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

David Sutherland

Department of Geological Sciences, University of Oregon

PLUS many collaborators:
Fiamma Straneo (WHOI)
Ginny Catania (UT-Austin)
Jonathan Nash, Emily Shroyer (OSU)
Leigh Stearns (UKansas)
Gordon Hamilton (UMaine)

GRISO meeting
June 2013

NASA NSF

UNIVERSITY OF OREGON

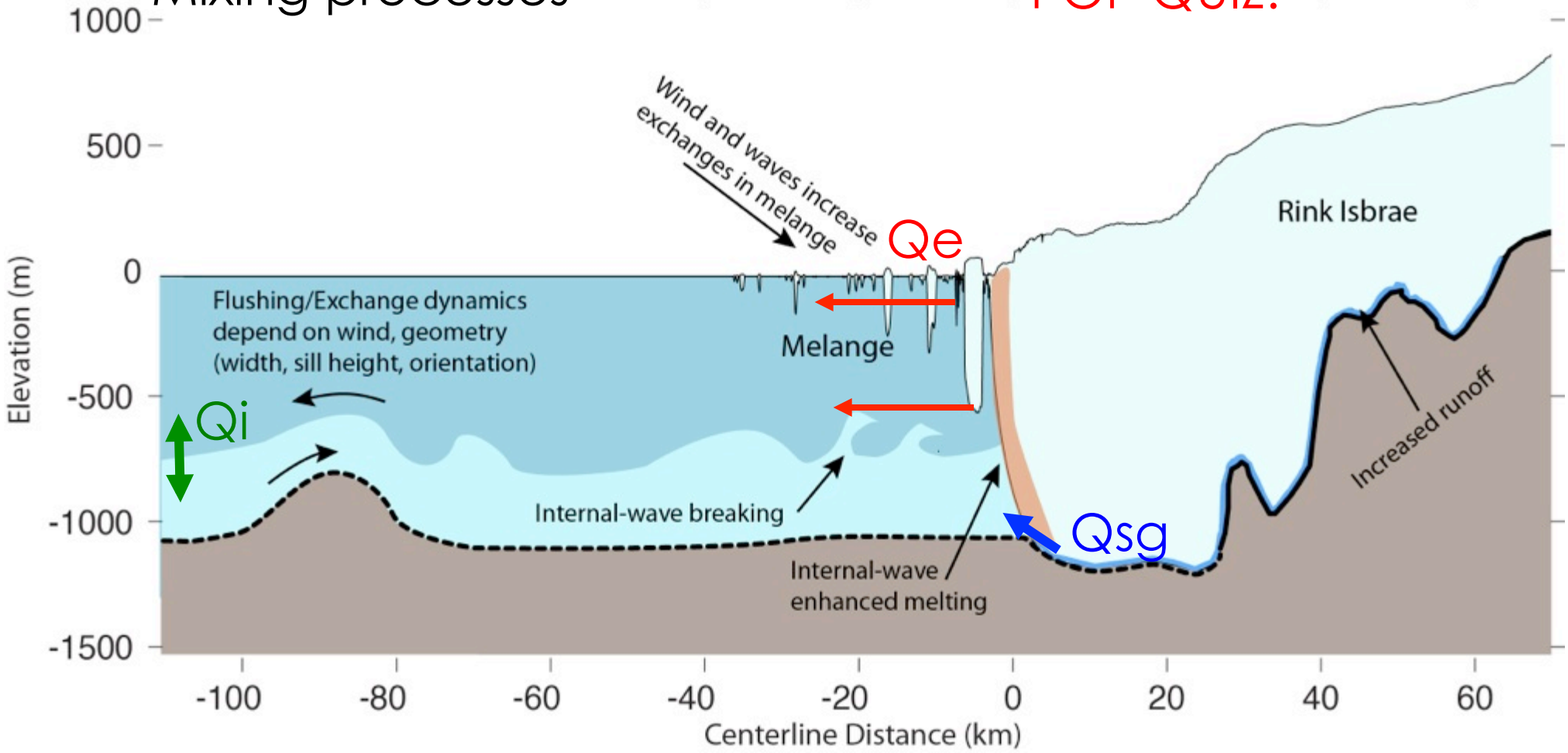
Greenland fjord circulation: and why do we care…

Fjord Circulation: → Linked to 3 triggering mechanisms discussed in BAMS article

Mechanisms:

- Estuarine circulation
- Intermediate circulation
- Mixing processes

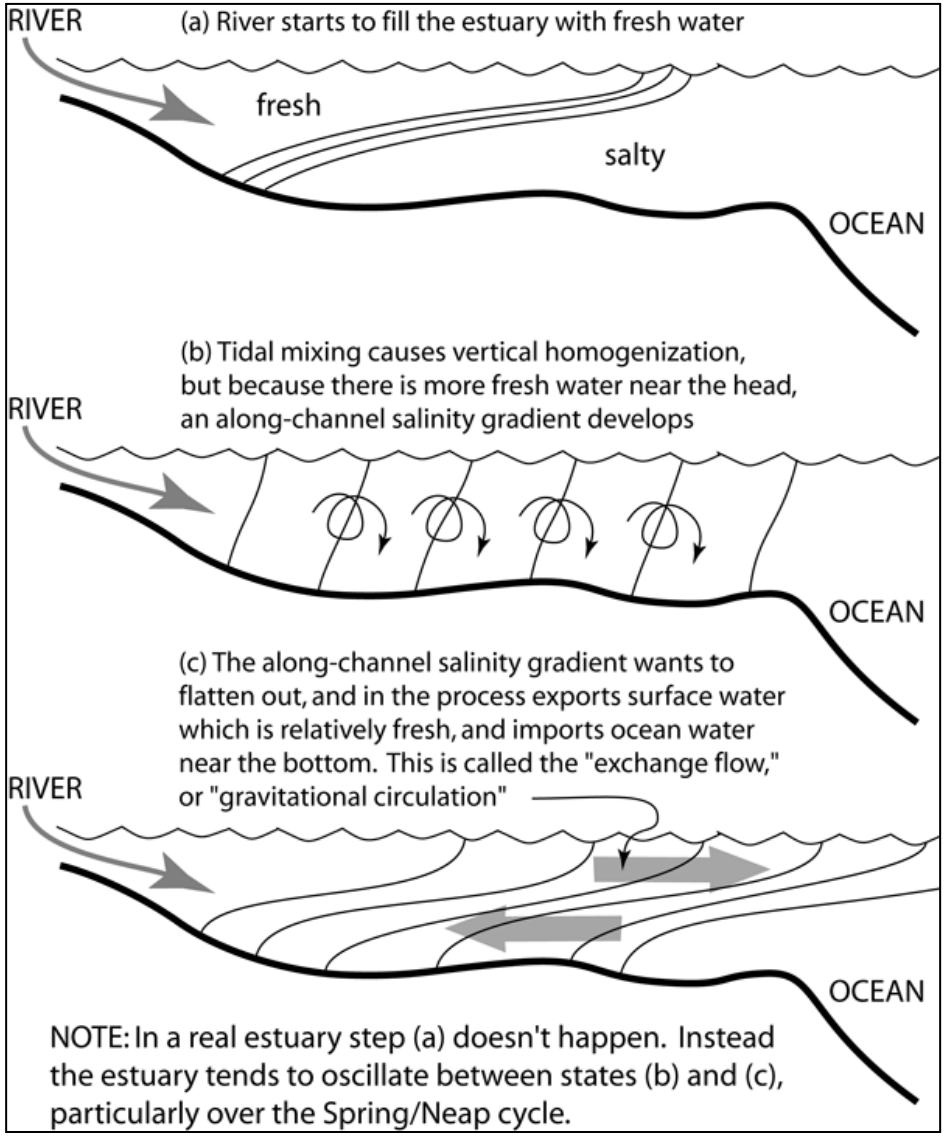
POP QUIZ!



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…

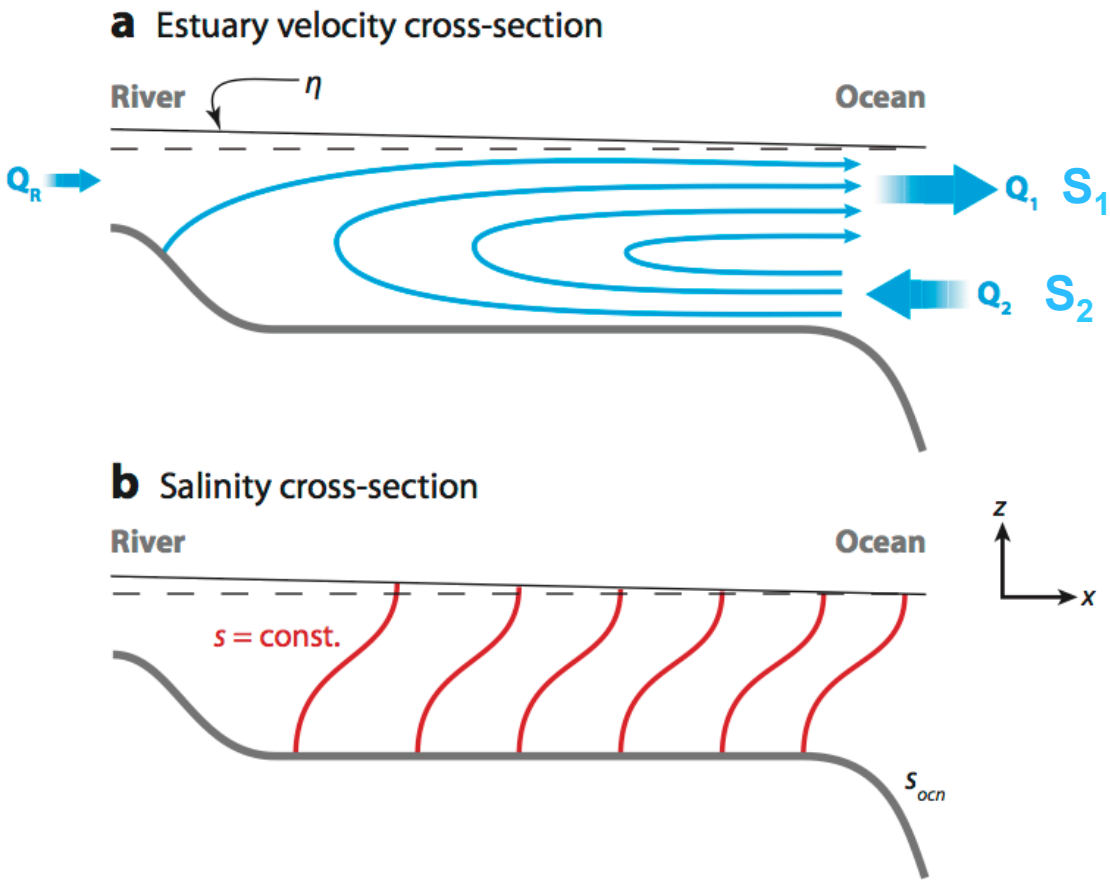
First result: KNUDSEN

$$VS_t = Q_2 S_2 - Q_1 S_1$$

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

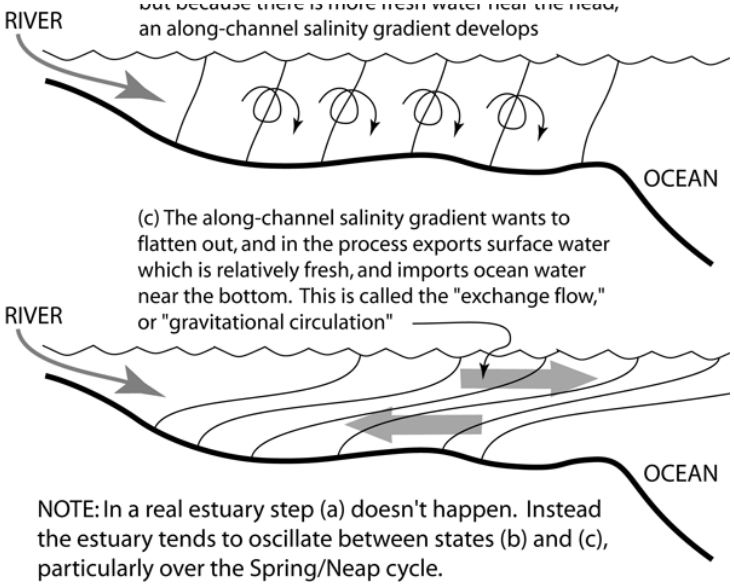
A little math behind the exchange flow…

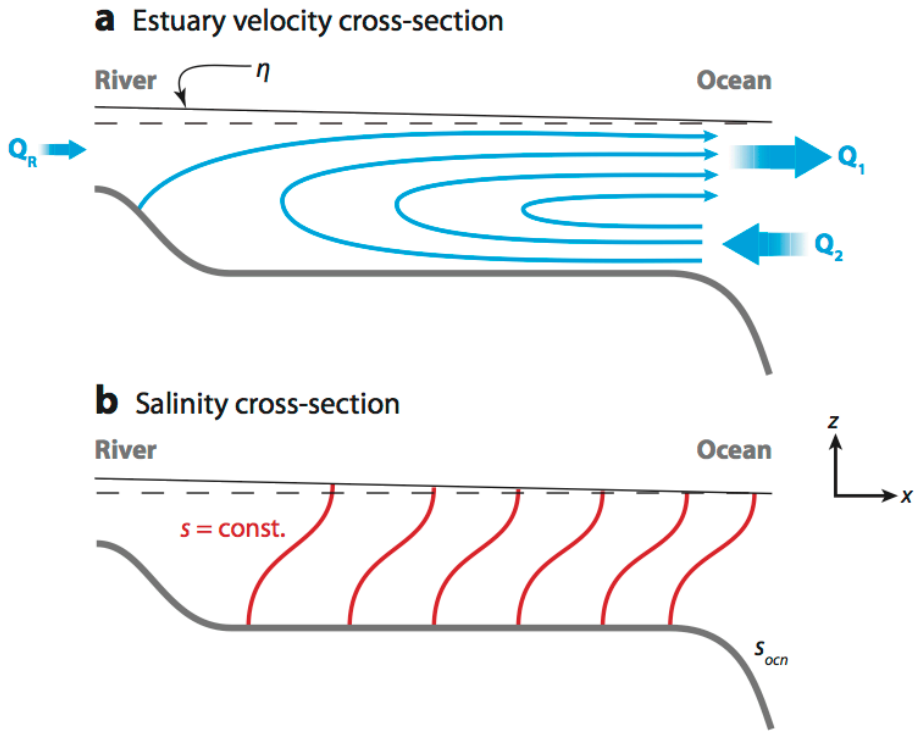
$$0 = -\frac{1}{\rho_0} p_x + K_M u_{zz}$$

Momentum balance

pressure gradient p_x:

$$-\frac{1}{\rho_0} p_x = -g\eta_x + g\beta \bar{S}_x z$$

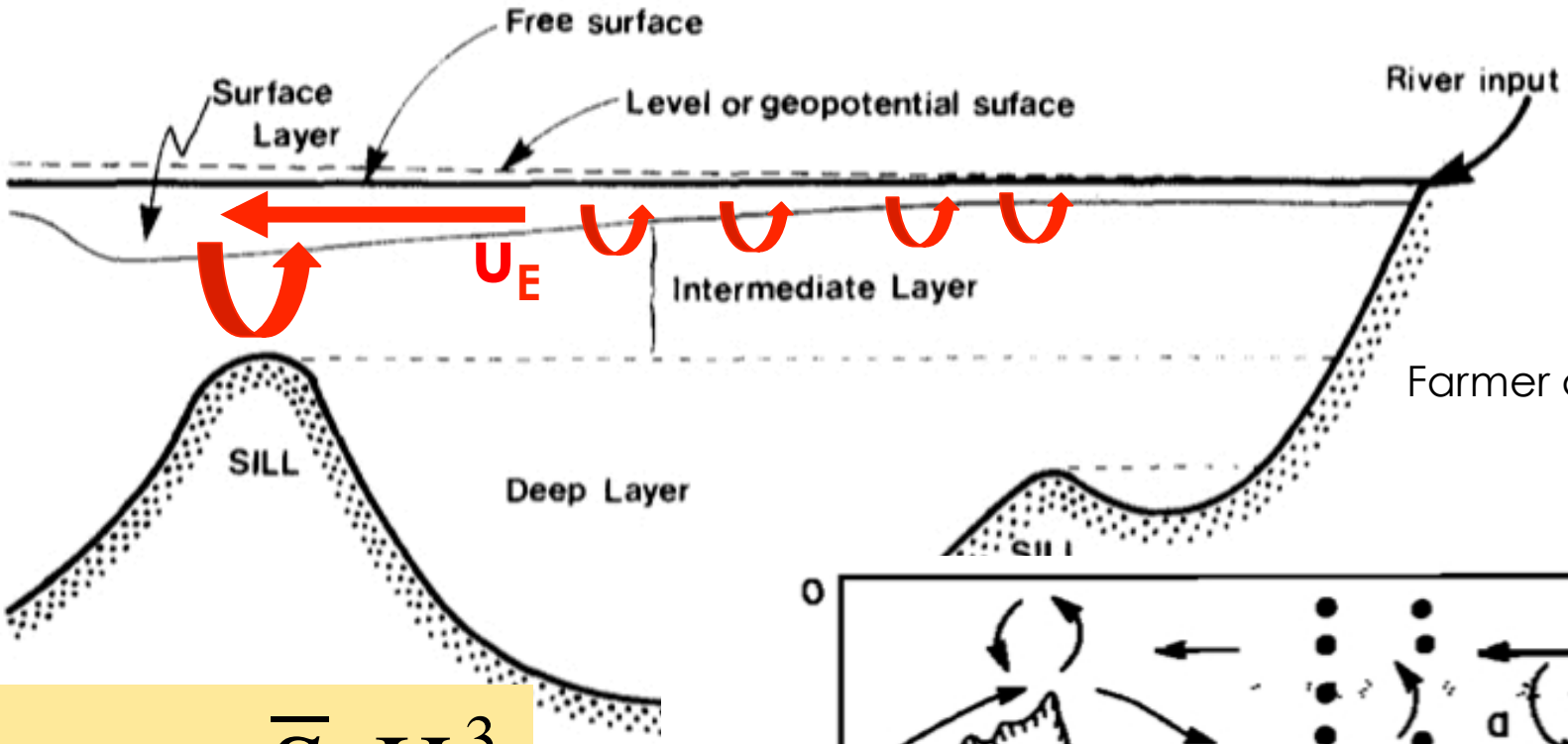




MacCready and Geyer, 2010

Fjords as estuaries:

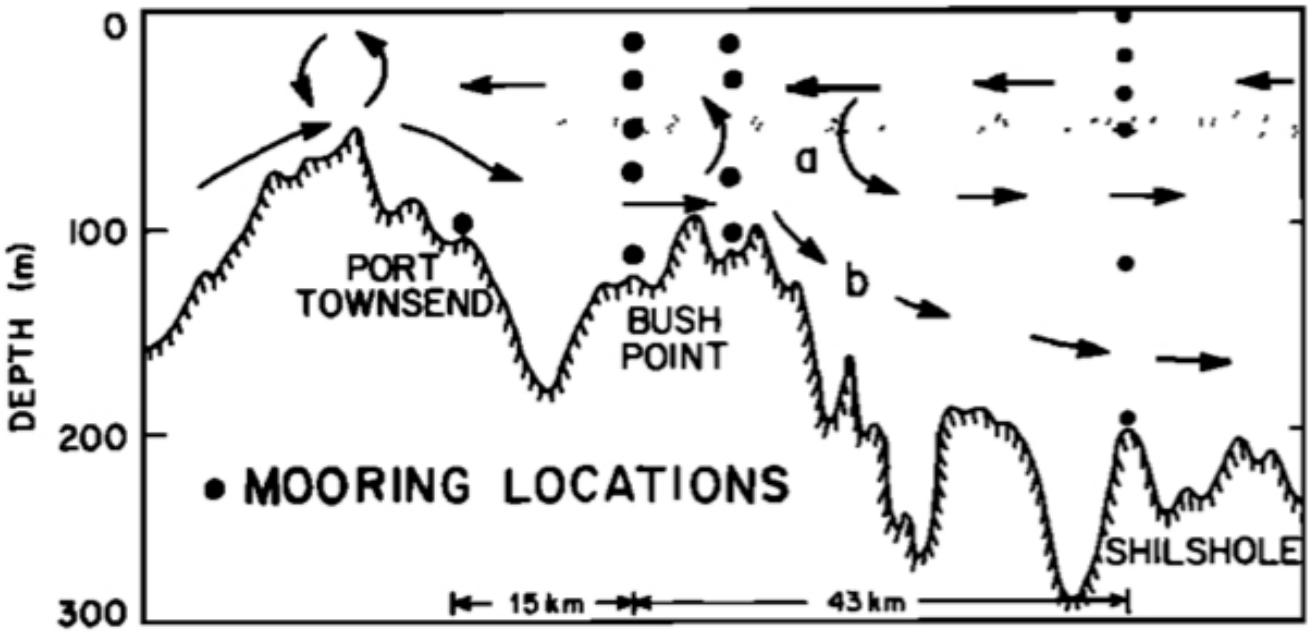
- by definition highly stratified
- deep, bottom drag less important



Farmer and Freeland, 1983

$$u_E \propto \frac{\overline{S}_x H^3}{K_M}$$

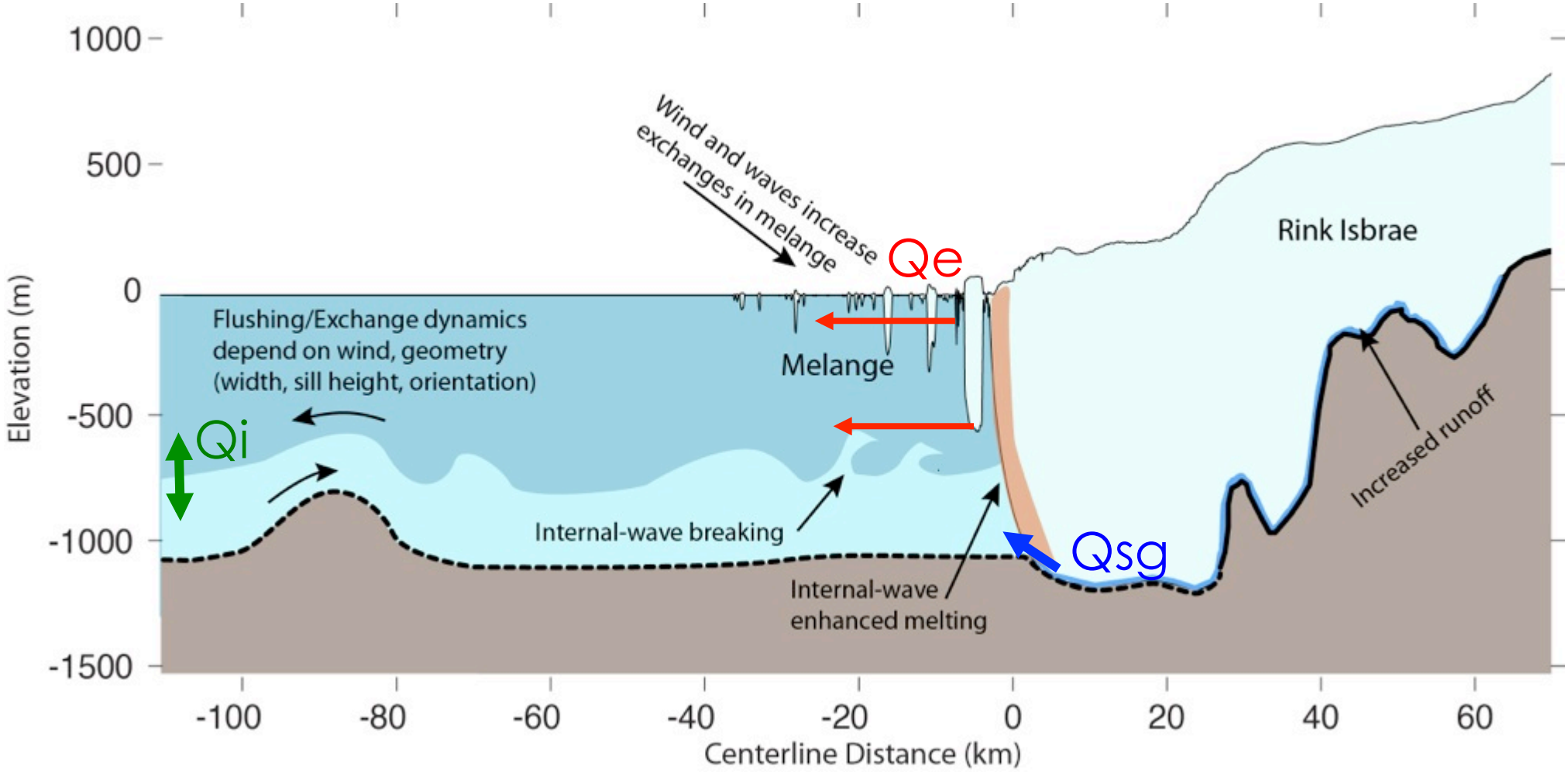
Can also use hydraulic control…



Geyer and Cannon, 1982

Tidewater glacier fjords as estuaries:

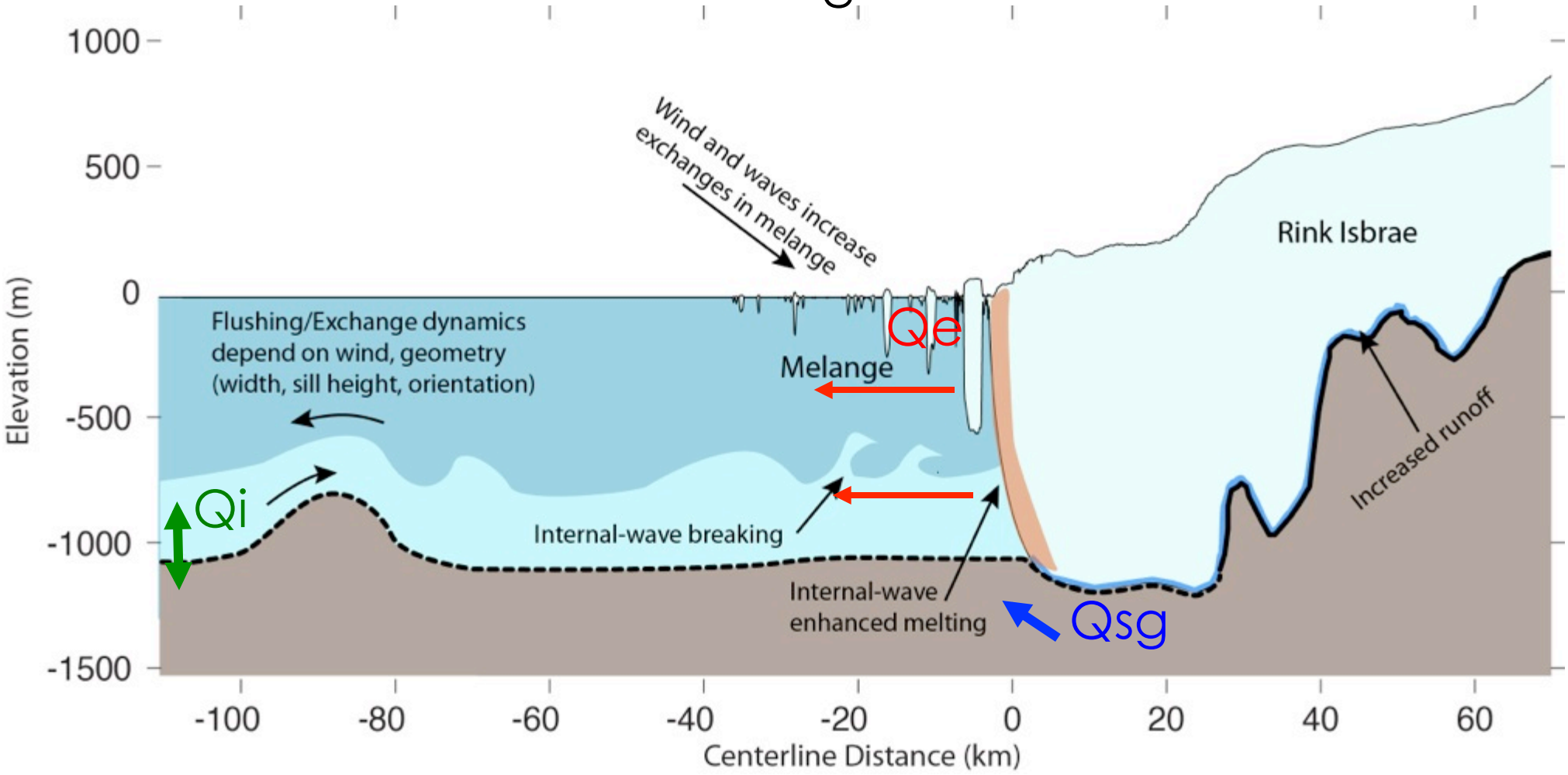
- runoff at depth
- stratification important, inherited from shelf
- presence of sill matters
- various mixing processes and zones



Fjord Circulation: processes

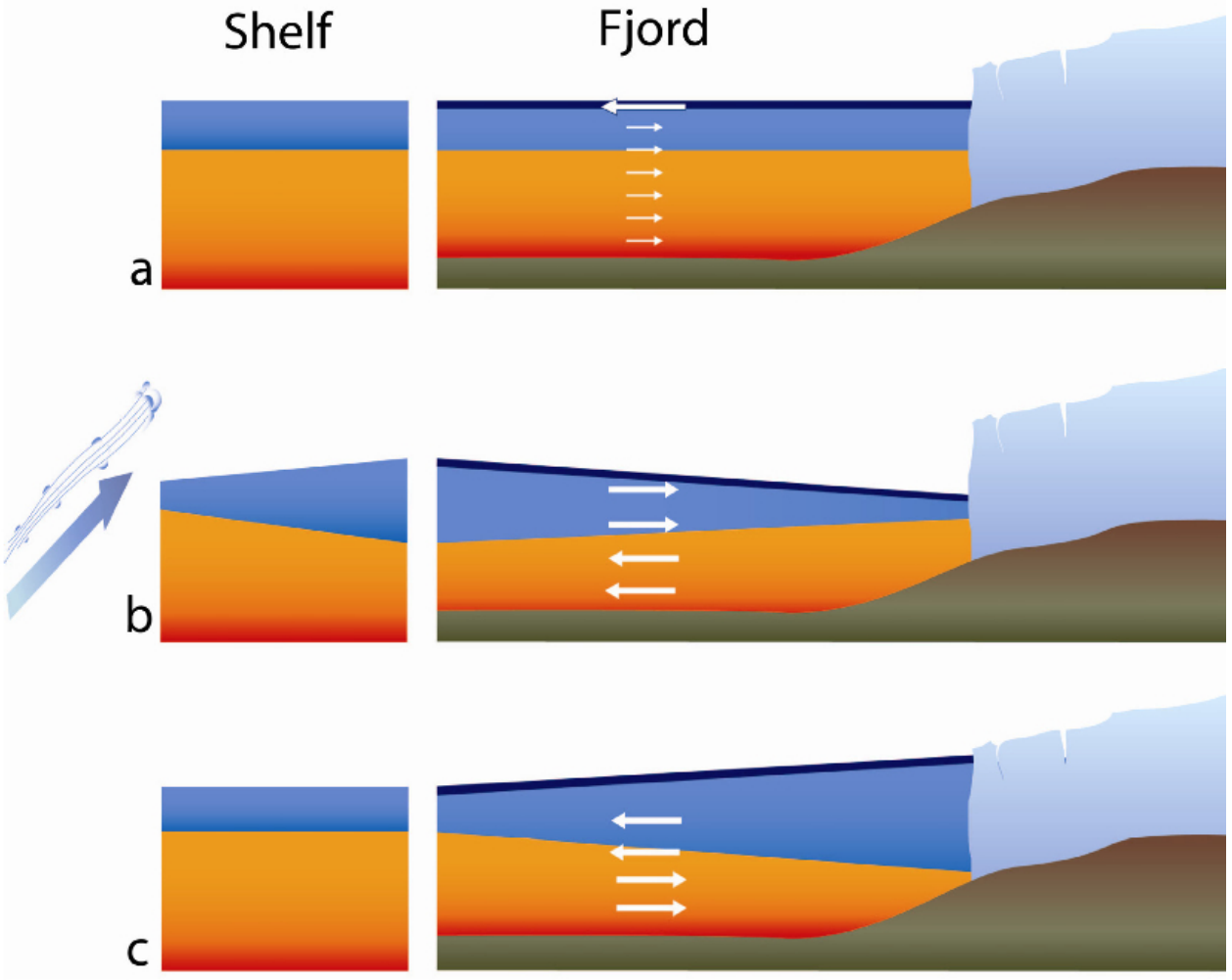
$$Qe = g\beta\overline{s}_x H^3 / (48 K_M)$$

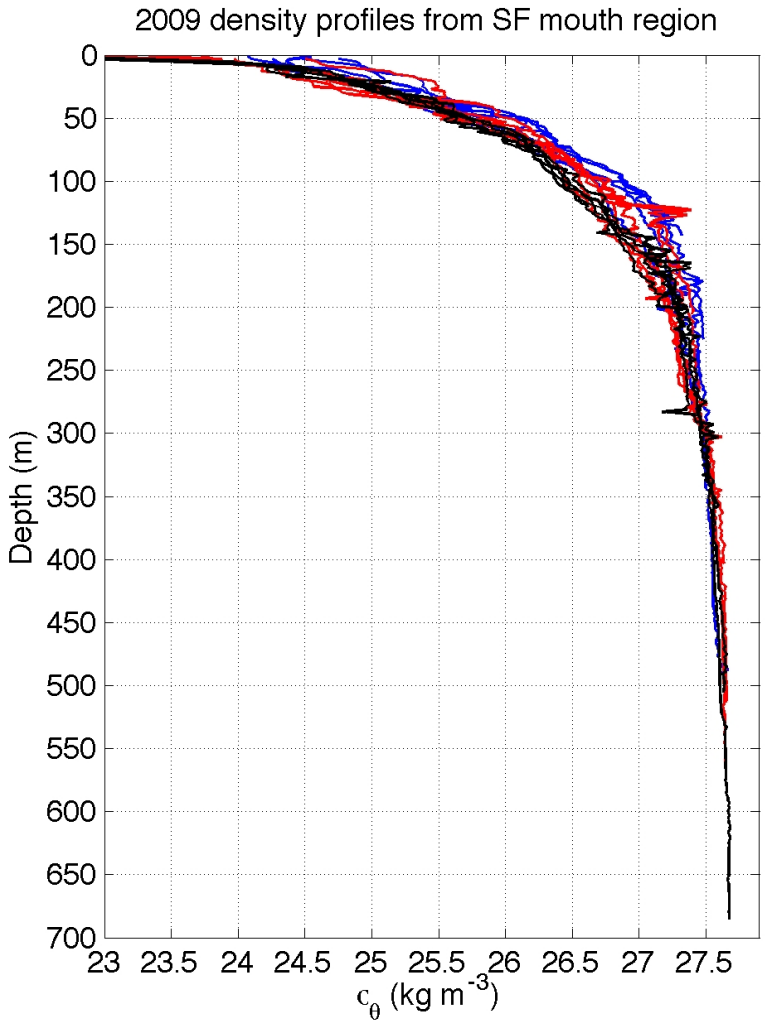
magnitude of estuarine circulation



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)





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

(Stigebrandt, 1990; Stigebrandt, 2012)

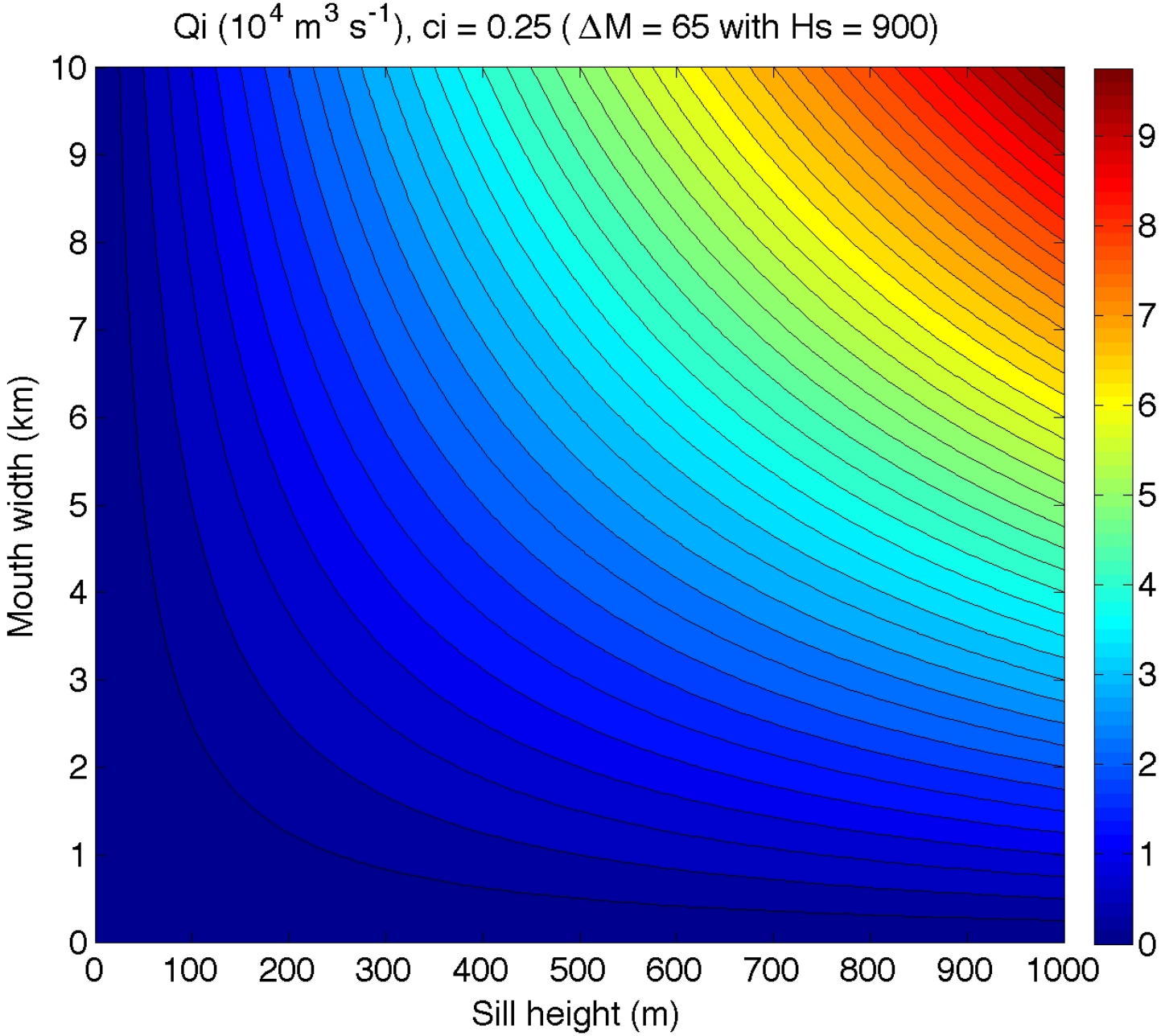
NOTE: Can be important to heat flux if temperature co-varies with Qi on these same time and space scales

Fjord Circulation: mechanisms

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

1) Estuarine circulation
2) Intermediate circulation

Which dominates?



But what about Qi?

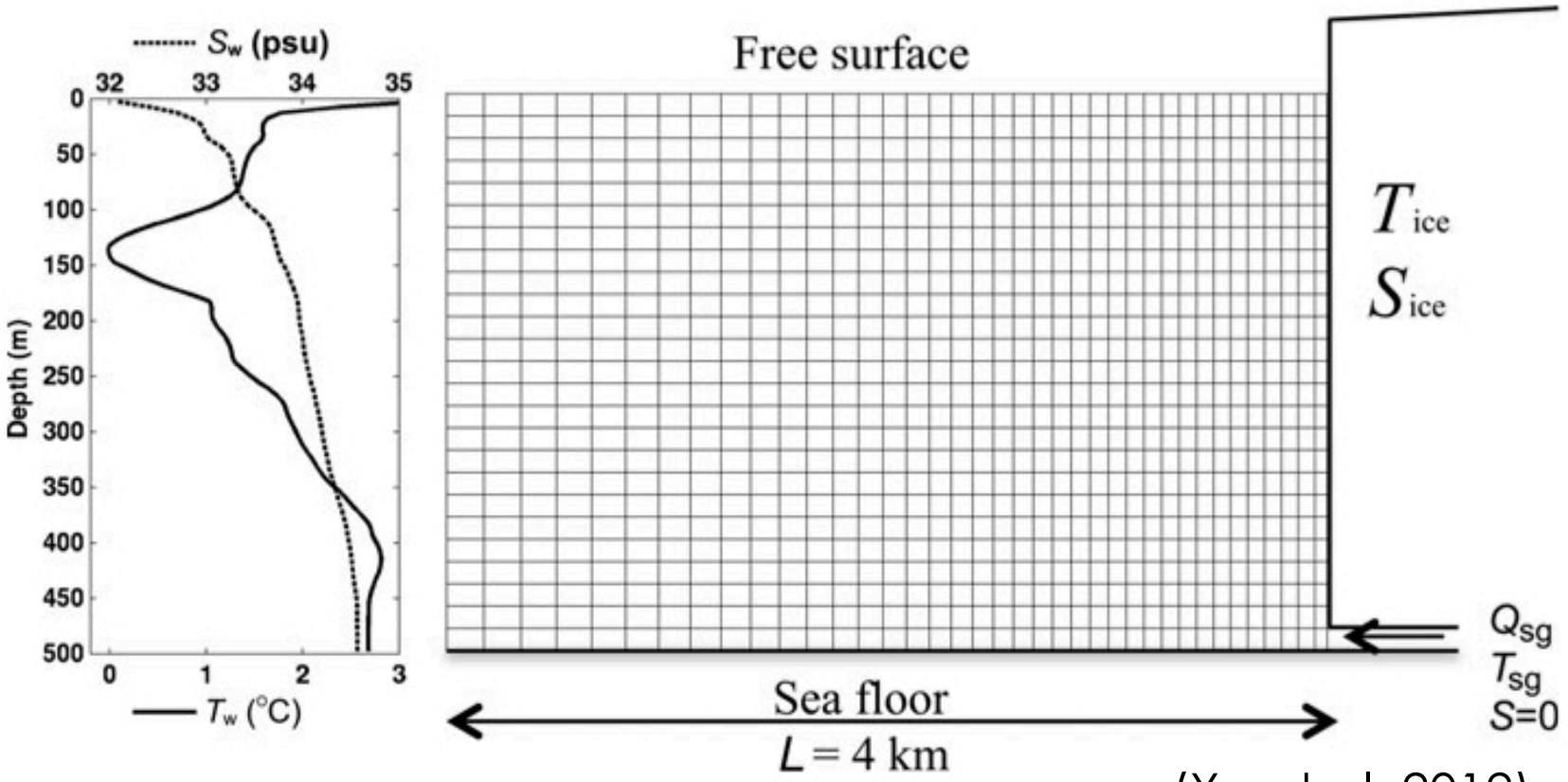
Ideally, we would make Qe vs. Qi parameter space for Greenland fjords

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

$$Qe = g \beta \overline{s}_x H^3 / (48 K_M)$$

(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 Qsg (estuarine circulation)

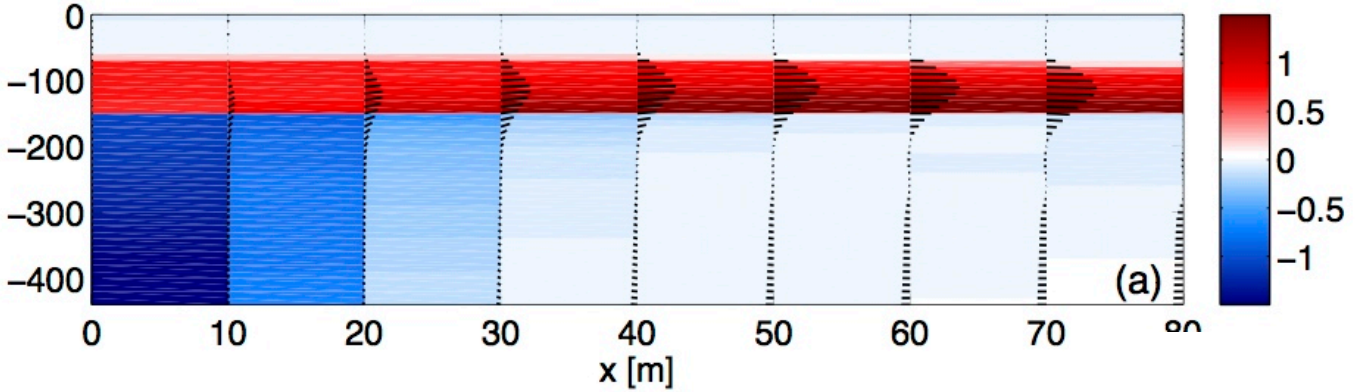
- Parameterized heat flux to glacier face based on 1-D plume models

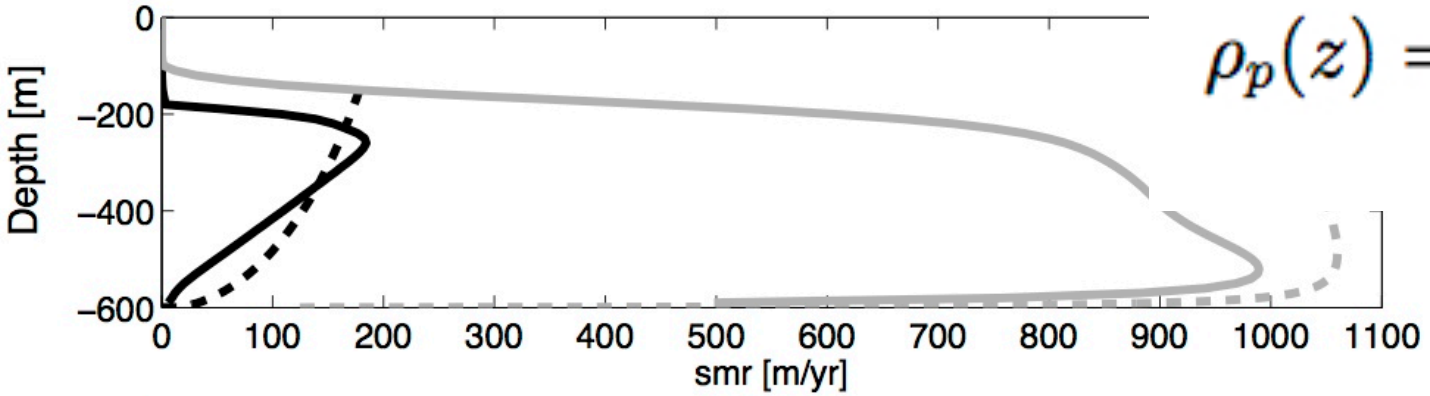
- Horizontal and vertical scales not really resolving plume yet—means relying on mixing parameterizations

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

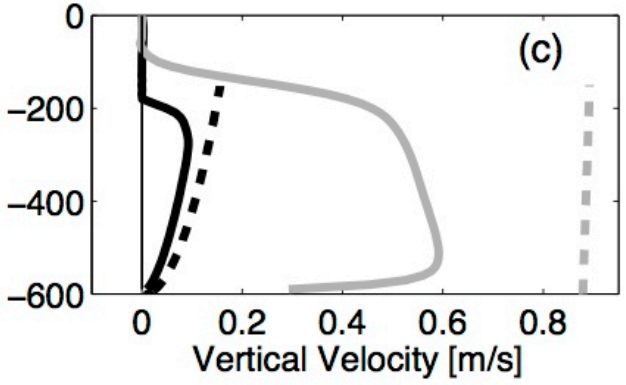
- Sciascia et al. (2013): 2-D model of Sermilik Fjord looking at dependence on mixing parameterizations, seasonality, Qsg, stratification
  → showed evidence for multicell estuarine flow

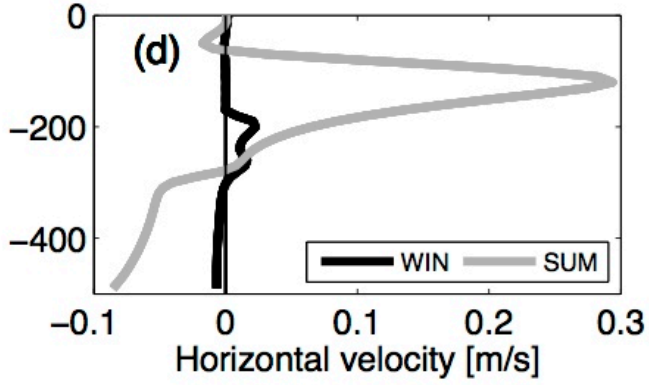




$$\rho_p(z) = \frac{\rho_{p0} Qsg + \rho_a Q_e}{Qsg + Q_e}$$

plume detachment depth





Fjord Circulation: challenges

Modeling:

-- Sensitivity studies of all different mechanisms

-- Careful attention to mixing processes

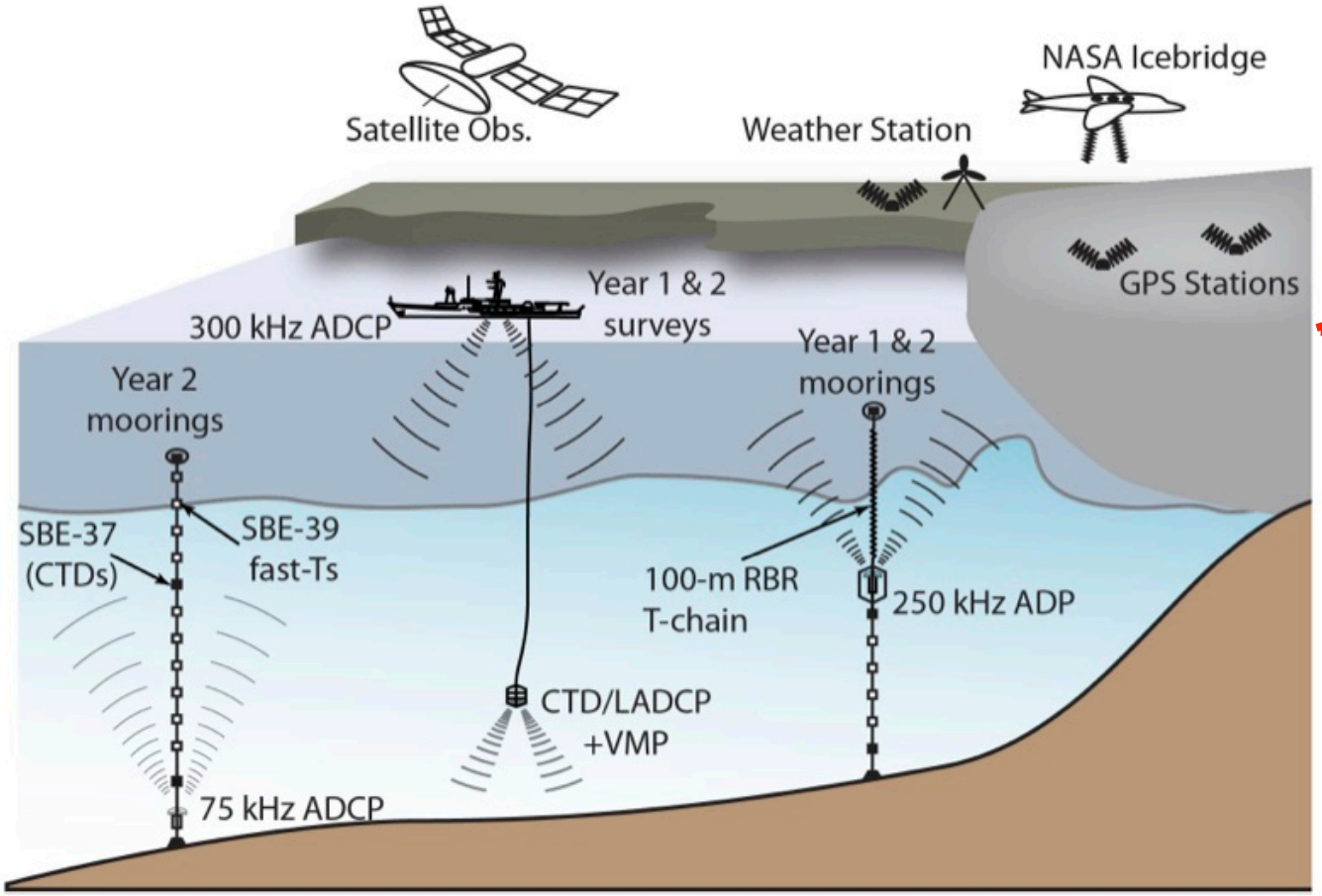
-- Caution with calculating melt rates on glacier face

Observations:

-- need new observations to add to classic moorings and hydrography surveys (and to validate

Bathymetry (an ocean IceBridge-like campaig 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,

Kahn et al., 2010; Joughin et al., 2010

In progress and in development (at least theoretically…)

Autonomous vehicles:

- Gliders in fjord and under ice
- Small remotely operated vehicles
- **NEED**: measurements under ice mélange

near glacier face, and seasonal measurements

Kahn et al., 2010; Joughin et al., 2010

OSU *Autonomous Research Vessel*

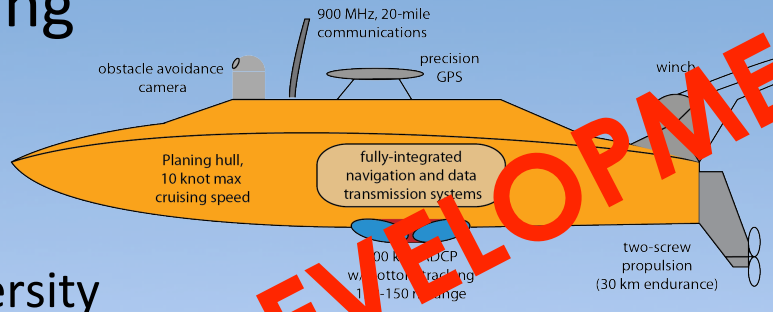
cruises at 8 knots → 20 km endurance / 5 km range

300 kHz ADCP + CTD profiling

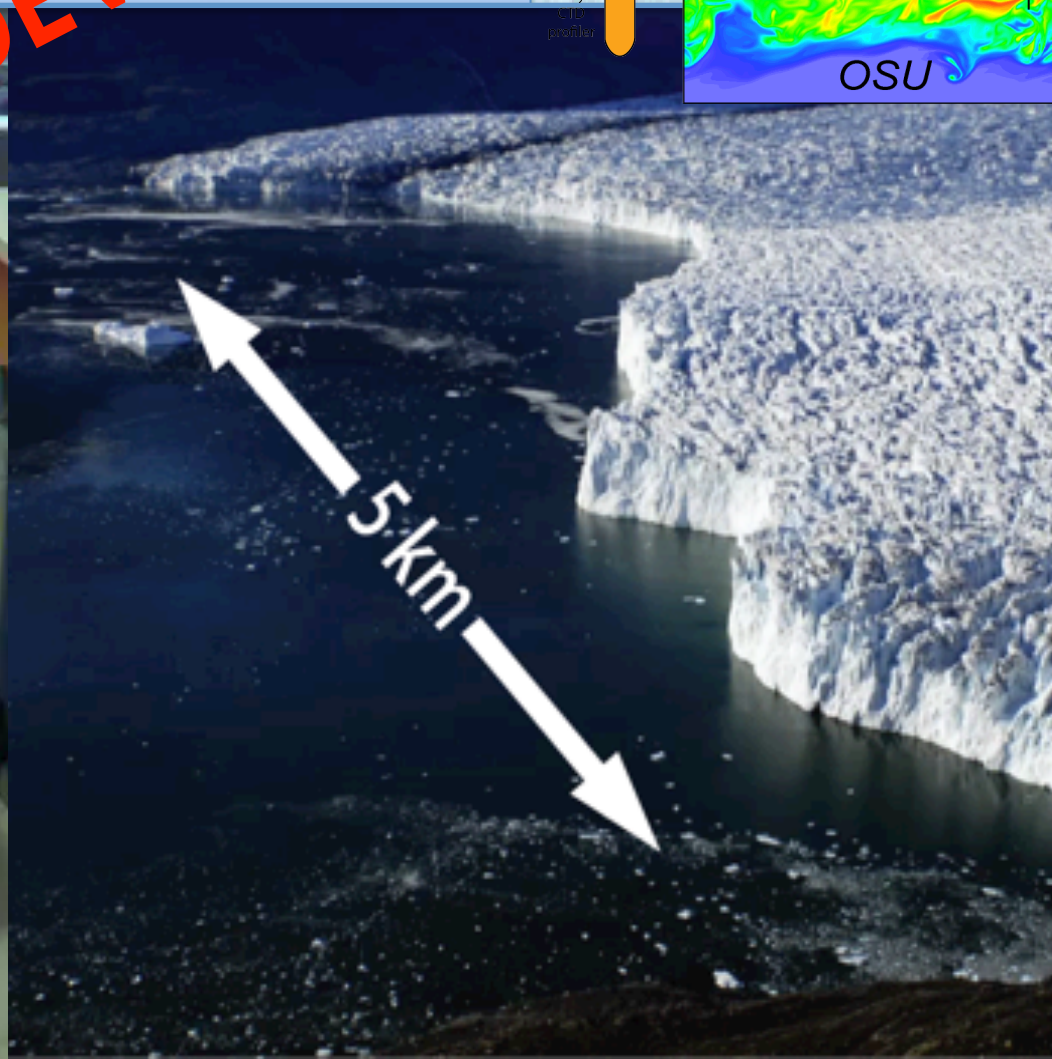
video and data telemetry

missions to the ice edge

Jonathan Nash / Oregon State University



UNDER DEVELOPMENT

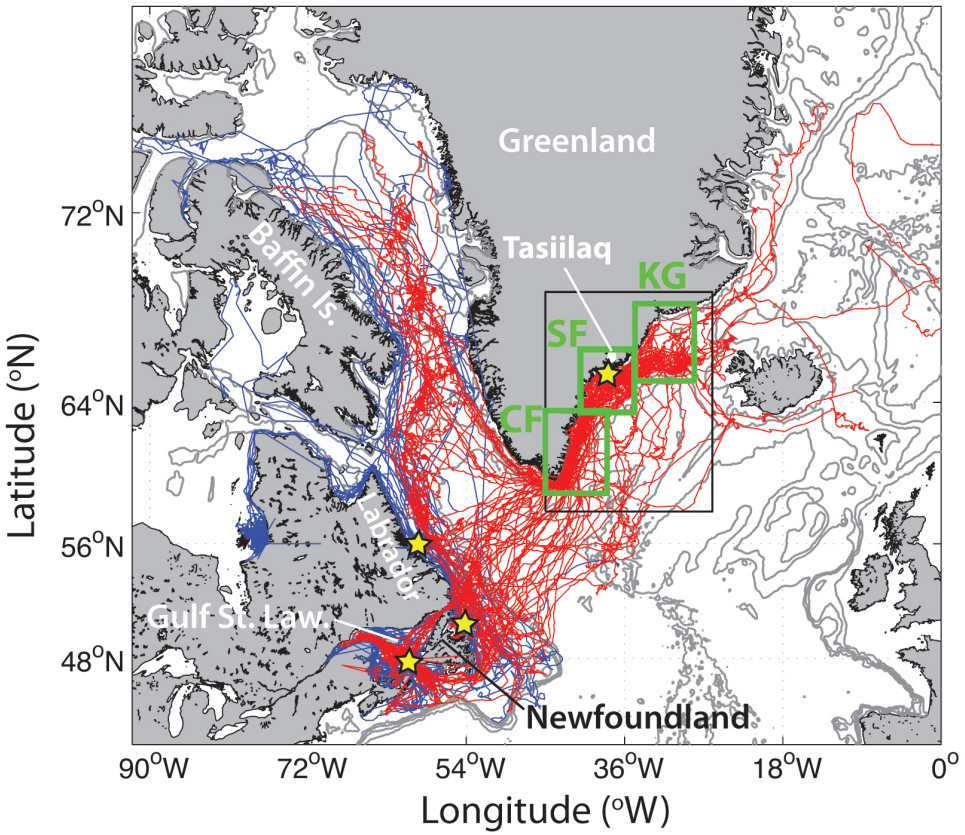


Autonomous vehicles:

- 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?



ɔnder ice mélange
ɐasonal measurements in
can help with **bathymetry**

Autonomous vehicles:

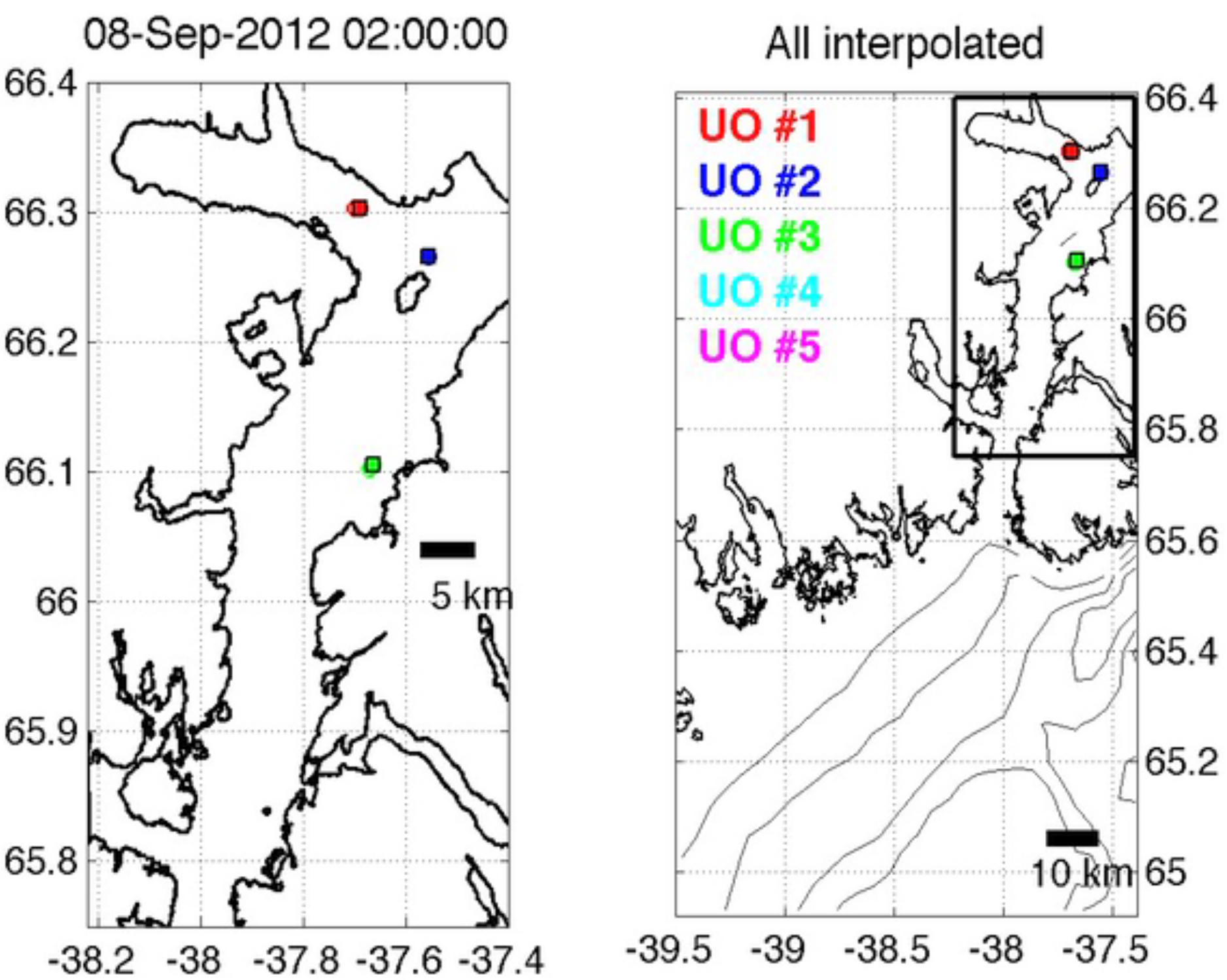
- Gliders in fjord and under ice
- Small remotely operated vehicles
- **NEED**: measurements under ice mélange near glacier face, and seasonal measurements

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**

Remote sensing:

- Surface circulation
- Upwelling plume
- Iceberg motion
- **Unknown**: what role do icebergs play? Can they effectively be used to track fjord motion?


08-Sep-2012 02:00:00
66.4
66.3
66.2
66.1
66
65.9
65.8
5 km
-38.2
-38
-37.8
-37.6
-37.4
All interpolated
UO #1
UO #2
UO #3
UO #4
UO #5
66.4
66.2
66
65.8
65.6
65.4
65.2
65
10 km
-39.5
-39
-38.5
-38
-37.5

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