An iceberg model to quantify the stability of the Atlantic MOC to freshwater forcing

Alan Condron[1] & Raymond S Bradley[2]
Climate System Research Center, University of Massachusetts Amherst, USA
[1]acondron@geo.umass.edu [2]rbradley@geo.umass.edu

1. Why simulate icebergs?

The goal of this project is to identify which regions of the Greenland and Antarctic ice sheets pose the greatest threat to the stability of the AMOC in the near-future (next 50-100 years). Simulating the discharge of icebergs from continental ice sheets allows us to accurately model the delivery of freshwater to the deep water convection regions that drive the AMOC.

The current generation of Earth System Models (ESMs) incorrectly simulate the discharge of freshwater to the ocean from continental ice sheets. These models often assume that freshwater runoff enters the ocean (1) entirely as liquid (2) evenly along the edge of an ice sheet. (3) at the coast.

In reality, a significant fraction of runoff occurs (1) not as liquid, but as icebergs [66 % for the Greenland Ice Sheet] (2) focused into several narrow fjords. (3) These icebergs drift many thousands of kilometers from their source, and only slowly release freshwater to the ocean as they melt. This changes how freshwater impacts open ocean deep convection and the AMOC.

Above: Tabular iceberg sighted off Cape Farewell, Greenland

2. The iceberg model (MITberg)

MITberg is being developed at the University of Massachusetts Amherst. The model incorporates the latest developments in Operational Iceberg Forecast model technology to simulate the drift and melting of icebergs as accurately as possible. It is coded in FORTRAN and coupled to the existing Massachusetts Institute of Technology general circulation model (MITgcm) to utilize parallel computing.

Each iceberg's drift trajectory is modeled by applying the equation of motion for an iceberg:

$$M_i \frac{dv_i}{dt} = -M_i f\hat{k} \times v_i + F_a + F_w + F_r + F_p + F_s$$

where M_i is iceberg mass, V_i horizontal velocity, f the Coriolis parameter, F_a is wind drag, F_w is water drag, F_r is wave radiation force, F_p the horizontal pressure gradient, and F_s the sea-ice drag.

The equations of motion are solved for each iceberg at each time step utilizing the fourth order Runge-Kutta method.

3. The main features of the iceberg model

MITberg

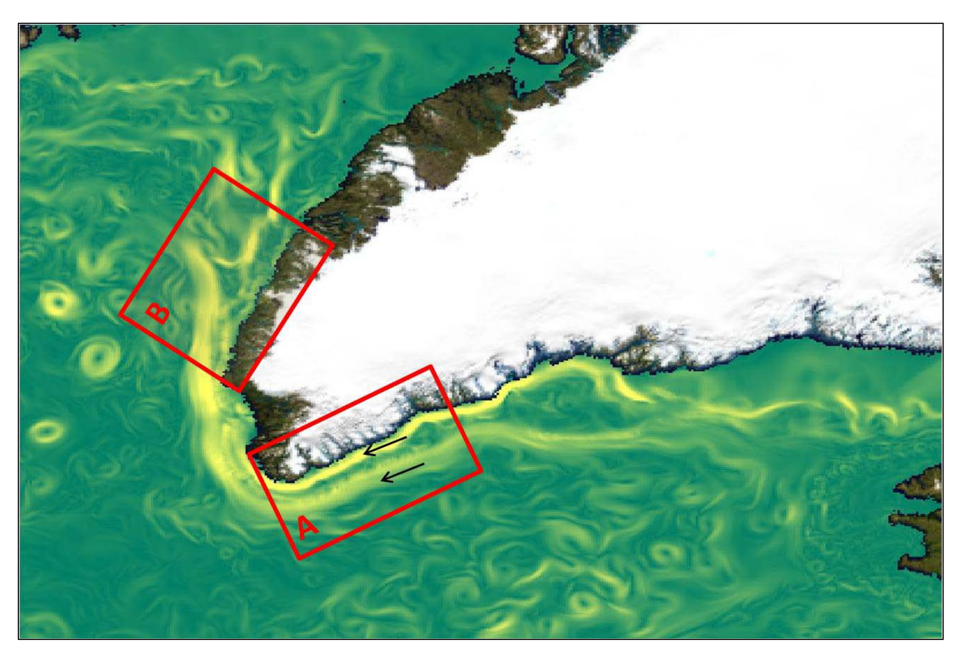
- **Motion** (Dynamics)
  - ***Keel Model*** — *Accurate keel shape design to improve total water drag*
  - ***Collisions/Grounding*** — *Scheme to allow collisions with other bergs & coastline*
  - ***Sea ice Resistance*** — *Drag exerted on icebergs by sea ice*
  - ***Stability*** — *Unstable (Tall-Skinny) icebergs can roll-over*
- **Sediment deposition**
  - ***Sediment Deposition (MITsed)*** — *Simulate transport and deposition of lithic material (IRD) in icebergs to the seafloor.*
- **Melting** (thermodynamics)
  - ***Calving Model*** — *Erosion will cause iceberg to break into smaller pieces*
  - ***Freshwater release*** — *Dye tracer tracks meltwater to NADW formation regions*
  - ***Albedo changes*** — *Reflectivity changes with sediment load & snow cover*
  - ***Wave Erosion*** — *Sea state influences lateral erosion rate*

4. Integrating the ocean component at a high spatial resolution

The iceberg model (MITberg) is coupled to MITgcm with the ocean resolved at a high (1/6°) and ultra-high (1/25°) spatial resolution.

This resolution captures eddies, narrow near-shore boundary currents, small islands and narrow fjords that influence the pathways of individual icebergs.

For example, at 1/25° the East Greenland Current separates into a near- and offshore component (A), while instabilities transport meltwater into the Labrador Sea (B).

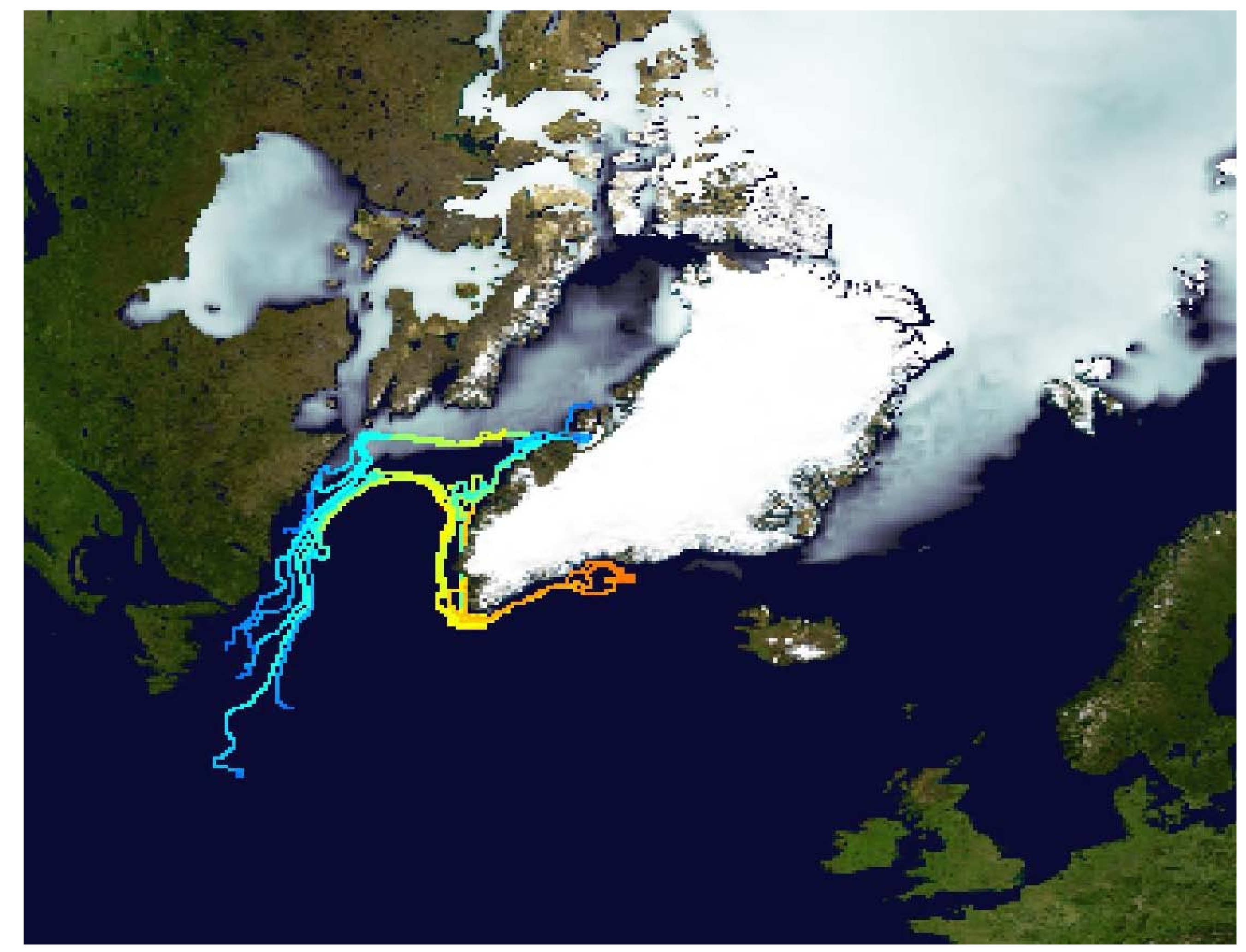


Above: Absolute velocity at 1/25° spatial resolution showing the narrow boundary currents and instabilities around Greenland that influence iceberg motion

5. Preliminary drift tracks

Our initial results show that icebergs are largely confined to the near-shore coastal boundary currents, with little penetration into the central Labrador Sea.

A large fraction (up to 80%) of freshwater is delivered more than 200 km offshore of the Greenland coast, suggesting that 'dumping' freshwater into the ocean along the edge of an ice sheet is not an effective way to understand the sensitivity of the climate system to changes in the melting of continental ice sheets.



Above: Drift tracks of icebergs calved from southern Greenland

6. What's next?

1) Determine which geographical iceberg calving regions produce the greatest response in the AMOC.

2) Identify specific regions or individual ice streams that pose the greatest threat to the stability of the AMOC in the near-future (next 50-100 years). This will allow real-time monitoring systems to be deployed in these 'sensitive' locations.

3) Run suite of iceberg experiments to understand the stability of the AMOC to past changes in freshwater forcing. Particular emphasis is being placed on Heinrich Event 1 (~16,800 yrs BP) to understand the relationship between abrupt cooling events recorded in the Earth's history and the episodic release of large numbers of icebergs into the North Atlantic.

4) The iceberg sediment model (MITsed) is being used to try and reconstruct the sediment patterns observed on the North Atlantic seafloor that were deposited by ice rafted debris during Heinrich Event 1. This model will allow us to inversely calculate the volume of icebergs discharged at this time.