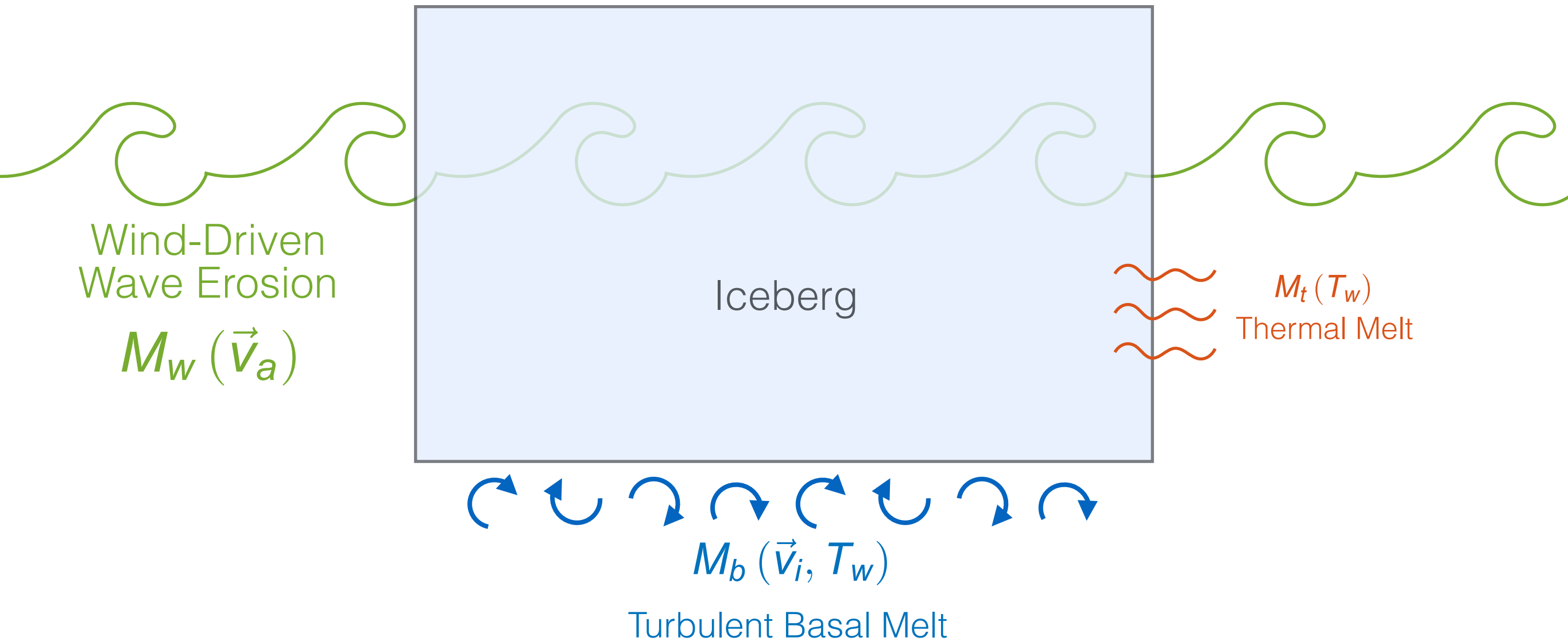
- $\alpha = \alpha(L, |\vec{v}_a|)$
- $\beta = \beta(L, |\vec{v}_a|)$

Idealized iceberg model
+ hi-res global climate model

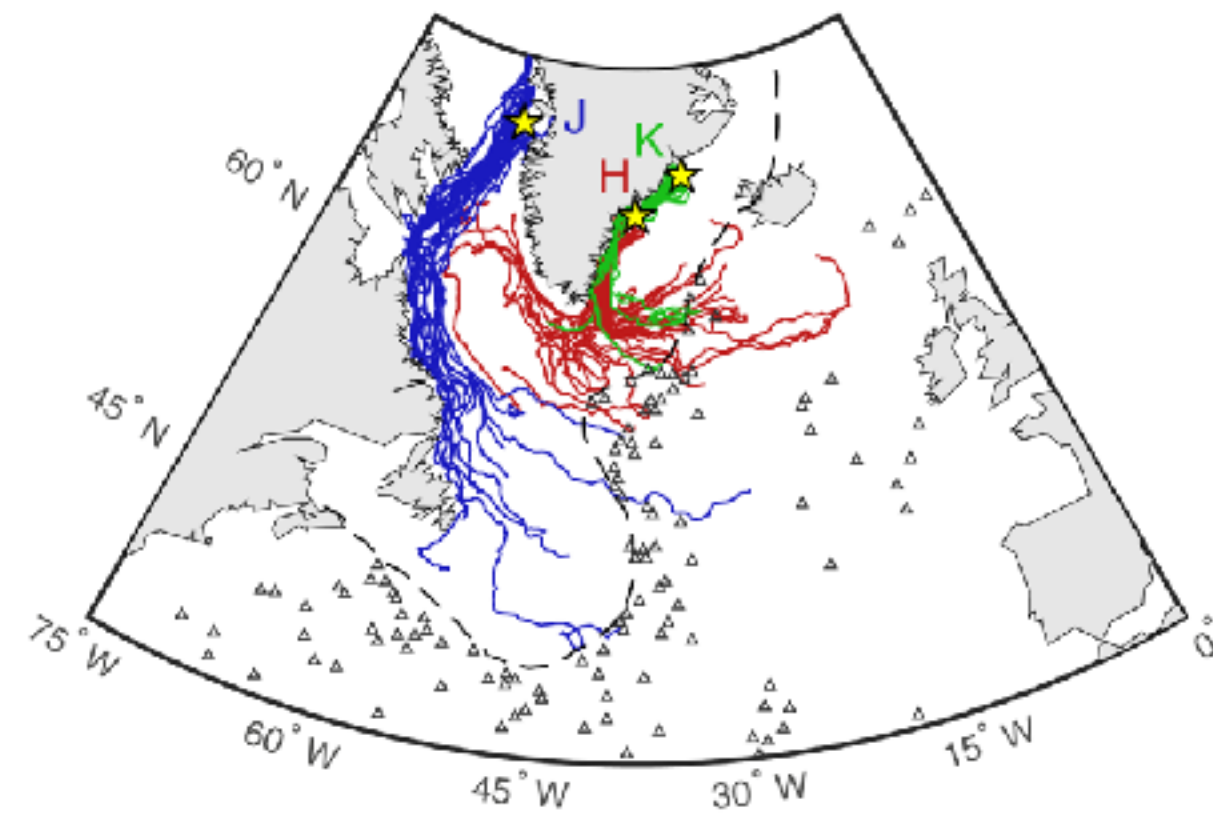


Decay Model

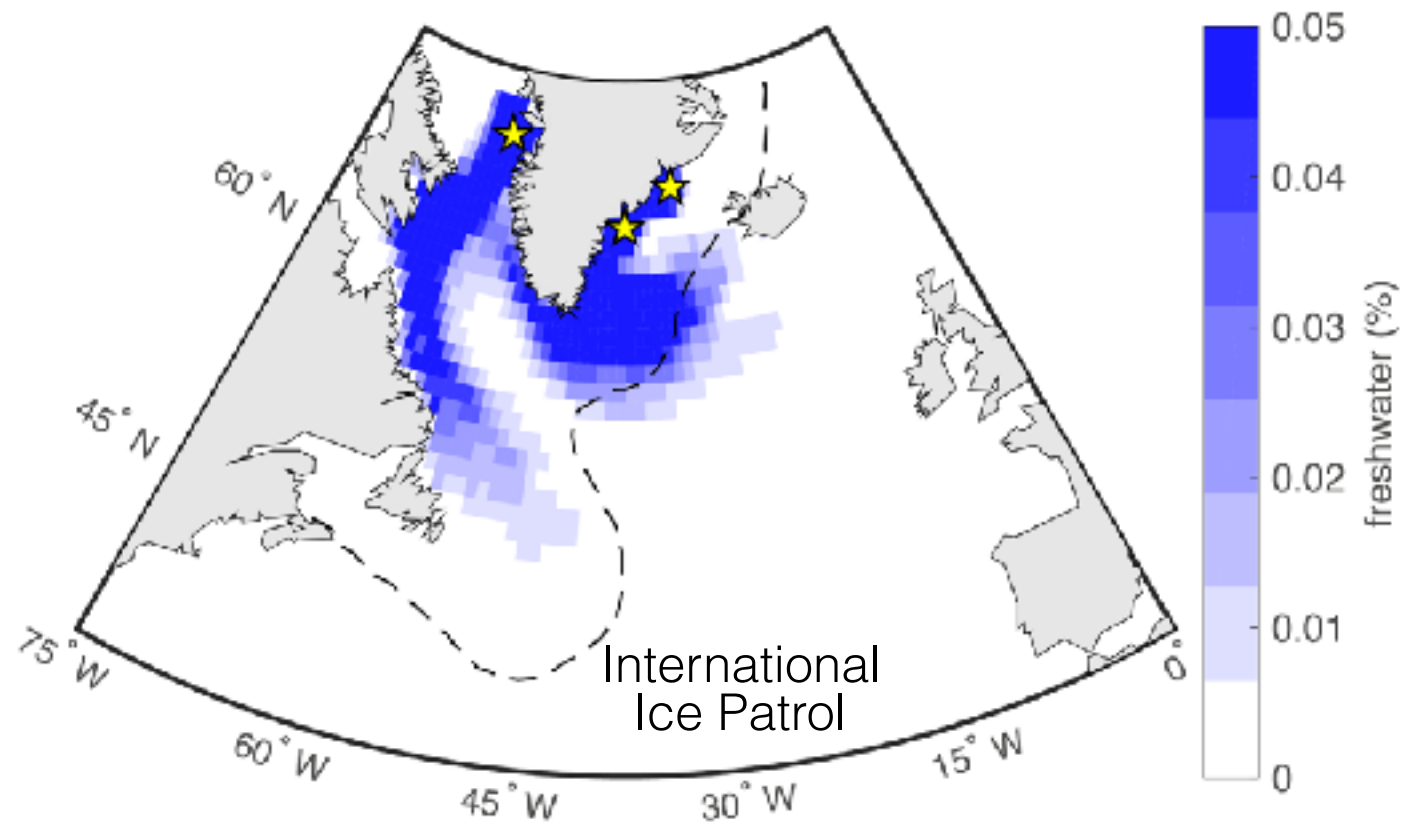
(Bigg et al, *Cold Reg Sci Tech*, 1997)



Model Validation

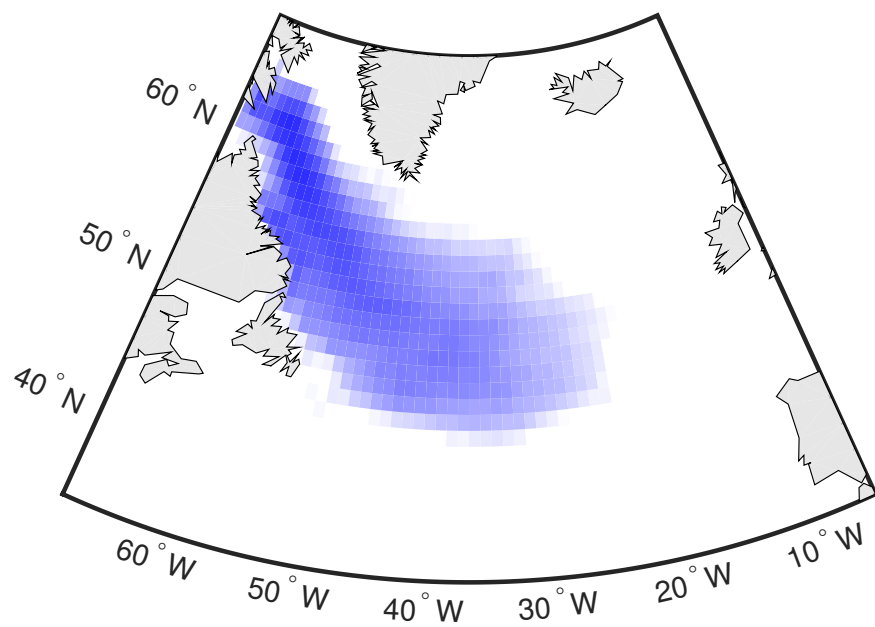
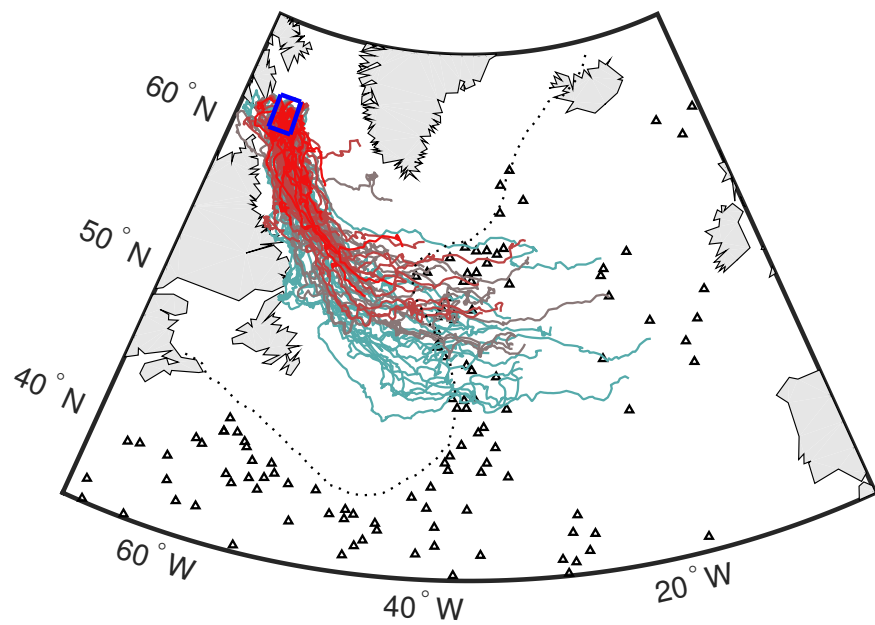


Iceberg Trajectories

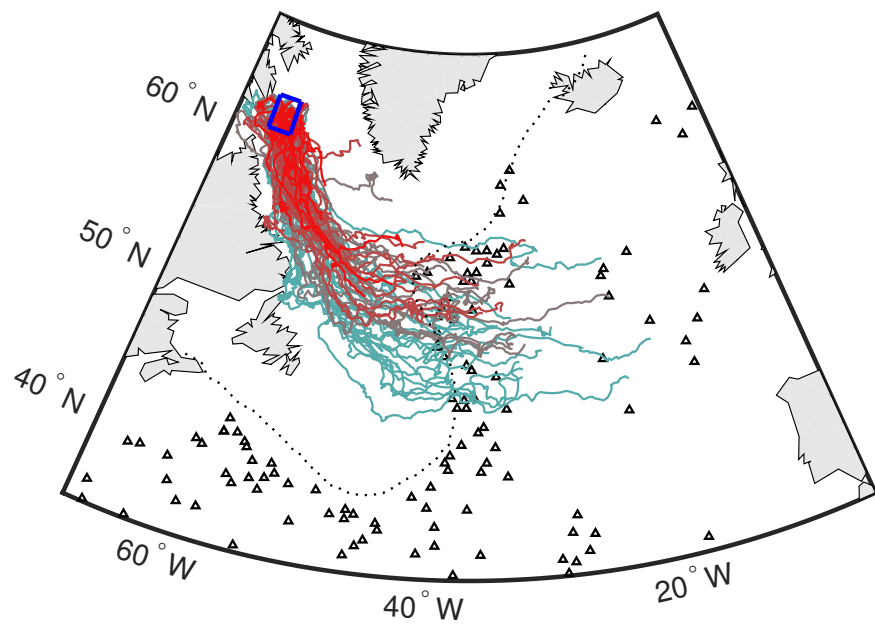


Freshwater Flux

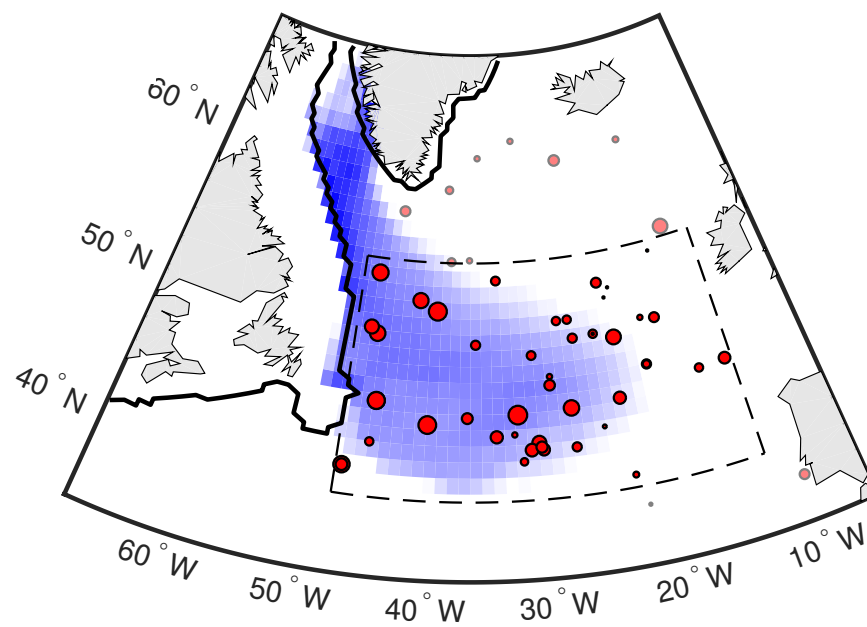
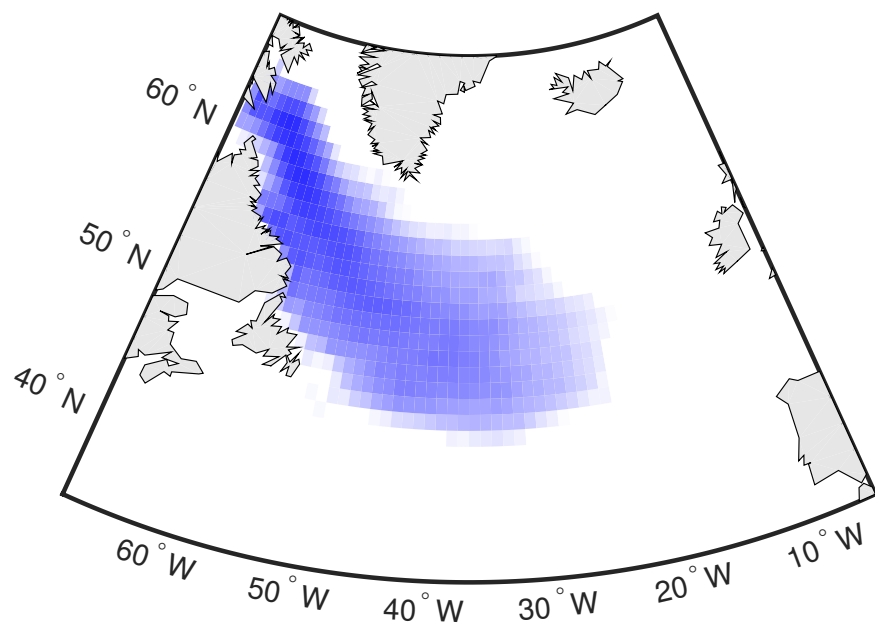
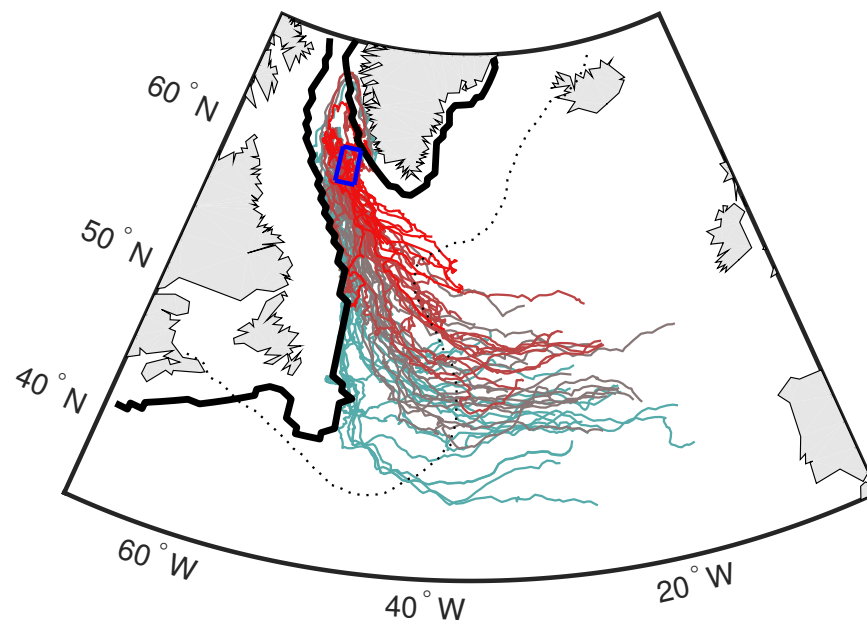
20C

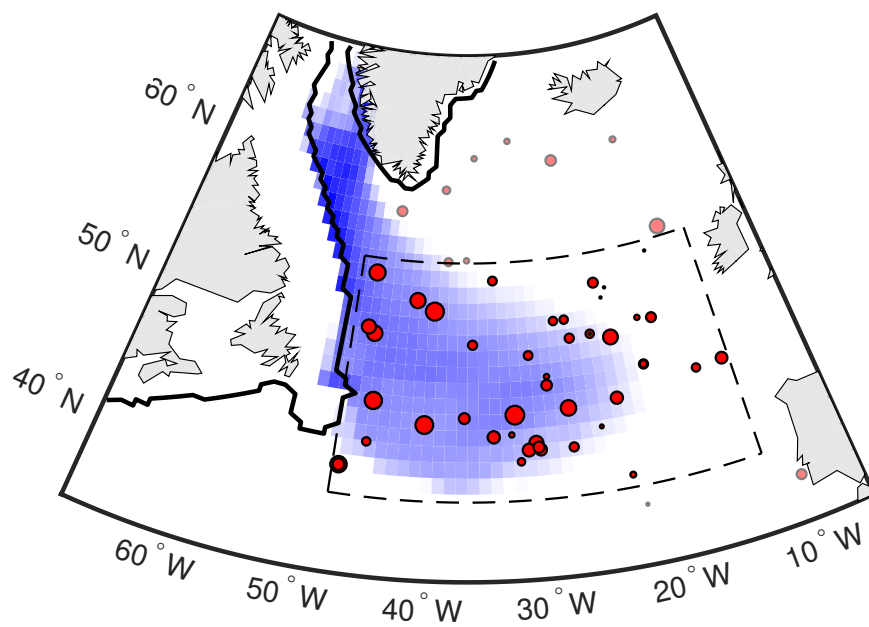
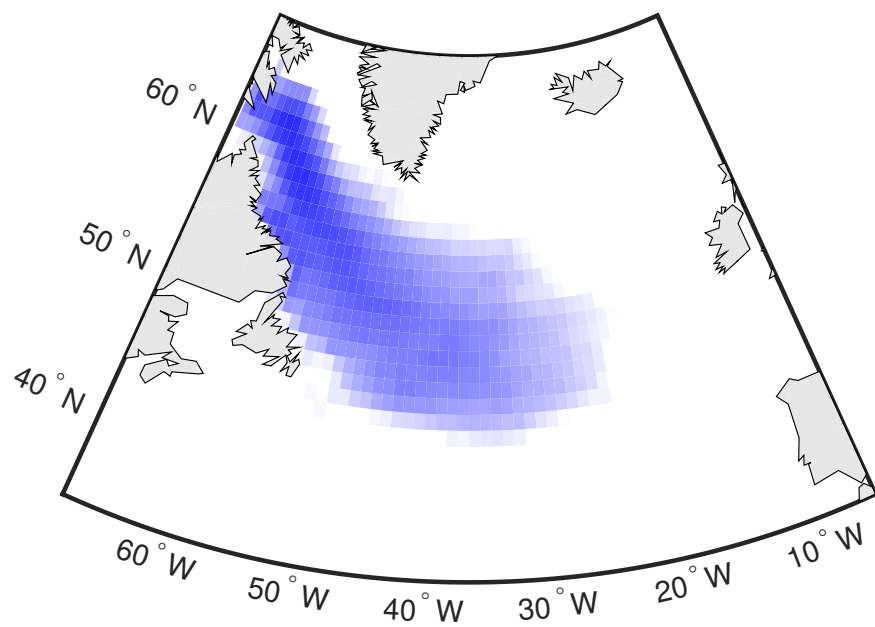
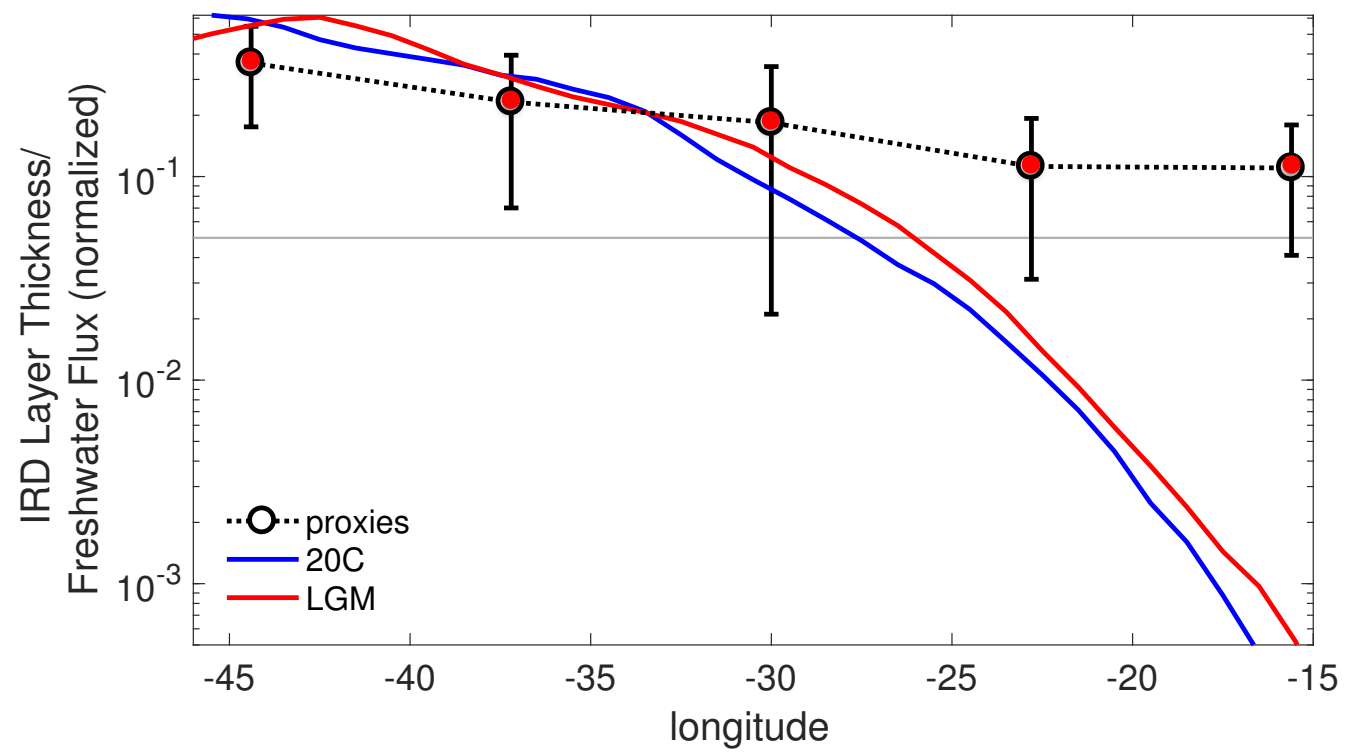


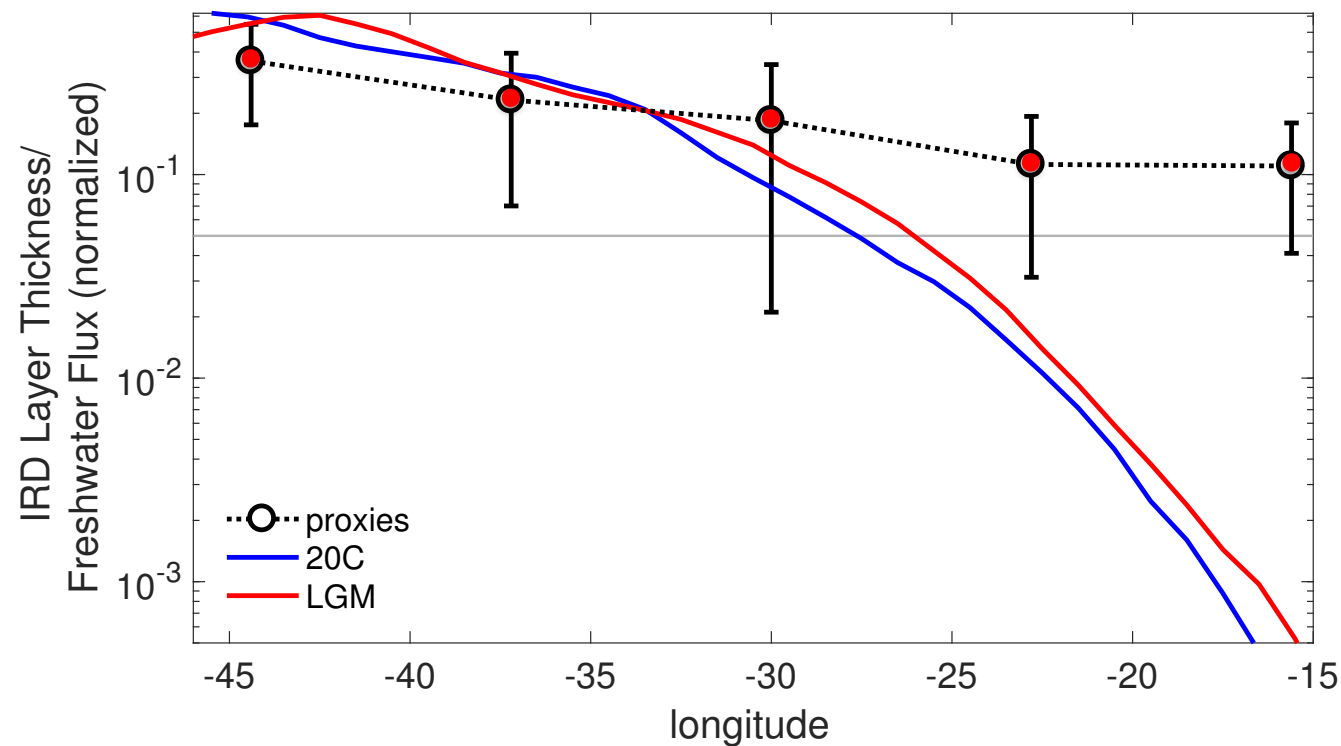
20C



LGM

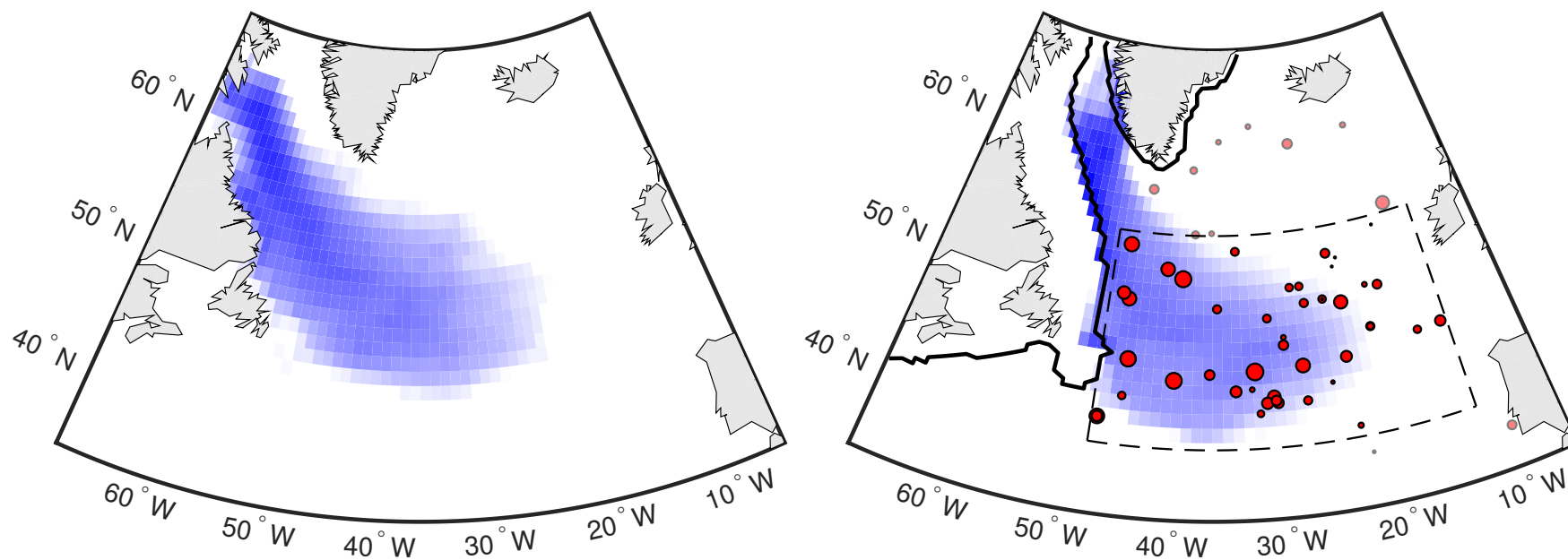


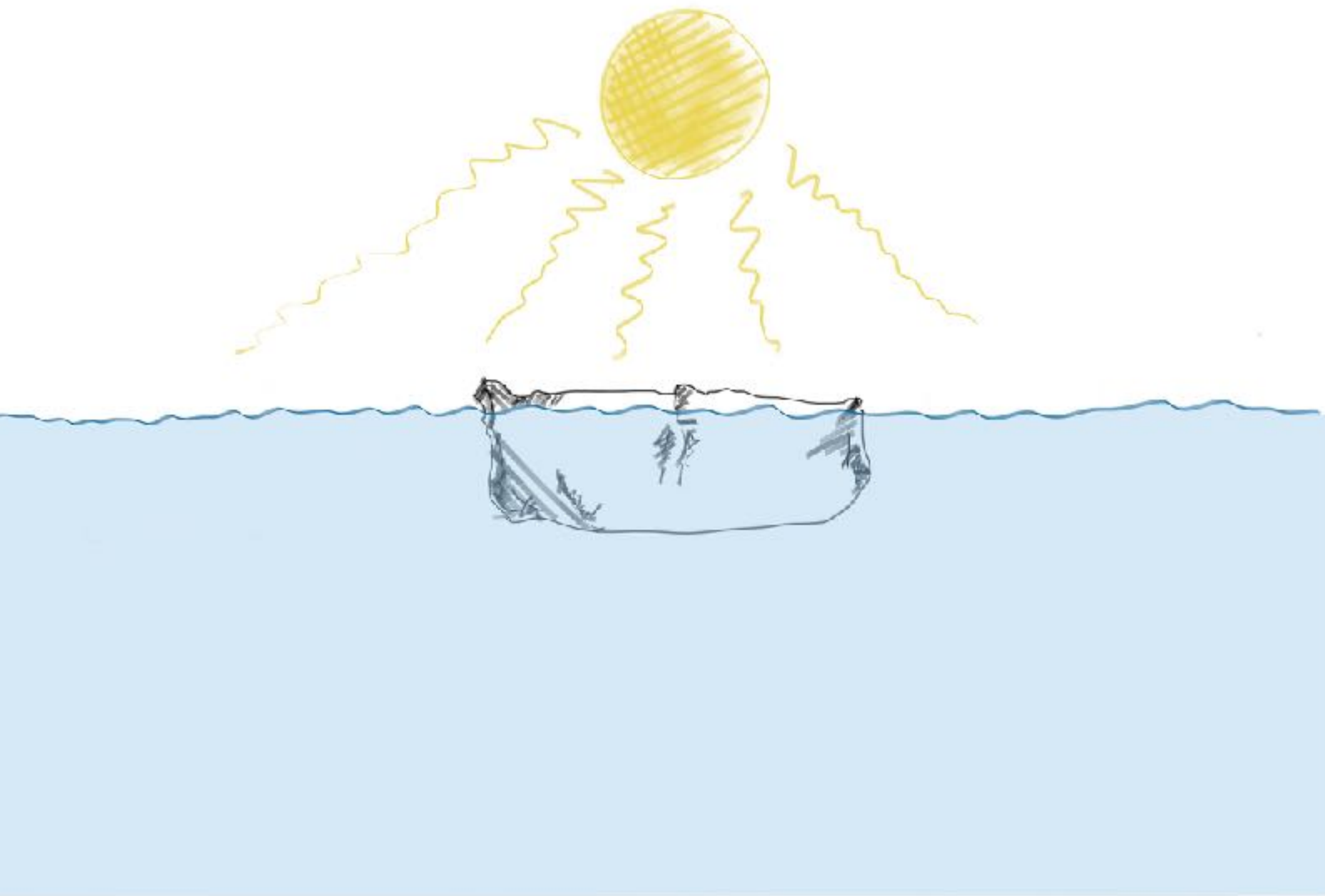




Hypothesis: armadas of icebergs create their own microclimate

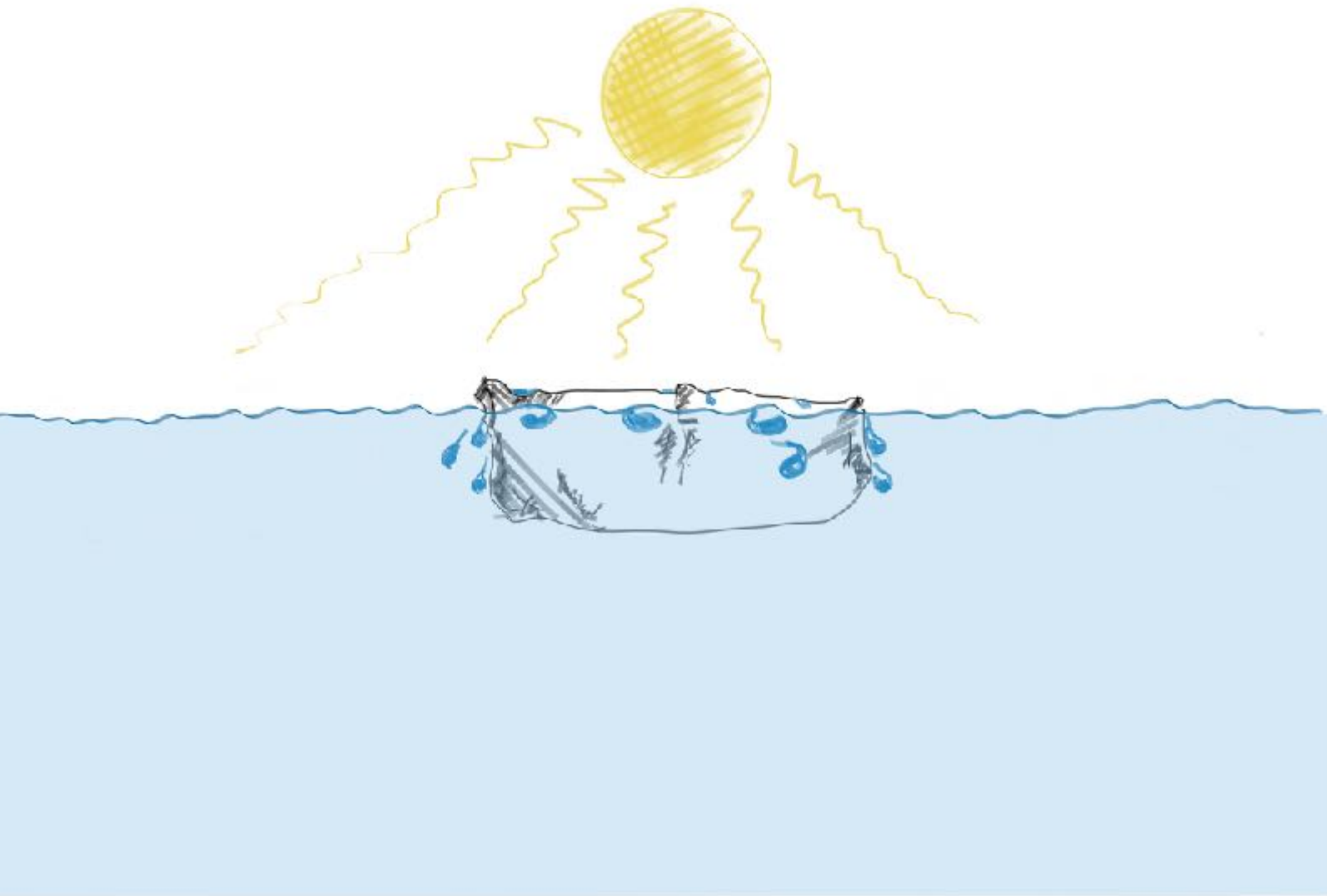
- Meltwater strengthens local halocline
- Allows for sea ice to grow more easily during winter





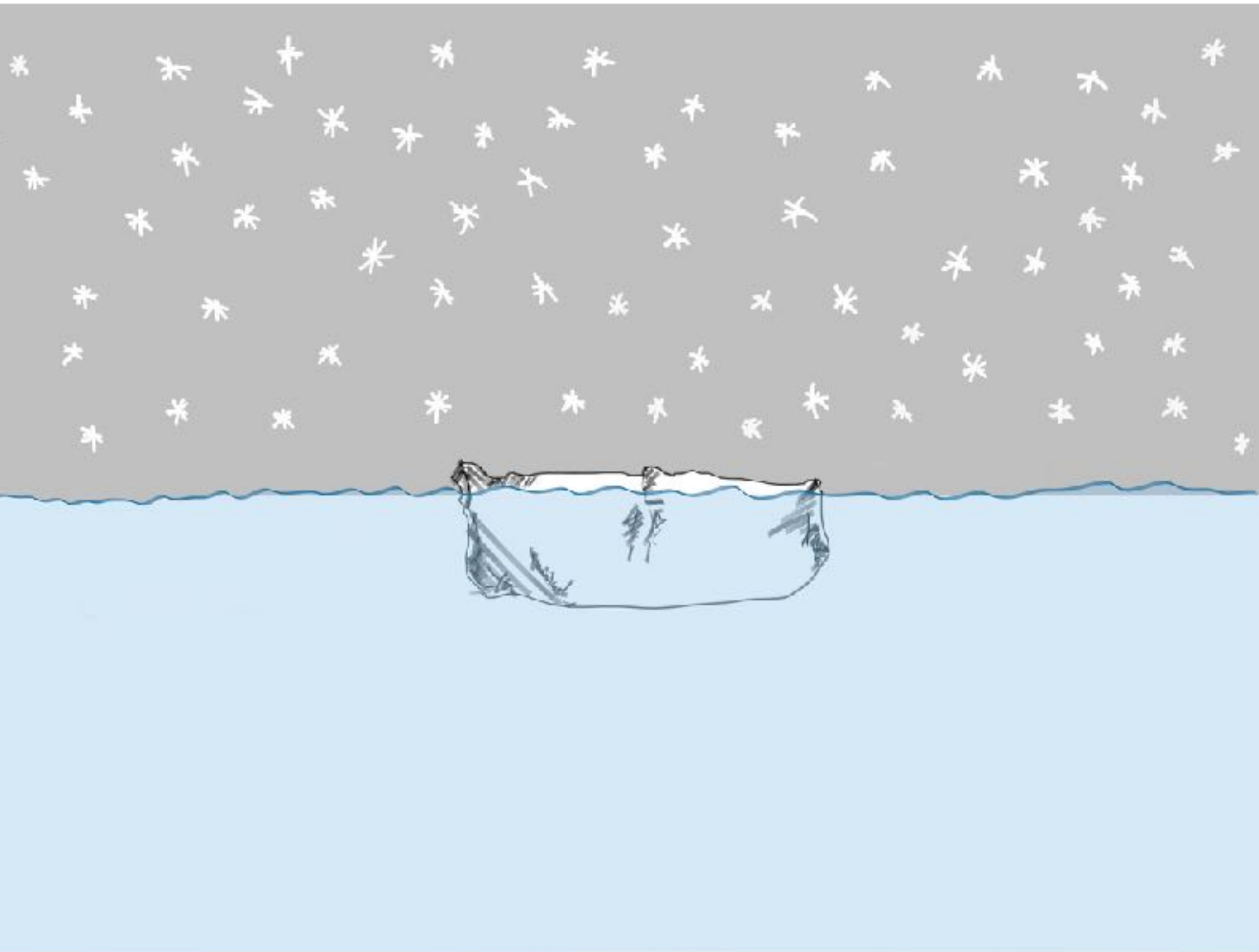
Iceberg in the Atlantic

Summer
melt

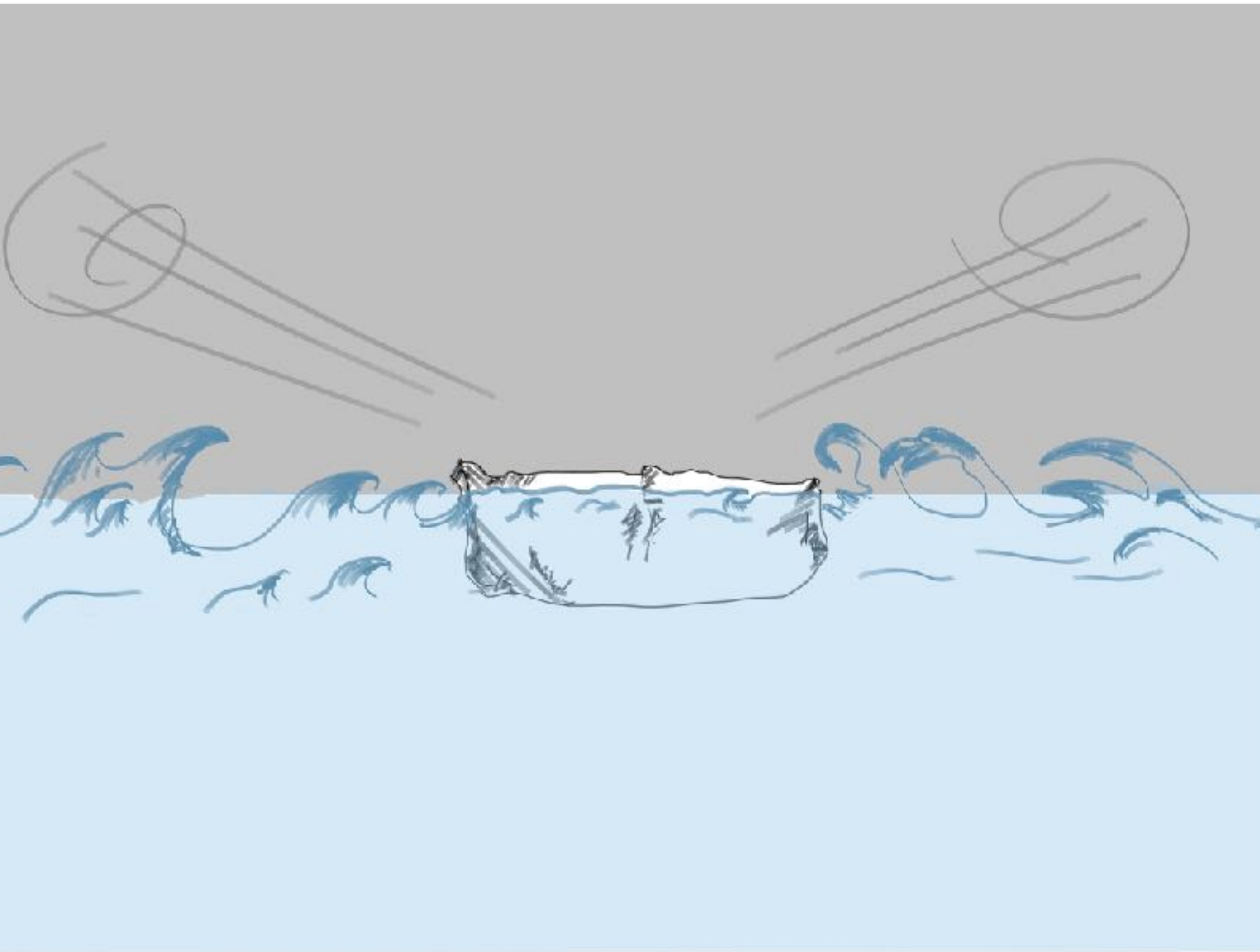


Iceberg in the Atlantic

Summer
melt



Iceberg in the Atlantic

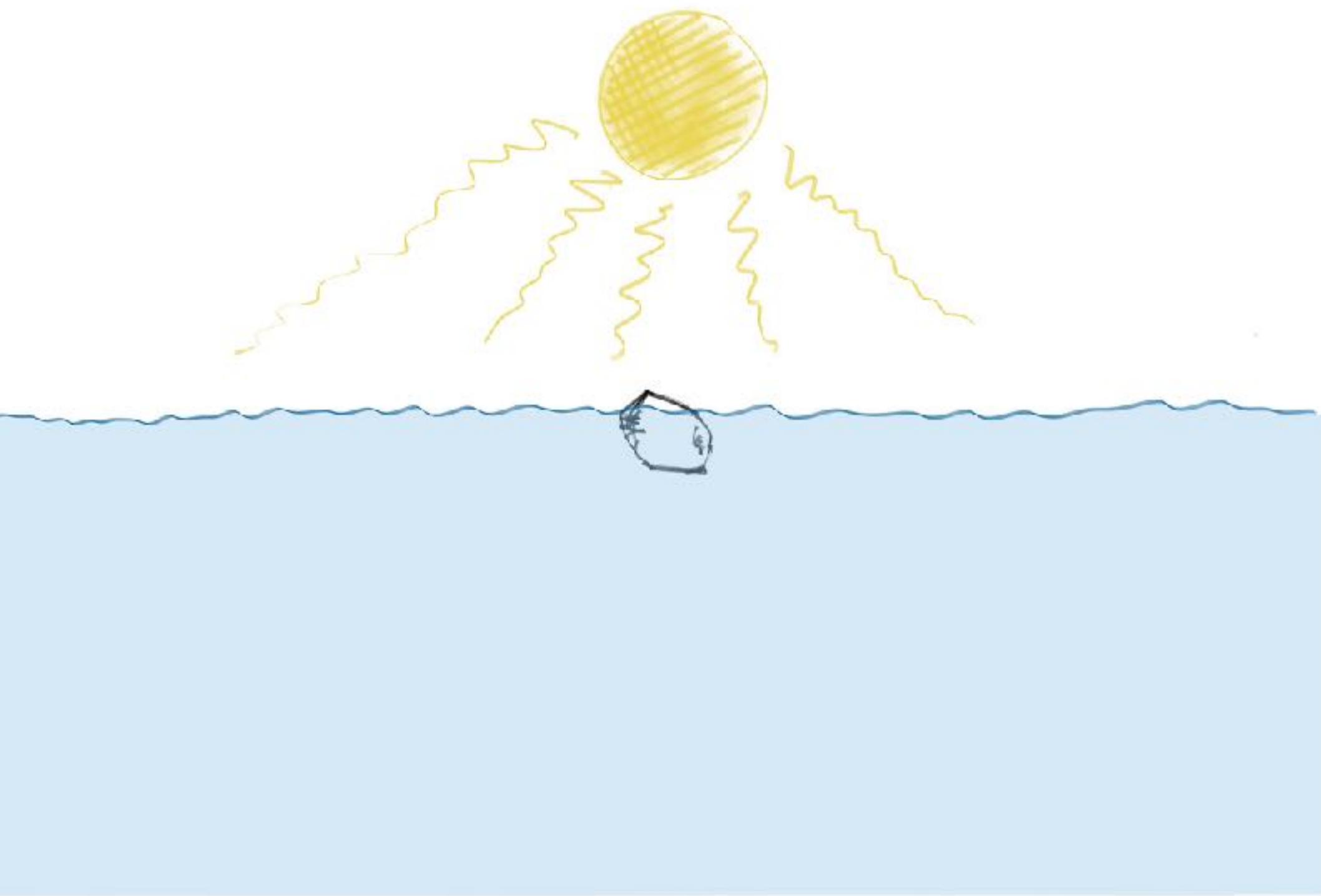


Summer
melt



Winter
wave
erosion

Iceberg in the Atlantic



Summer
melt

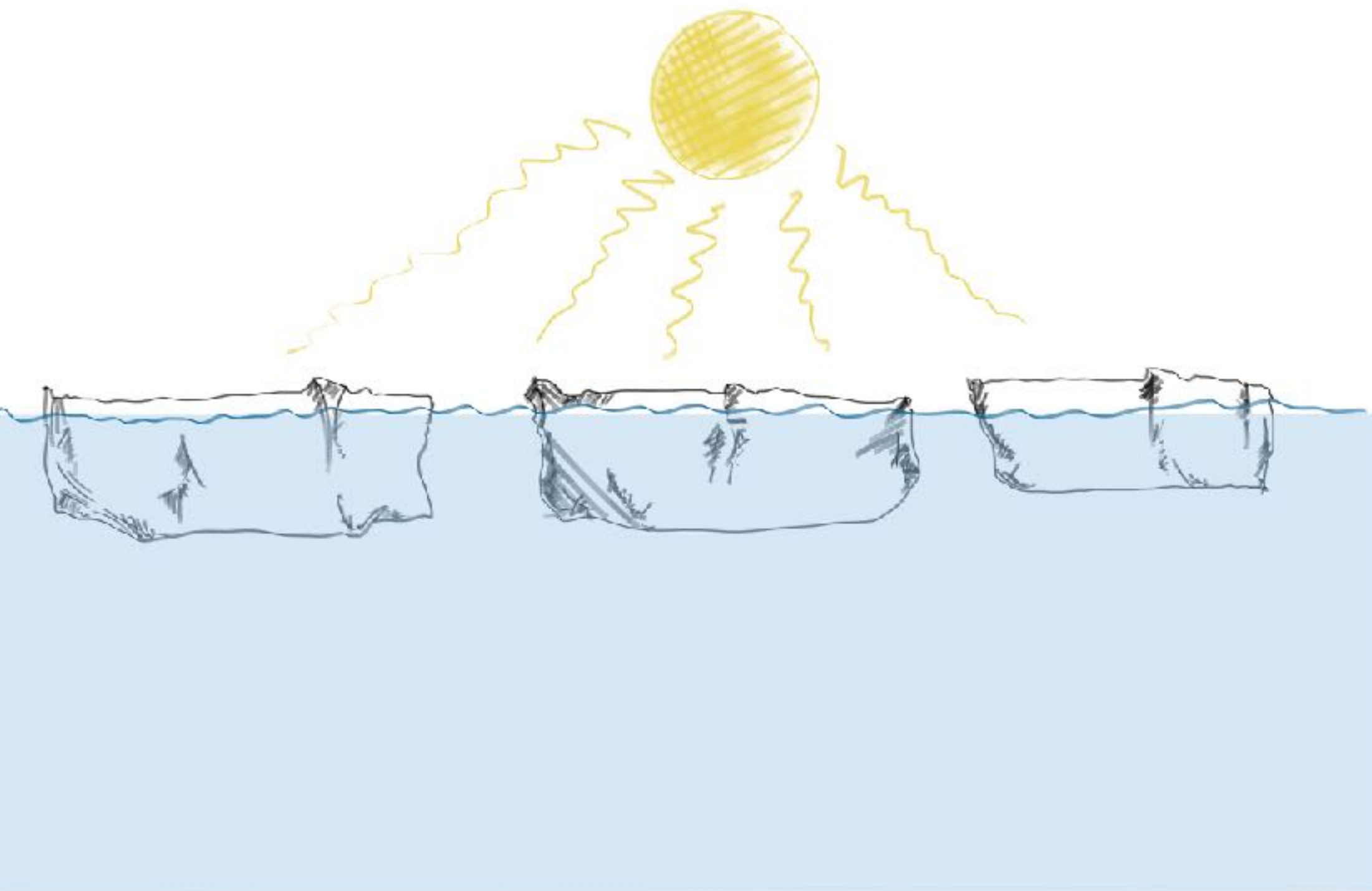


Winter
wave
erosion



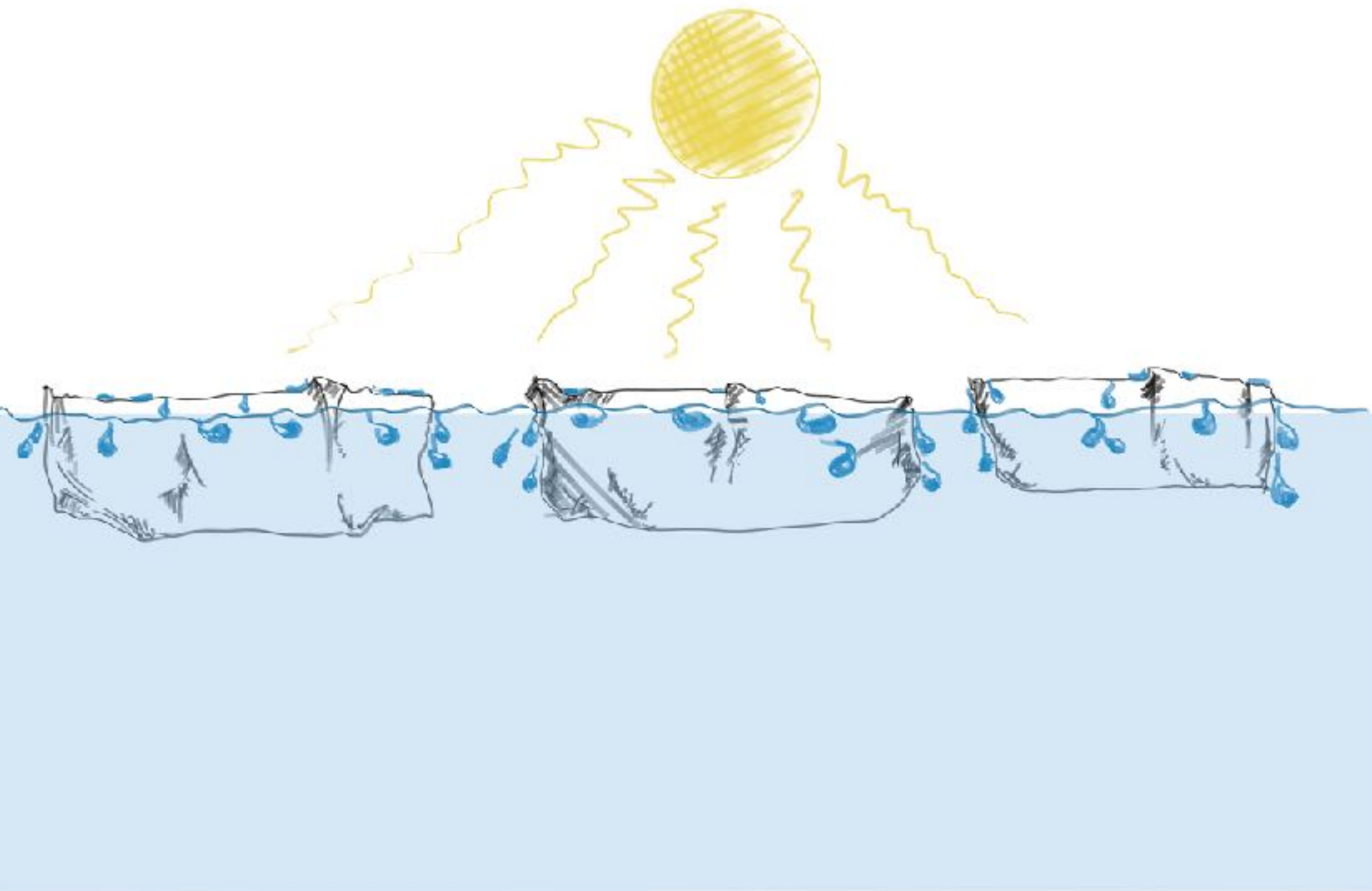
rapid
iceberg
melt

Iceberg in the Atlantic

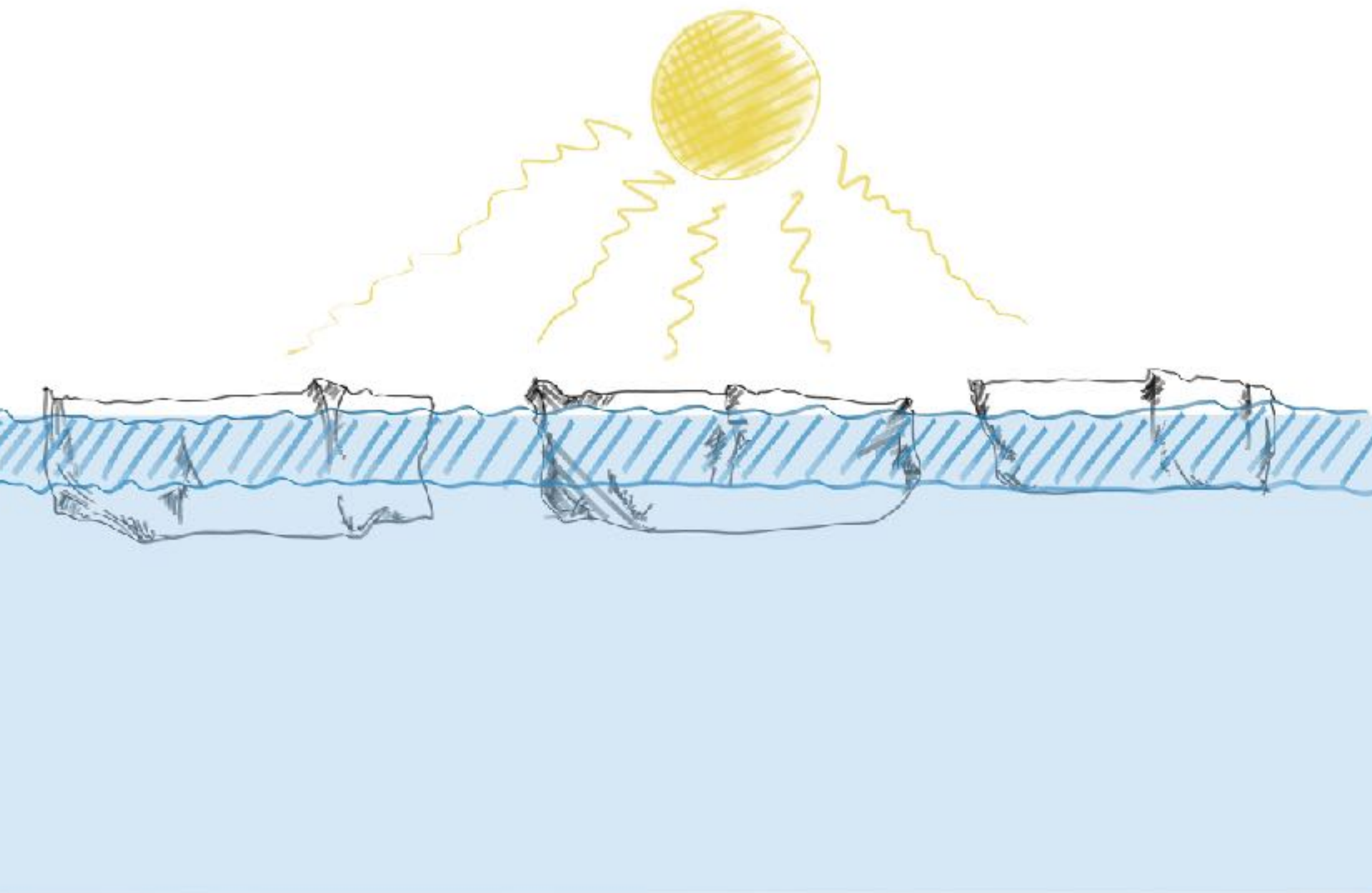


Armada of icebergs during Heinrich Events

Summer
melt



Armada of icebergs

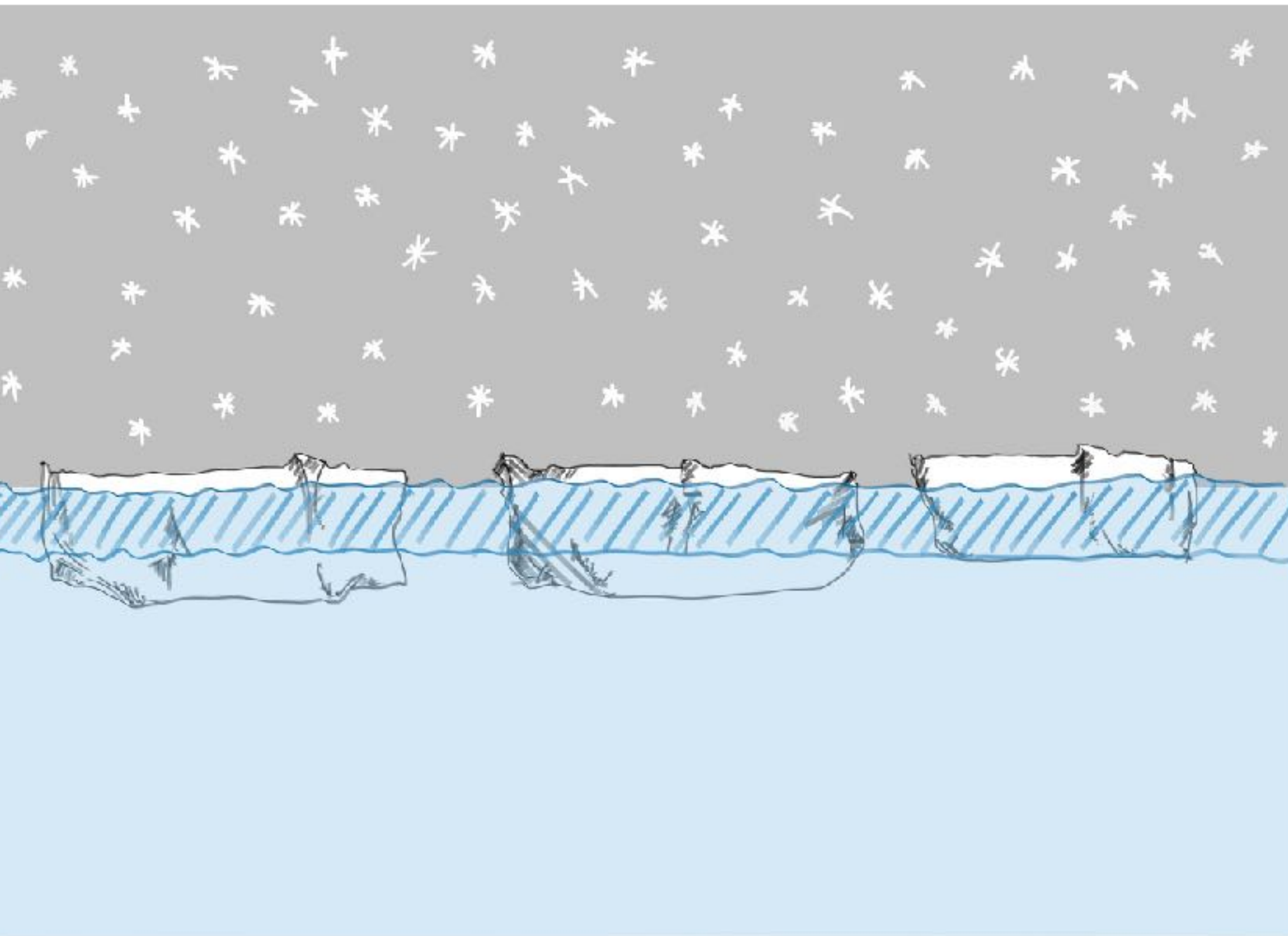


Summer
melt



Freshwater
layer/strong
halocline

Armada of icebergs

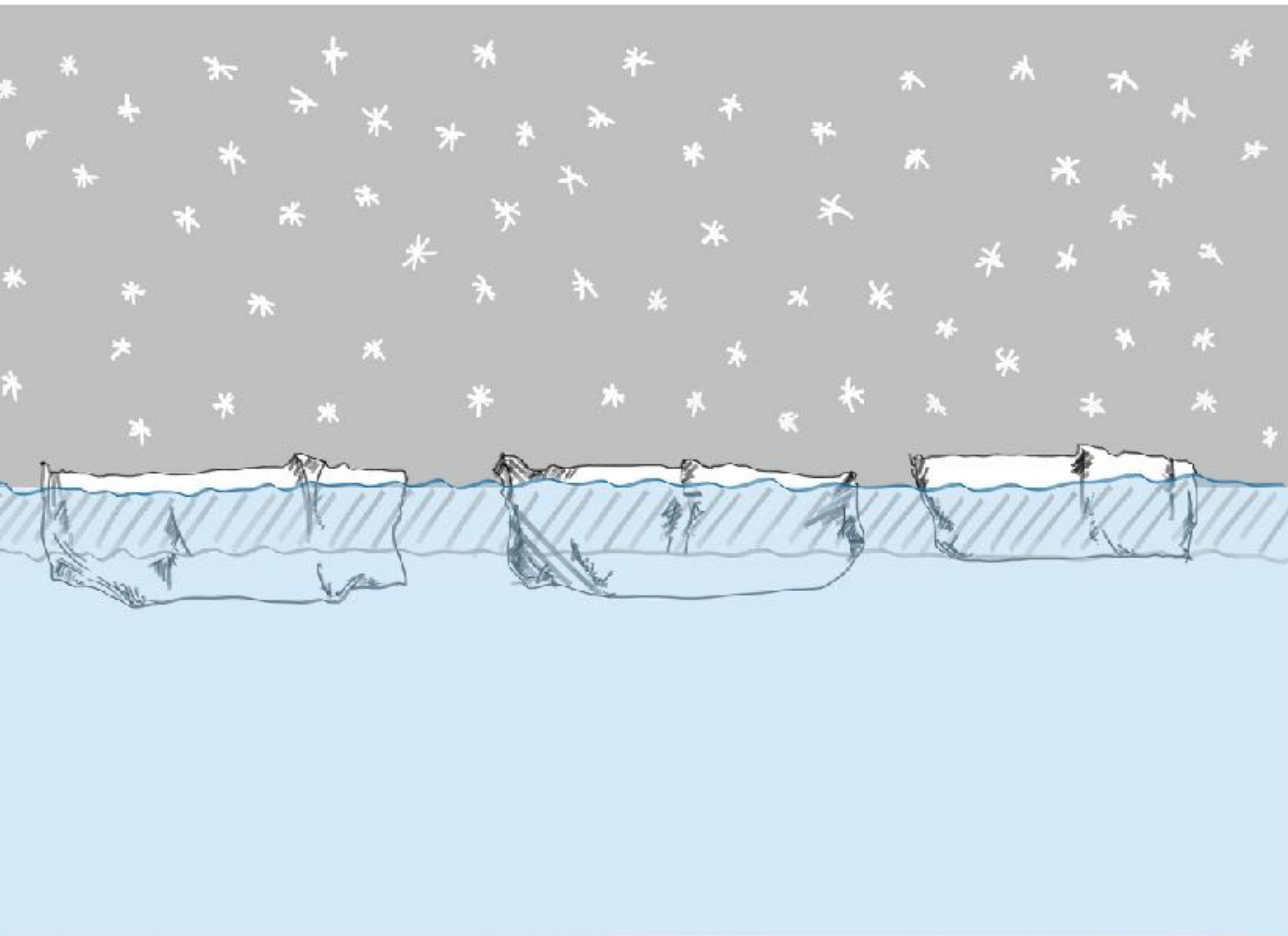


Summer
melt



Freshwater
layer/strong
halocline

Armada of icebergs



Summer
melt

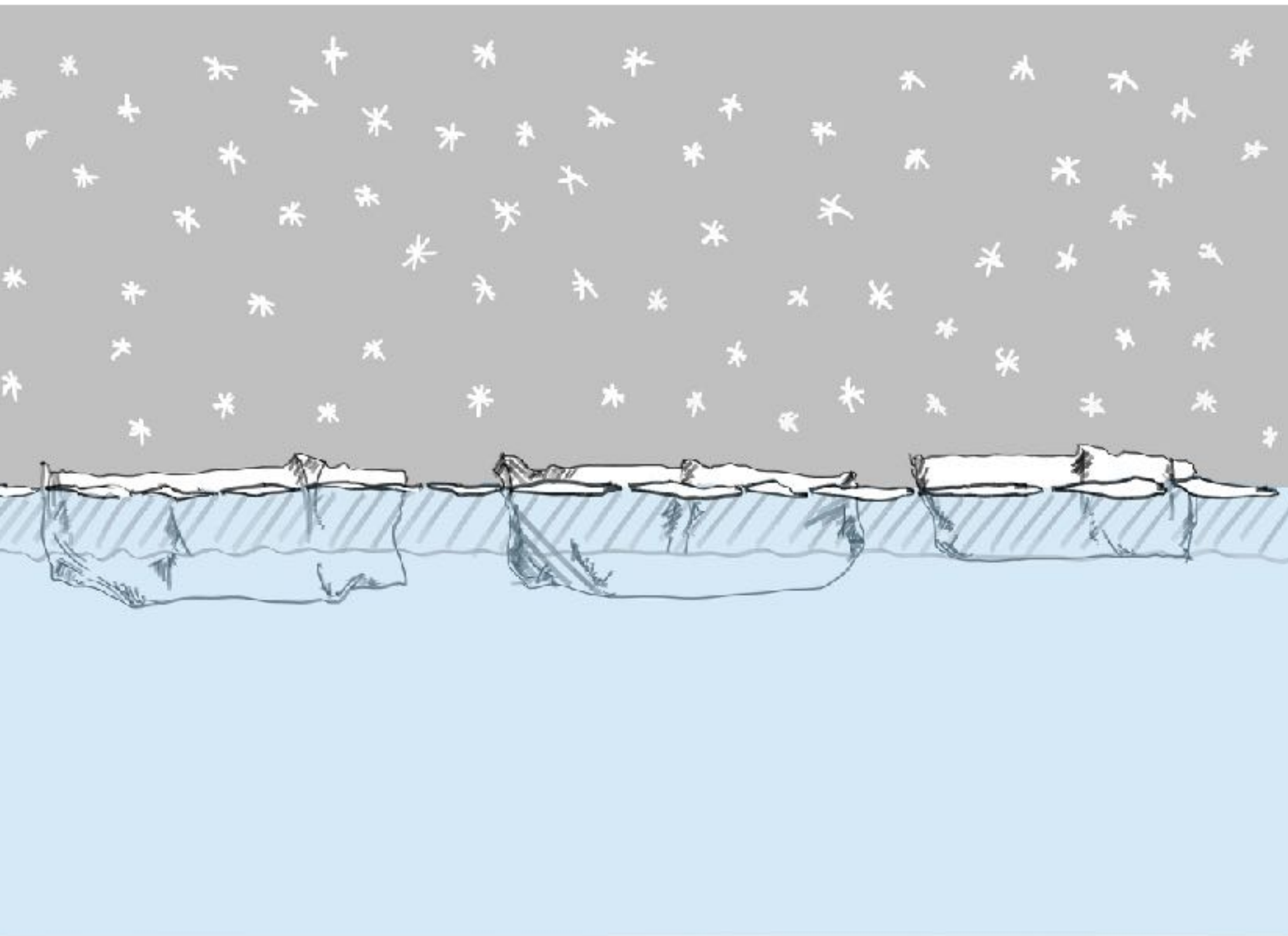


Freshwater
layer/strong
halocline



cold winter
halocline

Armada of icebergs



Summer
melt



Freshwater
layer/strong
halocline

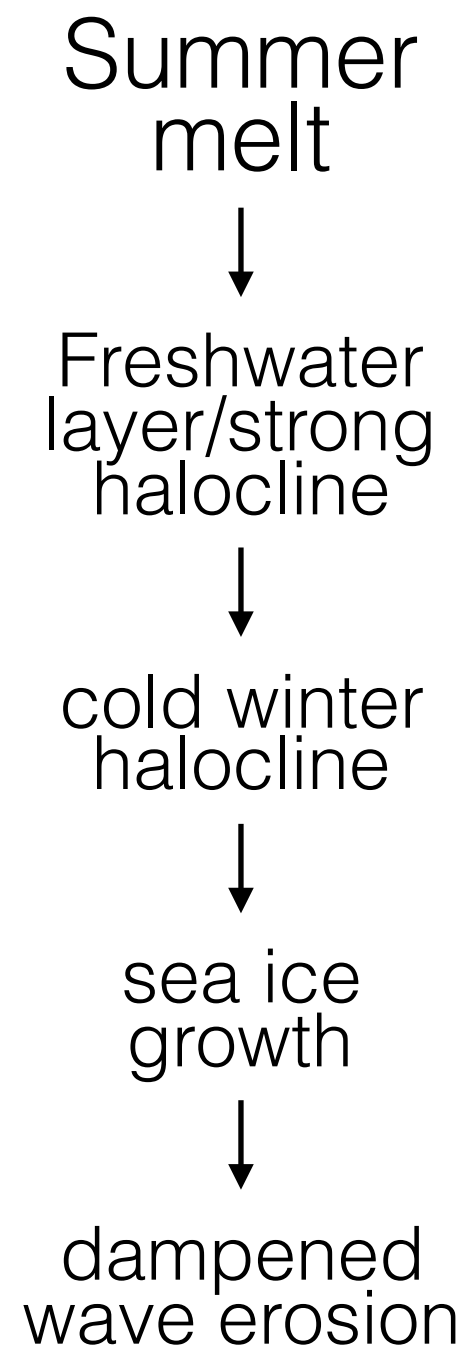
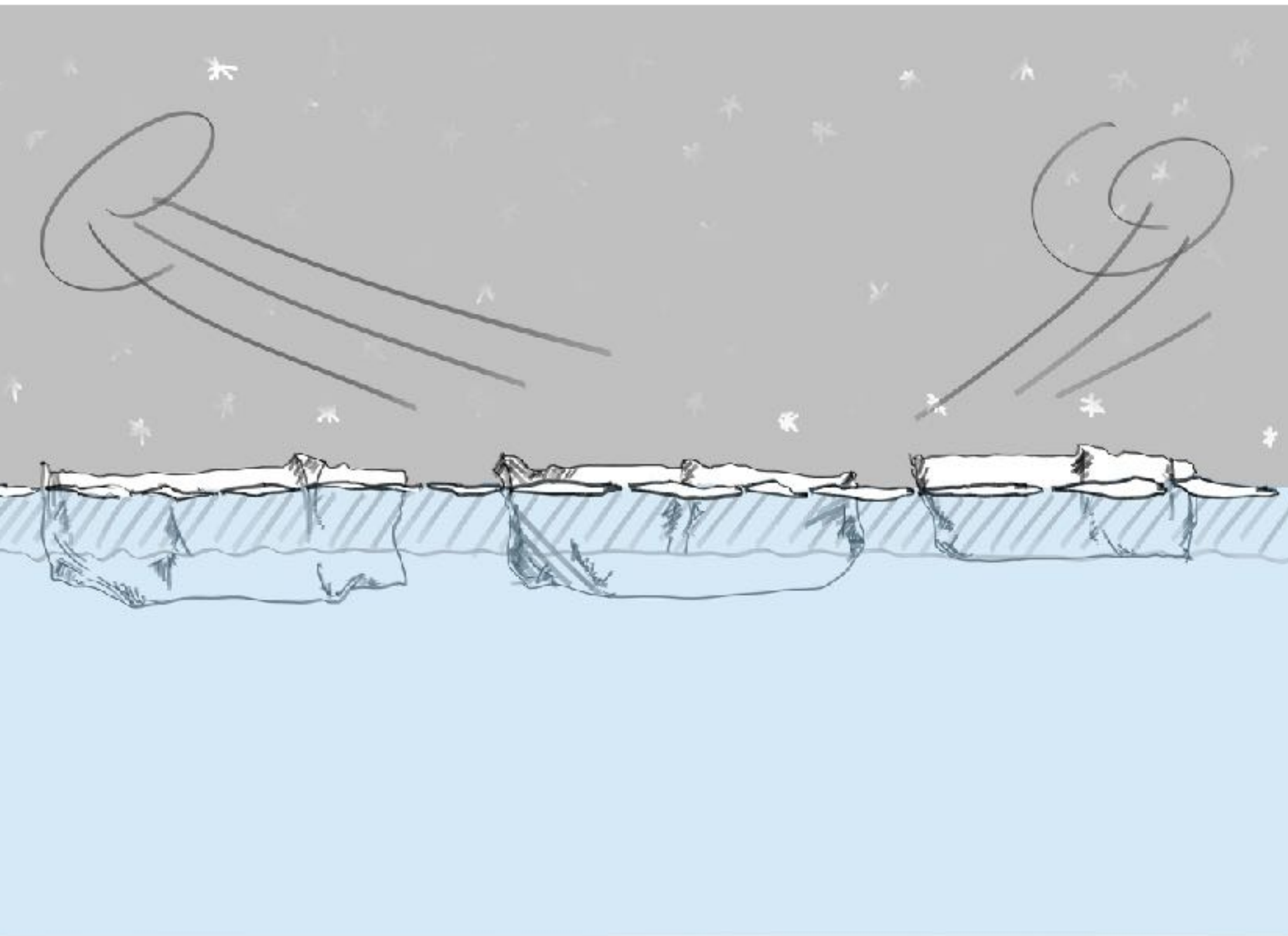


cold winter
halocline

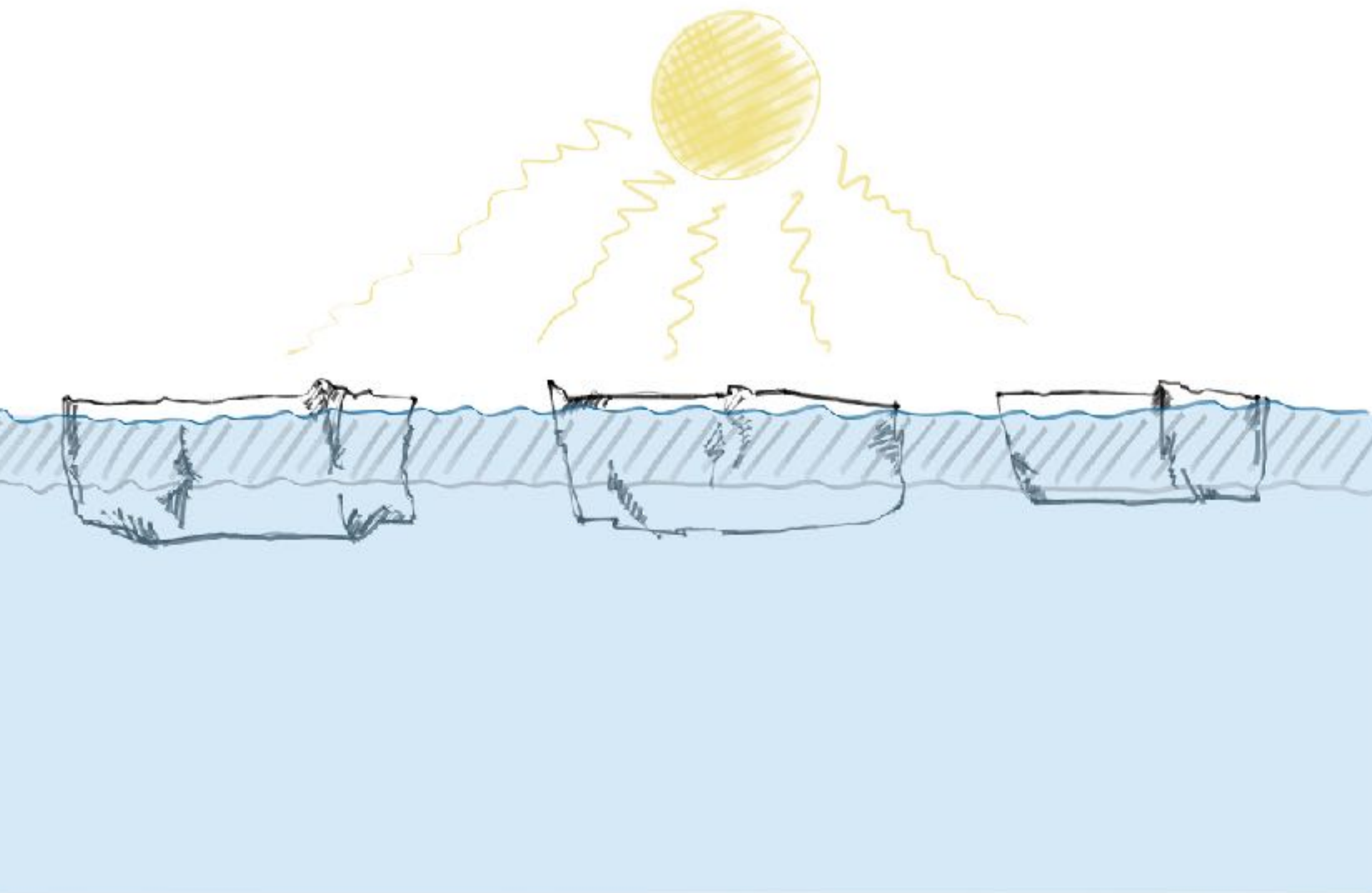


sea ice
growth

Armada of icebergs



Armada of icebergs



Armada of icebergs

Summer
melt



Freshwater
layer/strong
halocline



cold winter
halocline



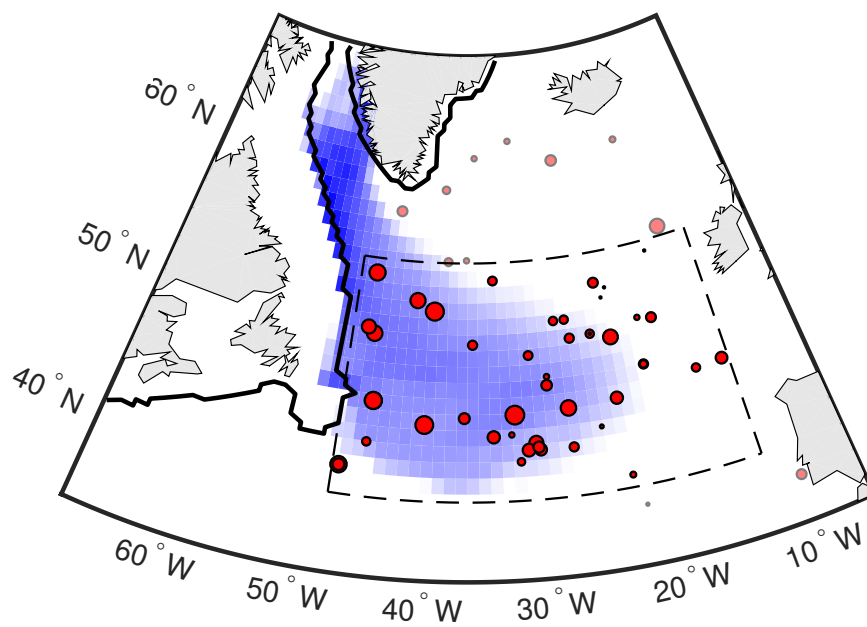
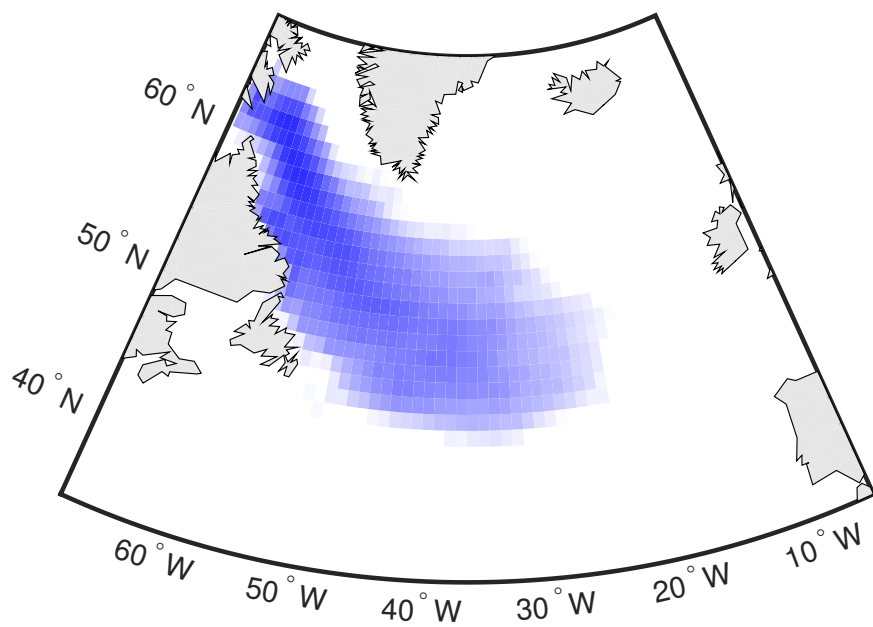
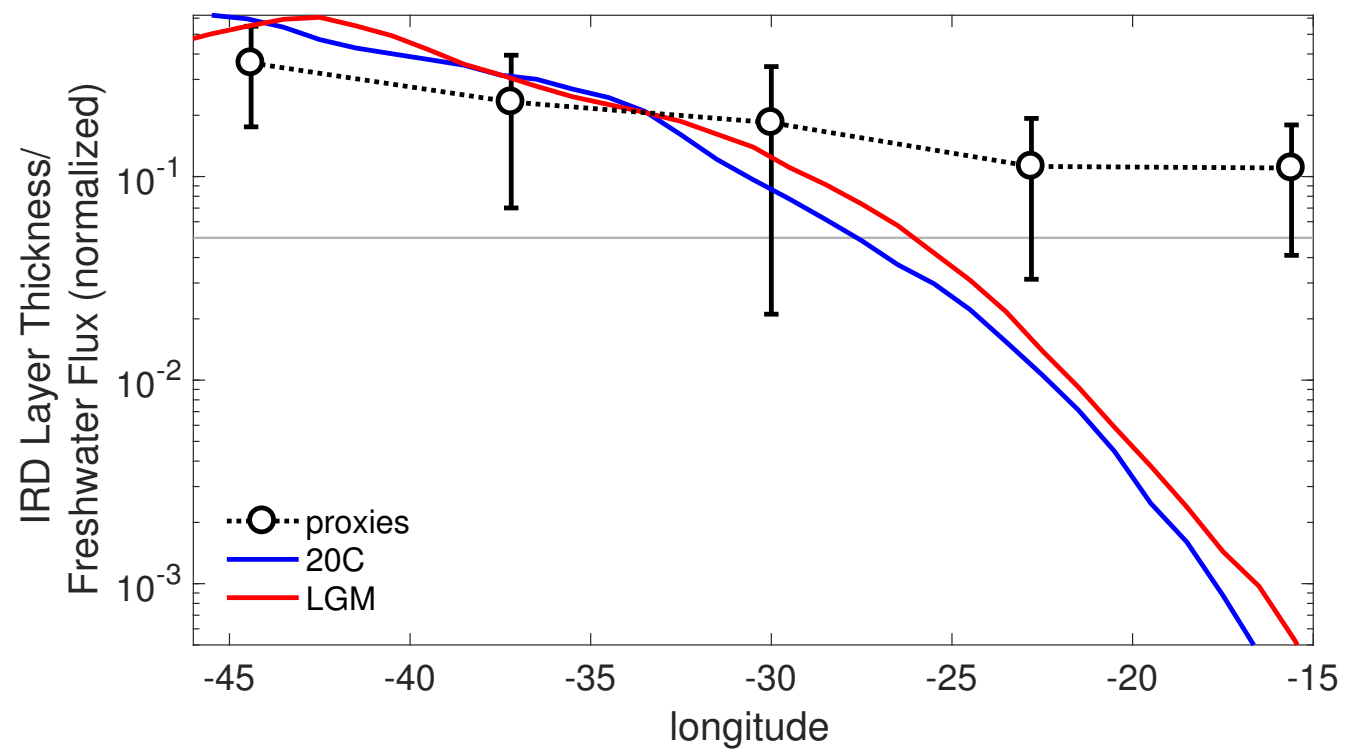
sea ice
growth

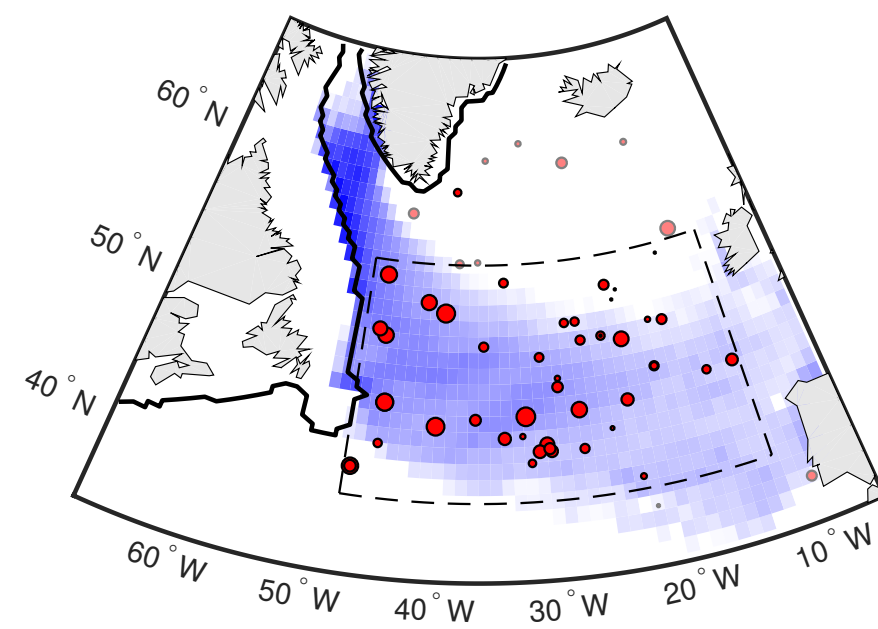
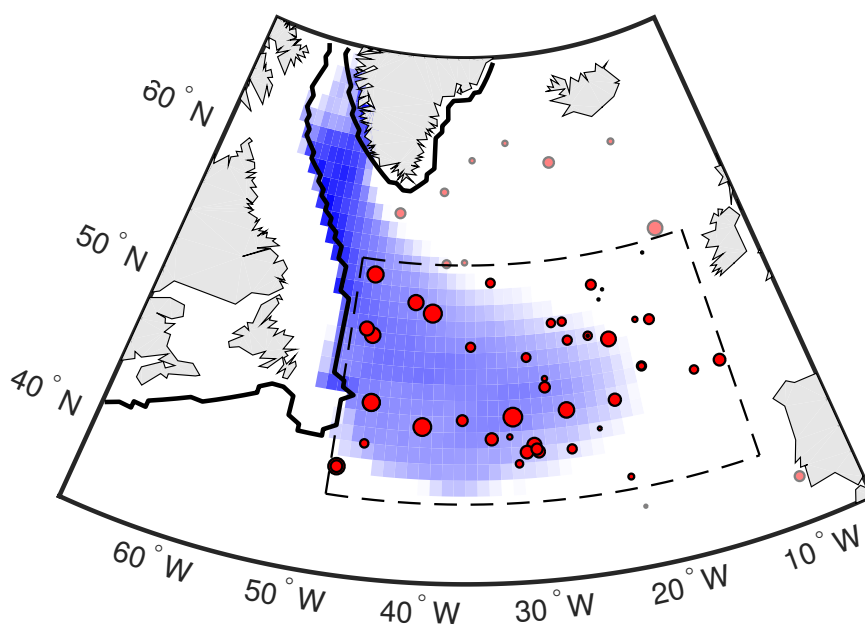
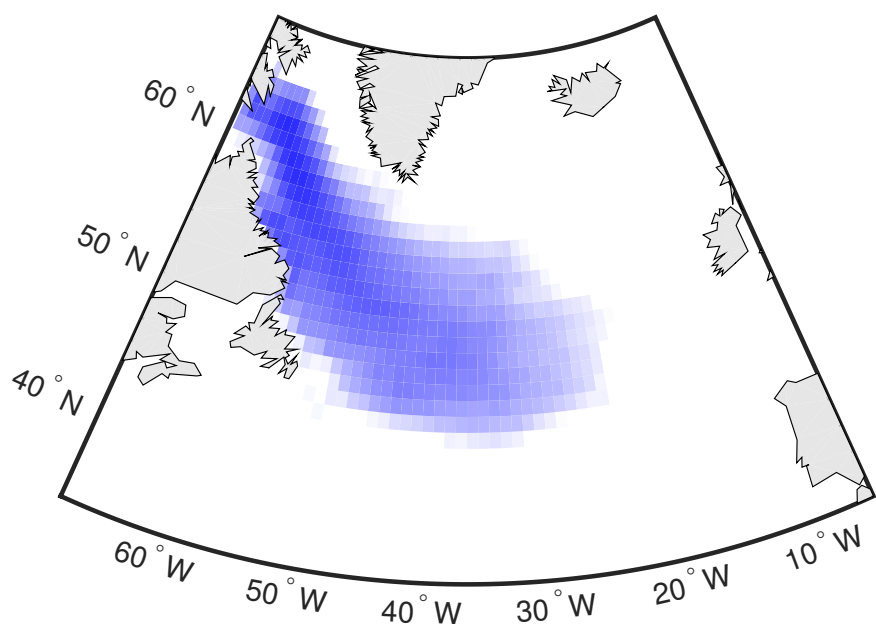
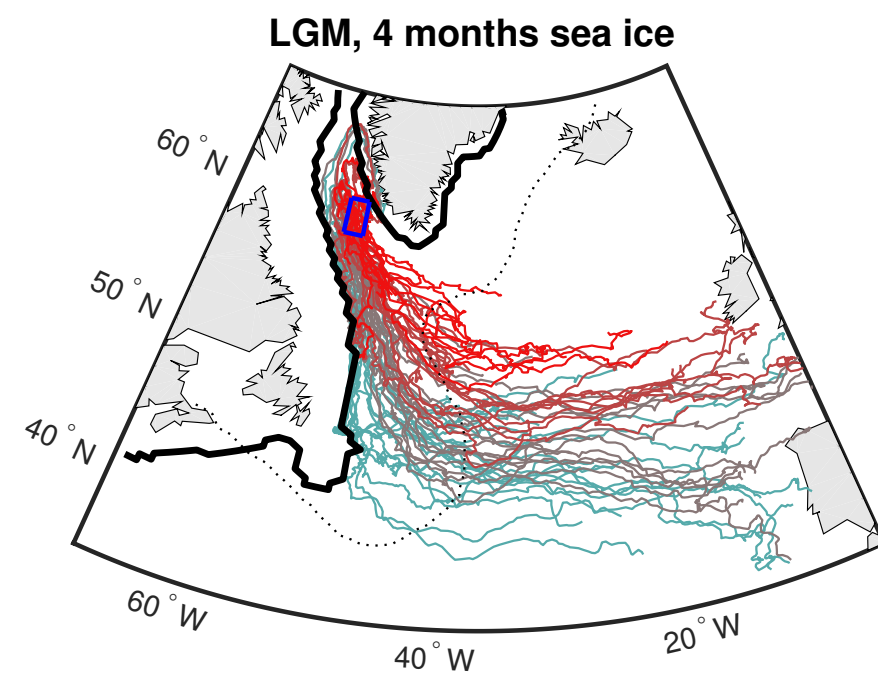
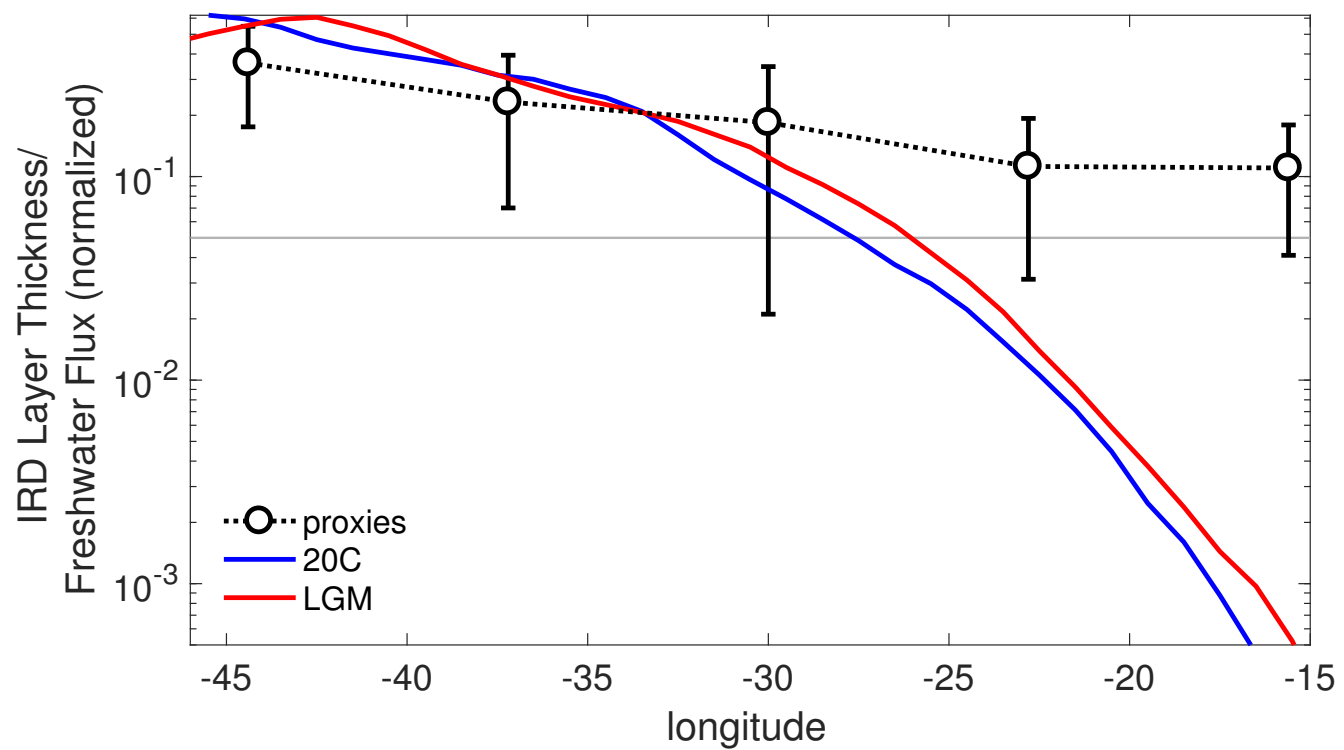


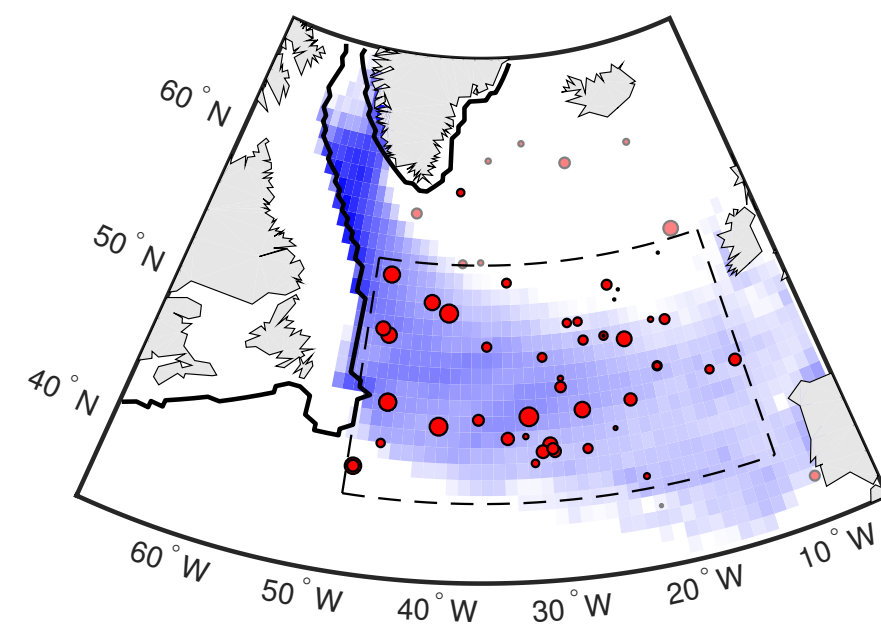
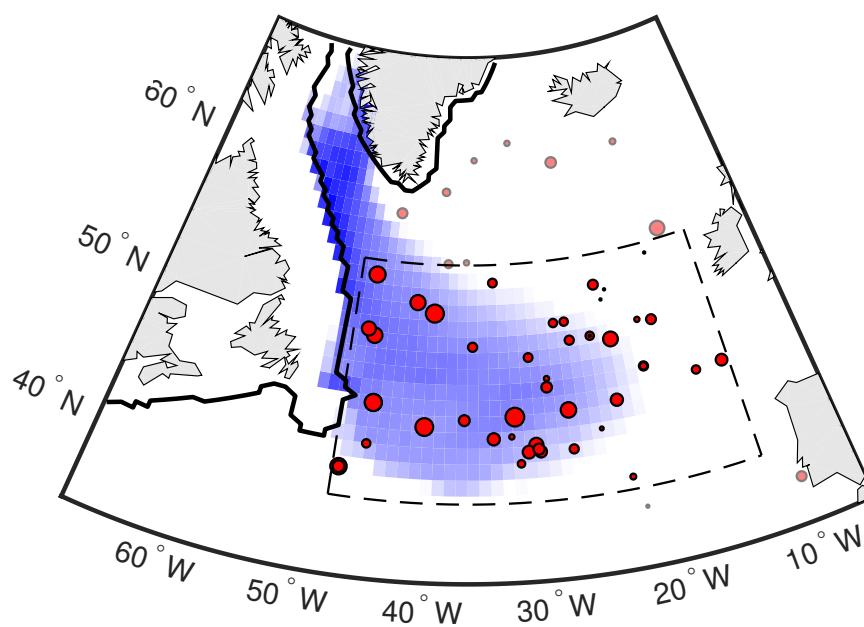
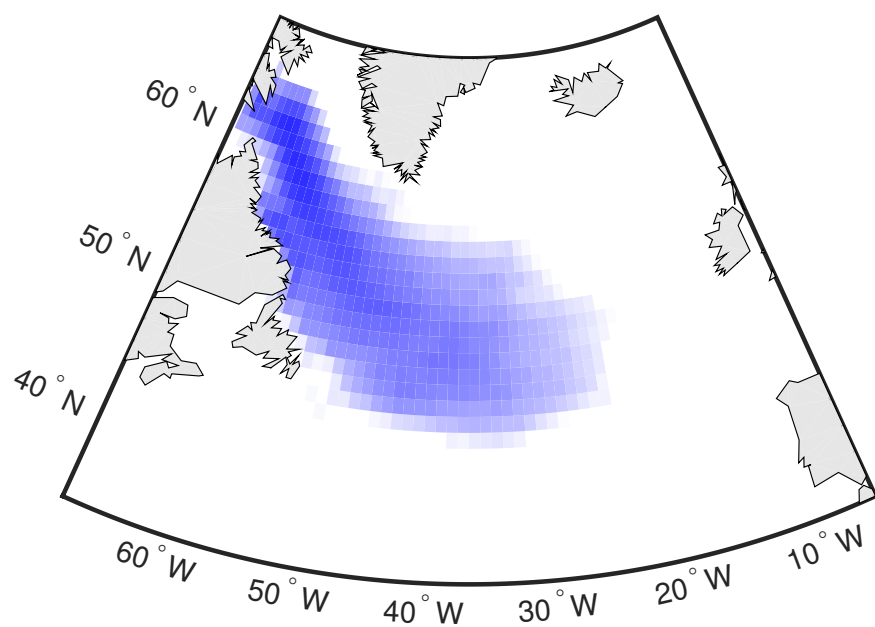
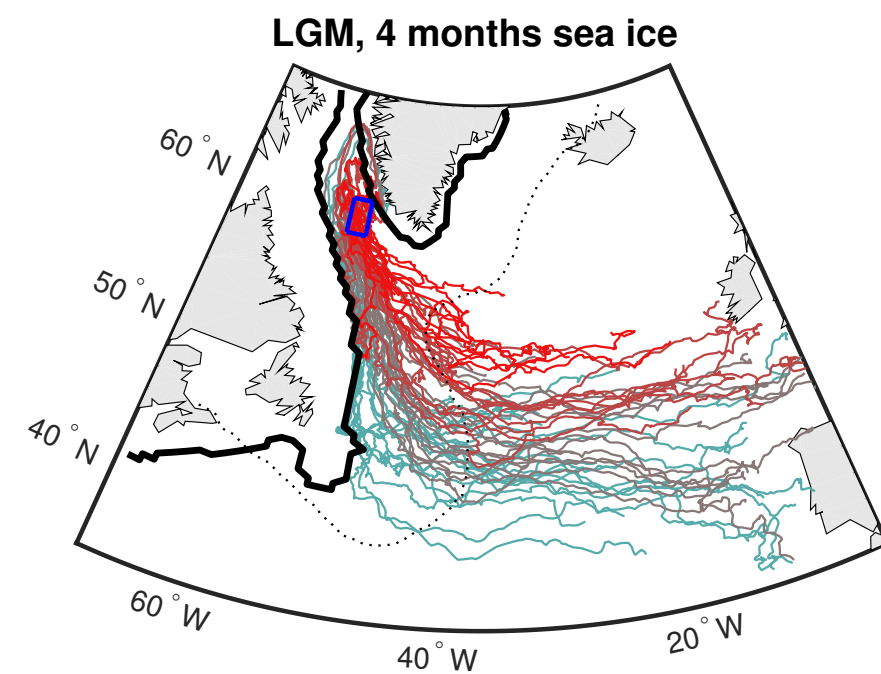
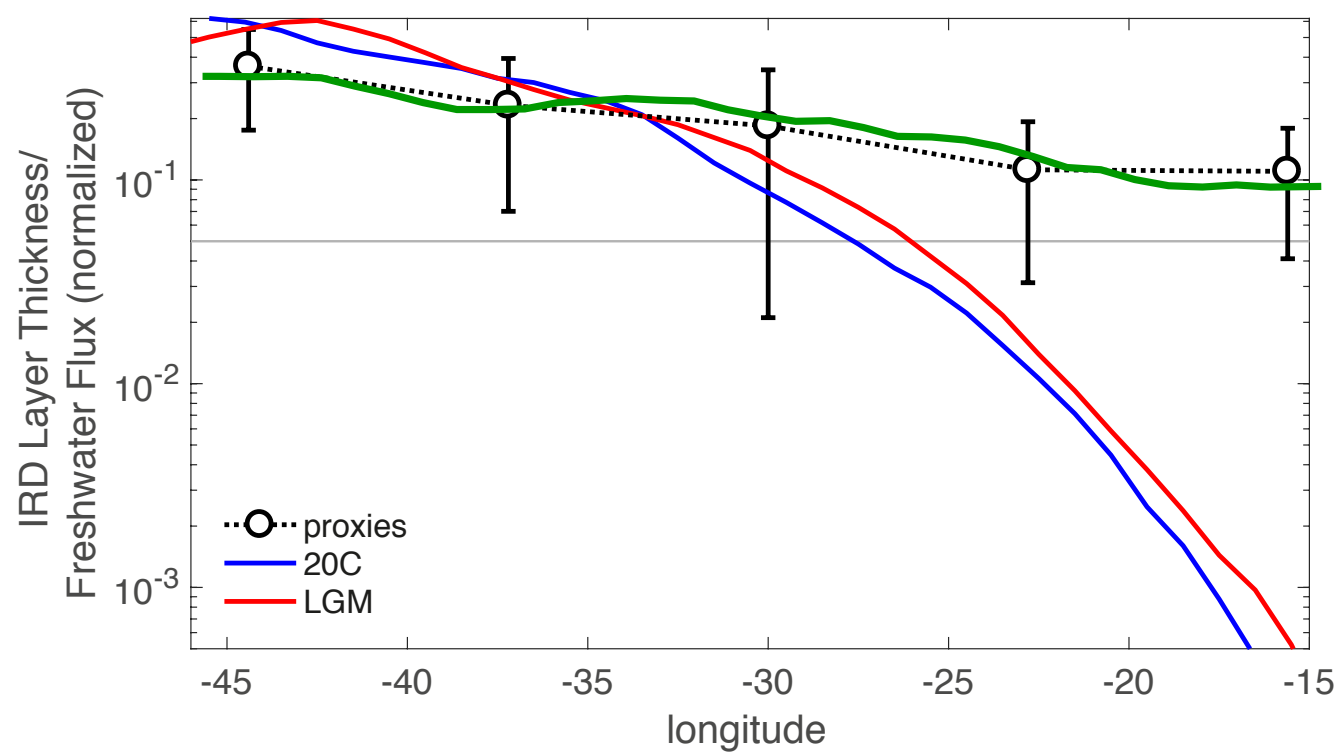
dampened
wave erosion

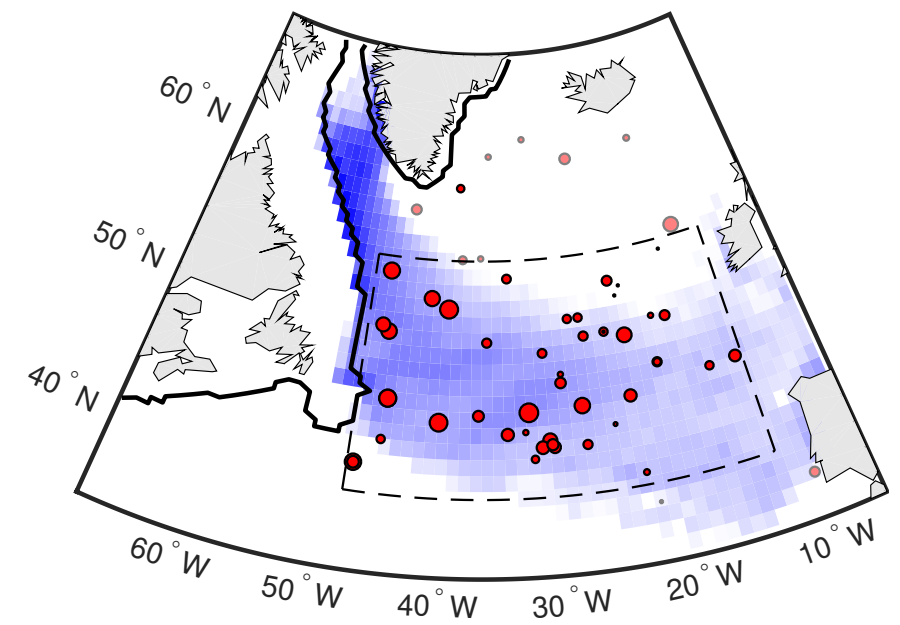
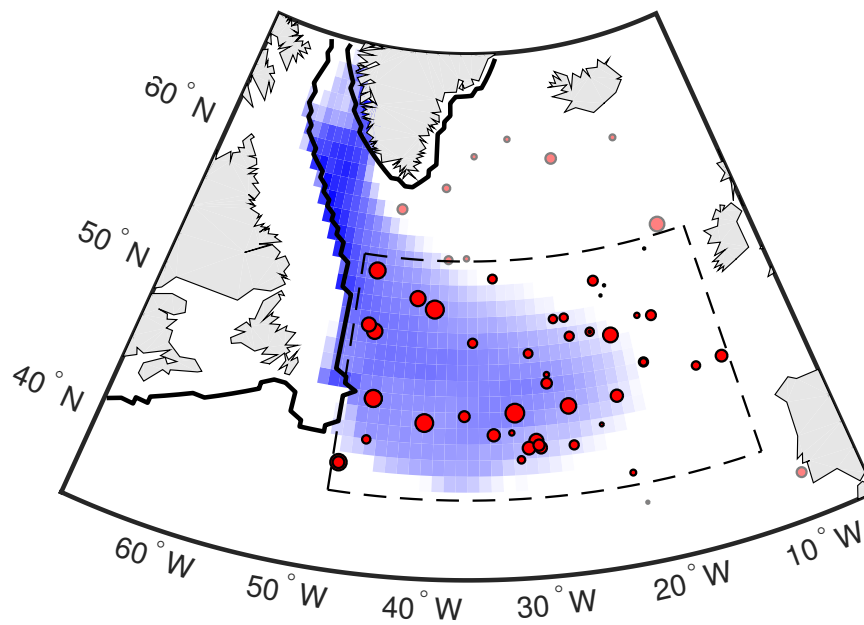
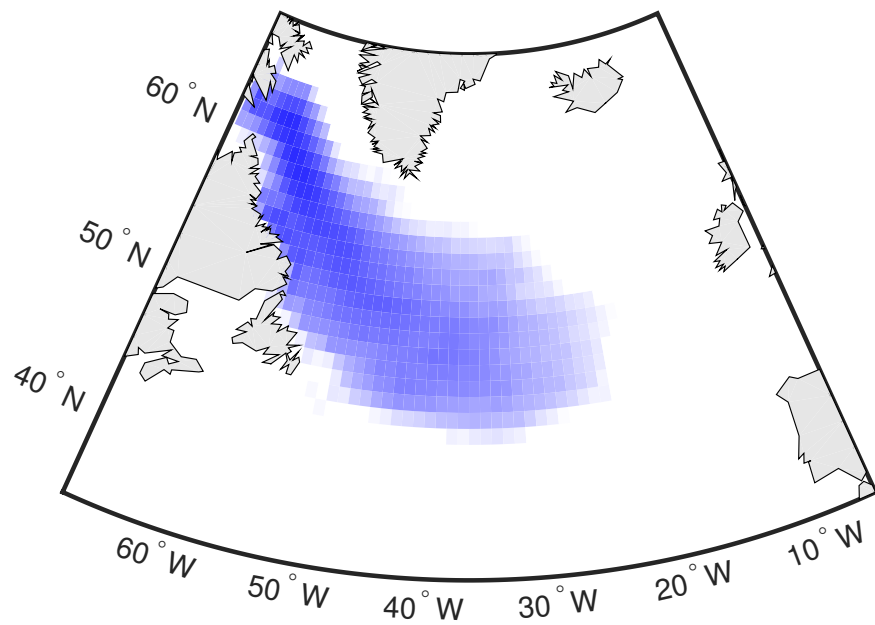
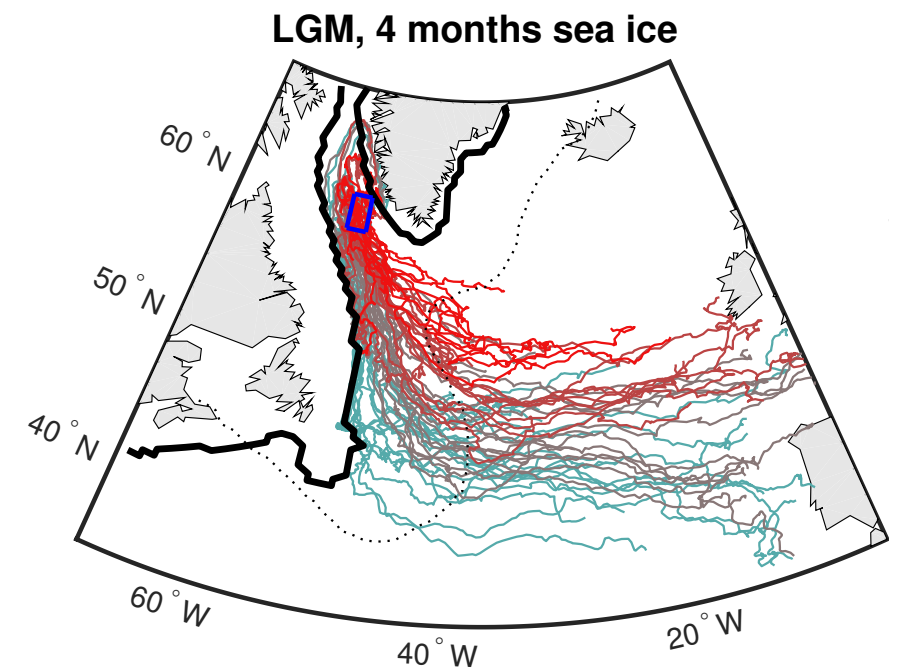
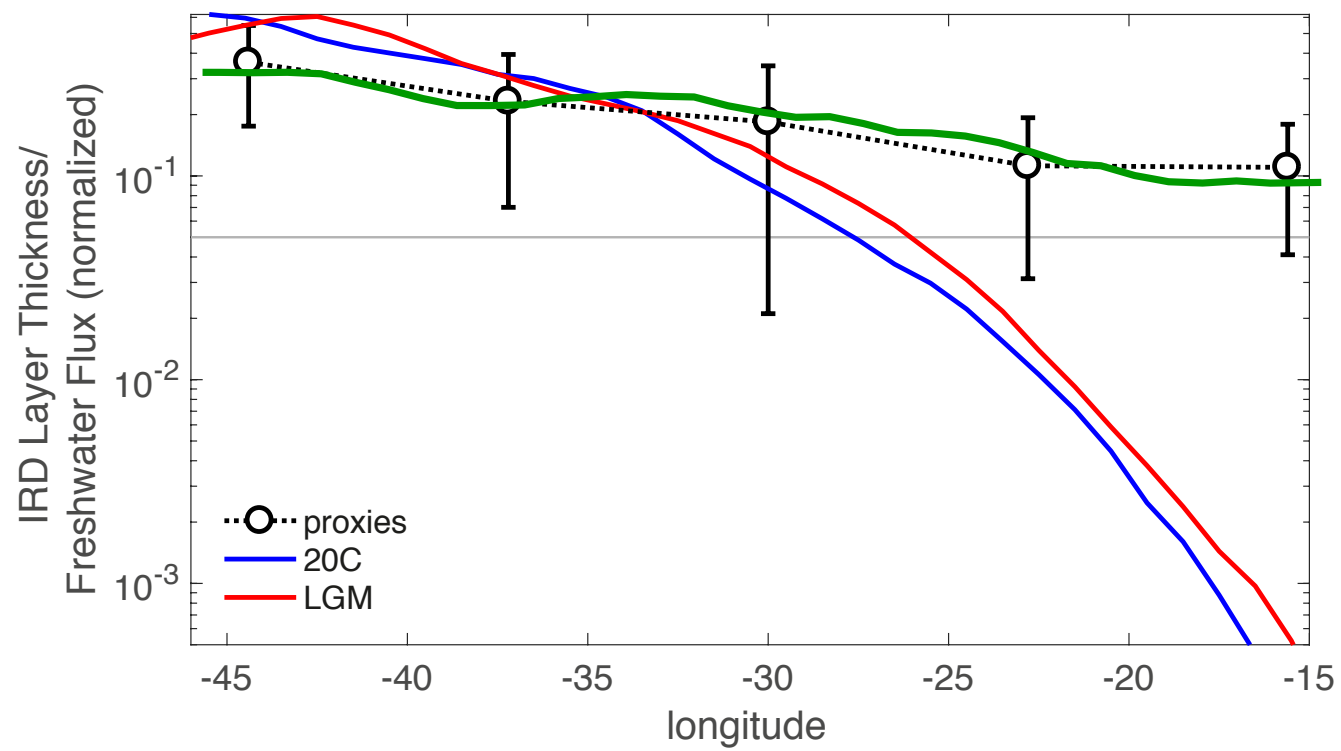


slowed
iceberg
decay









Wagner et al, *Wave inhibition by sea ice enables trans-Atlantic ice rafting of debris during Heinrich Events*, EPSL (in revision)

Thank You



