High resolution model development to quantify the impact of Icebergs on the Atlantic Meridional Overturning Circulation

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Project aims and goals

- Develop a sophisticated iceberg model to accurately simulate the delivery of freshwater from the Greenland Ice Sheet to the ocean.

- Couple the iceberg model to a state-of-the-art, high resolution Earth System Model, to accurately simulate iceberg motion and decay.

- Undertake past, present, future climate experiments to quantify sensitivity of the Atlantic Meridional Overturning Circulation (AMOC) to changes in freshwater discharge from the Greenland Ice Sheet.

Why simulate icebergs in Earth System Models?

The current suite of ESMs do not realistically simulate the delivery of freshwater from the polar ice sheets to the ocean.

Limitations:

(1) Freshwater incorrectly partitioned (assume 100 % liquid)

(2) Freshwater discharge locations incorrect

(3) Freshwater release is too close to its source.

These limitations lead to uncertainty in quantifying the likelihood that the AMOC will weaken in the near-future

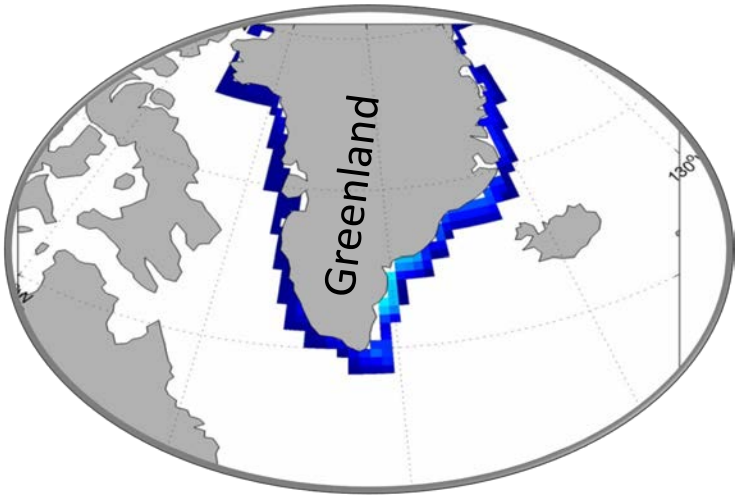
(1) Freshwater Partitioning (ice or liquid)

Models
Assume all freshwater runoff from an ice sheet is discharged into ocean as liquid.

Observations
>60 % of Greenland runoff is discharged into ocean as icebergs (Rignot and Kanagaratnam, 2006).

Kangerdlugssaq Glacier (SE Greenland) drains 8% of Greenland Ice sheet and 85 % of its runoff enters the ocean as ice (Mugford and Doweswell, 2010)

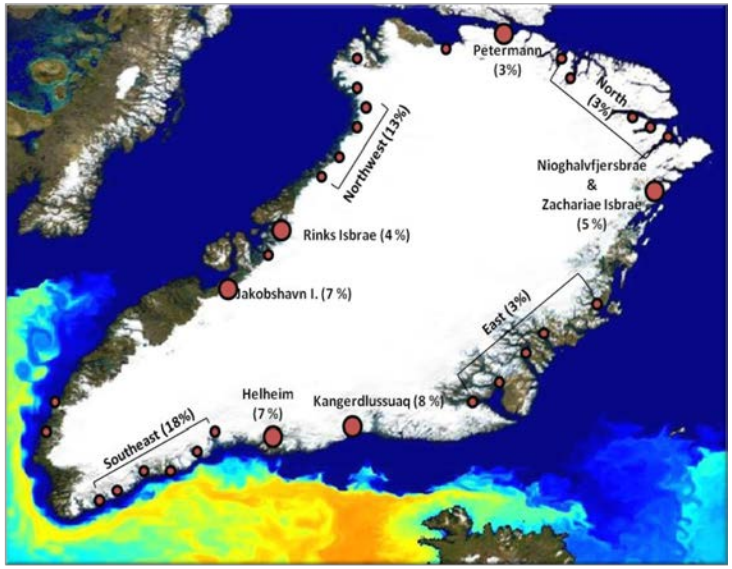
(2) Location of freshwater discharge



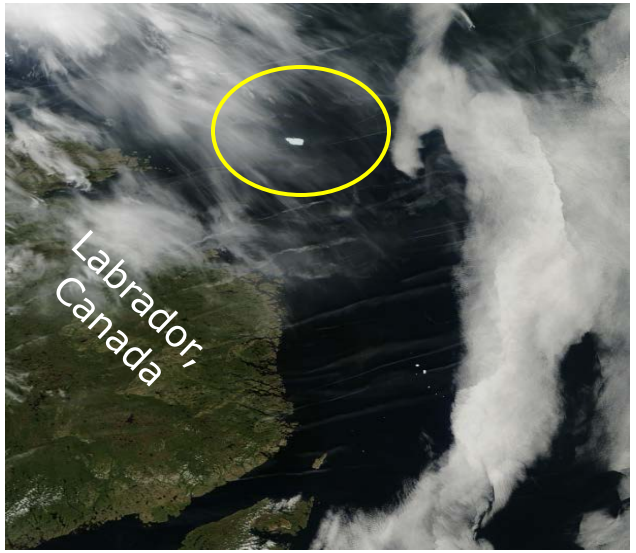
Models
Release freshwater uniformly along the entire margin of an ice sheet.

Observations
30% of the Greenland Ice sheet is drained by just 5 major glaciers.

Iceberg are calved into only a handful of locations → focuses freshwater runoff.



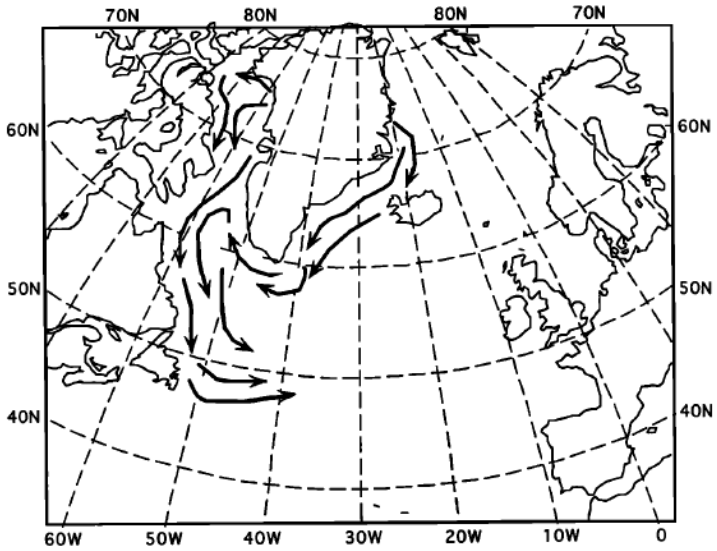
(3) Freshwater advection in the ocean



Models
Discharge freshwater in the model grid cells closest to the ice sheet margin.

Observations
Individual icebergs can drift 1000 km's before finally melting, and slowly release freshwater to the ocean as they melt.

→ freshwater released many miles from its original source.

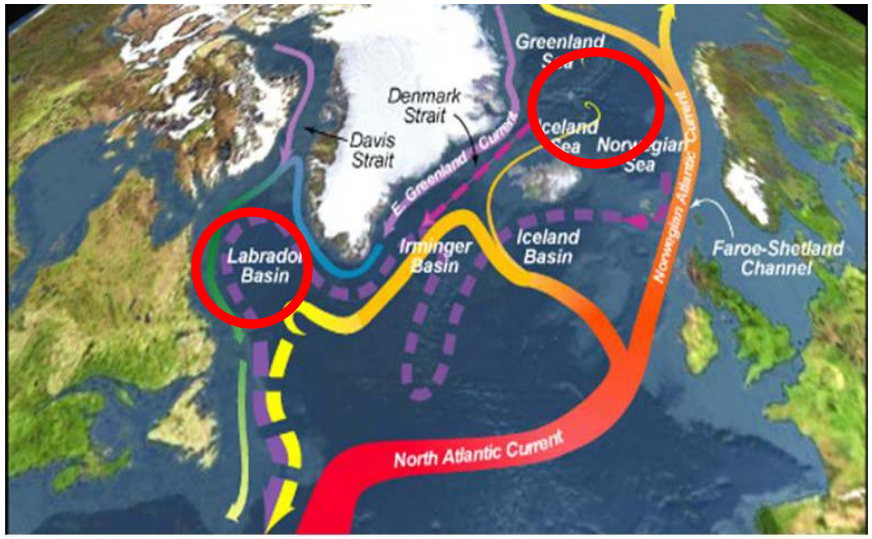


Icebergs and the stability of the AMOC

The Atlantic Meridional Overturning Circulation (AMOC) can be weakened by only minor increases in the flux of freshwater to key regions of the subpolar seas.

How will modeling icebergs alter the delivery of freshwater to the deep water formation regions in our model?

Will the stability of the AMOC to a known freshwater perturbation alter as a result?



Sites of deep convection

The iceberg model (MITberg)

Model Features
Iceberg Motion: keel model to accurately simulate drag below surface.
Thermodynamics: wave erosion and changes in albedo due to snow falling on icebergs
Calving (into smaller bergs) due to collisions or erosion.
Sediment model to simulate deposition of entrained debris to ocean floor
Grounding /collisions modeled
Dye tracer added to track freshwater in ocean after melting
Sea ice can exert a force on the icebergs

** Meltwater from individual icebergs will feedback into our ocean model to alter ocean salinity and temperature properties.

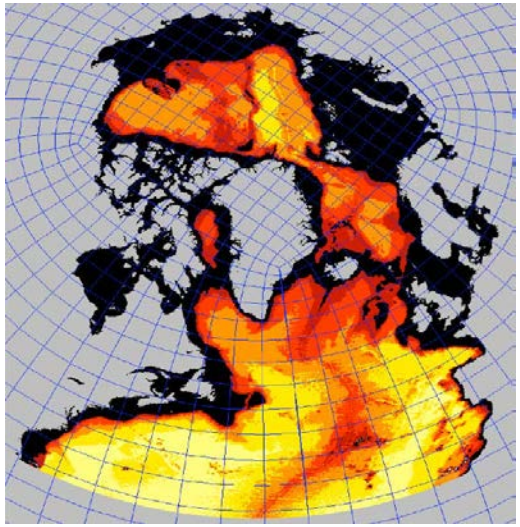
Coupling to a high resolution numerical ocean model

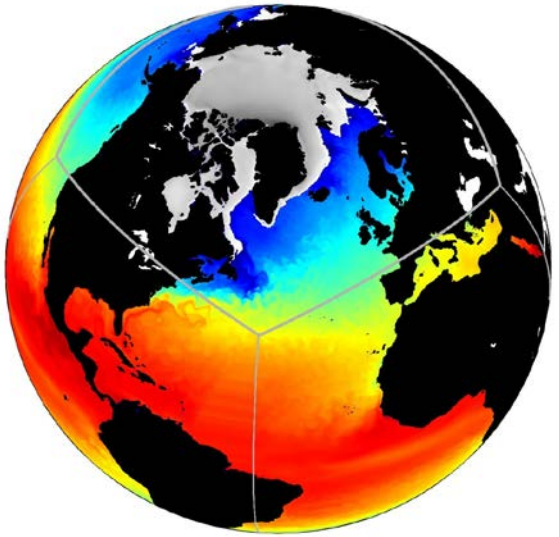
Couple to 1/6º (and higher) eddy permitting ocean sea-ice model (MITgcm).

Initial iceberg model validation is being carried out on a regional N. Atlantic-Arctic configuration (left)

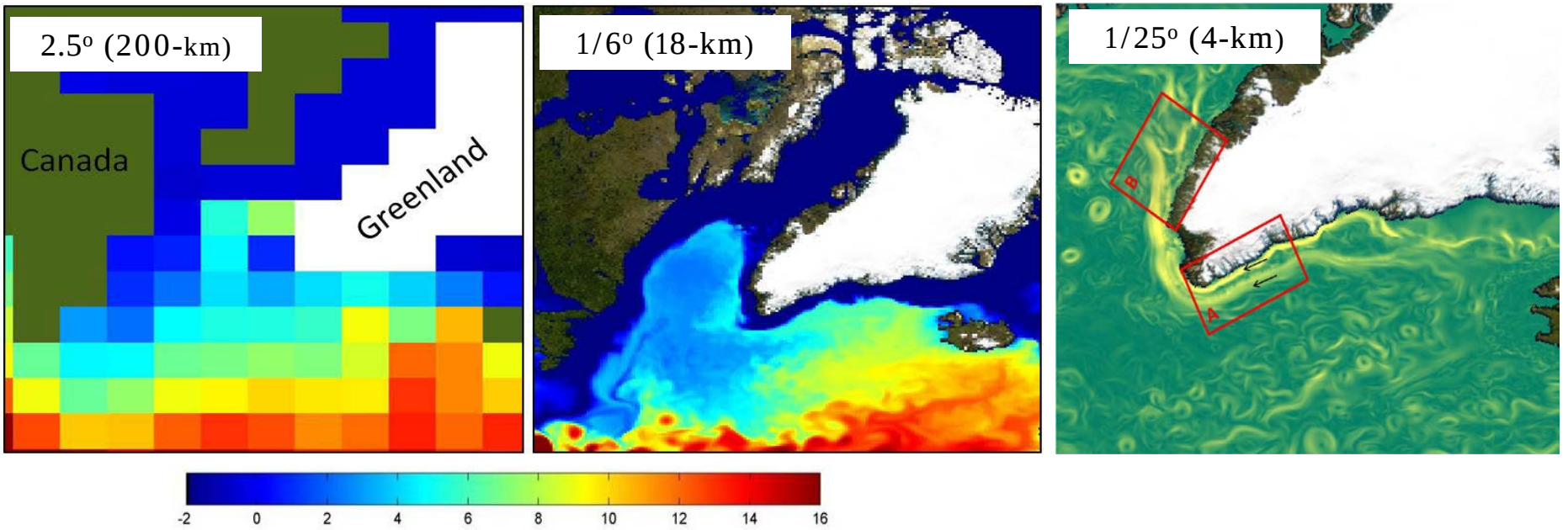
AMOC-iceberg discharge sensitivity studies will use the global domain (right)

All simulations will be run at **NERSC super computing center**



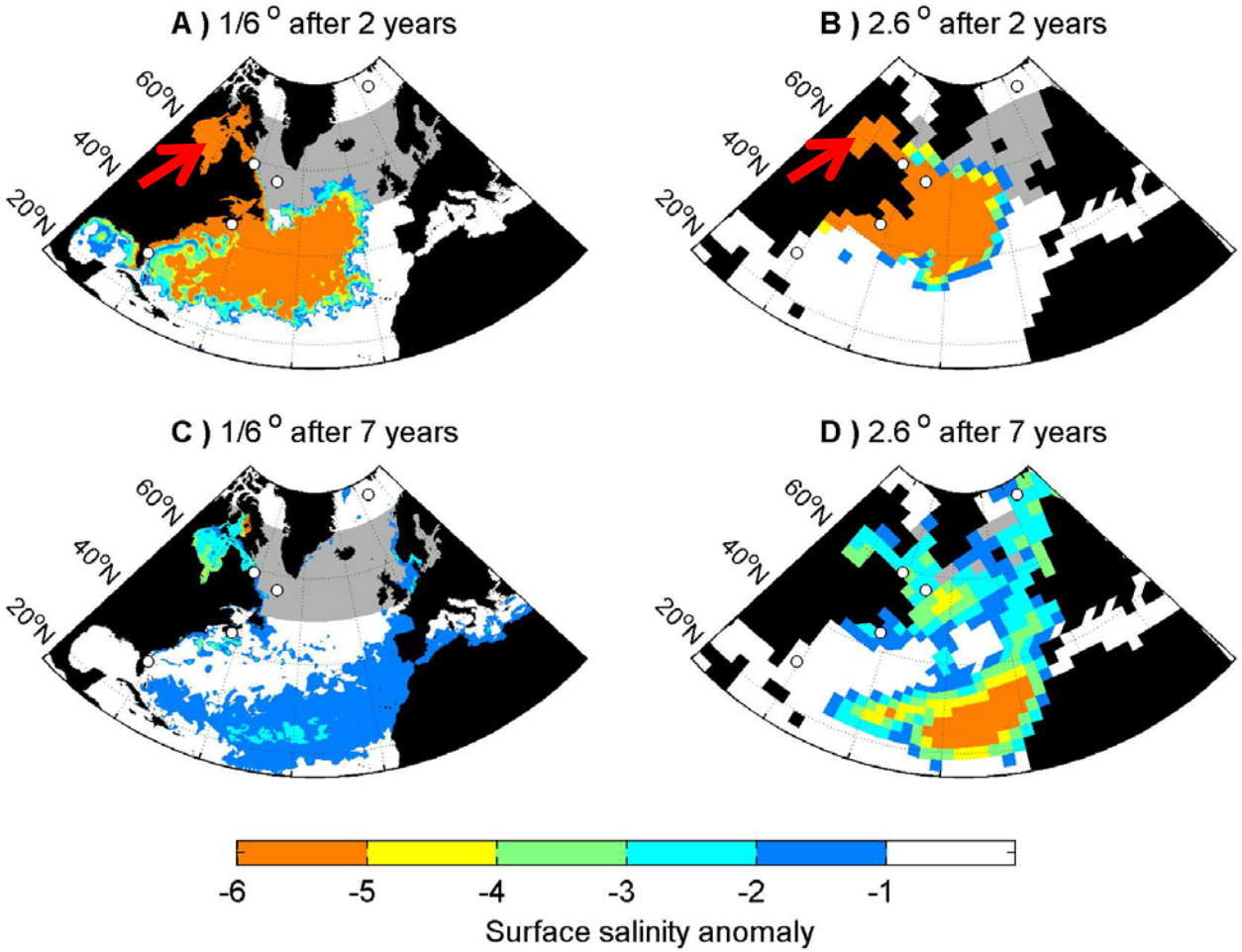


The importance of high spatial resolution for accurately simulating iceberg trajectories



Higher resolution resolves (i) near-shore coastal current, (ii) strong frontal zones, and (iii) eddies, which will be important for accurately simulating the trajectories of individual icebergs.

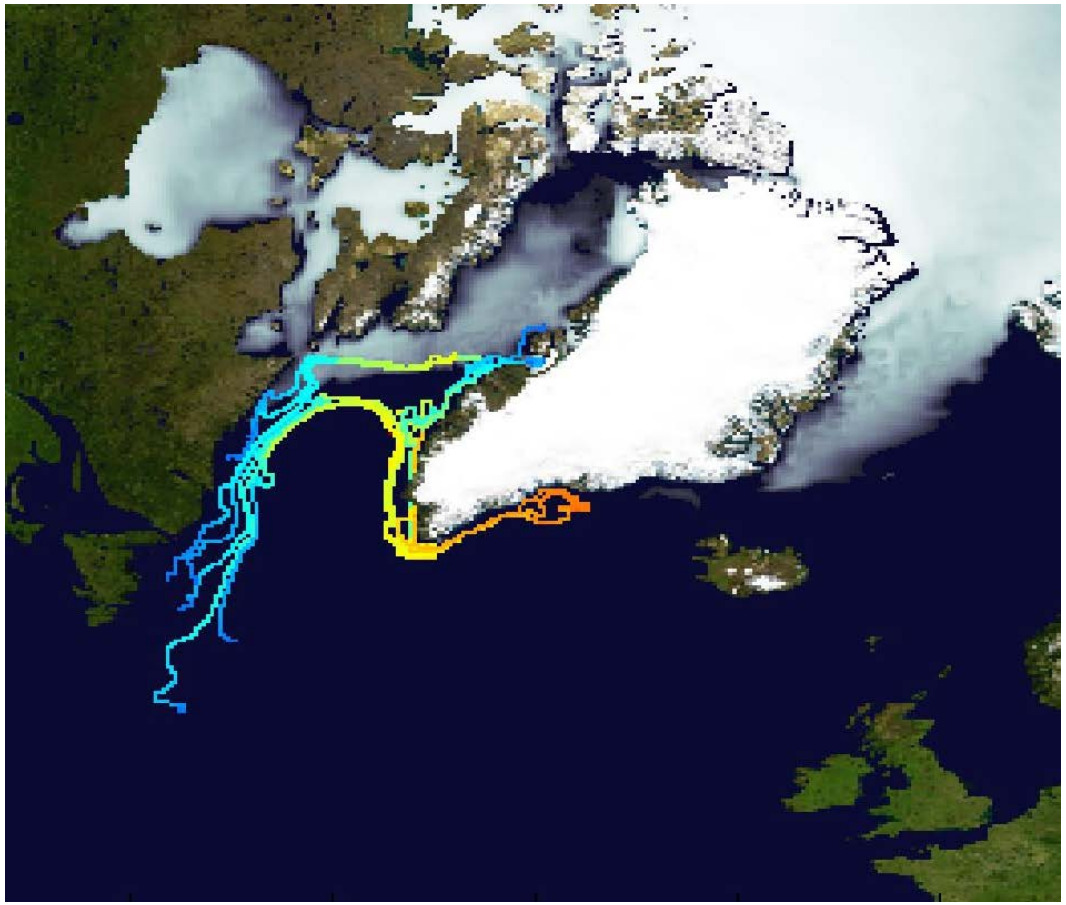
Prior work: The importance of numerical model resolution



A glacial meltwater flood is found to follow a very different pathway when the models resolution is altered

Condron and Winsor (2011) Geophys. Res. Lett. Funded by DoE

Preliminary Drift tracks (1/6 degree integration)



10 icebergs released at the edge of the major glaciers of Greenland

Icebergs confined to narrow coastal currents (in agreement with observations)

80% of the total volume of freshwater was released >200 km offshore of the Greenland Coast.

Summary of the main questions to answer

What fraction of freshwater from icebergs reaches the open-ocean convective regions in the Labrador and Greenland Seas?

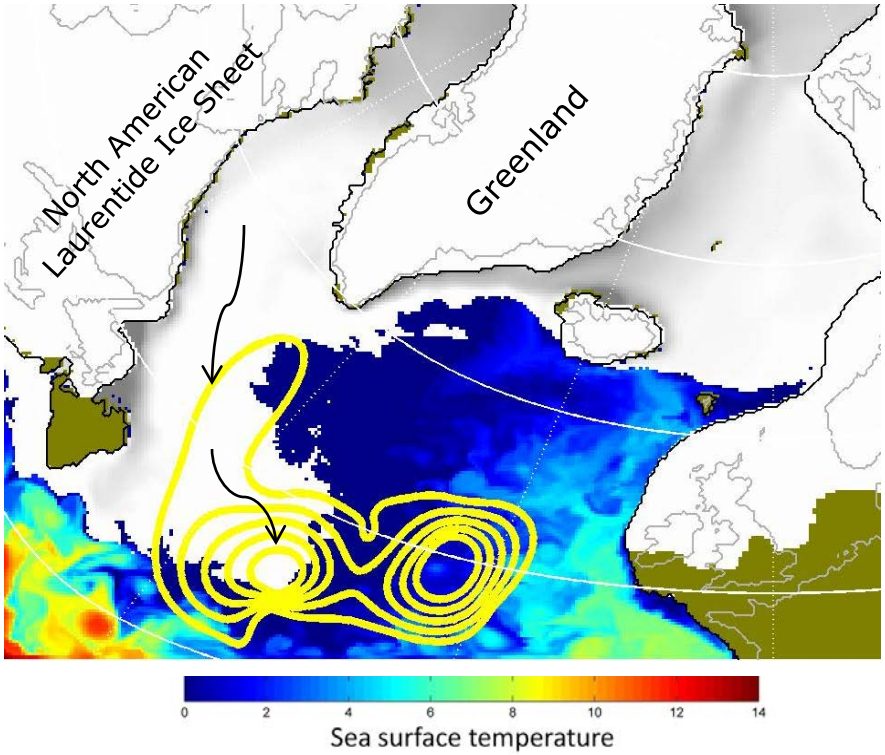
Which geographical discharge locations produce a response in the AMOC? Do some of Greenland's glaciers pose a greater threat to the stability of the AMOC than others in the future?

How important is the state (ice/liquid) of the freshwater to the response of the AMOC?

How does the AMOC response differ with changes in the (i) magnitude and (ii) duration of iceberg discharge events?

How does the sensitive of the AMOC differ to past, present and future iceberg discharges?

Past Climate sensitivity experiments - Heinrich event 1



Large iceberg discharge event into the N. Atlantic 16,800 years BP.

Marine sediments reveal thick layers of ice rafted debris (IRD) at 40 – 50 N in N (Hemming et al. 2007)

Volume of ice discharged at this time is unknown.

We are using our "iceberg sediment model" to quantify the volume of icebergs required to deposit this event, and the meltwater necessary to weaken the AMOC.

Future Climate Sensitivity Experiments

Quantify the stability of the AMOC to different melt rates of the Greenland Ice Sheet in the near-future (50-100 years).

Current estimates suggest a fairly large melt rate of 0.1 Sv is required to weaken the AMOC (e.g. Ridley et al. 2005; Hu et al. 2011), but scenarios tend to spread meltwater over the entire N. Atlantic, and assume meltwater is liquid.

How will the AMOC sensitivity differ when freshwater is discharged as icebergs?

Identify locations/glaciers on the Greenland Ice Sheet with the most potential to disrupt the AMOC. This will guide the deployment of an early warning system.

THANK YOU