First Order Estimation of Calving Losses from Gulf of Alaska Glaciers

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Introduction

Despite its importance in projections of sea level rise, dynamic mass loss from tidewater glaciers remains poorly constrained and understood. Owing to this difficulty, very few long-term or estimates of dynamic losses exist, and regional estimates of dynamic loss are nonexistent. Many studies have highlighted the importance of Alaska glaciers to sea level rise (e.g., Berthier and others, 2010). In this study, we present a detailed record of length fluctuations of Gulf of Alaska (GOA) tidewater glaciers, and propose a method to estimate calving fluxes on a regional level.

Gulf of Alaska

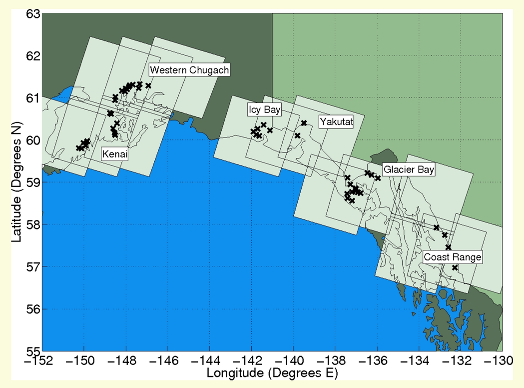
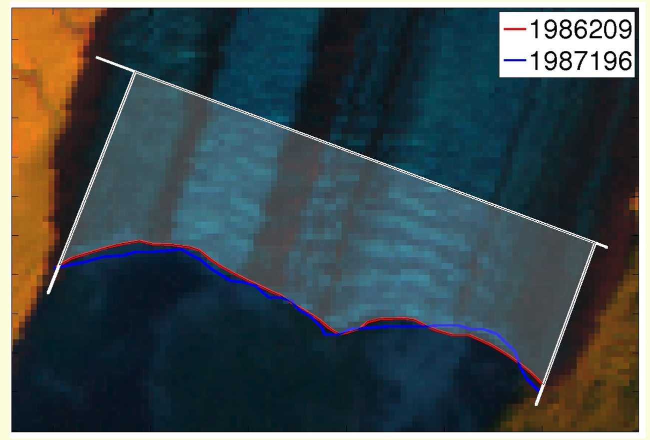


Figure: Location of tidewater glacier regions around the Gulf of Alaska. Individual glaciers are indicated by an *x*. Footprints of Landsat scenes are shown in light green.

For the purpose of this study, we divide the GOA into 6 subregions, based on geography and coverage with Landsat scenes. The number of glaciers varies between regions, with a total of 50 glaciers considered in the study. Not all of these glaciers calve into tidewater for the duration of the study.

Method

- Terminus outline is manually digitized for each Landsat scene.
- Length change calculated using "Box Method" (Moon and Joughin, 2008)
- Average distance from terminus to an arbitrary reference line.
- Reduces error in length calculation, results are more representative of glacier length.
- Glacier length is defined along a centerline coordinate system, individually determined for each glacier.



Harvard Glacier terminus. Landsat image from 28 July 1986.

Acknowledgements

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Length Changes

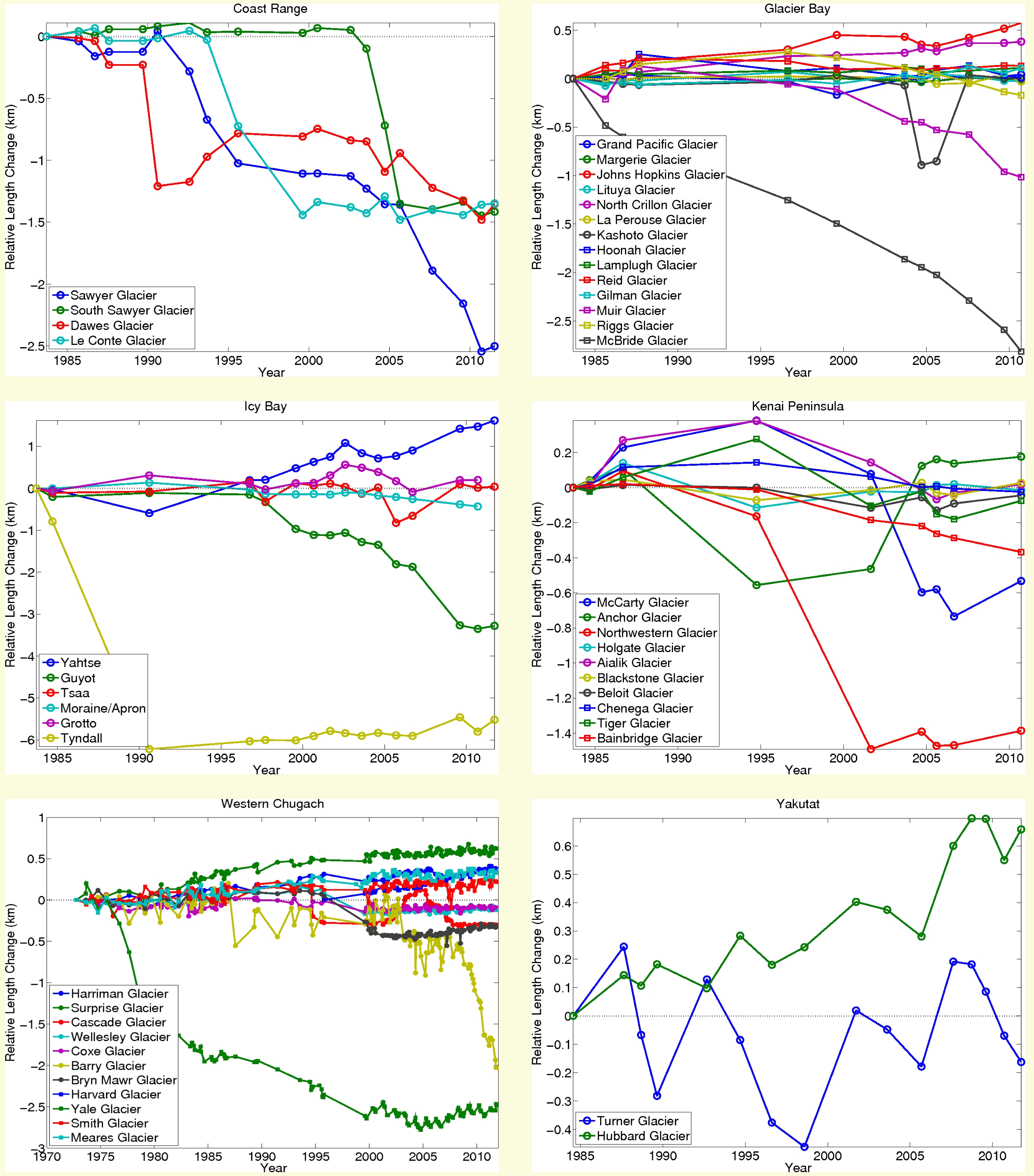

Figure: Calculated length change, relative to starting length, for each tidewater glacier region in the Gulf of Alaska. Clockwise from upper left, the regions are Coast Range, Glacier Bay, Kenai Peninsula, Yakutat, Western Chugach, and Icy Bay. Columbia Glacier (retreat of over 20 km) is omitted from the Western Chugach results, in order to show greater detail of the other glaciers.

Summary

- Very few Gulf of Alaska tidewater glaciers advance or retreat more than about 500 meters over the course of the study; only one glacier (Columbia Glacier) has retreated over 6 km in that time.
- Since ca. 2000, clear annual cycles in length change are observed in the glaciers of the Western Chugach. At present, this is the only region with such a detailed length record. Work is being completed on the other six regions.
- All four glaciers in the Coast Range (upper left figure, middle panel) show a similar pattern of $\sim$ 2 km retreat, followed by a period of stagnation. The timing of the retreats, however is not synchronous.
- Several of the glaciers in Icy Bay have begun to re-advance since hitting their length minimum.
- The two glaciers in the Yakutat region (Hubbard and Turner Glaciers) appear to exhibit multi-year cyclic behavior.

Calving Losses and Future Work

Basic assumption: mean ice thickness (H_m) can be related to glacier length, L: $H_m = \alpha_m \sqrt{L}$.
This gives us an expression for volume,

$$V = WLH_m = WL\alpha_m\sqrt{L} = \alpha_m WL^{3/2}, \quad (1)$$

where W is the mean glacier width.
With this, we can arrive at an expression for the glacier length change over time:

$$\frac{dL}{dt} = \frac{2(B+F)}{3W\alpha_m}L^{-1/2}, \quad (2)$$

where B and F are the surface mass balance and calving fluxes, respectively.
Doing some quick algebra and integral calculus on equation (2), we arrive at the following equation:

$$\int_{t_0}^{t} F(t')\,dt' = \alpha_m W\left(L(t)^{3/2} - L(t_0)^{3/2}\right) - \int_{t_0}^{t} B(t')\,dt'. \quad (3)$$

That is, we can obtain the total calving loss over a period $[t_0, t]$, given the surface mass balance as a function of time and the glacier length at each time t_0, t.
Once digitization work is finished, calving losses will be estimated on a yearly basis for all Gulf of Alaska tidewater glaciers. B will be calculated using modeled surface mass balances.

References

Moon, T. and I. Joughin, 2008. Changes in ice front position on Greenland's outlet glaciers from 1992 to 2007, Journal of Geophysical Research, 113(F02022), doi:10.1029/2007JF000927.

Berthier, E., E. Schiefer, G. K. C. Clarke, B. Menounos and F. Rémy, 2010. Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery, Nature Geoscience, 3, 92–95.