Recent advances in glacier/ocean interactions

Fiamma Straneo

Woods Hole Oceanographic Institution
Advance collective understanding of Greenland and Arctic land-ice change, and its interaction with the climate system.


- International Workshop and report synthesizing scientific priorities (Heimbach et al. 2014; US CLIVAR Report)

1: Dynamic ice sheet mass loss triggered by ocean forcing

Greenland ice loss (twice that of Antarctica)
- Quadrupled over the last two decades
- Accounts for $\frac{1}{4}$ of sea level rise
- $\frac{1}{2}$ is due to the speed up of glaciers

2. Impact of Ice Sheet Discharge on the Ocean

Total freshwater flux from Greenland

\[ \approx 900 \text{ km}^3/\text{yr} \quad 1960-1990 \]

\[ \approx 1200 \text{ km}^3/\text{yr} \quad 2000-2010 \]

Exceptional slowdown of the AMOC due to Greenland melt?

*Rahmstorf et al. 2015*

*van den Broeke et al. 2009; Bamber et al. 2012*
A hierarchy of scales and processes
Relevance to climate models: ice sheet forces ocean

*Ocean models include Greenland ice loss as a surface freshwater flux*

Discrepancies exist in:

- Magnitude 0.01 to 1 Sv
  
  \( \text{(1200 km}^3/\text{yr} = 0.038 \text{ Sv)} \)

- Input location (distributed versus localized)

- Timing

---

*Eg Marsh et al, 2010; Weijer et al. 2012; Hu et al. 2013*
Discharge from the ice sheet is not a surface freshwater flux.

Tundra

\[ \sim 200 \text{ km}^3/\text{yr} \]

Icebergs + Submarine melt = 400 km\(^3\)/yr

Subglacial discharge

\[ \sim 600 \text{ km}^3/\text{yr} \]

van den Broeke et al. 2009; Bamber et al. 2012; Enderlin et al. 2014
Discharge is highly seasonal and localized by drainage basins.

NASA ICESAT Data, van den Broeke et al. 2009; von Angelen et al. 2013
Significant amount discharged hundreds of meters below the surface

Subglacial discharge

Submarine melt of glaciers and icebergs

Kimura et al. 2015

Jenkins 2011; Straneo and Cenedese, 2015; Carroll et al. 2015; Stevens et al. 2015
Discharge at depth forms **glacially modified waters**

Land-Ice discharge at the head of the fjord $\rightarrow$ export of surface and subsurface water masses (not freshwater at the surface)

*Straneo et al. 2011; Beaird and Straneo, in prep.*
Tracers show that glacially modified waters contain less than 1-4% meltwater.

Volume of transformed waters about 30-100 times glacial input.
Export of glacially modified waters onto shelf is lagged with respect to land-ice input (fjord dynamics)

Glacial meltwater observed from moorings in Sermilik Fjord, SE Greenland

Beaird and Straneo, in prep.
Relevance to climate models: ice sheet forces ocean

Target – Improved boundary conditions for ocean models

1. Localized, seasonal discharge

2. Separation into different components

3. Parameterization Plume Dynamics: Transformation of discharge based on plume dynamics, laboratory, and numerical simulations → GMW formation

4. Parameterization: Fjord dynamics that governs the timing of the export of glacially modified waters
Relevance to climate models: Ocean forces ice sheet

Ice sheet models need submarine melt rates → SMR (x,t)

Ice/Ocean Boundary Layer Parameterization

\[ SMR (x,t) = f(U_A, \vartheta_A) \]

Hellmer and Olbers, 1989; Holland and Jenkins 1999; Jenkins et al. 2010
A hierarchy of scales and processes
Water properties at the fjord’s mouth

Link between shelf processes and properties at the fjord’s mouth
Near glacier properties are affected by glacier

![Graph showing depth vs. potential temperature for different locations, including Near Glacier and Mid Fjord.]

Implication → ice/ocean exchange must be resolved or parameterized in the model.
Parameterization of plumes

Cowton et al. 2015; Carroll et al. 2015; Straneo and Cenedese, 2015
Submarine Melting of glacier

Ice sheet models need submarine melt rates → SMR (x,t)

$$SMR (x,t) = f(U_A, \theta_A)$$

Steps to provide SMR

1. Large scale model provides properties on shelf near fjord mouth

2. Fjord/shelf exchange either resolved or parameterized

3. Plumes at ice edge parameterized to provide properties at the ice edge → submarine melt rates
Land-ice/Ocean exchanges are absent or poorly represented in ice sheet, ocean and climate models.

Even though we need to predict ice sheet variability and its impact on the climate system.

Good News – Considerable progress in understanding – fjord, ice/ocean exchanges, plume dynamics.

Parameterizations needed for glacier/ocean exchanges (improved boundary layer, plumes) and fjord transformation.