Greenland fjord circulation: what do we expect? (i.e., theoretically and from modeling)

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Greenland fjord circulation: and why do we care...

**Fjord Circulation:**
Mechanisms:
- Estuarine circulation
- Intermediate circulation
- Mixing processes

Linked to 3 triggering mechanisms discussed in BAMS article

**POP QUIZ!**

Greenland fjord circulation: and why do we care...
Quick review on estuarine physics

On timescales > tidal, estuarine exchange flow develops

- The observed along-channel flow is mostly “two layered” in tidally-averaged sense
- Surface flows out, deep flows in
- Due to river input and mixing

MacCready 2010
Quick review on estuarine physics

A little math behind the exchange flow...

First result: KNUDSEN

$$V S_t = Q_2 S_2 - Q_1 S_1$$

Salt balance

$$Q_1 = \frac{S_2}{\Delta S} Q_R$$

($$\Delta S = S_2 - S_1$$)

MacCready and Geyer, 2010
Quick review on estuarine physics

A little math behind the exchange flow...

Momentum balance:

\[ 0 = -\frac{1}{\rho_0} p_x + K_M u_{zz} \]

Pressure gradient \( p_x \):

\[ -\frac{1}{\rho_0} p_x = -g\eta_x + g\beta \bar{S}_{xz} \]

MacCready and Geyer, 2010
Fjords as estuaries:
- by definition highly stratified
- deep, bottom drag less important

Can also use hydraulic control...

Geyer and Cannon, 1982

Farmer and Freeland, 1983
Tidewater glacier fjords as estuaries:
- runoff at depth
- stratification important, inherited from shelf
- presence of sill matters
- various mixing processes and zones
Fjord Circulation: processes

\[ Q_e = \frac{g \beta s_x H^3}{(48 K_M)} \]

magnitude of estuarine circulation

2) **Intermediate circulation** – driven by changes in coastal density field (Stigebrandt, 1990; Klinck et al., 1981, Straneo et al. 2010)
2) Intermediate circulation – driven by changes in coastal density field (Stigebrandt, 1990; Klinck et al., 1981, Straneo et al. 2010)

\[ Q_i = \beta \left[ H_s B_m A_f g \Delta M / \rho_0 \right]^{1/2} \]

(Stigebrandt, 1990; Stigebrandt, 2012)

**NOTE:** Can be important to heat flux if temperature co-varies with \( Q_i \) on these same time and space scales.
Fjord Circulation: mechanisms

1) Estuarine circulation
2) Intermediate circulation

Which dominates?

\[ Q_i = \beta \left[ \frac{H_s B_m A_f g \Delta M}{\rho_0} \right]^{1/2} \]

\[ Q_i \text{ (10}^4 \text{ m}^3 \text{ s}^{-1}), \; c_i = 0.25 \; (\Delta M = 65 \text{ with } H_s = 900) \]

But what about \( Q_i \)?
Ideally, we would make $Q_e$ vs. $Q_i$ parameter space for Greenland fjords

$$Q_i = \beta \left[ H_s B_m A_f g \Delta M / \rho_0 \right]^{1/2} \quad Q_e = g \beta \bar{s}_x H^3 / (48 K_M)$$

(or at least from Knudsen)

...or some other measure of estuarine strength (phi)

**Fjord Circulation: modeling**

(Xu et al. 2012)
**Fjord Circulation:** modeling

- Mostly 2-D to date, focusing on buoyancy driven flow due to $Q_{sg}$ (estuarine circulation)

- Parameterized heat flux to glacier face based on 1-D plume models

- Horizontal and vertical scales not really resolving plume yet—means relying on mixing parameterizations
**Fjord Circulation:** modeling results in recent literature

- **Salcedo-Castro et al. (2011):** plume dependence on Qsg outflow velocity (Froude #) and shape

- **Gladish et al.:** Investigating renewal of Jakobshavn Isbrae on timescales < 1 year, including wind and buoyancy driven flow

- **Carroll et al.:** Including realistic bathymetry in a 3D model with winds and Qsg

- **Sciascia et al. (2013):** 2-D model of Sermilik Fjord looking at dependence on mixing parameterizations, seasonality, Qsg, stratification → showed evidence for multicell estuarine flow
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**Fjord Circulation: challenges**

**Modeling:**
-- Sensitivity studies of all different mechanisms
-- Careful attention to mixing processes
-- Caution with calculating melt rates on glacier face

**Observations:**
-- need new observations to add to classic moorings and hydrography surveys (and to validate models)

**Bathymetry** (an oceanographic underwater IceBridge-like campaign; open data)
This summer: more of the same…
but with a natural experiment

NASA project to investigate if ocean, glacier, or atmospheric dynamics dominate in Rink Isbrae and KS systems

(with Ginny Catania, Jonathan Nash, Emily Shroyer, Ryan Walker)
Autonomous vehicles:
• Gliders in fjord and under ice
• Small remotely operated vehicles
• NEED: measurements under ice mélange near glacier face, and seasonal measurements
OSU Autonomous Research Vessel cruises at 8 knots → 20 km endurance / 5 km range
300 kHz ADCP + CTD profiling
video and data telemetry missions to the ice edge

Jonathan Nash / Oregon State University
Autonomous vehicles:
- Gliders in fjord and under ice
- Small remotely operated vehicles
- **NEED**: measurements under ice mélange near glacier face, and seasonal measurements

Marine mammals:
- Hooded seals, narwhals, others?

...under ice mélange seasonal measurements in can help with **bathymetry**...
Remote sensing:
- Surface circulation
- Upwelling plume
- Iceberg motion
- **Unknown:** what role do icebergs play? Can they effectively be used to track fjord motion?

Marine mammals:
- Hooded seals, narwhals, others?
- **NEED:** measurements under ice mélange near glacier face, and seasonal measurements in fjord and on shelf→ also can help with **bathymetry**

Autonomous vehicles:
- Gliders in fjord and under ice
- Small remotely operated vehicles
- **NEED:** measurements under ice mélange near glacier face, and seasonal measurements
Icebergs: do they matter?

Iceberg Trackers in Sermilik Fjord

- Tides – (circles behind each moving square shows the last 6 hours)
- Other events like calving that push the trackers in the melange out of the fjord
- Circulation of upper layer waters in fjord
Conclusions

• Fjord circulation variable on time scales from hours to days to seasons to interannual – question dependent on what we want to resolve and fjord dependent on what mechanism dominates

• Progress in modeling has been fast, need to think about parameterizing glacial fjords as estuaries in climate models (need to know amplification of Qsg)

• Can learn a lot from classic fjord literature—but need new observations to overcome unique features of tidewater glacier fjords