Does Calving Matter?

Evidence for significant submarine ice melt at Yahtse Glacier, Alaska

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Key Questions:

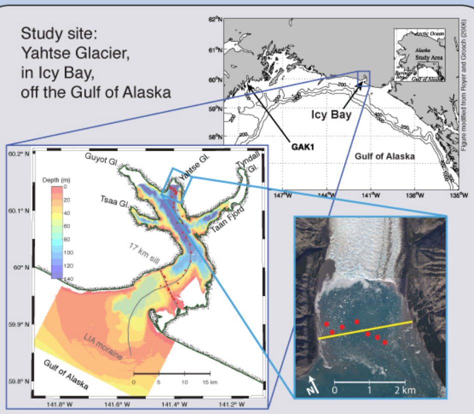
1) How common are the >10 m/d submarine melt rates reported at other Alaskan tidewater glaciers?

2) To what extent are the waters of Icy Bay linked to the Alaska Coastal Current?

Methods: (match numerals with panels)

I) Measure water properties throughout Icy Bay
II) Interpret the first-order water circulation pattern
III) Identify the meltwater content near the terminus
IV) Identify the current near the terminus
V) Calculate the terminus-average submarine melt rate by combining III) and IV)
VI) Place these findings within a broader temporal context

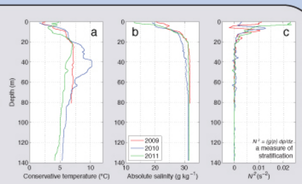
Study site:
Yahtse Glacier,
in Icy Bay,
off the Gulf of Alaska



The Alaska Coastal Current (ACC) is a 10-20 km wide, baroclinic jet of low-salinity water that sweeps past the mouths of Alaska's fjords and bays, including Icy Bay.

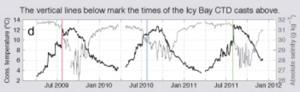
I) Icy Bay CTD casts:

Water in Icy Bay is stratified, with glacially-modified water overlying water from the Alaska Coastal Current (ACC). Glacially modified water is a mixture of i) submarine ice meltwater, ii) subglacial discharge, and iii) ACC water.



A mooring in the ACC:
The character of ACC water varies seasonally. It is warmer and less saline during the summer. Here we plot 20-m-depth temp. and salinity from GAK1, a station 450 km west of Icy Bay (see map).

The vertical lines below mark the times of the Icy Bay CTD casts above.



In 2010, the ACC had abruptly warmed and freshened 18 days prior to our Icy Bay casts. The warm temperatures and low salinity of Icy Bay water recorded in 2010 demonstrate a tight link between the ACC and Icy Bay water.

We find:

1) Submarine melt can equal the near-terminus ice speed.

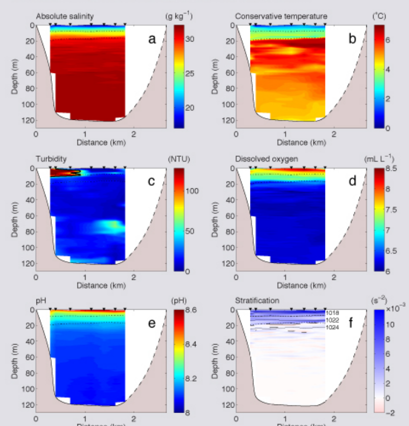
- Early during the melt season, in a cold month, the terminus melt rate was > 9 m/d and can easily equal 17 m/d.
- The mechanics of iceberg calving (the search for a "calving law") are thus irrelevant in this case. Subaerial calving occurs when the submarine ice "pedestal" melts away and the terminus is undercut.
- Melt rates at least this large can occur 6 months out of the year, from June through November (peaked in September).

2) Warm, essentially unaltered water from the Alaska Coastal Current can reach within 1.5 km of the terminus of Yahtse Glacier.

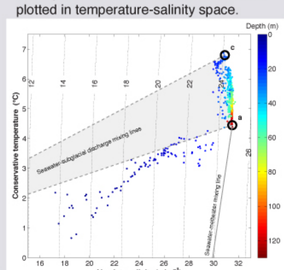
- Temperatures can exceed 10° C in the later summer and fall.

I) Near-terminus water properties:

At a profile 1.5 km from the terminus of Yahtse Glacier, the glacially-modified water (< 18 m deep) is markedly different than the ambient (ACC) water at depth. The turbid plume, visible in the vertical and oblique photographs is clearly delineated at depth.



Below, the same near-terminus casts are plotted in temperature-salinity space.

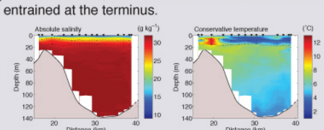


The near-surface water is colder than can be expected from mixing subglacial discharge into ambient seawater. The shallow, glacially-modified water contains a significant amount of ice melt.

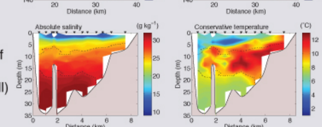
II) Estuarine circulation:

The CTD casts are consistent with a single-cell estuarine circulation, in which glacially-modified water flows out of Icy Bay near the surface. Deeper than 15-20 m, sea water flows in from the ACC to replace water entrained at the terminus.

Along-bay section



Across-reef section (at 17 km sill)



We suggest:

1) Alaska's 50 glacierized fjords represent relatively simple, accessible natural experiments with which to learn about the submarine melt process and test numerical models.

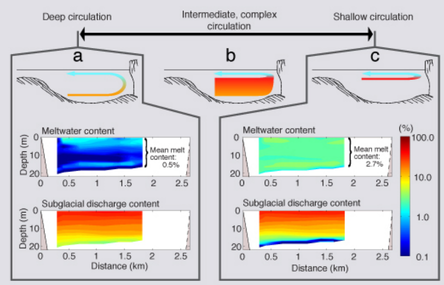
- Alaskan fjords have only one source for ambient water and a summer buoyancy flux larger than most Greenlandic fjords.

2) Large (> 10 m/d) submarine melt rates are not sufficient on their own to drive terminus retreat.

- Yahtse Glacier is advancing at 100 m/yr.
- Most Alaskan tidewater glaciers have stable termini (McNabb et al., in prep.), despite Alaska Coastal Current warming of ~1° C over 35 years (Royer and Grosch, 2006, GRL).

III) Unmixing the meltwater and subglacial discharge:

We use the observed temperature and salinity of our near-terminus cross-section to unmix the shallow, glacially-modified water. Results using two extreme ambient seawater end members, (a) and (c), bracket the true water contents.



IV) Identifying surface current speed:

Field measurements of surface drift and timelapse imagery reveal that a persistent, turbid plume at the glacier terminus flows at an approximately constant rate of 0.5 m/s away from the terminus. Averaging this current over the glacially-modified water layer implies a mean current of 0.08 m/s.

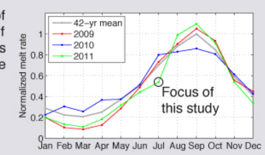
V) The submarine melt rate:

The melt rates for our two extreme sea water end members, (a) and (c), are 9 and 52 m/d. The true melt rate lies between these bounds, but does not exceed the terminus glacier velocity of 17 m/d.

VI) Seasonal and annual timescale context:

Submarine melt rate $\dot{m}$ depends on both the flux of subglacial discharge q, and the ambient water temperature Θ: $\dot{m} \propto q^p \Theta$ where $p \sim 1/3$ (or 1/2) (Jenkins, 2011; Xu et al., 2012; Sciascia et al., 2013).

Data from GAK1 and a model of freshwater discharge to the Gulf of Alaska (Royer, 1982) allow us to assess the timing and relative magnitude of submarine melt. Melt peaks in September. In 2011, September submarine melt potentially doubled the rates we measured in July.



A manuscript describing this work is under minor revision following review by EPSL. It is available upon request to tbartholomaus@gi.alaska.edu

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