Improving ocean-ice interactions
A dynamic-thermodynamic iceberg model to simulate high-latitude freshwater forcing

UMASS AMHERST — CLIMATE SYSTEM RESEARCH CENTER

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PINNACLE (Parallel hIgh resolutioN Numerical iCeberg modeLing project)/MITberg is a state-of-the-art iceberg model being developed at the University of Massachusetts Amherst in response to BER SciDAC Initiative DE-FOA-0000452 to better simulate the coupling between the cryosphere and the ocean in Earth System and Climate models.

The iceberg model incorporates the latest developments in Operational Iceberg Forecast model technology to simulate the drift and melting of icebergs as accurately as possible in order to realistically resolve the interaction of freshwater runoff from the cryosphere with the ocean. **PINNICLE/MITberg** is parallel coded in FORTRAN90 to maximize scalability on high-performance super computing and is freely available for download for interested parties.

1. Why simulate icebergs?

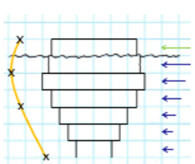
The latest future predictions for the Antarctic ice sheet show the potential for rapid ice sheet retreat/collapse in the next 50-300 years, accompanied by the discharge of *enormous* fluxes of icebergs and freshwater to the Southern Ocean. Determining climate sensitivity to high-latitude freshwater forcing in realistic models is vital. Most of the latest generation of EaSMs do not simulate icebergs and attempt to understand changes in high-latitude runoff by (unrealistically) freshening large sections of the subpolar oceans. In reality, increased cryosphere melt will occur at point source locations (individual calving margins) and will be partitioned into both liquid and ice; e.g. Antarctic runoff is split ~50/50 between iceberg calving and basal melt. In addition, unlike liquid freshwater, icebergs drift 1000's km from their source and gradually release freshwater to the ocean.

2. The iceberg model (PINNACLE/MITberg)

Iceberg drift trajectories are calculated 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. Icebergs are **'multi-level'** to account for changes in horizontal ocean velocity with depth, and can assume a variety of shapes (tabular, pinnacle) based on a novel keel model.



(Above) A keel model is used to more accurately simulate ocean drag.

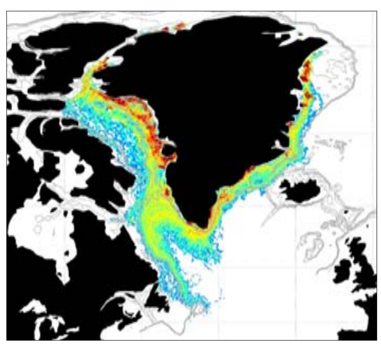
Iceberg melt occurs due to buoyant vertical convection (along side walls), sensible heat exchange, wave erosion, and radiative heating (above the waterline). Erosion at the waterline also creates overhanging ice that can calve into the ocean to form 'bery-bits'. **Coupling:** Melting ice both freshens and cools the ocean model. A dye tracer can be added to the freshwater to trace/map ocean freshwater pathways.

3. The main features of the iceberg model

PINNACLE MITberg

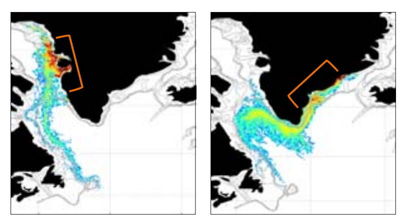
- **Motion** (Dynamics)
  - ***Keel Model*** — *Accurate keel shape design to improve total water drag*
  - ***Collisions/Grounding*** — *Scheme to allow collisions with other bergs & coastline*
  - ***Sea ice Resistance*** — *Drag exerted on icebergs by sea ice*
  - ***Stability*** — *Unstable (Tall-Skinny) icebergs can roll-over*
- **Sediment deposition**
  - ***Sediment Deposition*** — *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 deep convection regions*
  - ***Albedo changes*** — *Reflectivity changes with sediment load & snow cover*
  - ***Wave Erosion*** — *Sea state influences lateral erosion rate*

4. Iceberg drift and calving



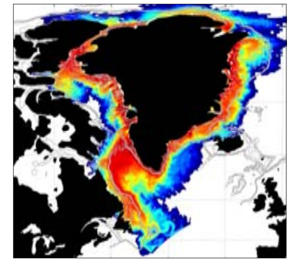
Above: Modern-day drift tracks from icebergs calved from Greenland, integrated at 1/6deg.

The calving scheme partitions runoff into both liquid runoff and icebergs. The iceberg drift patterns shown here were created by icebergs calved from 34 locations around Greenland, based on modern-day data (Rignot et al. 2008)



Above: Each calving point has a unique ID# to allow icebergs from different sources to be tracked.

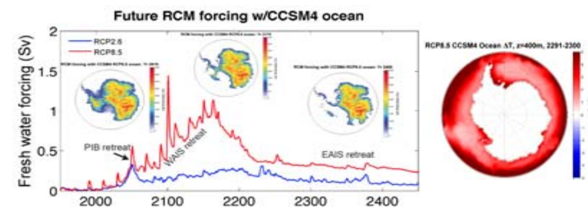
5. Tracing freshwater pathways



Freshwater release to the ocean from melting icebergs is traced in the ocean model using a passive dye tracer. Dye tracing is improving our understanding of how freshwater from ice sheets influences deepwater formation and the AMOC. Meltwater from Greenland is confined to narrow coastal boundary currents, with more limited offshore transport.

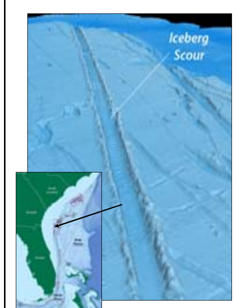
6. Climate-freshwater sensitivity experiments

High-resolution, coupled (ocean/seaice/iceberg) model simulations are planned to more accurately determining AMOC sensitivity to projected increases in Greenland and Antarctic ice sheet runoff..



(Above) *Total Antarctic freshwater runoff from the ice sheet model of D. Pollard forced by NCAR CCSM4 for RCP8.5 (red) and RCP2.6 (blue). Peak discharge (~2100AD) occurs when the Ross Ice Shelf collapses, producing a meltwater surge in Siple Coast outlet*

7. Paleoclimate: subtropical icebergs



Iceberg scours have been identified along the U.S. continental margin from South Carolina to Florida. PINNACLE/MITberg has been coupled to a high-resolution glacial ocean model to investigate the source of these icebergs and circulation patterns necessary to transport icebergs to the subtropics. Model runs indicate that the scours were created by *massive* meltwater floods that significantly freshened the subtropical North Atlantic (Hill & Condron, Science, Under-Review) .

8. CESM Iceberg model development

We are now in the process of initiating a collaboration between UMass Amherst and COSIM (LANL) to help advance iceberg model development for CESM and to further DOE efforts in understanding ocean-ice interactions and AMOC response to high-latitude freshwater forcing. Visits between our two groups are planed to begin in the next few months to start a joint collaboration on these efforts.