Field Guide to Glacier Bay

International Glaciological Society Pre-conference Excursion to Glacier Bay, June 2022

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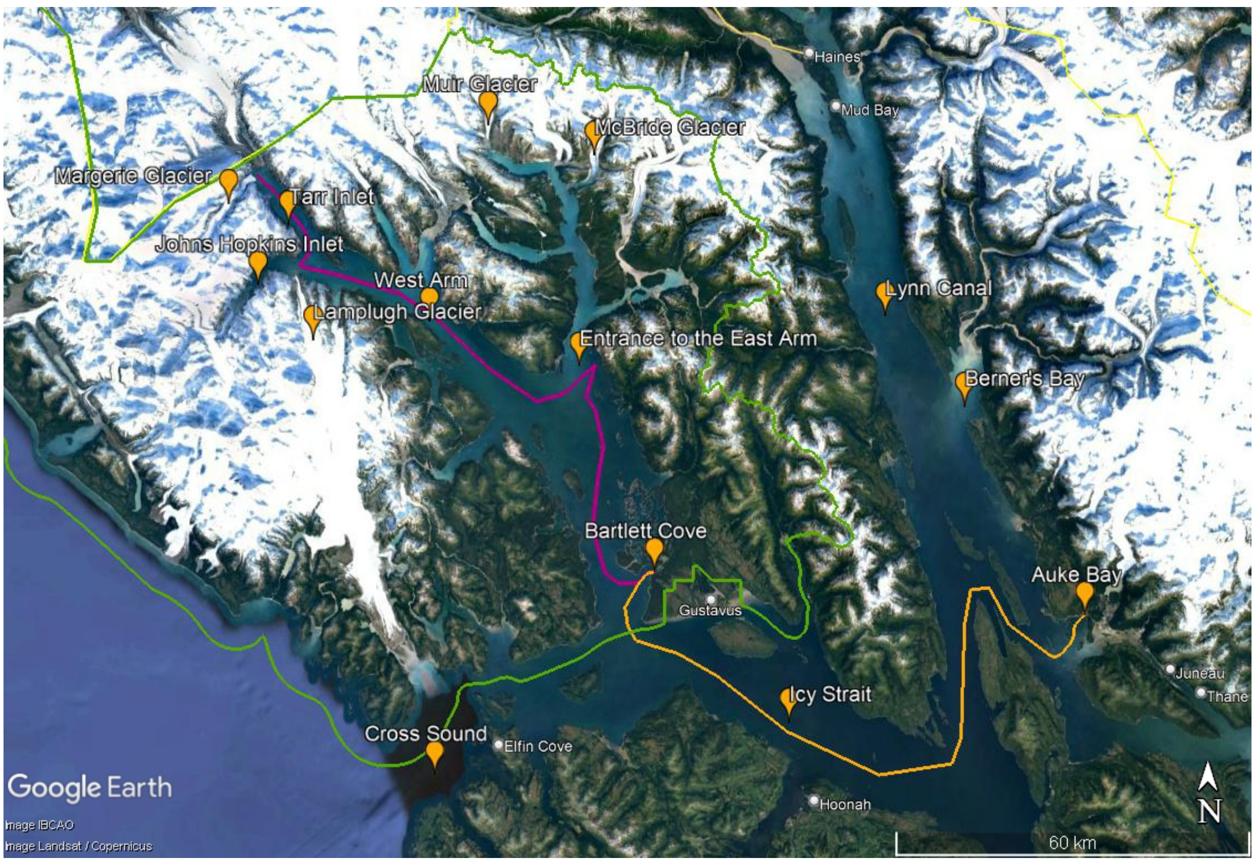
Xunaa Káawu Aaní áwé yéi xat yatee ka ax' yéi jixané
We live and work in Huna Tlingit Homeland.

Our route



The orange line is our route for Day 1 and 3, purple line is Day 2.

General information

Glacier Bay National Park and Preserve (GLBA) https://www.nps.gov/glba/index.htm
NPS App (see your favorite app store). Highly recommended! Save GLBA for offline use before the trip.
Park Newspaper https://www.nps.gov/glba/learn/news/newspaper.htm
Symposium website https://uas.alaska.edu/conferences/igs2022/
This guide as a Google Doc

Huna Tlingit

Excerpt from https://www.nps.gov/glba/learn/historyculture/huna-tribal-house-project.htm
Glacier Bay National Park is the ancestral homeland of the Huna Tlingit clans who sustained themselves for centuries on the abundant resources of the land and sea. Although villages inside the Bay were overrun by the Little Ice Age glacial advance of the 1700's, the Huna Tlingit re-established numerous fish camps and several villages in Glacier Bay soon after glacial retreat. The Huna Tribal House memorializes the clan houses that once lined the shores of present day Bartlett Cove, now the site of National Park Service headquarters in Glacier Bay. The project also provides an opportunity to revitalize Tlingit artistic traditions. Through a cooperative agreement between the tribal government and NPS, master craftsmen have trained a cadre of local apprentices and students in traditional Tlingit art and design, carving, adzing, and spruce root weaving. Over seven years, carvers have crafted and installed the elaborately carved and painted cedar panels that adorn the house front, four richly detailed interior cedar house posts and an interior house screen which depicts the stories of the four primary Huna Tlingit clans. Raven and Eagle totems were completed and installed in 2017 as well as the Healing Pole in August 2018. These precious cultural elements impart spiritual value to the Tribal House and its surroundings, but as importantly, their design and completion has expanded the circle of tribal members who share in cultural knowledge.

The Tribal House serves as a box of knowledge to learn about Tlingit culture as well as for Tlingit communities and organizations to offer cultural workshops on topics such as Native art, woodworking, weaving, song and dance, healthy living, and more.

Tlingit Place Names of Huna Káawu
Lower Glacier Bay

Long before Euroamerican explorers mapped and named the mountains and bays of Glacier Bay, Huna Tlingit place names captured the history, emotions and stories of their enduring relationship with a living, evolving landscape.

The Four Glacier Bay Clans	Phonetic	Moiety	Clan Crest
Chookaneidí	"Chew-kuh-nay-DEE"	Eagle	Porpoise, Bear
Kaagwaantaan	"Kog-wahn-tawn"	Eagle	Wolf, Killer Whale
Wooshkeetaan	"Whoosh-key-tawn"	Eagle	Shark, Murrelet
T'akdeintaan	"Tuck-dane-tawn"	Raven	Kittiwake, Whale

1. The various Tlingit names for Glacier Bay reflect the Huna Tlingit's long term relationship with their homeland. As the landscape changed over time, so too did the names that described it:

S'é Shuyee "T-SEH-shoe-yee"
"Edge of the Glacial Silt"
Former glacial outwash plain, before glacier advanced.

Xáatl Tú "Haatl-TOO"
"Among the Ice"
Bay choked with icebergs during the time of glacial retreat.

Sít' Eeti Geiyí "SIT-ee-tea-gay-YEE"
"Bay in Place of the Glacier"
The bay carved out by glacial retreat. Present day Glacier Bay.

2. **L'éiwshaa Shakee Aan** "CLAY-oh-shaw-shuh-key-on"
"Sand Mountain Land"
Area of glacially created dunes surrounding present day Bartlett Cove.

3. **Gaat Héeni** "Got-HEEN-ee"
"Sockeye River"
Early village site located in present day Bartlett Cove.

4. **T'ooch' Gil'i** "Ta-ooch-GIT-lee"
"Black Cliff"
Site of an early village before the glacial advance.

5. **L'éiw X'áati** "Clay-oh-CAUGHT-he"
"Glacial Sand Island"
Strawberry picking place

6. **Chookanhéeni** "Chew-con-HEEN-ee"
"Grassy River"
Chookaneidi Clan village inhabited after the glacier retreat.

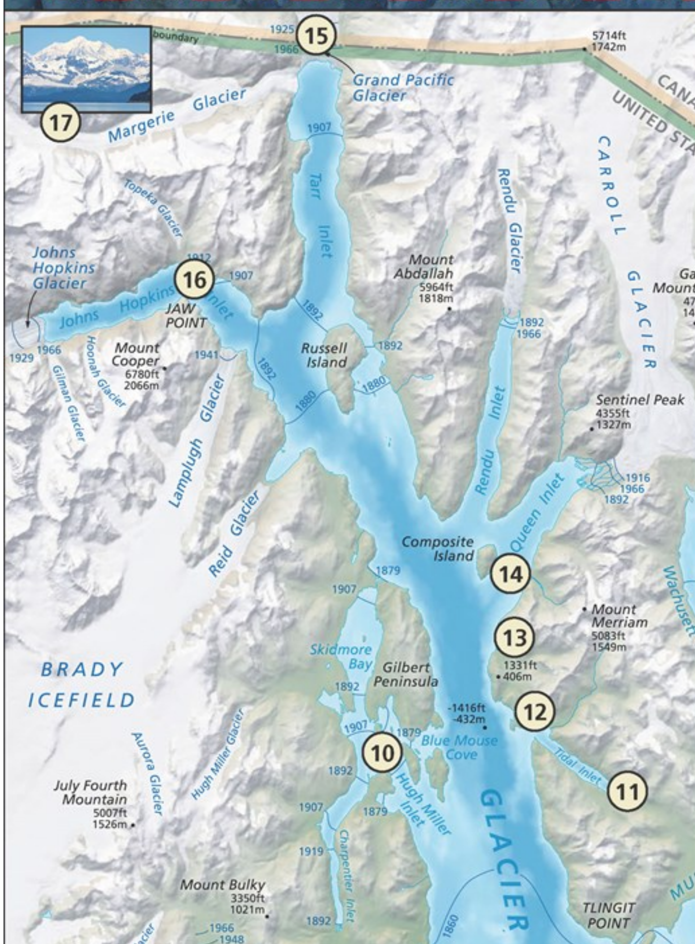
7. **Gooch Héeni** "gooch-HEEN-ee"
"Wolf Creek"

8. **K'wát' Aaní** "KWUT-on-EE"
"South Marble Island"
Land of the Seagull Eggs

9. **Wudzidugu Yé** "Woodsy-dook-oh-YEH"
"Place Wooded with Cottonwood"

Tlingit Place Names of Huna Káawu

Upper Glacier Bay



10. Anax̲ K̲uyaawal'ix'i Yé
"Ah-nuck-coo-yah-wuh-click-ee-YEH"

"Place Where the Glacier Broke Through"

11. Tsalgi G̲eiyí
"T-suth-gee-gay-YEE"

"Ground Squirrel's Bay"

12. Gus'k'iyee K̲wáan G̲eiyí
"Goose-key-yee-KWON-gay-YEE"

"People From Under the Clouds' Bay"
Bay where Euroamericans historically camped.

13. Jánwu Aaní
"JAN-woo-on-KNEE"

"Mountain Goat's Land"
Traditional goat hunting area.

14. T'ooch' G̲eiyí
"Ta-ooch-gay-YEE"

"Black, Dirty Bay"

15. Sít' Tlein
"SIT-clane"

"Large Glacier"
Glacier believed to have forced Huna clans from Homeland.

16. Tsalx̲aan Niyaadé Wool'éexi Yé
"T-suth-hon-knee-yah-DAY-Woo-CLEE-key-YEH"

"Passage that Broke Through Towards Mt. Fairweather"

17. Tsalx̲aan
"Tsuth-hon"

"Ground Squirrel Land"
Mount Fairweather. Sacred mountain of the T'ak̲deintaan clan.

Learn More!

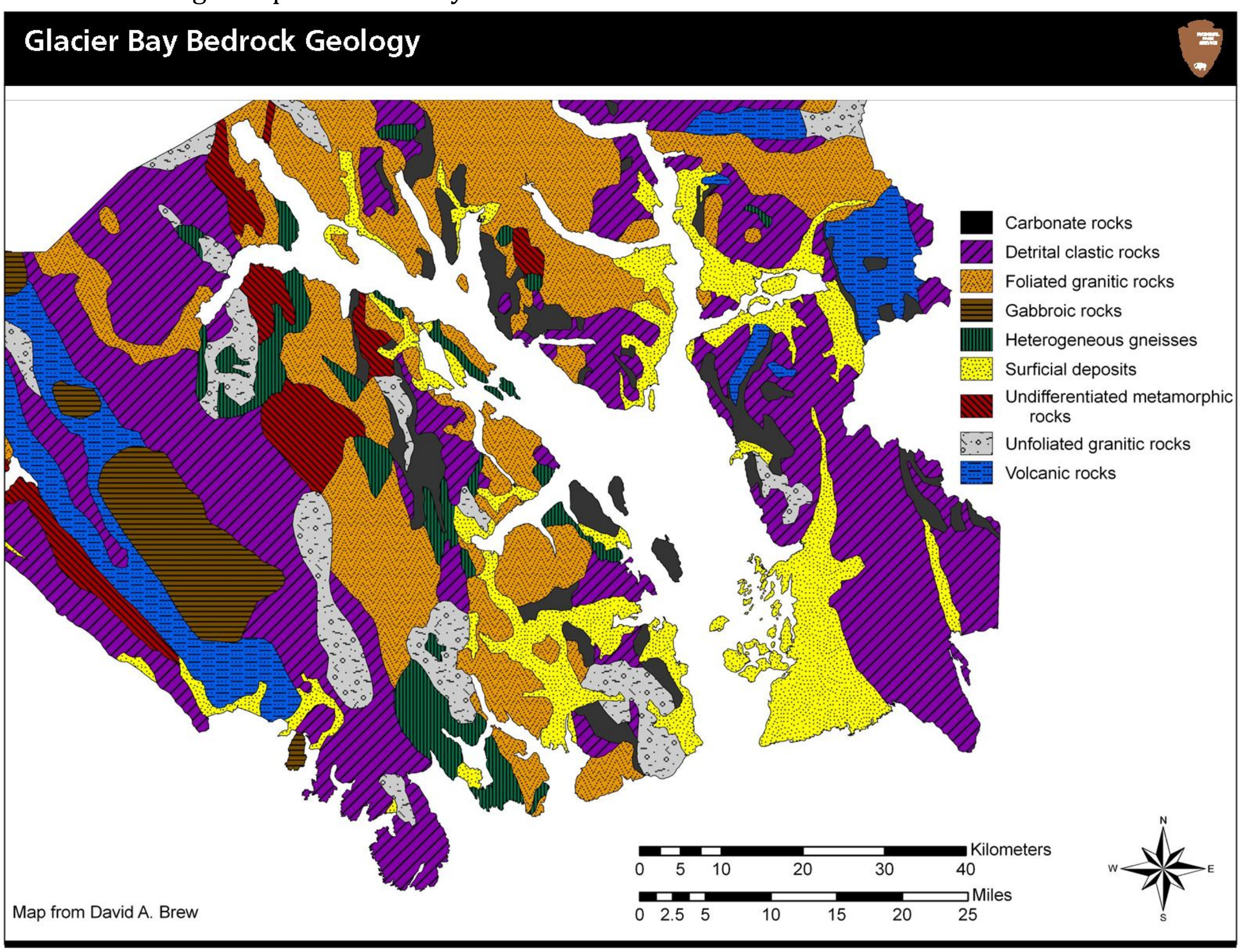
A wall map displaying hundreds of Huna Tlingit place names is available.

Hoonah Indian Association
PO Box 602
Hoonah, AK 99829
(907) 945-3545

Geology

Excerpt from https://www.nps.gov/glba/learn/nature/geology.htm
The Glacier Bay region's extreme topography reveals that it is a landscape driven by immense energies. This is a result of the area's position astride the active collision zone between the North American and Pacific plates. This major plate boundary, the Fairweather-Queen Charlotte Fault system cuts across Glacier Bay's western edge. For over 50 million years, the Pacific Plate and Yakutat Microplate have been moving northwest along this fault boundary and plowing obliquely into the North American Plate at about the speed your fingernails grow, or about 50 millimeters per year.

Generally, during this collision, the Pacific plate has been forced under the North American plate, but occasional "bits" such as island arcs, pieces of sea floor, fragments of continental margin have been scraped off one plate or the other, shattered, and smeared along the leading edge of the North American plate. These geologic bits are called "terranes." Four such terranes have accumulated in a largely northwest-southeast pattern to form the Glacier Bay region. You may notice this pattern when examining a map of Glacier Bay.



At the present time, the outboard-most terrane and the present continental margin are still "closing the gap." Frequent earthquakes dramatically illustrate that plate motion continues. As these two plates are forced against each other, the compression has pushed the land upward to form mountain chains. Others are forced downward and melted in the process. Molten rock then oozes volcanically through the shattered landscape. When it cools, it welds together one of the world's most complex geological jigsaw puzzles: Glacier Bay.

One of the mountain ranges formed by this process is the Fairweather Range, which makes up the western portion of the park. With several peaks over 10,000 feet and the tallest, Mount Fairweather, at 15,300 feet, this is one of the highest coastal mountain ranges in the world.

Tectonic Setting:

From Elliot et al 2010

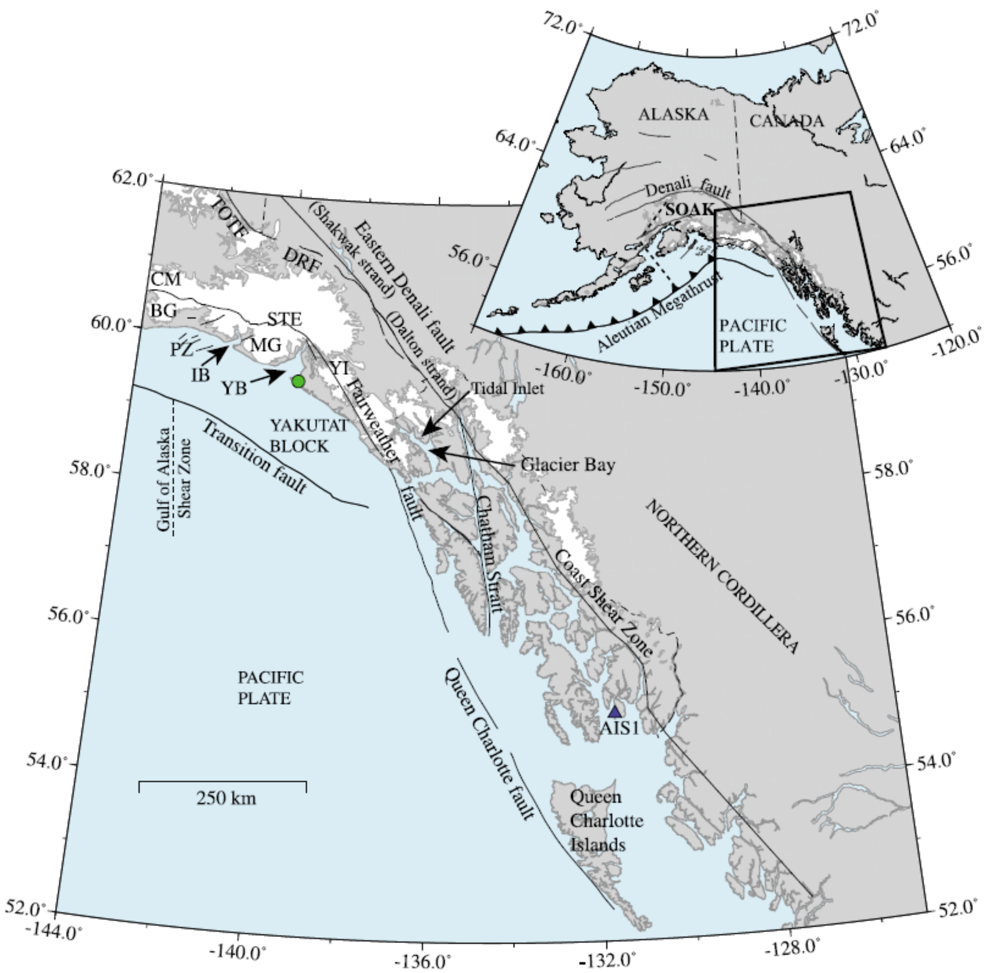


Figure 1. Tectonic setting of southeast Alaska. Green dot marks the city of Yakutat. Abbreviations are CM, Chugach Mountains; BG, Bering Glacier; PZ, Pamplona fault zone; IB, Icy Bay; MG, Malaspina Glacier; STE, St. Elias Mountains; YB, Yakutat Bay; YI, Yakutat ice field; DRF, Duke River fault; TOTF, Totschunda fault; and SOAK, Southern Alaska block. Faults are based on *Plafker et al.* [1994b], *Brew and Ford* [1998], and *Pegler and Das* [1996].

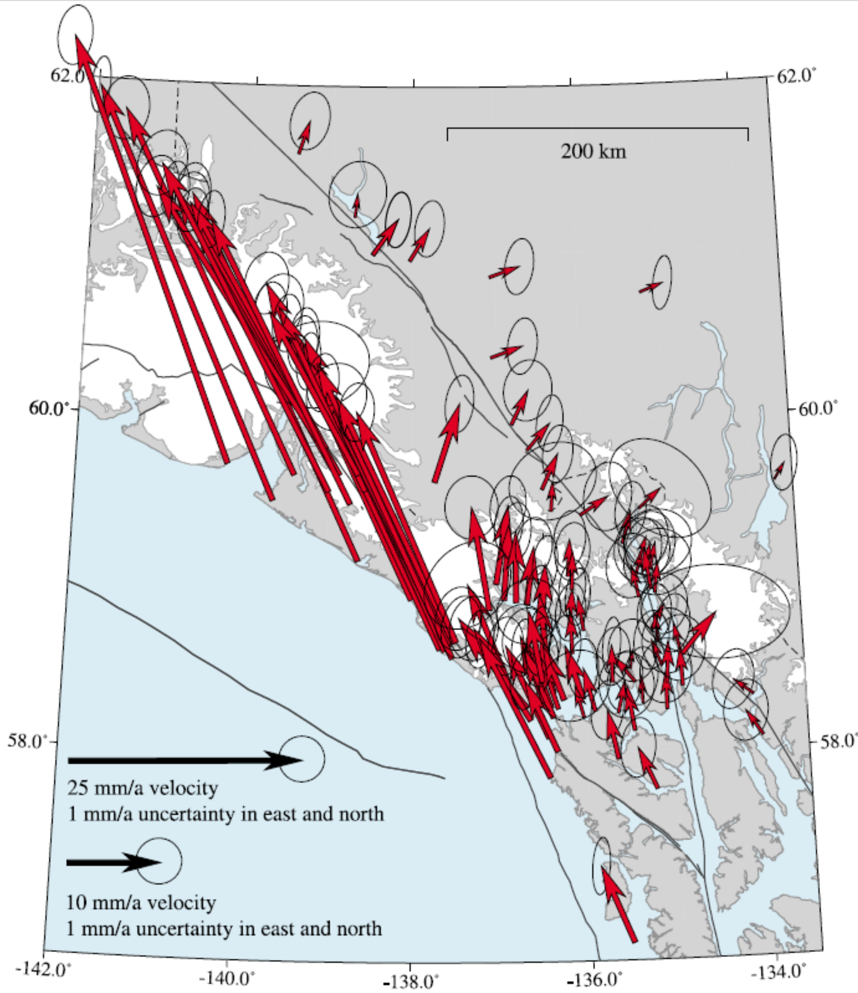


Figure 4. GPS velocities with GIA model predictions applied for southeast Alaska and the adjacent portion of the Canadian Cordillera. Figure S4 shows all of the GPS velocities used in our model.

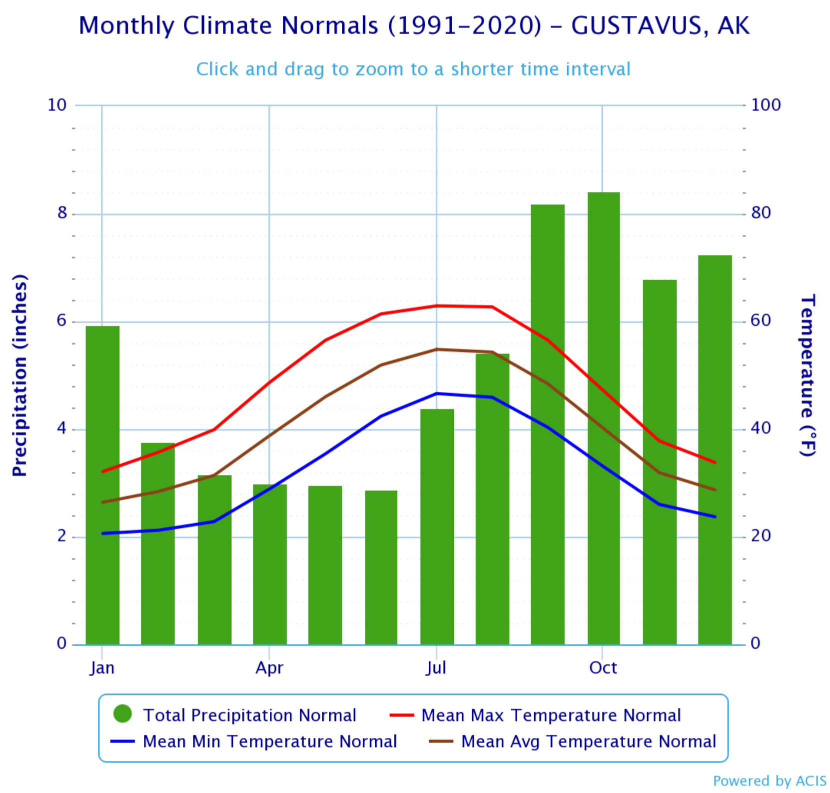
References:

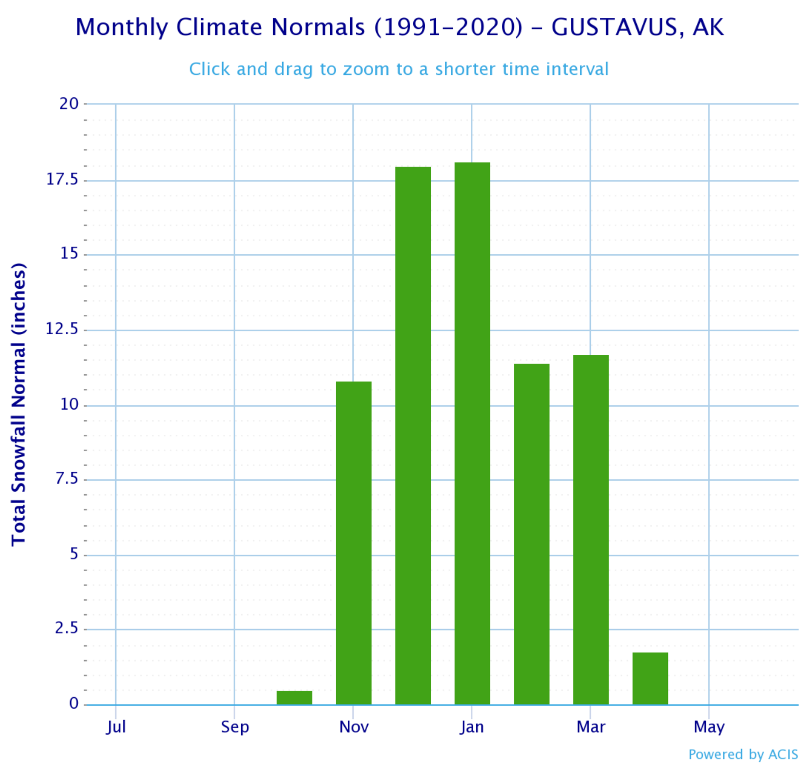
Elliott, J. L., C. F. Larsen, J. T. Freymueller, and R. J. Motyka, 2010, Tectonic block motion and glacial isostatic adjustment in southeast Alaska and adjacent Canada constrained by GPS measurements, J. Geophys. Res., 115, B09407, doi:10.1029/2009JB007139. Link

Weather and Climate

Southeast Alaska has a cool and wet maritime climate. Gustavus, Alaska (elevation 10 m a.s.l.) has a mean annual temperature of 4.5 °c, with monthly means ranging from -3.1 °c in January to 12.7 °c in July. Annual precipitation (water equivalent) averages 1.58 m with September and October being the wettest months and June the driest. Annual snowfall is 2.0 m.

Climate normals from 1991-2020 https://www.weather.gov/wrh/climate?wfo=ajk





Of course, the weather in the mountains is different from sea level:
Excerpt from https://www.nps.gov/glba/learn/nature/geology.htm:
Moisture-laden air blown in off the Gulf of Alaska collides with these peaks. As the air rises to go over the mountains, it cools. Cold air holds less moisture than warm air so the air drops its moisture

in the form of snow and rain. For at least seven million years, snows have accumulated in the uplands and morphed into glacial ice. Many times in the past when the climate has cooled, these glaciers have slid down the mountains invading the lowlands. During the height of the most recent of these Great Ice Ages about 20,000 years ago, an ice sheet covered all of the Glacier Bay region except the highest peaks and certain headlands. Back then, it would have been possible to walk from Glacier Bay to Cape Cod without ever getting off the ice!

The Juneau area from the Last Glacial Maximum to present

Áak'w K̲wáan Aaní káx' yéi x̲at yatee.
We reside on the land of the Áak'w K̲wáan Lingít.

References:

Miller, R., 1972, Surficial geology of the Juneau urban area and vicinity, Alaska, with emphasis on earthquake and other geologic hazards: USGS open-file report 72-2550. link

Miller, R 1975a. Gastineau Channel Formation, a composite glaciomarine deposit near Juneau, Alaska. Geologic Survey Bulletin 1394-C. link

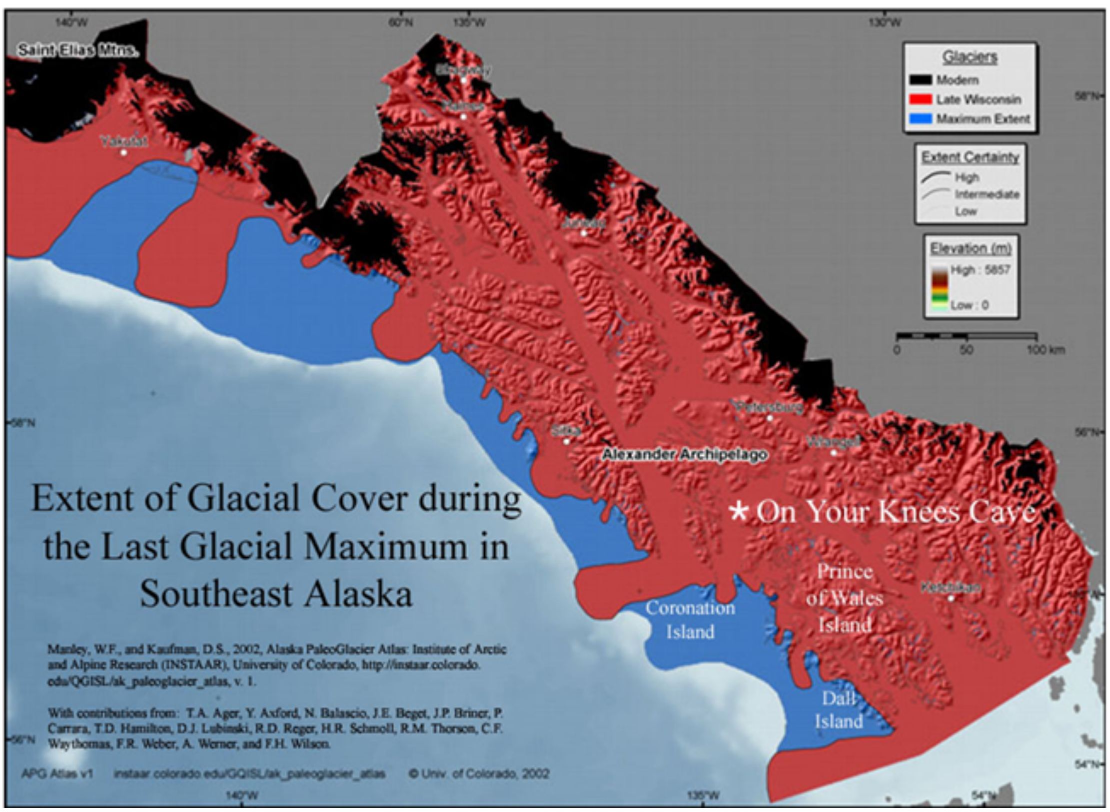
Miller, R. 1975b. Surficial geology map of the Juneau urban area and vicinity, Alaska. USGS Miscellaneous Investigations Series I-885. Link

Connor, C.L. and R. J. Motyka, R.J., 2009: Quaternary Geology of Southeast Alaska and Juneau: FOP 2008 Fieldtrip Guide Alaska Cell of the Friends of the Pleistocene. Alaska Quaternary Center. https://www.uaf.edu/aqc/files/DraftFOPSEAK2008.pdf

Report by Richard Carstensen of Discovery SE, a must read for the Juneau area: http://juneaunature.discoverysoutheast.org/wp-content/uploads/2017/06/1867-2017.pdf

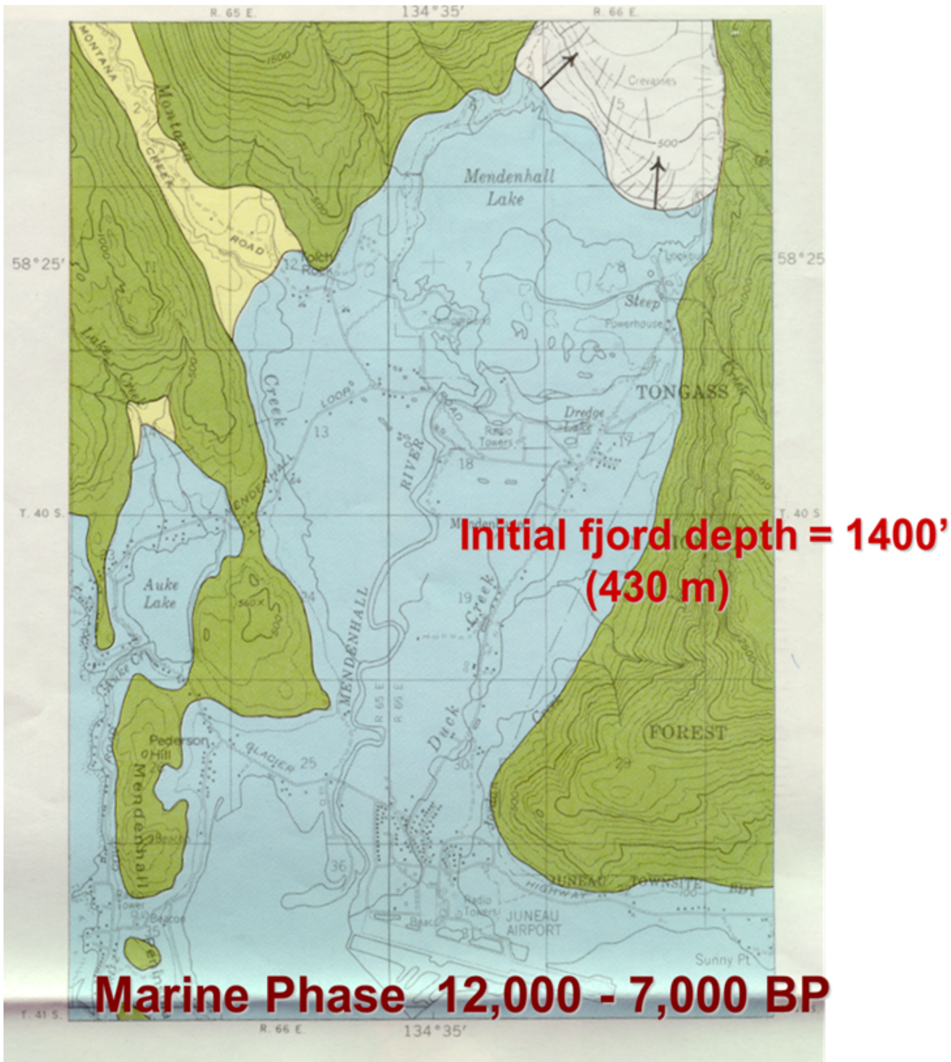
Juneau Icefield

Background: SE AK Landscape mainly carved by multiple major glaciations



During the last major glaciation:
Global sea level was 130 m lower than present.
Locally, in the Juneau area, earth's crust depressed ~250 m meters under the weight of ice.

Retreat of ice sheets:
Sea level rises as ice melts.
But earth rebounds! But at a slower rate.
Over millennia, glacial isostatic adjustment uplifts glacio-marine, delta and beach deposits up to 200 m above sea level! (Miller, 1972; 1975)



MARINE PHASE (10,000–4500 B. C.)

Classic tidewater glacier cycle

References:

Mercer JH (1961) The response of fjord glaciers to changes in the firn limit. *J. Glaciol.*, 9(29), 850–858. link

Post, Austin (1975) *Preliminary Hydrology and Historic Terminal Changes of Columbia Glacier, Alaska.* Washington, DC: U.S. Geological Survey Hydrological Investigation Atlas, HA-559, 3 sheets, scale 1:10,000. link

Meier MF and Post A (1987) Fast tidewater glaciers. *J. Geophys. Res.*, 92(B9), 9051–9058 (doi: 10.1029/JB092iB09p09051). link

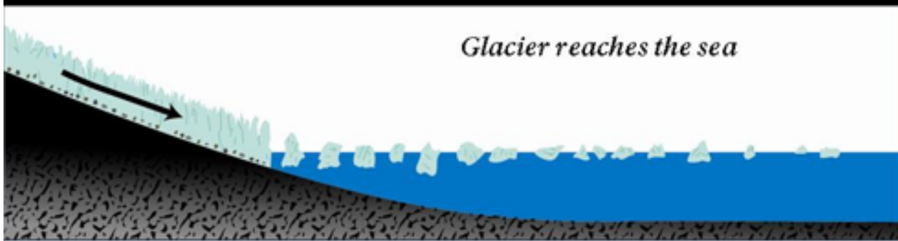
Post A and Motyka RJ (1995) Taku and LeConte Glaciers, Alaska: calving-speed of late-Holocene asynchronous advances and retreats. *Phys. Geogr.*, 16, 59–82. link

Pfeffer WT (2007) A simple mechanism for irreversible tidewater glacier retreat. *J. Geophys. Res.*, 112(F3) (doi: 10.1029/ 2006JF000590). link

Post A, O'Neel S, Motyka RJ and Streveler G (2011) A complex relationship between calving glaciers and climate. *Eos, Trans. Am. Geophys. Union*, 92(37), 305 (doi: 10.1029/2011EO370001). link

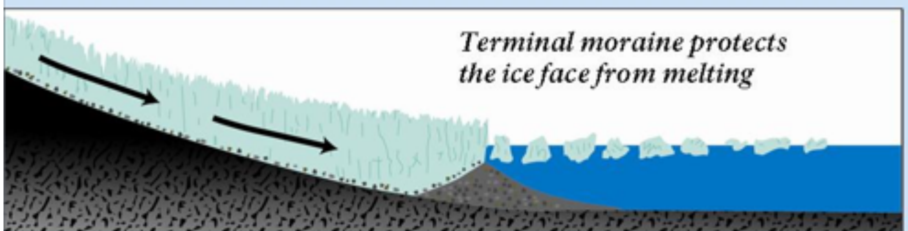
Brinkerhoff, D., Truffer, M., and Aschwanden, A. (2017). Sediment transport drives tidewater glacier periodicity. *Nature Communications*, 8(1), 90–98. http://doi.org/10.1038/s41467-017-00095-5. Link

Tidewater Glacier Cycle



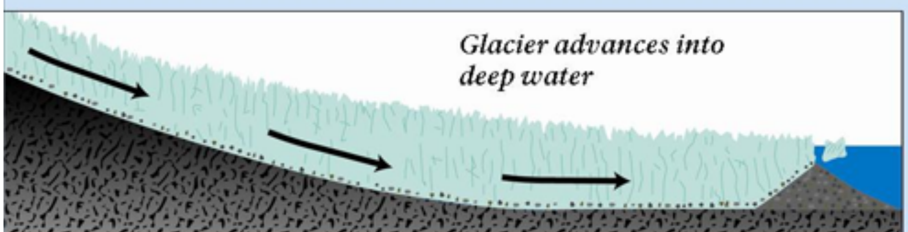
If fed by enough snowfall, a glacier may advance downslope to reach the sea.

Ocean water rapidly melts and undermines the ice, keeping the glacier at the water's edge.



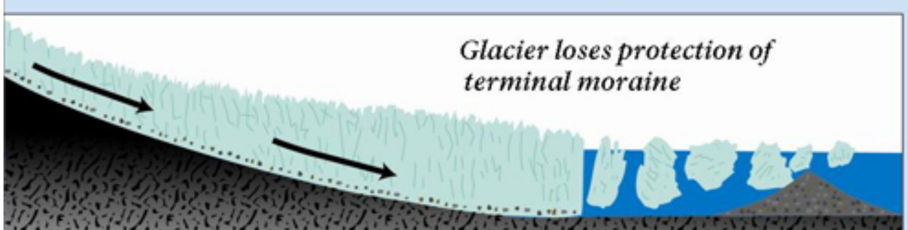
Over time, the glacier may build up a terminal moraine.

This pile of gravel, silt, and rock can protect the ice from the melting action of seawater.

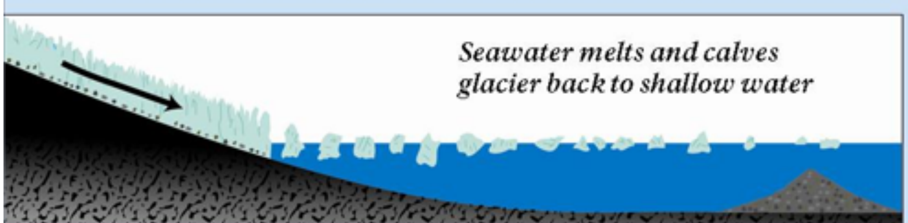


With an intact terminal moraine, the glacier may slowly advance down the fjord and far into deep water.

Multiple times, Glacier Bay has been filled with such a glacier.

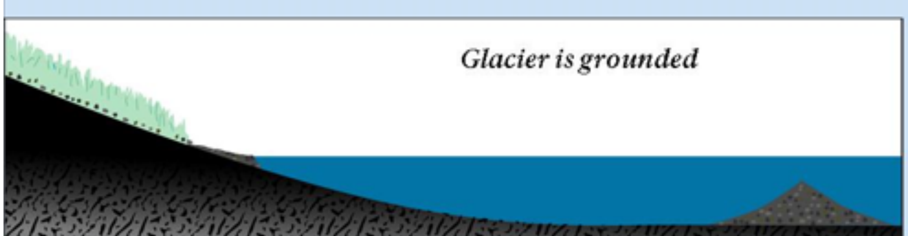


If the glacier loses contact with its terminal moraine, seawater will quickly undermine the face, causing massive calving and catastrophic retreat of the glacier.



Without the protection of its terminal moraine, a glacier cannot supply ice to its snout fast enough to counteract the melting power of the sea.

The glacier face will retreat back toward shallow water.



Glacier is eaten back to dry land and is no longer tidewater.

With enough snowfall, this glacier might once again build up a terminal moraine and advance into the sea.

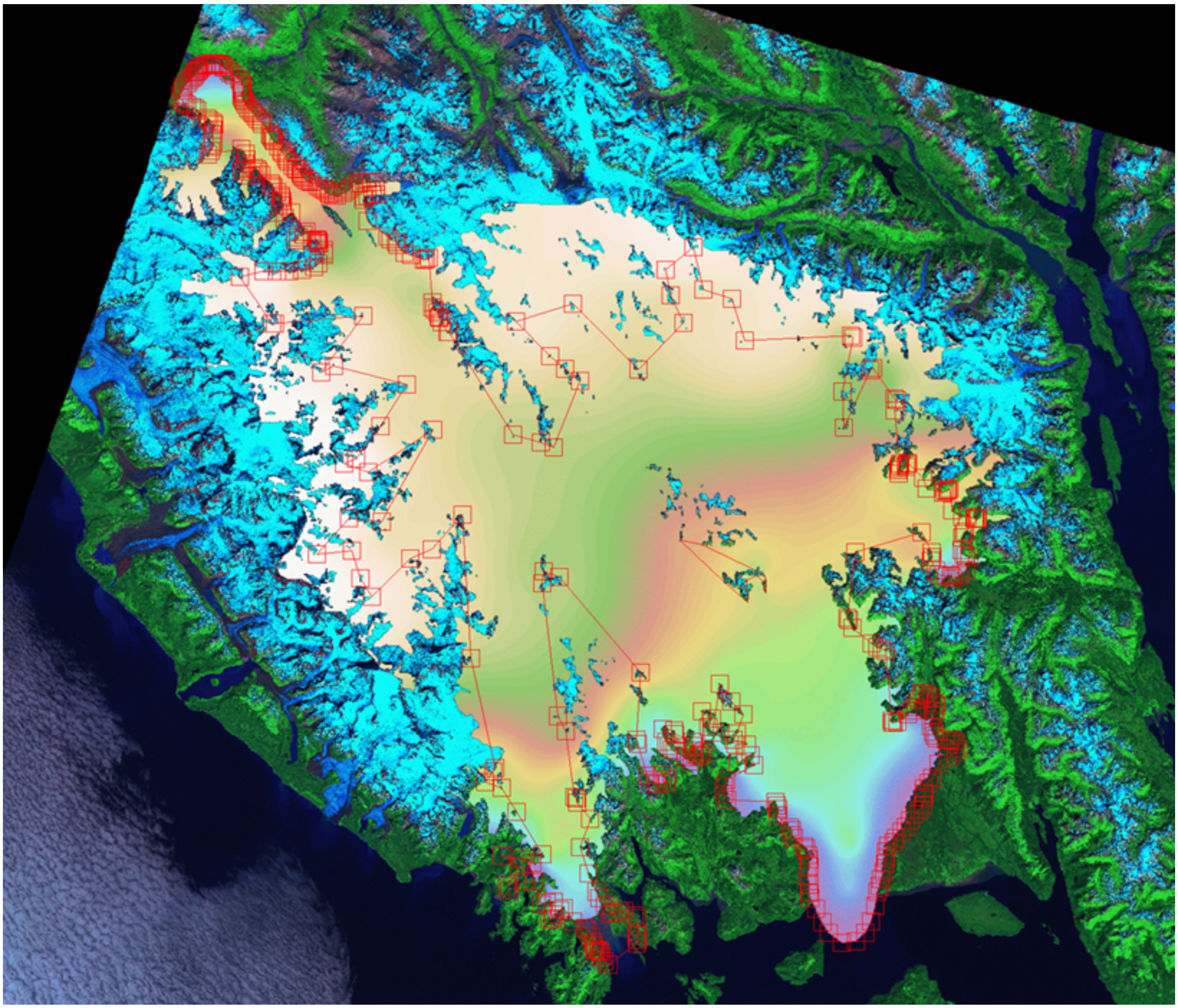
Little Ice Age advance

References:

Connor C, Streveler G, Post A, Monteith D, Howell W. The Neoglacial landscape and human history of Glacier Bay, Glacier Bay National Park and Preserve, southeast Alaska, USA. The Holocene. 2009;19(3):381-393. doi:10.1177/0959683608101389. Link

Larsen, CF, Motyka, RJ, Freymueller, JT, Echelmeyer, KA, Ivins, ER, 2005. Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 237, 548– 560. link

Reconstruction of LIA Glacier Bay



Reconstruction of LIA maximum glacier surface in Glacier Bay (~1750 AD) (modified from Larsen et al. 2005). The LIA maximum ice surface was determined by mapping geomorphic markers shown as *squares (trimlines, lateral moraines and terminal moraines). These markers were identified through aerial inspection, vertical airphoto analysis, high resolution digital elevation model (DEM) analysis, and field observations. Modern-day glacier analogues were used to construct the Glacier Bay LIA icefield surface from the geomorphic markers. This surface was then differenced with a DEM of present-day topography to determine ice thickness change since LIA.*

Post-Little Ice Age retreat

References:

Cai and Powell, 1995. Glacier Fluctuations and Sediment Yields Interpreted from Seismic-Reflection Profiles in Johns Hopkins Inlet, Glacier Bay, Alaska. In: *Proceedings of the Third Glacier Bay Science Symposium*: September 15-18, 1993, Glacier Bay Lodge, Glacier Bay National Park and Preserve, Gustavus, Alaska. United States: U.S. Department of the Interior, National Park Service, 1995. Link

Cowan, Ellen A., Keith C. Seramur, Ross D. Powell, Bryce A. Willems, Sean PS Gulick, and John M. Jaeger. 2010. Fjords as temporary sediment traps: History of glacial erosion and deposition in Muir Inlet, Glacier Bay National Park, southeastern Alaska. *GSA Bulletin* 122, no. 7-8: 1067-1080. doi: 10.1130/B26595.1 Link

Gaglioti, Benjamin V., Daniel H. Mann, Gregory C. Wiles, Benjamin M. Jones, Josh Charlton, Nicholas Wiesenberg, and Laia Andreu-Hayles. 2019. Timing and potential causes of 19th-century glacier advances in coastal Alaska based on tree-ring dating and historical accounts. *Frontiers in Earth Science* 7: 82. Link

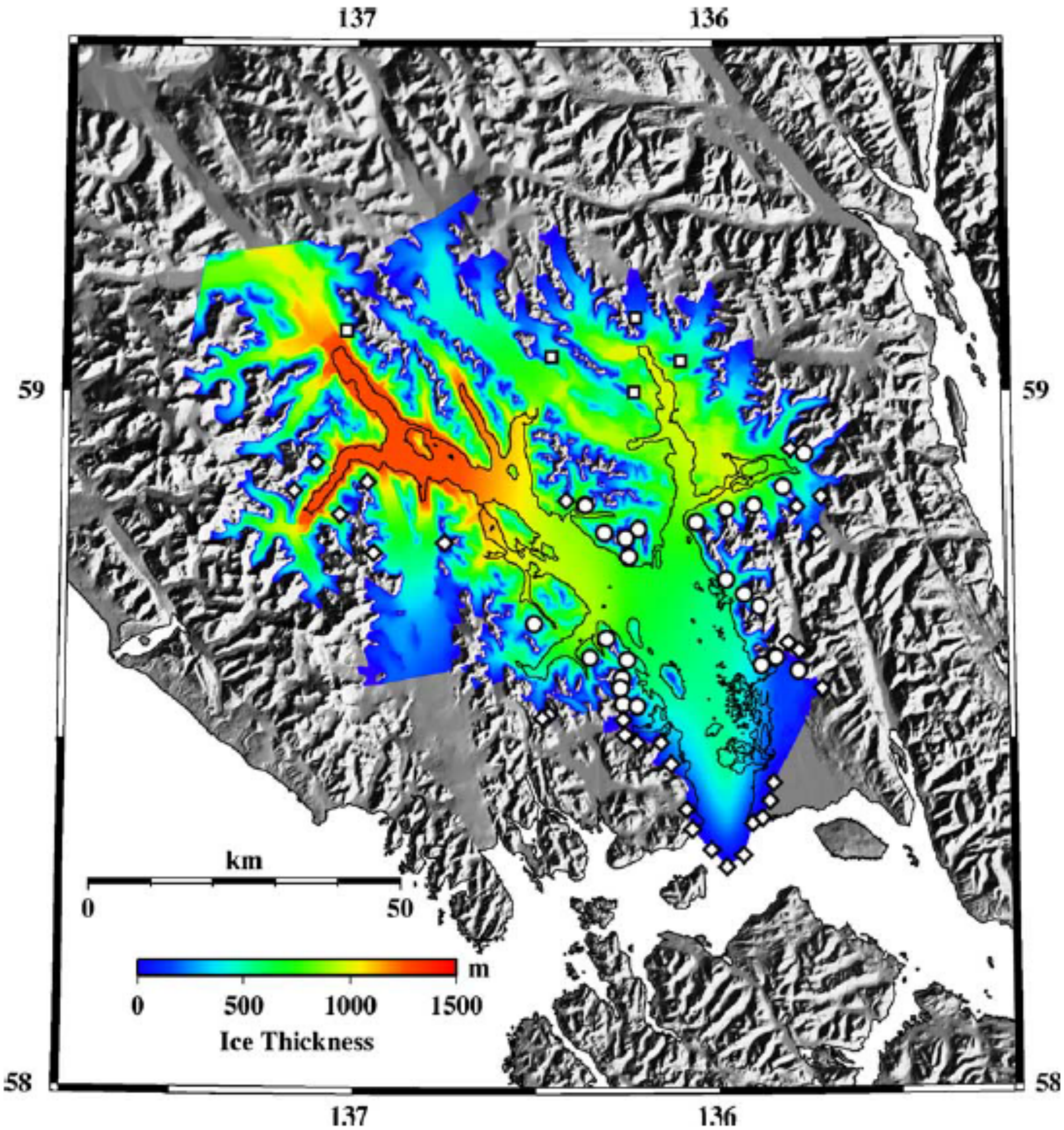
Larsen, CF, Motyka, RJ, Freymueller, JT, Echelmeyer, KA, Ivins, ER, 2005. Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 237, 548– 560. link

Larsen, CF, RJ Motyka, AA Arendt, KA Echelmeyer, and PE Geissler, 2007. Glacier changes in southeast Alaska and northern British Columbia and contribution to sea level rise. *J. Geophys.Res., Earth Surface*. 112, F01007, doi:10.1029/2006JF000586. Link

Post, A., S. O'Neel, R. J. Motyka and G. Streveler. 2011. A complex relationship between calving glaciers and climate, *EOS*, 92(37):305. doi: 10.1029/2011EO370001. Link

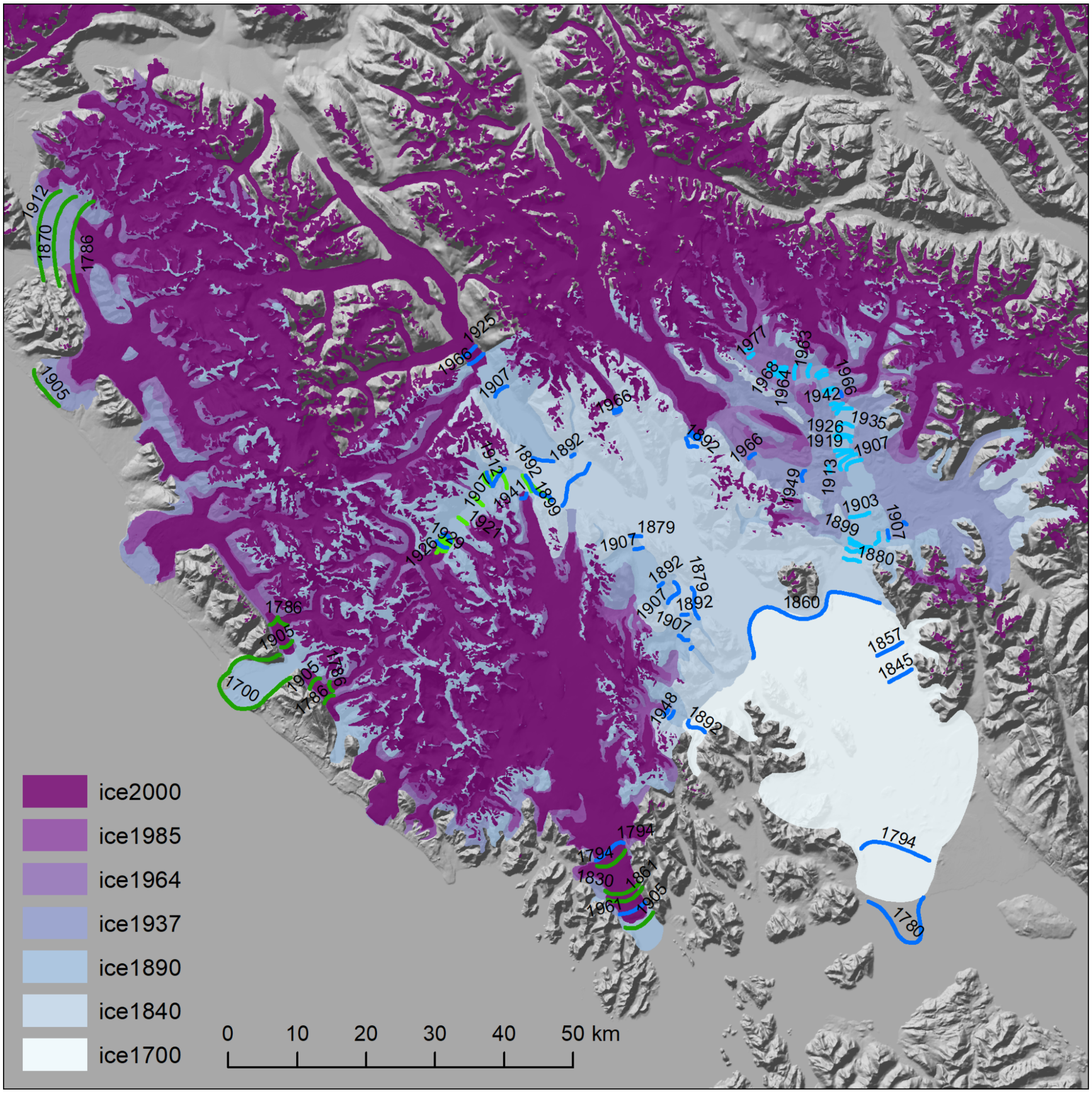
Powell, R.D., 1980. Holocene glacimarine sediment deposition by tidewater glaciers in Glacier Bay, Alaska Doctoral dissertation, The Ohio State University. Link

Ice thickness change from the Little Ice Age to present



Total volume of the ice loss is 3030 km^3, equivalent to 8 mm rise in global sea level. The modern shoreline in Glacier Bay is outlined beneath the thickness changes. The LIA maximum ice surface was determined by mapping geomorphic markers (trimlines, lateral moraines and terminal moraines). These markers were identified through aeral inspection (circles), vertical airphoto analysis (squares), and high-resolution digital elevation model (DEM) analysis (diamonds). The furthest south three points shown as diamonds are from bathymetric evidence of the LIA terminal moraine. Modern-day glacier analogues were used to construct the GB LIA icefield surface from the geomorphic markers. This surface was then differenced with a DEM of present-day topography to map LIA ice thickness. **(Larsen et al. 2005)**

Glacier area change



Since the end of the Little Ice Age in ~1780, the glaciers of Glacier Bay retreated over 100 km. The glacier outlines here come from: purple polygons (Glacier Bay GIS files attributed to Streveler, Howell, Eichenlaub, and perhaps others), blue lines (the Glacier Bay brochure, based on a variety of data), bright green (Cai and Powell 1995), light blue (Cowan et al 2010), dark green (Gaglioti et al 2019). Compiled by Andy Bliss.

Glacier length change

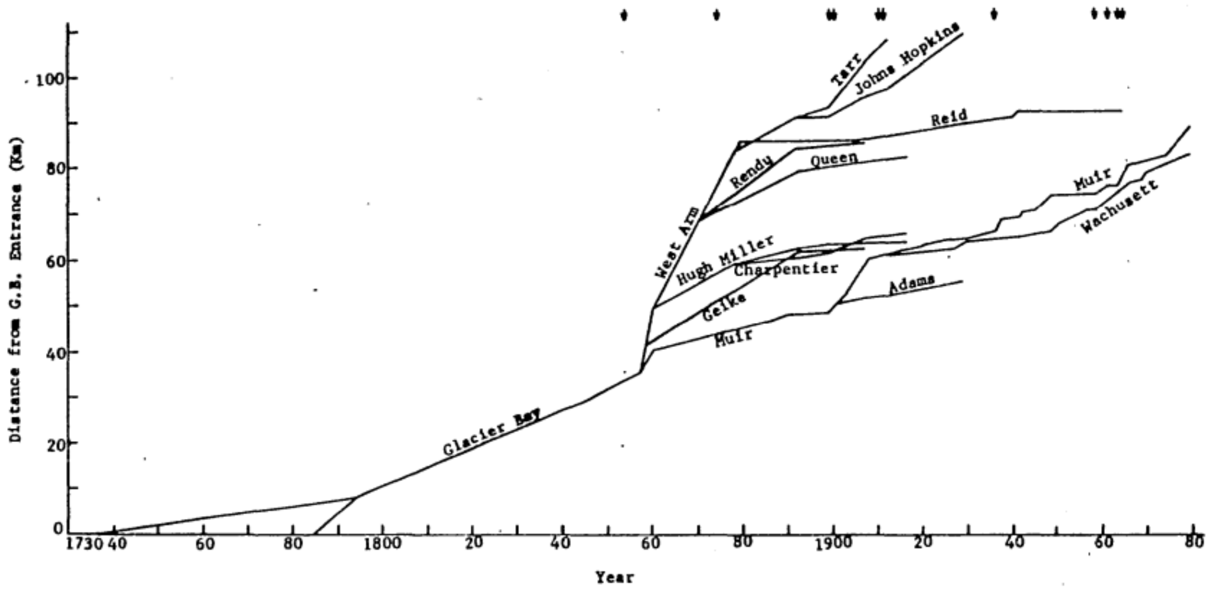


Figure 3: Position of the ice front in a given year with respect to distance from Glacier Bay entrance. Arrows mark specific years for earthquakes larger than magnitude 7.0.

Figure from Powell 1980.

Glacial Isostatic Adjustment

References:

Elliott, J. L., C. F. Larsen, J. T. Freymueller, and R. J. Motyka, 2010, Tectonic block motion and glacial isostatic adjustment in southeast Alaska and adjacent Canada constrained by GPS measurements, J. Geophys. Res., 115, B09407, doi:10.1029/2009JB007139. link

Hicks, S.D., and W. Shofnos. 1965. The determination of land emergence from sea-level observations in southeast Alaska. Journal of Geophysical Resources 70:3315-3320. link

Larsen, CF, Motyka, RJ, Freymueller, JT, Echelmeyer, KA, Ivins, ER, 2005. Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 237, 548– 560. link

Larsen, CF, RJ Motyka, JT Freymueller, KA Echelmeyer, and ER Ivins, 2004. Rapid uplift of southern Alaska caused by recent ice loss. Geoph. Journ. Internat., 158, 1118-1133. link

Larsen, C.F., K.A. Echelmeyer, J.T. Freymueller, and R.J. Motyka. 2003. Tide gauge records of uplift along the northern Pacific-North American plate boundary, 1937 to 2001. Journal of Geophysical Resources 108: 2216. DOI:10.1029/201JB001685. link

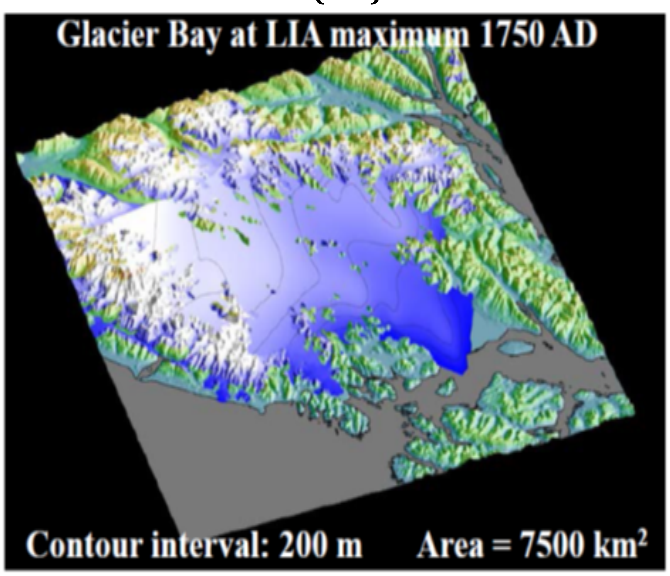
Motyka, RJ, 2003. Post little ice age uplift at Juneau, Alaska reconstructed from dendrochronology and geomorphology. Quatern. Res., 59, 300-309. link

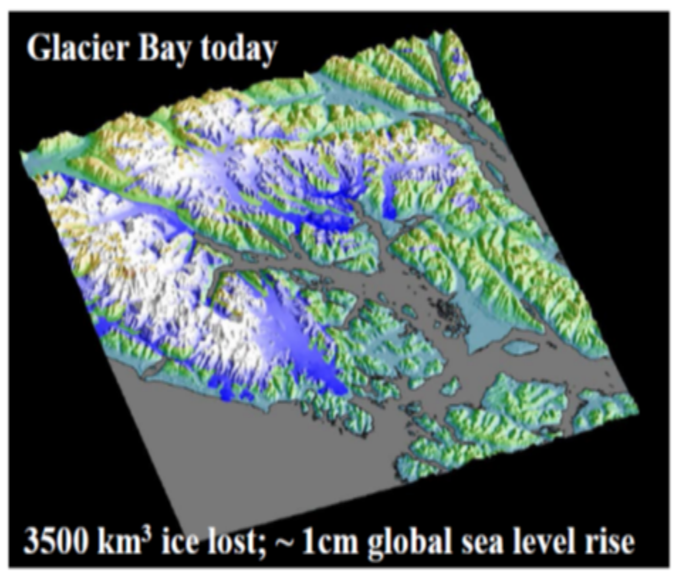
Motyka, R.J., C.F. Larsen, J.T. Freymueller and K.A. Echelmeyer. 2007. Post Little Ice Age Glacial Rebound in Glacier Bay National Park and Surrounding Areas. Alaska Park Science, 6(1), 36-41. Link

Excerpted from Motyka et al, 2007:

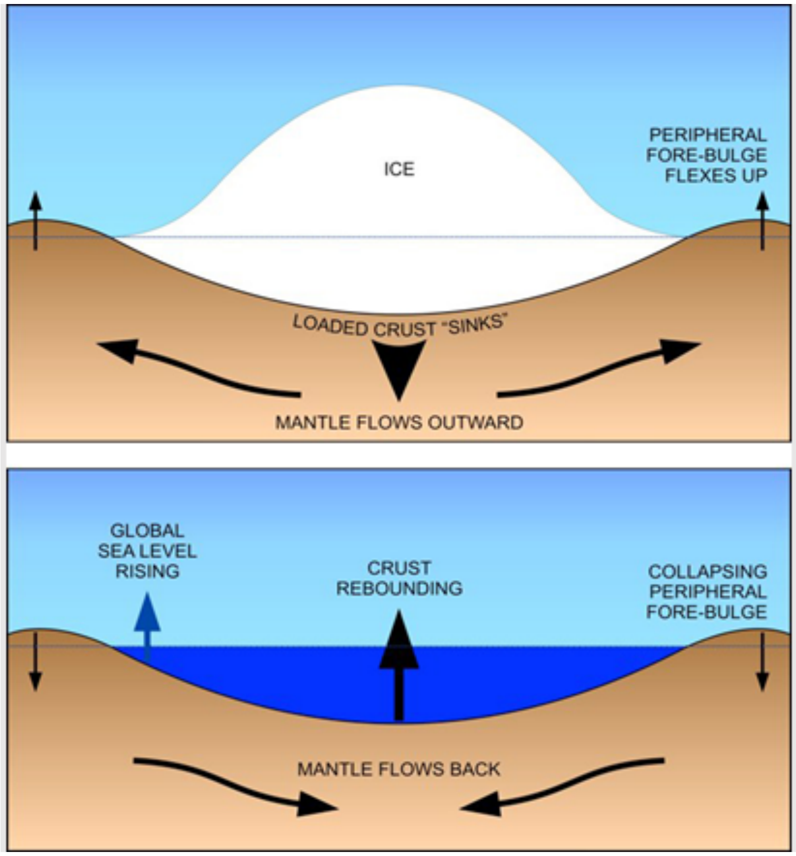
In Southeast Alaska we have measured the world's fastest present-day isostatic uplift using GPS geodesy combined with studies of raised shorelines and tide gauges. The uplift pattern documented here spans an area of over 100,000 km^2 centered on the coastal mountains along the Gulf of Alaska (See Figures). The data set depicts a regional pattern of uplift, with peaks of 30-32 mm/yr centered over upper Glacier Bay and Yakutat Icefield. The peak uplift rates are found in regions that have experienced the highest rates of ice loss. Raised shorelines that date back to 1770 ± 20 AD indicate total sea level fall in the range 1.0 to 5.7 m. The onset of uplift measured at the raised shoreline sites correlates with when the Glacier Bay Icefield began its dramatic collapse. GIA modeling results provide robust constraints on lithospheric elastic thickness, asthenosphere thickness and asthenosphere viscosity (Larsen et al. 2005). The simultaneous onset of unloading and sea level change is a direct observation of the causal relationship between glacial unloading and the region's uplift. Climate changes rather than tectonic forces have primarily forced these regional sea-level changes. These adjustments to LIA glacier loading and unloading are producing significant stresses on the earth's crust in Glacier Bay, which can affect seismicity and regional tectonics. The rising land is also continually changing the shorelines and geomorphic texture of shoreline throughout the park and causing changes in hydrologic patterns, erosion and sedimentation. All these changes have a direct impact on the ecosystems of the park.

Ice Loss Since Little Ice (LIA) Maximum

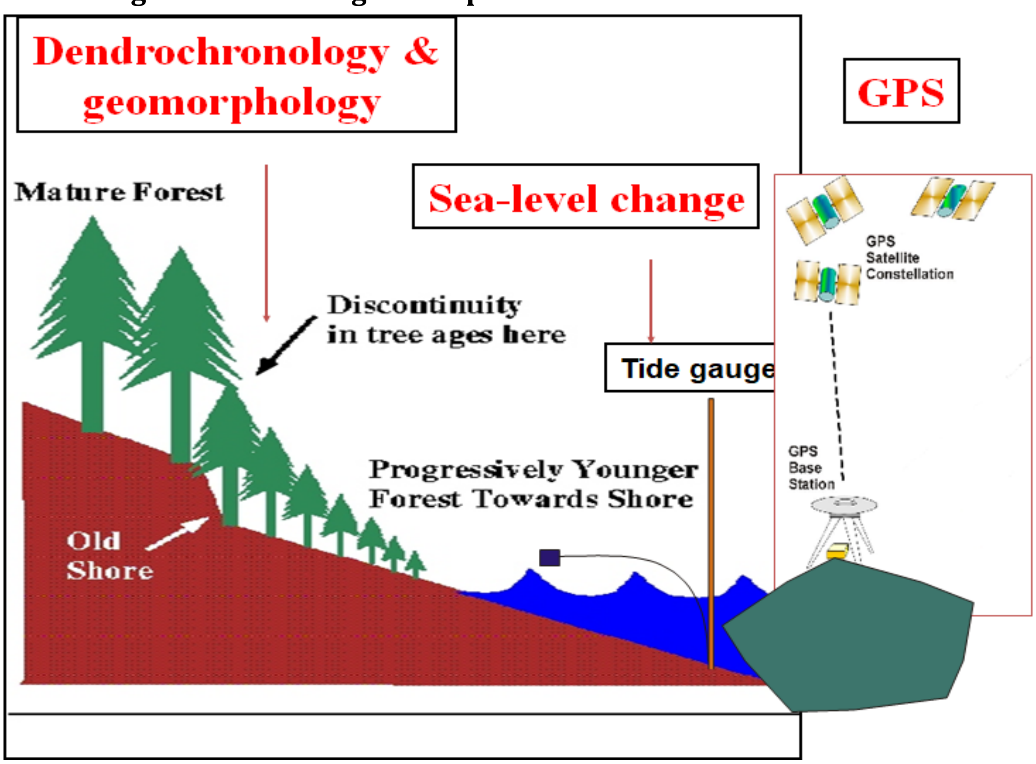




Glacial Isostatic Adjustment (GIA)



Measuring Sea Level Change and Uplift



Three complementary methods to measure uplift:
1) precision GPS geodesy,
2) relative sea-level change from tide gauge measurements,
3) raised shoreline studies.

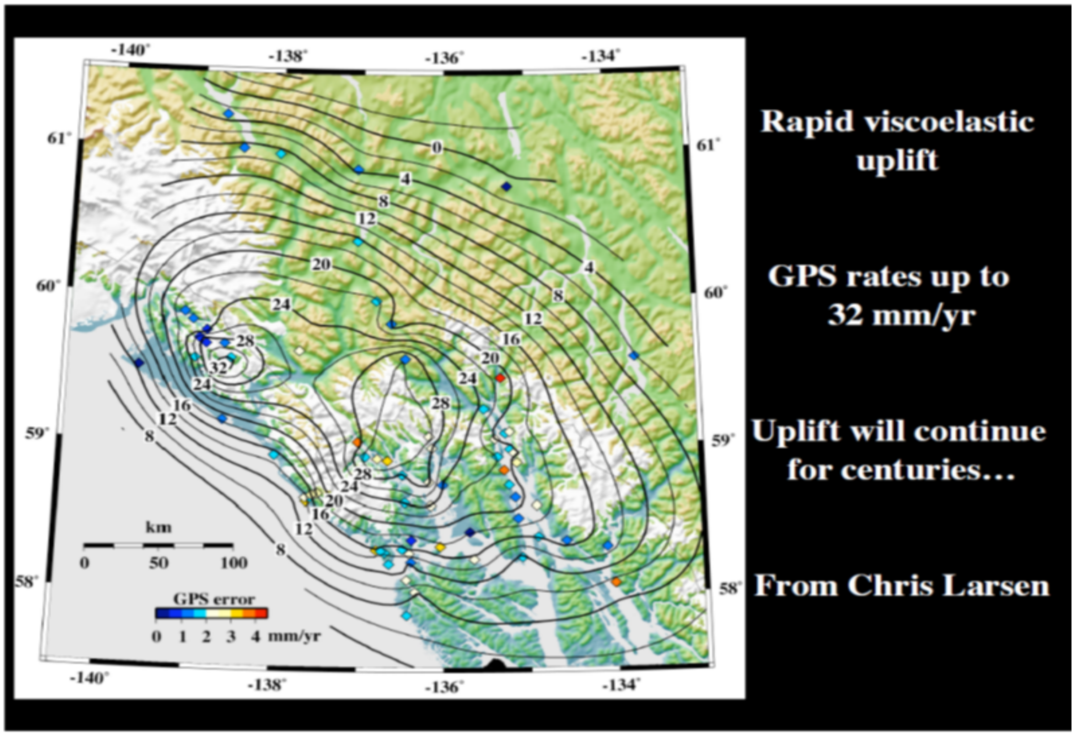


Figure 2. GPS uplift observations in Southeast Alaska (from Larsen et al. 2005). GPS uplift rates are in mm/yr; contour interval is 0.08 in/yr (2 mm/yr). GPS stations are shown with diamonds, colored according to the uplift rate error at each site as indicated by the color scale bar. Peak uplift rates are found in Glacier Bay (southern peak) and the Yakutat Icefield (northern peak).

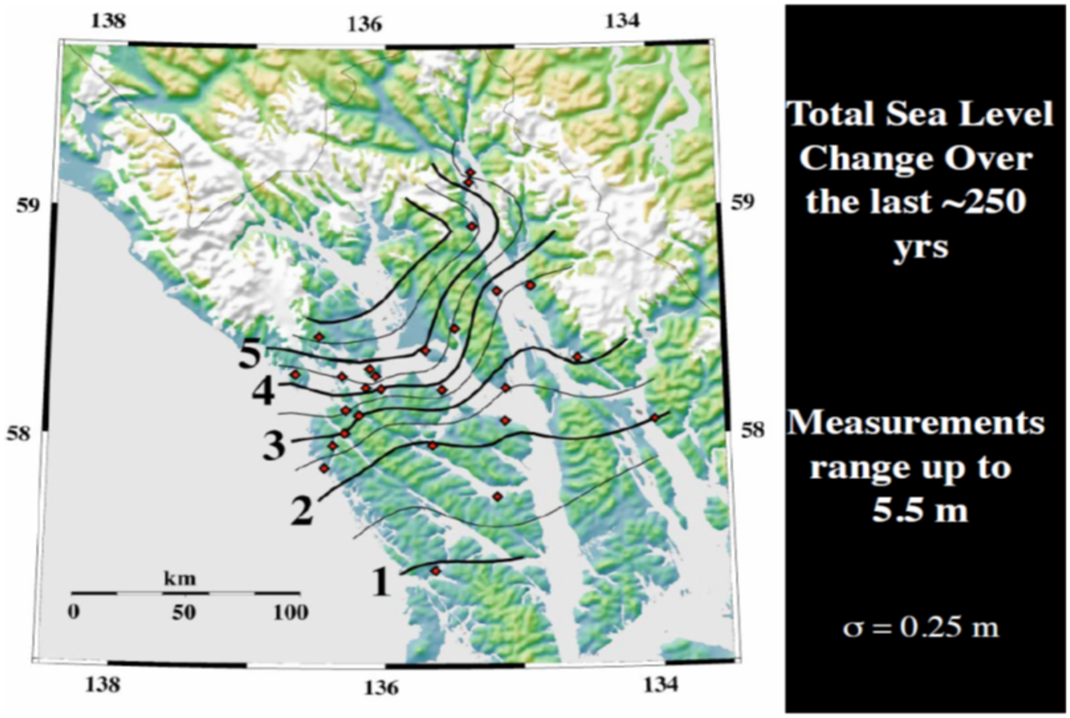


Figure 5. Relative sea level change (from Larsen et al. 2005). Raised shoreline sites are shown with red diamonds. Contour interval is 1.64 ft (0.5 m).

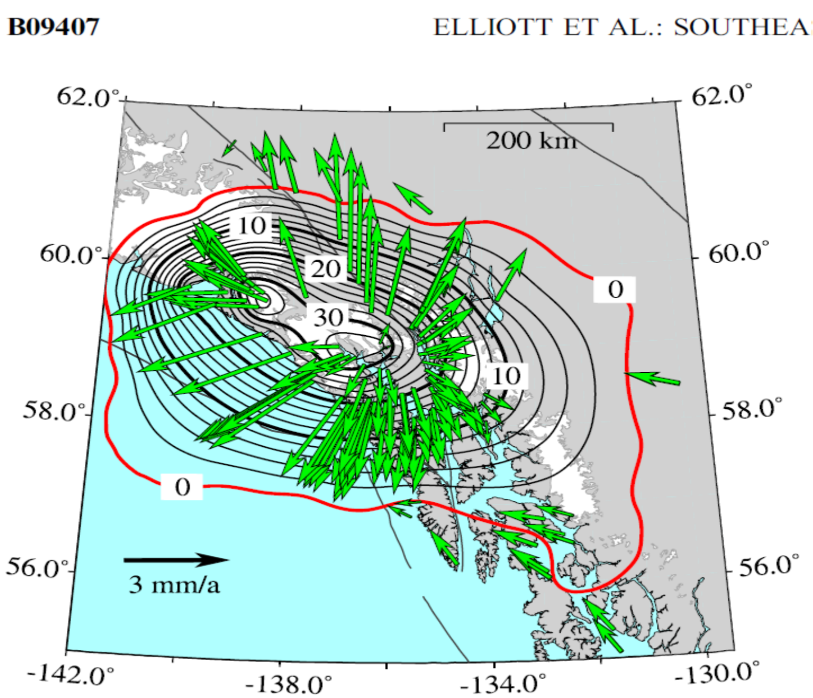


Figure 3. Glacial isostatic adjustment model predictions for southeast Alaska. Vectors show the horizontal motion while the contours show the vertical motion. Contour label units are mm/a (Figure S1 shows a larger version).

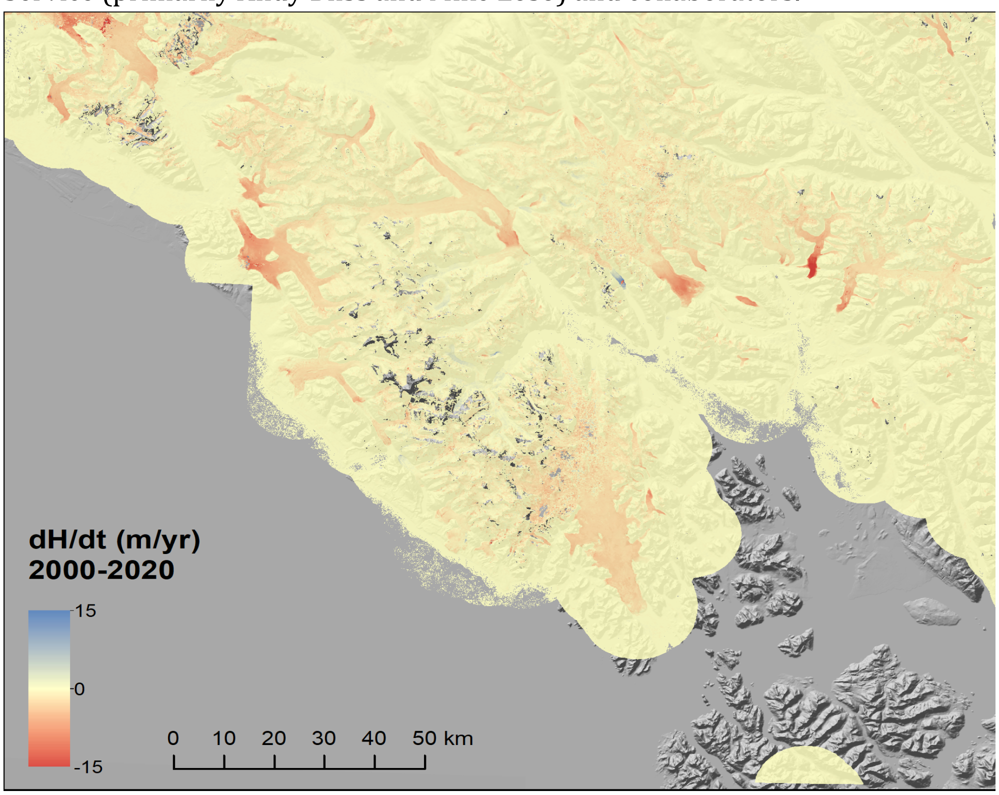
Current state of Glacier Bay glaciers

References:

Hugonnet, R., McNabb, R., Berthier, E., Menounos, B., Nuth, C., Girod, L., Farinotti, D., Huss, M., Dussaillant, I., Brun, F. and Kääb, A., 2021. Accelerated global glacier mass loss in the early twenty-first century. Nature, 592(7856), pp.726-731. Link

McNabb, R.W., Hock, R. and Huss, M., 2015. Variations in Alaska tidewater glacier frontal ablation, 1985–2013. *Journal of Geophysical Research: Earth Surface*, 120(1), pp.120-136. Link

The vast majority of glaciers in Glacier Bay have been retreating in recent years due to climate change. However, up until a few years ago, the big tidewater glaciers (Margerie, Johns Hopkins, and Lamplugh) were relatively stable. Park interpreters have explained this as a part of the tidewater glacier cycle - after coming out of the Little Ice Age, the glaciers found a steady front position and were able to build substantial terminal moraines that protected them from the changing climate. Now Margerie and Lamplugh have started to retreat, and Johns Hopkins is noticeably thinning. Current efforts to monitor these glaciers, largely via remote sensing, are ongoing by the Park Service (primarily Andy Bliss and Mike Loso) and collaborators.

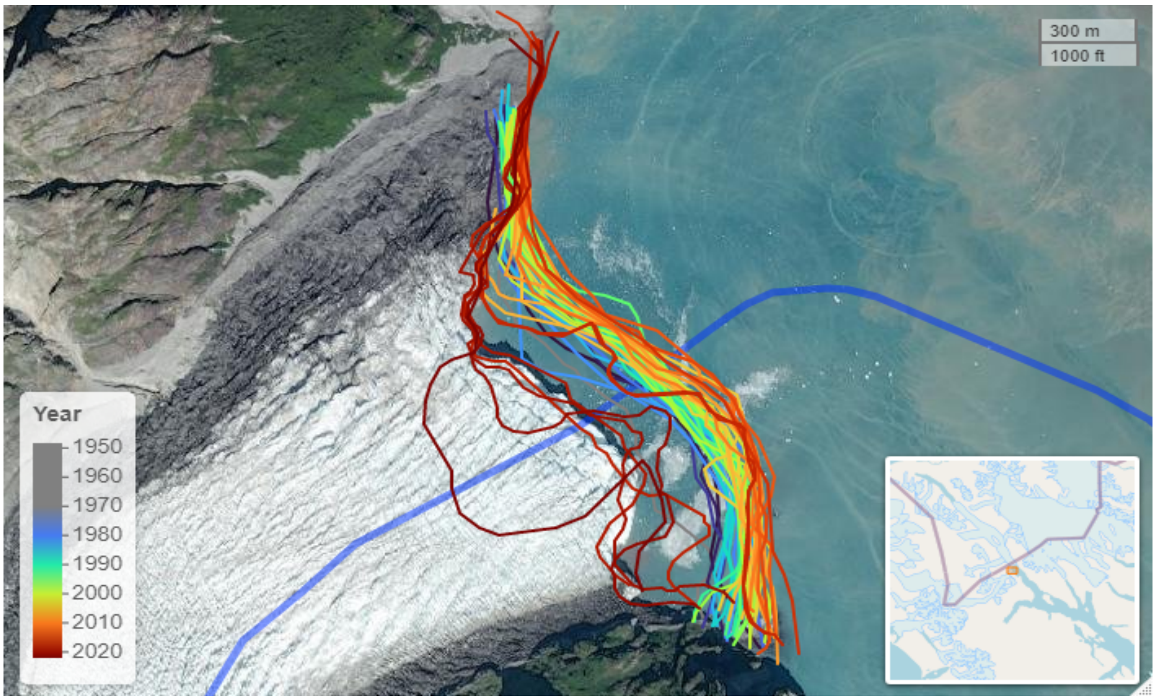


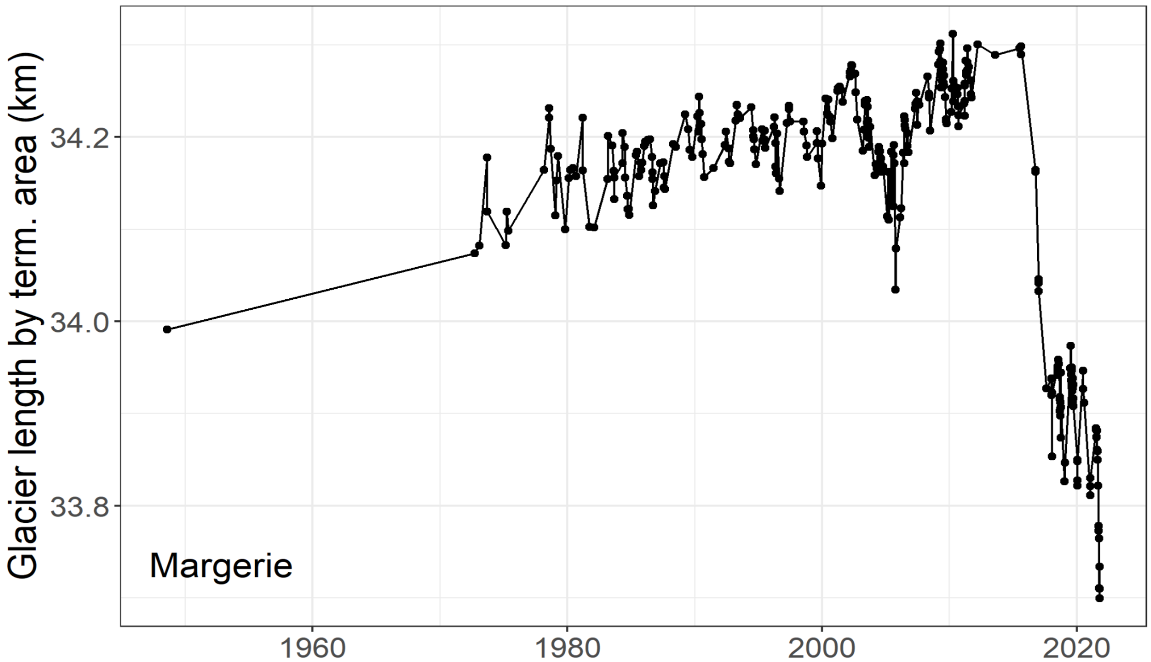
Glacier thinning rates for 2000-2020 from Hugonnet et al. (2021).

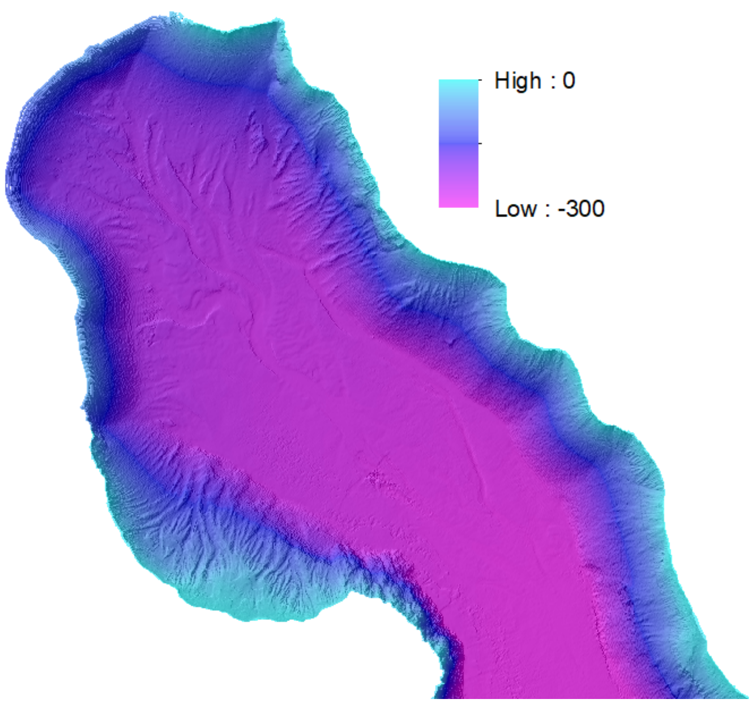
Glacier outline methods for figures below: McNabb and Hock (2014) digitized terminus positions for tidewater glaciers across Alaska from Landsat imagery (1972-2012). Andy Bliss has continued the record through the present for glaciers in the park. Glacier length is calculated by one of two methods – either the centerline length (along the thick blue line on the maps) or by an area-averaging method that accounts for oddly-shaped glacier fronts (Margerie and Lamplugh). For simplicity, the maps only show the last outline from each year that had more than one outline. For more details or data, please reach out! Andrew_Bliss@nps.gov.

Margerie Glacier

Margerie Glacier has retreated about 300 meters (1000 ft) in the last few years after many years of stability or slow advance.



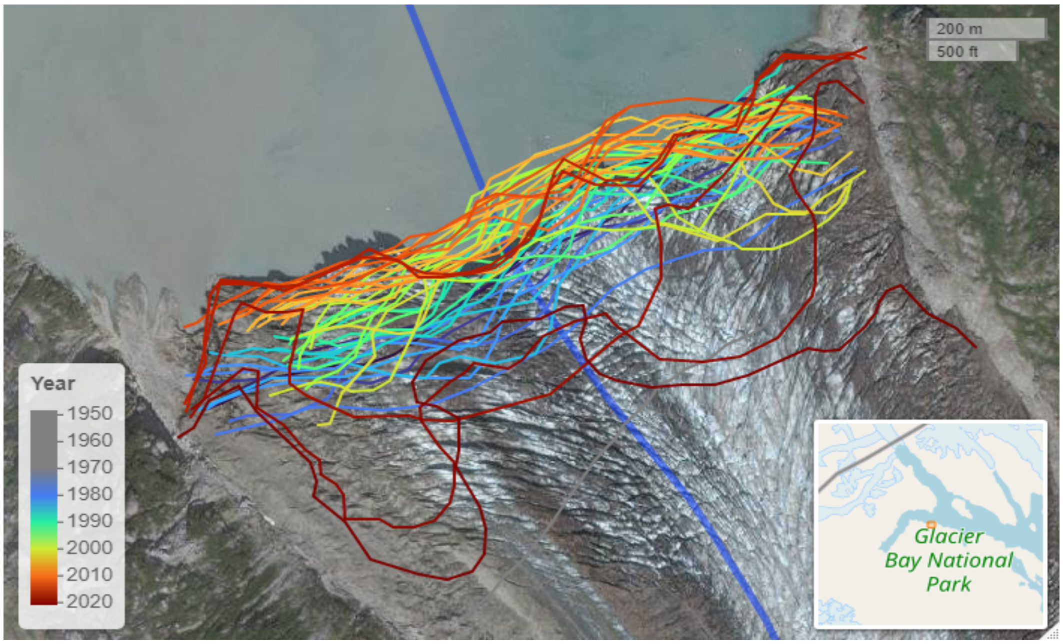


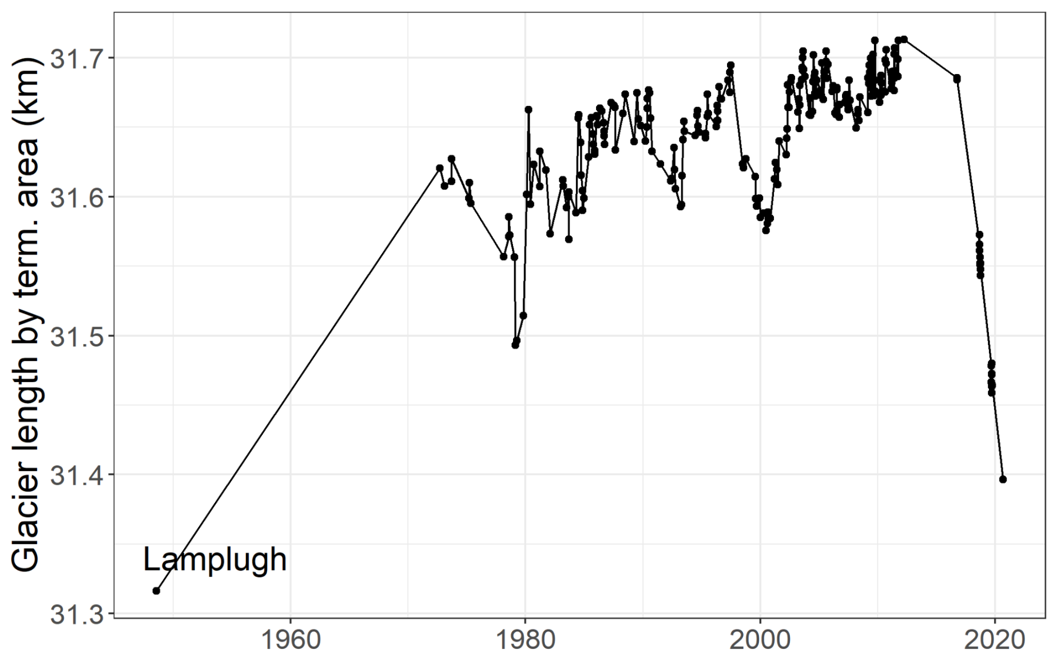


Bathymetry of Tarr Inlet (Margerie Glacier is in center left, Grand Pacific at the top). Units are meters.

Lamplugh Glacier

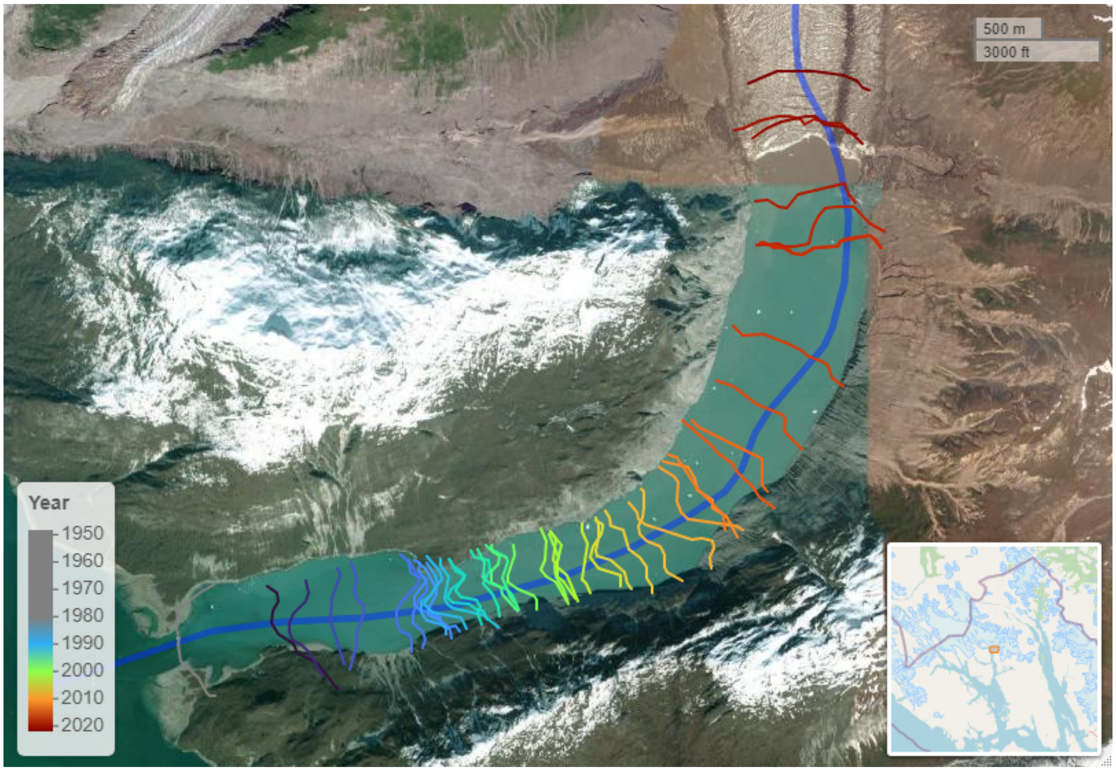
Like Margerie Glacier, Lamplugh Glacier has retreated about 300 meters (1000 ft) in the last few years after many years of stability or slow advance.

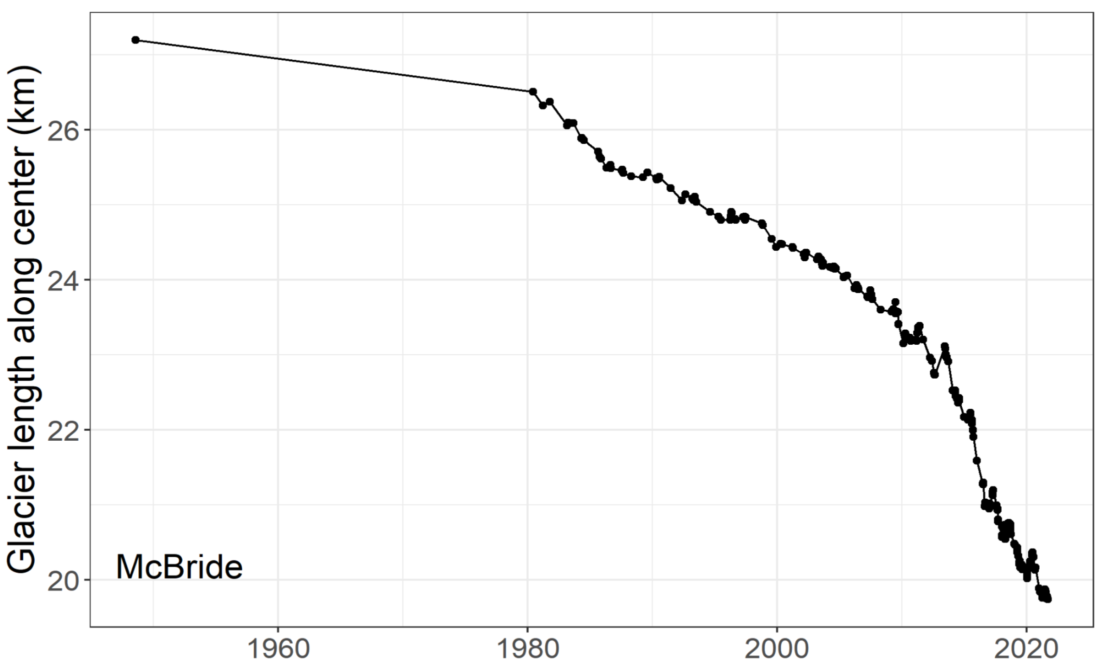




McBride Glacier

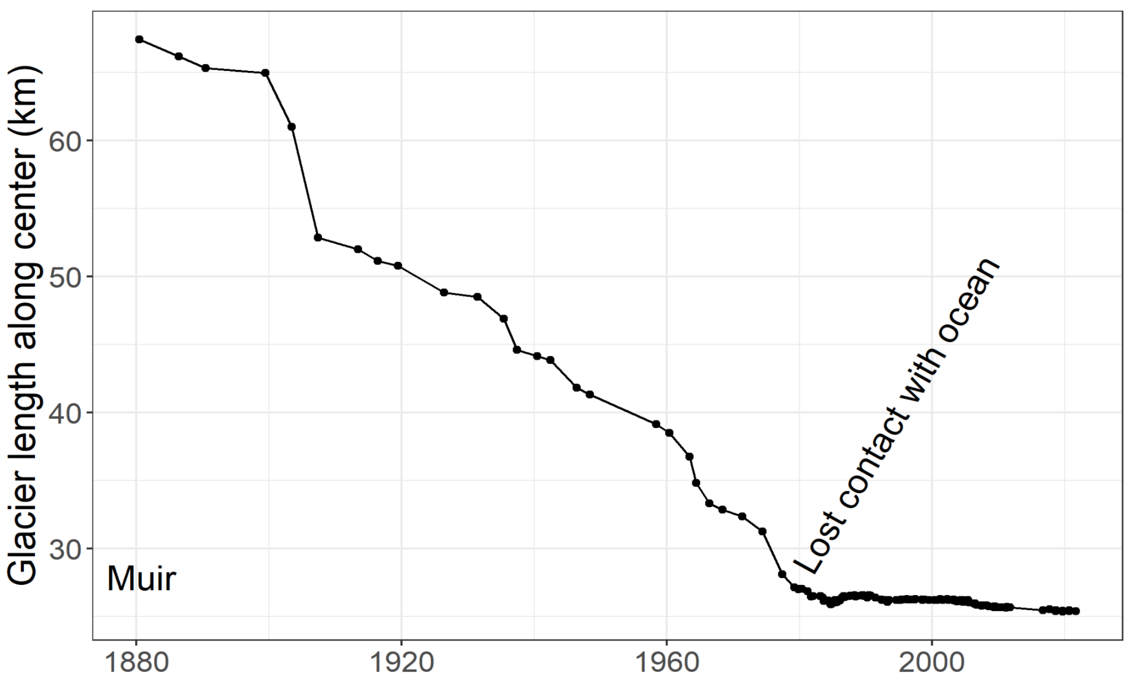
McBride Glacier in the East Arm has retreated more than 3 kilometers (2 miles) in the last 10 years. Between 1980 and 2021, it has retreated 6.8 km (4.2 mi) and lost an area of about 13.7 km^2 (5.3 mi^2).



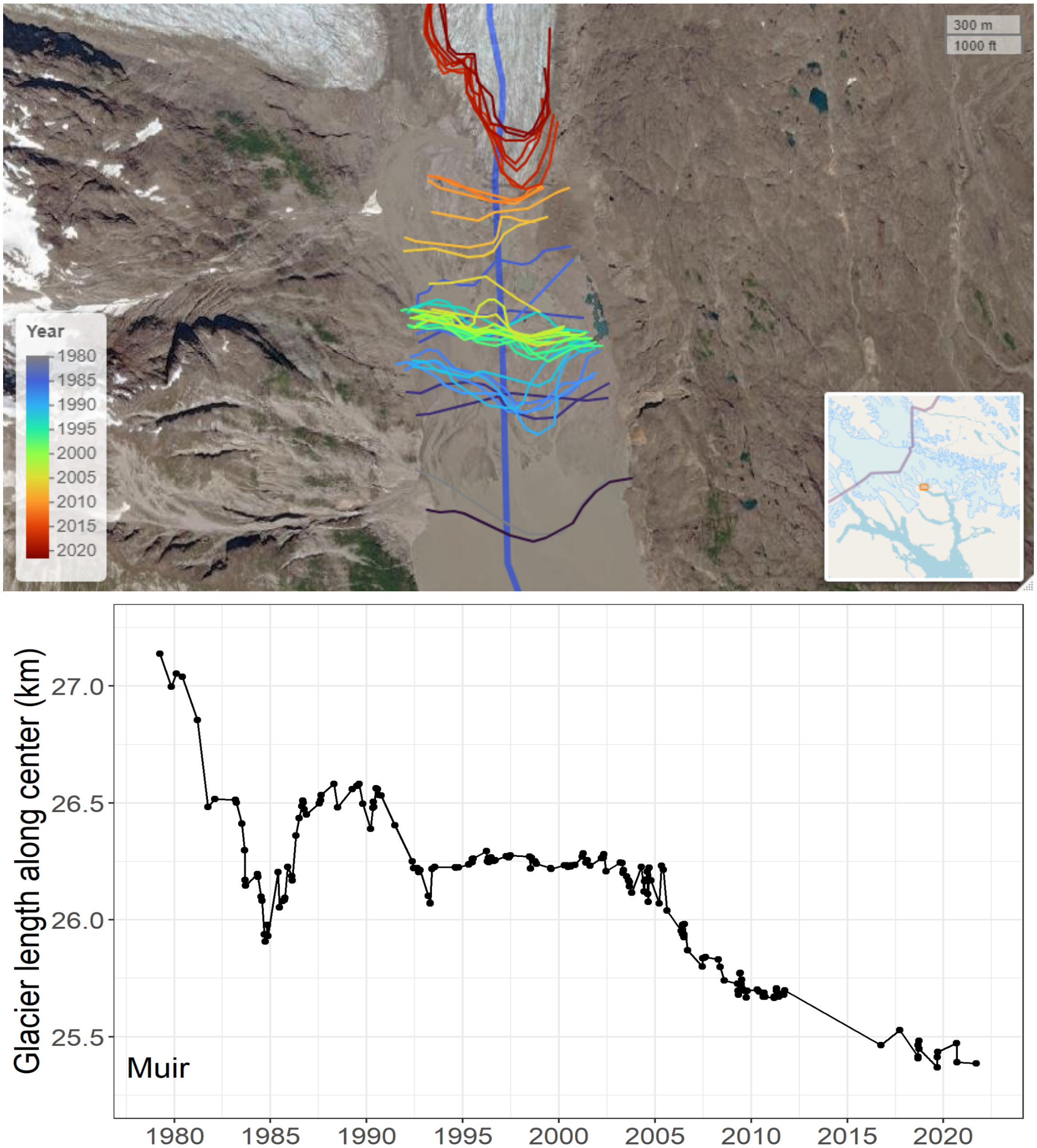


Muir Glacier

Muir Glacier retreated the entire length of the East Arm (about 42 kilometers) since 1880.

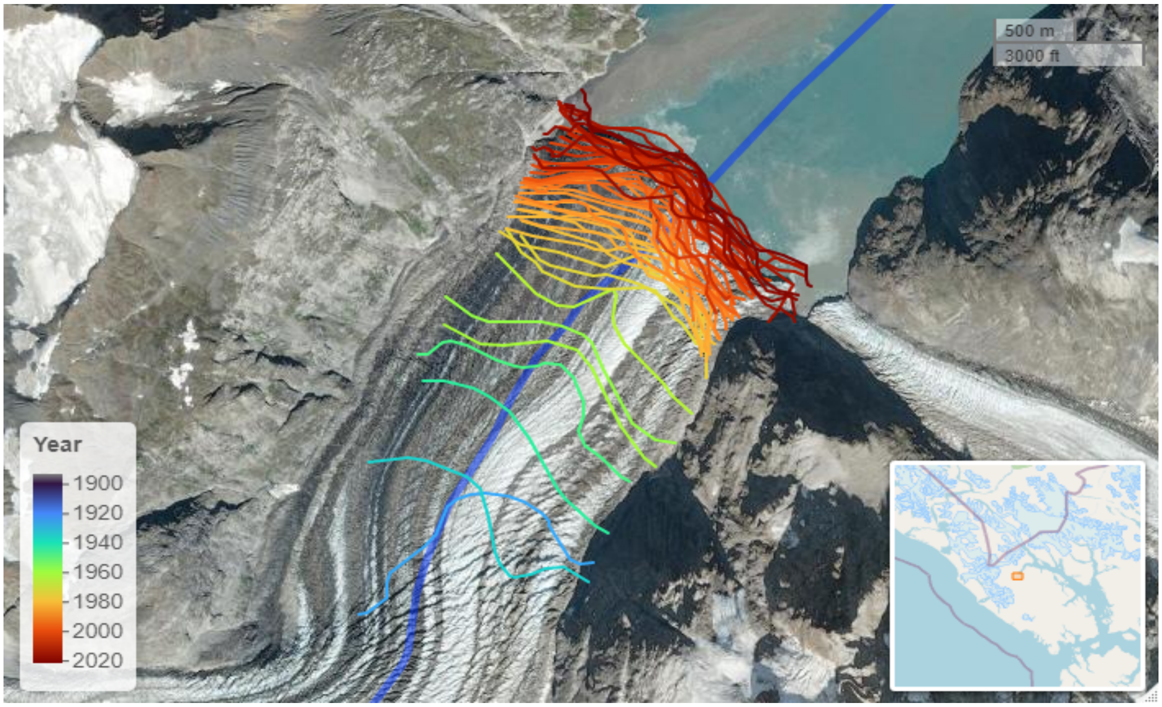


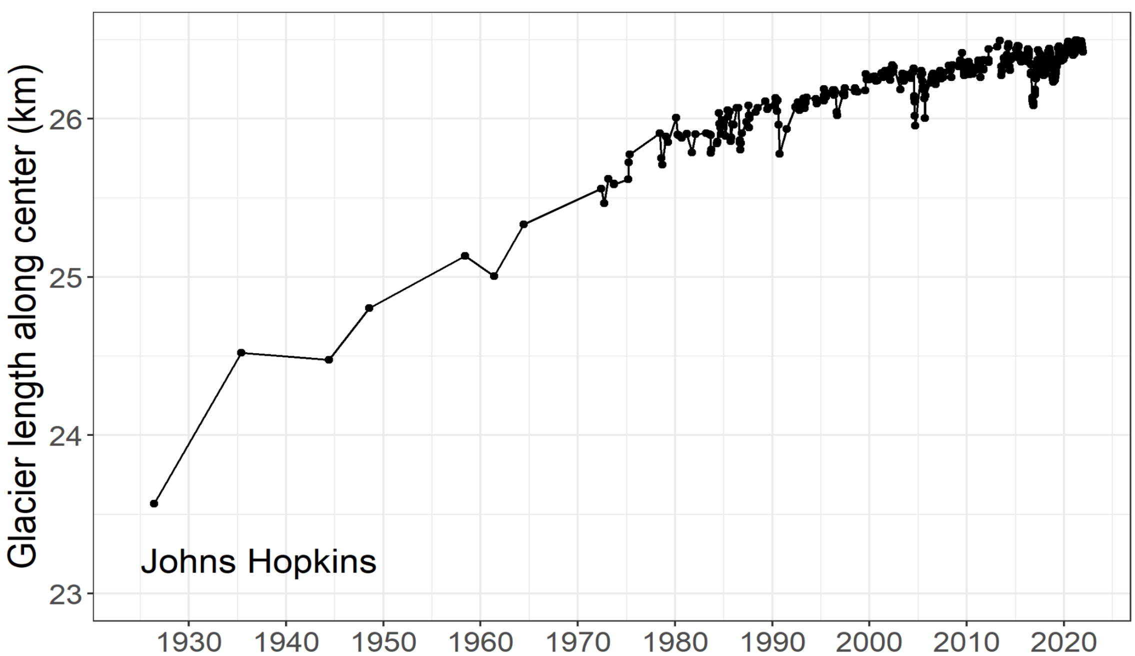
Muir Glacier lost contact with the ocean around 1980 and stopped retreating shortly thereafter. In 1985/6 it advanced about 0.5 km and stabilized there for a few years before stepping back 0.25 km and hanging there for a dozen years. In 2005 a slow retreat began which continues to today. In this time, Muir and the neighboring Morse Glacier have built a substantial delta (1.5 km long, 0.6 km wide, depth could be on the order of 100 m).

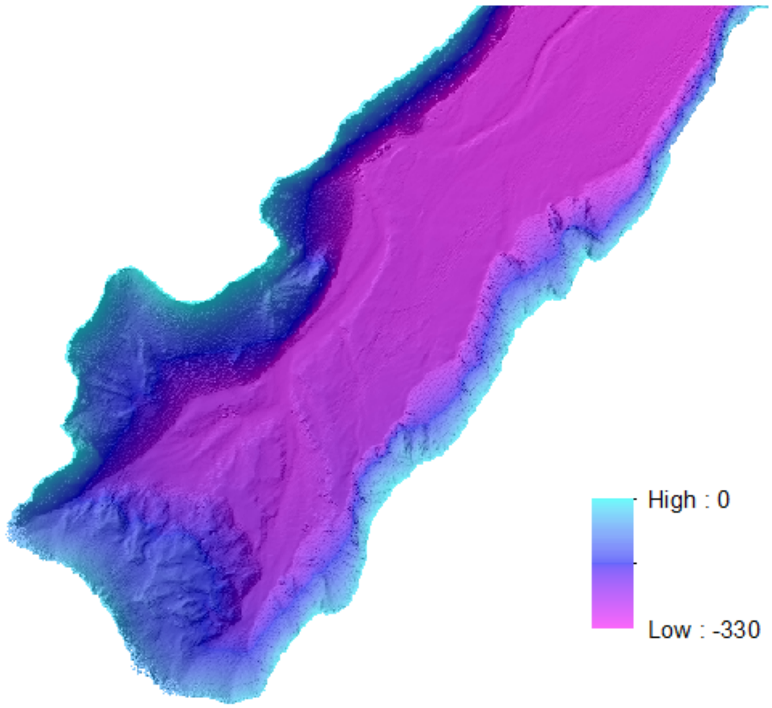

300 m
1000 ft
Year
1980
1985
1990
1995
2000
2005
2010
2015
2020
Glacier length along center (km)
27.0
26.5
26.0
25.5
Muir
1980
1985
1990
1995
2000
2005
2010
2015
2020

Johns Hopkins Glacier

After the Little Ice Age, the Glacier Bay glacier retreated up the West Arm faster than the East Arm. In Johns Hopkins Inlet, that retreat ended in about 1920 and Johns Hopkins Glacier's terminus has been consistently, slowly advancing in recent years. The warm summer of 2016 caused more retreat than usual, but the glacier recovered the following winter.







Bathymetry of Johns Hopkins Inlet (glacier is in lower left). Units are meters.

Interactions between glaciers and harbor seals

References:

Womble, Jamie N., and Scott M. Gende. "Post-breeding season migrations of a top predator, the harbor seal (Phoca vitulina richardii), from a marine protected area in Alaska." *PLoS One* 8.2 (2013): e55386.

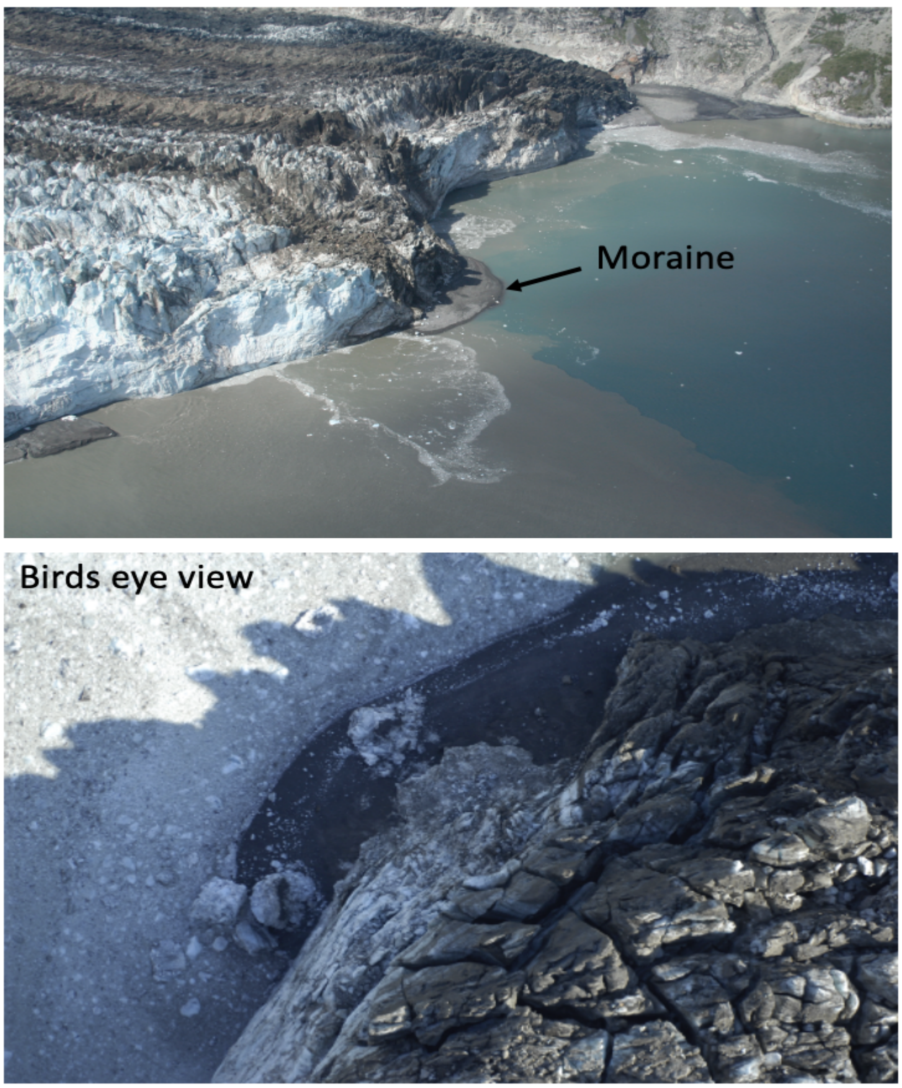
Womble, J. N., P. J. Williams, R. W. McNabb, A. Prakash, R. Gens, B. S. Sedinger, and C. R. Acevedo. 2021. Harbor seals as sentinels of ice dynamics in tidewater glacier fjords. Frontiers in Marine Science. Link

Womble, J. N., J. M. Ver Hoef, S. M. Gende, and E. A. Mathews. 2020. Calibrating and adjusting counts of harbor seals in a tidewater glacier fjord to estimate abundance and trends from 1992-2017. Ecosphere 11(4): e03111. Link

Tidewater glacier fjords are important ecosystems for harbor seals. Upwelling plumes at glacier termini transport nutrients and entrain zooplankton, providing food for upper trophic levels–fish are thought to be denser in nutrients in these systems. Additionally, icebergs found in fjords provide safe haul-outs for seals. Ice provides a stable platform for nursing and resting as well as refuge from predation. However, there are trade-offs for the seals that choose to occupy glacial sites. To catch food, they have to dive deeper to forage and for longer time periods compared to seals that occupy terrestrial sites.

Previous research has shown that harbor seals travel widely during the post-breeding season from September to April. However, during the breeding season in May and June, harbor seals exhibit a high degree of fidelity to tidewater glacier fjords, with individuals returning to these habitats from one year to the next. A satellite tagging study in Glacier Bay found that 93% of seals returned to Glacier Bay and 78% returned to their original glacier ice site (Womble et al 2013).

While harbor seals tend to return to Glacier Bay from year to year, they have migrated between different tidewater fjords over the past several decades. Greater than 1,500 seals used the area at the foot of Muir Glacier in the 1970's and by the early 1990's the glacier had retreated onto land and was no longer calving ice that could be used by harbor seals as habitat. Many of these seals migrated to Johns Hopkins Inlet at this point, and Johns Hopkins currently hosts the largest breeding site in Glacier bay, with greater than 2,000 seals occupying the inlet during the pupping season in June and molting season in August.



Aerial photos taken in August of 2019 during a seal survey.

Preliminary results from fieldwork from 2019-2021 show a decline in the number of seals during this time period. Satellite and aerial observations indicate the surfacing of a terminal moraine in 2019. The current hypothesis is that the decline in seal population is due to an overall decrease in iceberg discharge as the terminus becomes more grounded.. Preliminary observations indicate the recent reduction in iceberg concentration has caused the seals to migrate to the nearby McBride Inlet.

Glacier erosion and morainal banks

References:

Cai and Powell, 1995. Glacier Fluctuations and Sediment Yields Interpreted from Seismic-Reflection Profiles in Johns Hopkins Inlet, Glacier Bay, Alaska. In: *Proceedings of the Third Glacier Bay Science Symposium*: September 15-18, 1993, Glacier Bay Lodge, Glacier Bay National Park and Preserve, Gustavus, Alaska. United States: U.S. Department of the Interior, National Park Service, 1995. Link

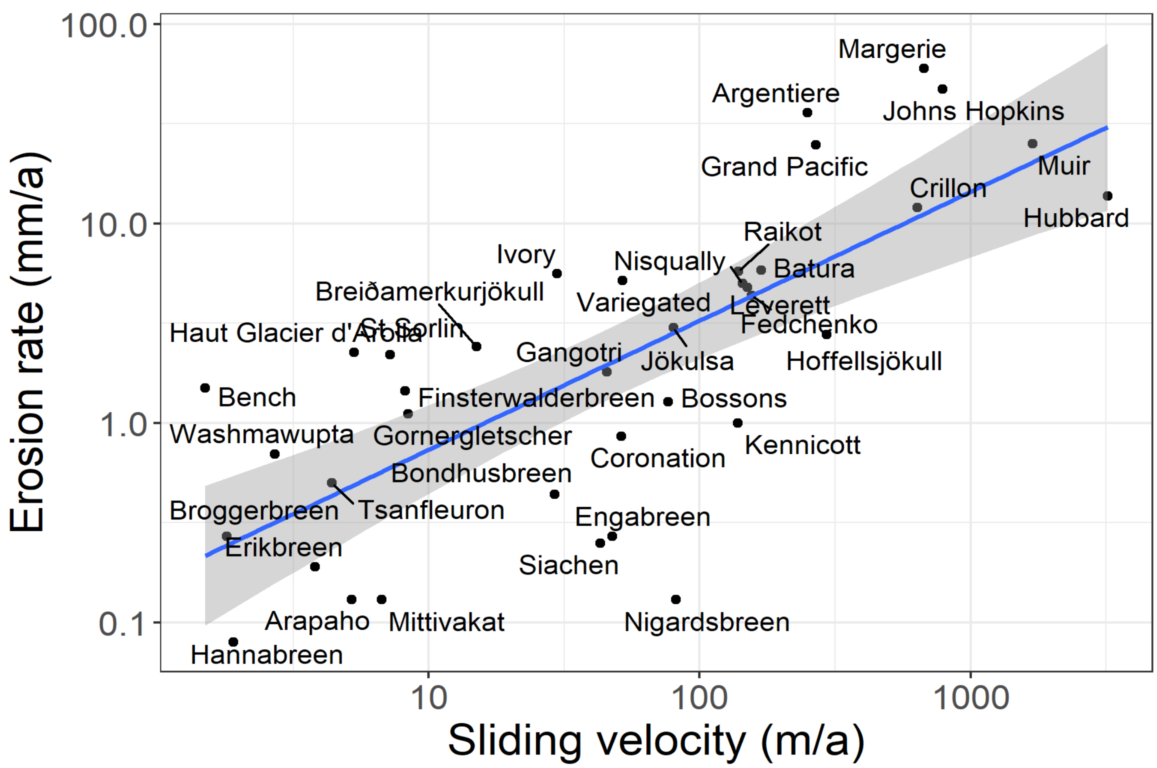
Cook, S.J., Swift, D.A., Kirkbride, M.P. et al. The empirical basis for modelling glacial erosion rates. Nat Commun 11, 759 (2020). https://doi.org/10.1038/s41467-020-14583-8. Link

Cowan, Ellen A., Keith C. Seramur, Ross D. Powell, Bryce A. Willems, Sean PS Gulick, and John M. Jaeger. 2010. Fjords as temporary sediment traps: History of glacial erosion and deposition in Muir Inlet, Glacier Bay National Park, southeastern Alaska. *GSA Bulletin* 122, no. 7-8: 1067-1080. doi: 10.1130/B26595.1 Link

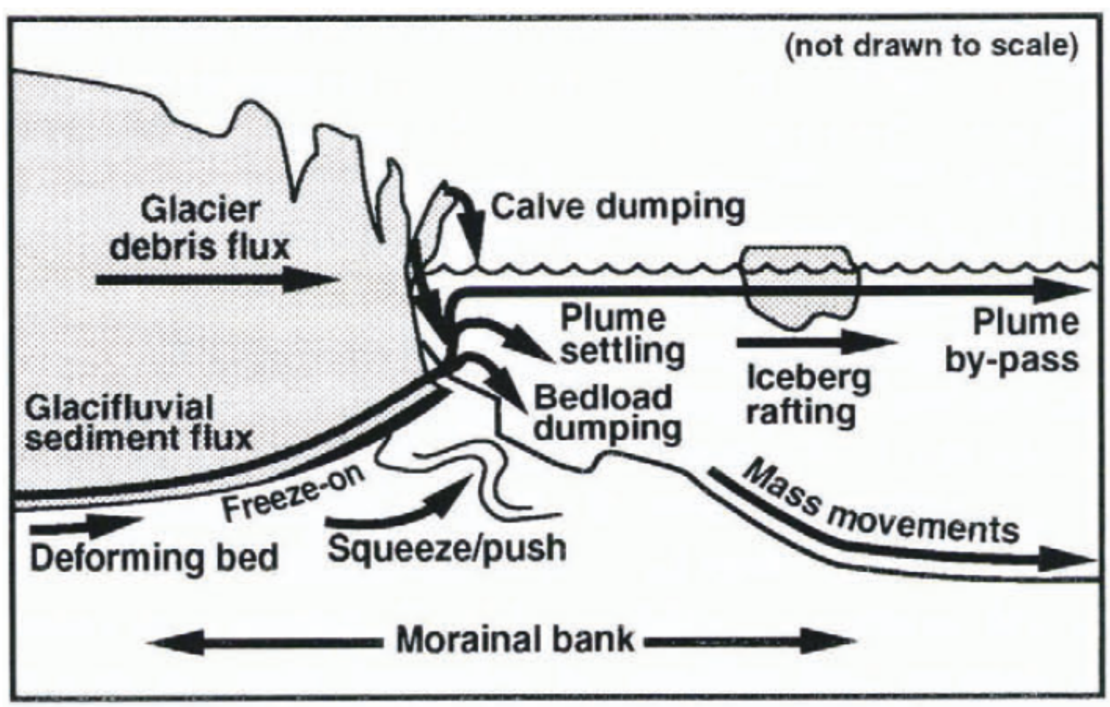
Hunter, L., Powell, R., & Lawson, D. (1996). Flux of debris transported by ice at three Alaskan tidewater glaciers. Journal of Glaciology, 42(140), 123-135. doi:10.3189/S0022143000030586. Link

Hunter, L., Powell, R., & Lawson, D. (1996). Morainal-bank sediment budgets and their influence on the stability of tidewater termini of valley glaciers entering Glacier Bay, Alaska, U.S.A. Annals of Glaciology, 22, 211-216. doi:10.3189/1996AoG22-1-211-216. Link

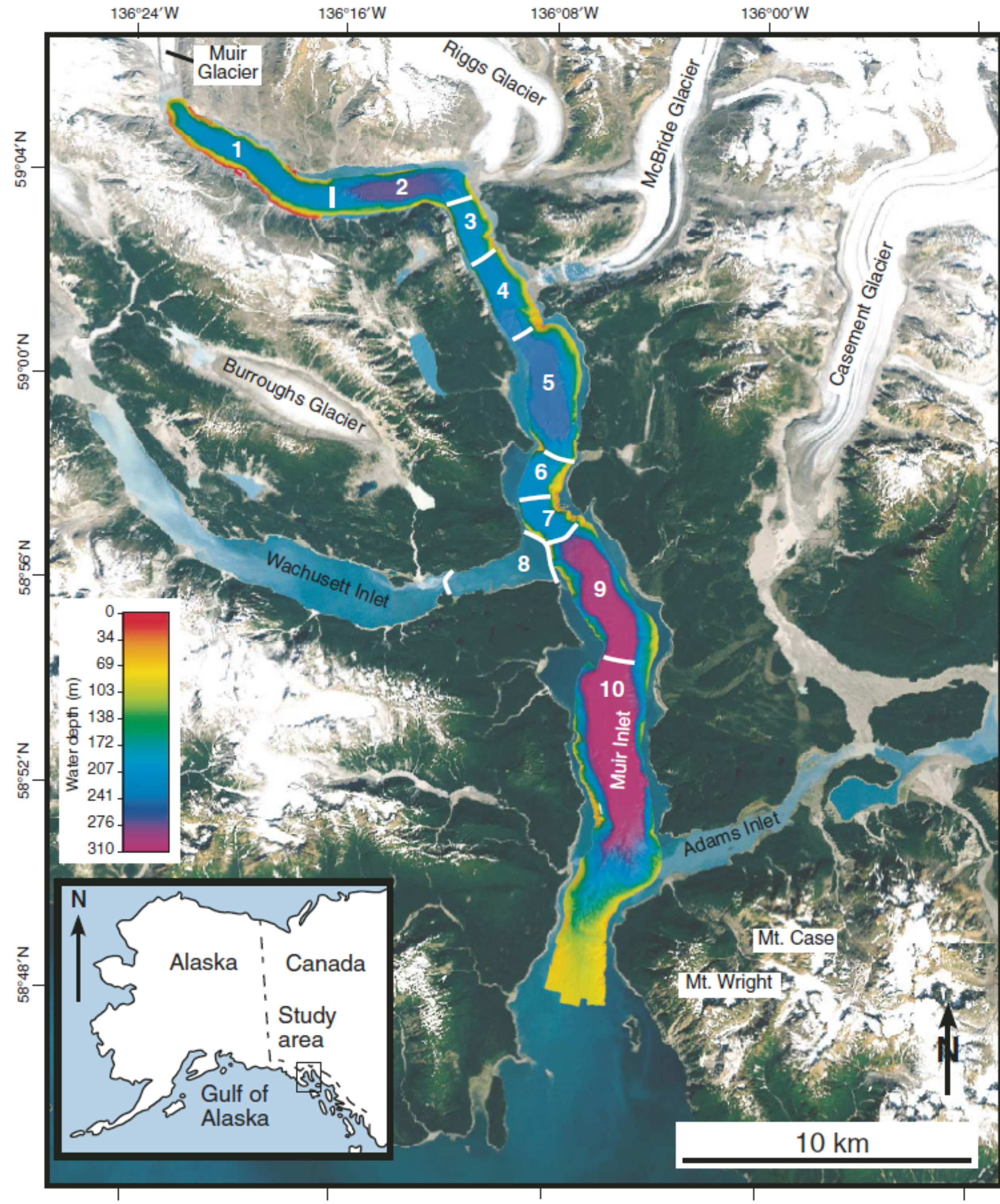
Glacier Bay hosts the fastest erosion rates measured anywhere in the world (Margerie Glacier 6 cm/yr, Cook et al 2020). This is due to (1) the highly-erodable bedrock and (2) the high sliding velocities of the glaciers caused by the maritime climate. Sediment volumes were determined by seismic studies of the bay (Cai and Powell 1995, Hunter et al 1996a and b, Cowan et al 2010). Cowan provides important context: “The sediment flux during LIA retreat should not be considered to represent only bedrock erosion supplied by varying ice flow velocities. Instead, much sediment is contributed from persistent tributary glaciers and is redistributed from bedrock highs into deep basins. Additionally, a significant volume of LIA basin fill is eroded from LGM sediment stored within the deeper basins.”



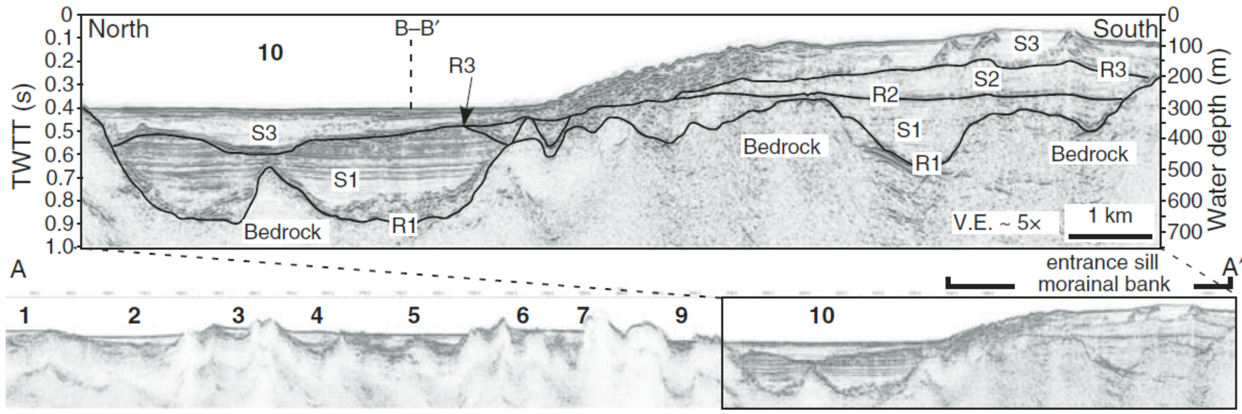
Plot by Andy Bliss with data from Cook et al. (2020).



Primary sedimentary processes at a tidewater terminus. (Hunter et al 1996)



Landsat image of Muir Inlet with swath bathymetry collected in September 2004. Muir Glacier is at the head of the fjord, and tributary glaciers are labeled. Basins discussed in the text are labeled 1–10. Cowan et al 2010.

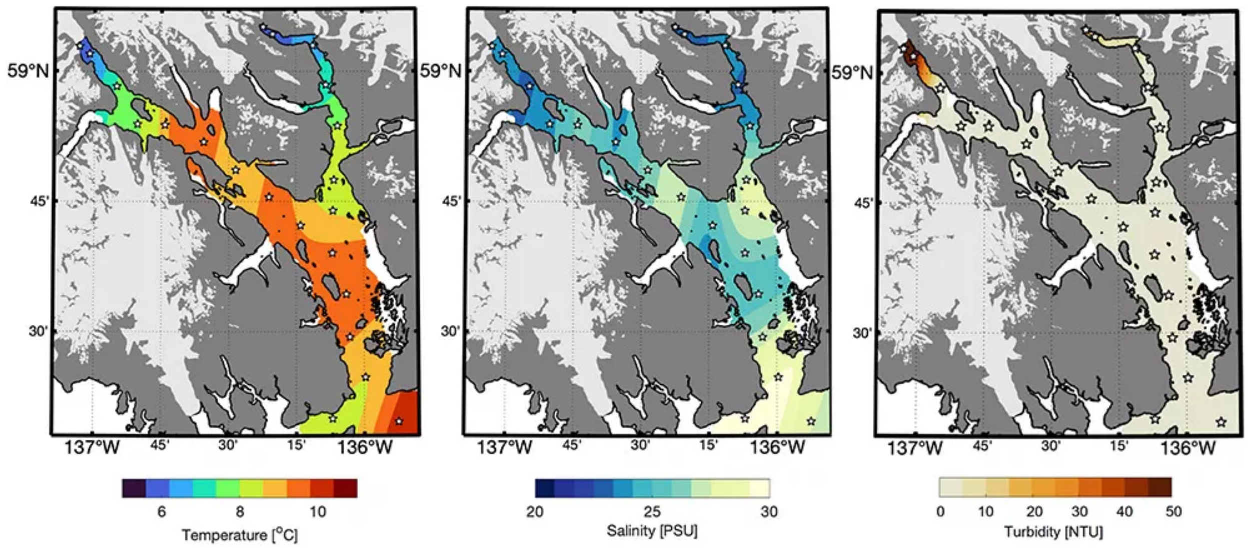


Generator-injector (GI) gun profile from A–A′. Numbered basins correspond with locations on map above. Basin 10 and the entrance sill morainal bank are shown enlarged in the inset. Shot points are shown across the horizontal axis for reference. Identified erosional reflectors (R1–R3) and depositional sequences (S1–S3) are labeled. TWTT—two-way traveltime. Cowan et al 2010.

Oceanography

Excerpt from https://www.nps.gov/articles/000/glbaoceanography2020.htm
Once filled with ice, the glacially carved fjords of Glacier Bay National Park and Preserve are now inundated with cold, nutrient-rich seawater fueling extraordinary biological productivity. Many of the park's animals, including humpback whales, brown bears, salmon, and puffins, rely upon and are influenced by the ocean. Understanding how local marine and terrestrial environments interact and change over time is critical for stewardship of Glacier Bay, one of the most pristine coastal areas in the world.

Oceanographic research has occurred in the park annually since 1993, providing data that informs conservation and management efforts. In 2009, oceanography became a "vital sign" for the Southeast Alaska Inventory & Monitoring Network. National Park Service scientists measure physical, chemical, and biological conditions for a broad understanding of how Glacier Bay functions. This monitoring program has built an extensive dataset that can be explored in a variety of ways, from tracking seasonal dynamics to detecting long-term change. From the East Arm to the West Arm, and from the far northern reaches of Glacier Bay to where park waters meet the open Pacific Ocean, the marine ecosystem varies in both subtle and dramatic ways. Core oceanographic indicators of environmental health also influence patterns in abundance and distribution of the wildlife that thrive in Glacier Bay and draw thousands of visitors each year.

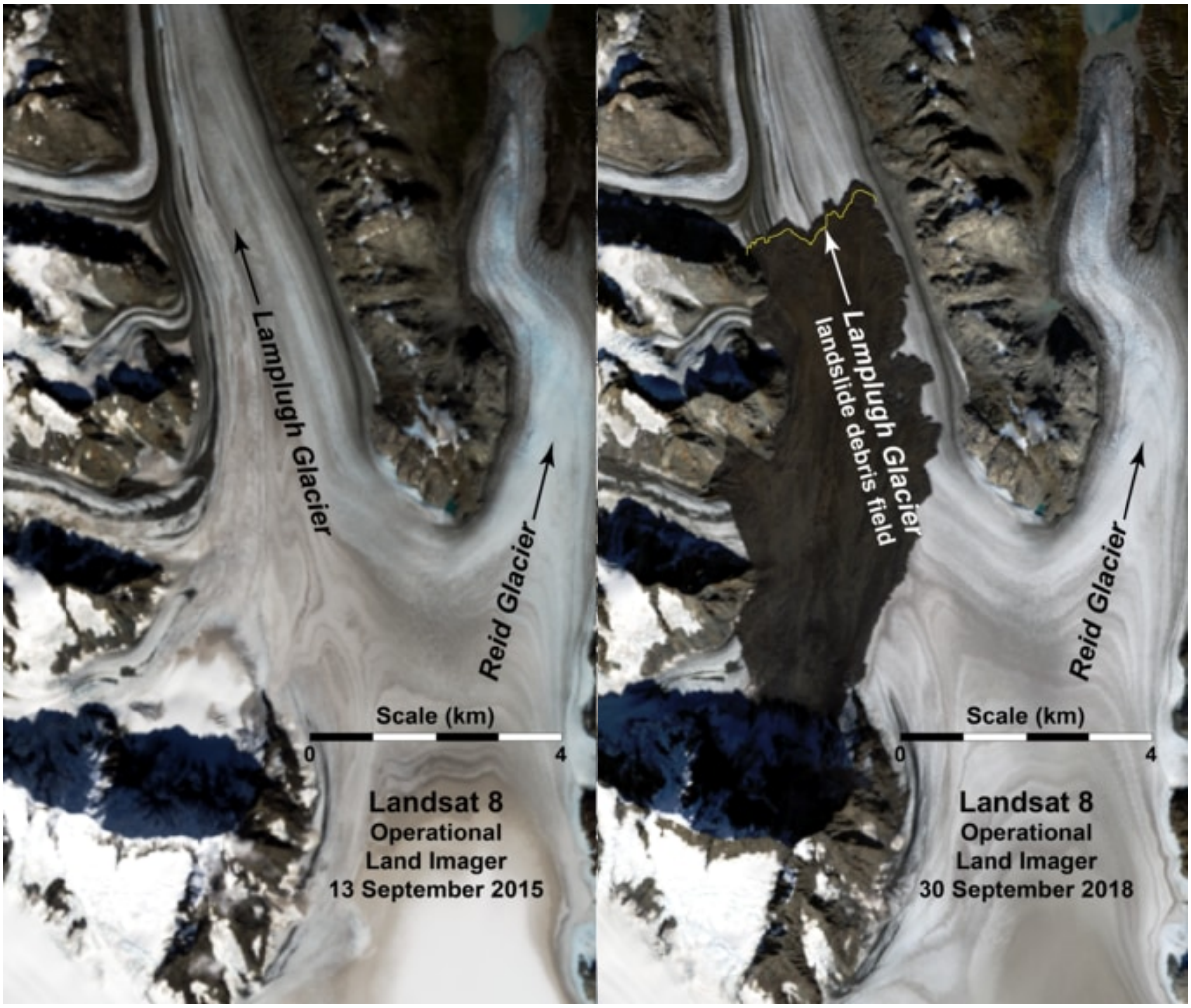


Surface water temperature (left), salinity (center), and turbidity (right) conditions throughout Glacier Bay during July 2020, with glacier coverage in light gray. Maps show 0-5 m conditions from the upper water column, the most dynamic zone directly influenced by precipitation, river inputs, glaciers, and other processes. Glacier Bay's regional differences are most distinct in the summer.

Landslide hazards

Lamplugh Glacier landslide

Excerpt from: https://svs.gsfc.nasa.gov/31042



Seismic data on 28 June 2016 indicated a very large landslide released the equivalent energy of a magnitude 5.2 earthquake in Glacier Bay National Park, Alaska. Researchers at Lamont-Doherty Earth Observatory not only identified when the 1.2 km high (4000 ft) mountainside released a mass estimated at 120 million metric tons (132 million short tons) within the Park but also additional details of the event such as how rapidly it moved. The total mass of the slide is the equivalent of some 60 million mid-size SUVs.

Tidal Inlet landslide

References:

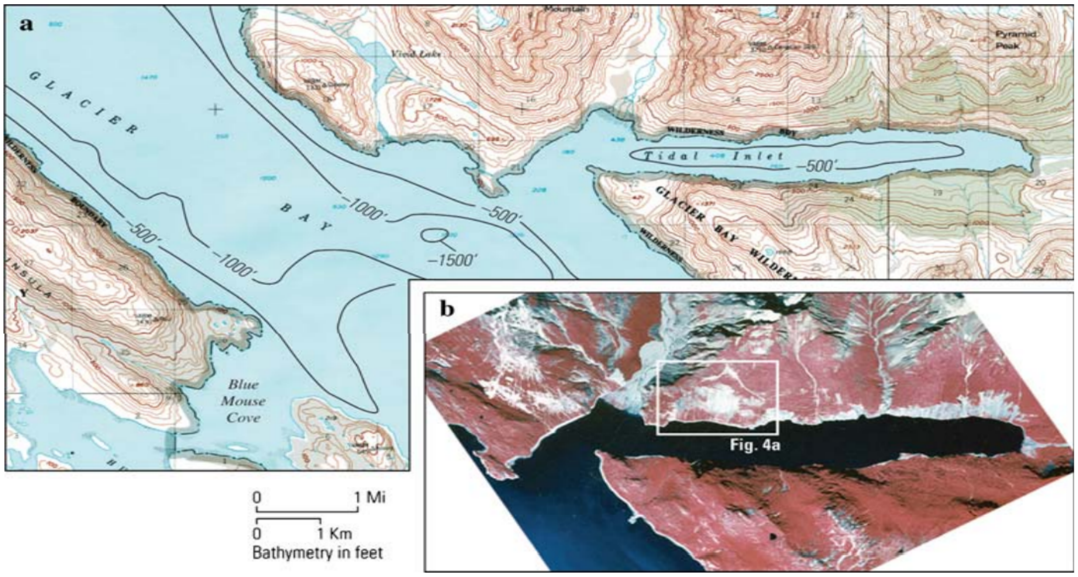
Wieczorek , G.F., E. L. Geist, R. J. Motyka, M. Jakob, 2007. Hazard assessment of the Tidal Inlet landslide and potential subsequent tsunami, Glacier Bay National Park, Alaska. *Landslides*, DOI 10.1007/s10346-007-0084-1, 11 p. Link

Hooge PN, Hooge ER, Dick CA, Solomon EK (2000) Glacier Bay oceanography and the oceanographic analyst GIS extension: CD-ROM set. US Geological Survey, Alaska (No link)

https://www.nps.gov/glba/planyourvisit/landslides-and-giant-waves.htm

https://www.nps.gov/articles/aps-18-1-4.htm

Excerpt from Wieczorek et al 2007:
An unstable rock slump, estimated at 5 to 10×10^6 m^3, lies perched above the northern shore of Tidal Inlet in Glacier Bay National Park, Alaska. This landslide mass has the potential to rapidly move into Tidal Inlet and generate large, long-period impulse tsunami waves. Field and photographic examination revealed that the landslide moved between 1892 and 1919 after the retreat of the Little Ice Age glaciers from Tidal Inlet in 1890. Global positioning system measurements over a 2-year period show that the perched mass is presently moving at 3–4 cm annually indicating the landslide remains unstable. Numerical simulations of landslide generated waves suggest that in the western arm of Glacier Bay, wave amplitudes would be greatest near the mouth of Tidal Inlet and slightly decrease with water depth according to Green's law. As a function of time, wave amplitude would be greatest within approximately 40 min of the landslide entering water, with significant wave activity continuing for potentially several hours. A catastrophic, rapid failure of the landslide would result in a significant hazard to park visitors in the vicinity of Tidal Inlet. Modeling indicates that the maximum volume slide would generate very high waves (tens of meters in amplitude with possible greater-than-100-m wave runup) near the source in Tidal Inlet. Depending on the timing and impact direction, there is a considerable chance of waves impacting ships in the West Arm.



a) *Topographic map of Tidal Inlet with a contour interval of 100 ft. General landslide region within white box in both figures. Simplified bathymetry from Hooge et al. (2000).* ***b)*** *Portion of aerial photograph showing Tidal Inlet landslide impact region into Tidal Inlet shown within the white square.*

Landslide perched above the northern shore of Tidal Inlet. Peak at the top right edge of the photo is about 1,130 m high. In the lower left, the distance across Tidal Inlet is about 800 m. Photograph taken on July 12, 2002.

Marine mammals

Excerpt from https://www.nps.gov/glba/learn/nature/mammals.htm with additional references added.

Harbor Seal *Phoca vitulina richardsi*

Harbor seals have a dappled gray coat that can be highly variable between individuals. A thick layer of fat allows them to keep warm in otherwise chilling conditions. Unlike the sea lion, harbor seals have no external earflap and when out of the water, cannot support themselves on their flippers. On ice floes, they resemble plump sausages that move around by scooting on their ample bellies. In the water, they display admirable grace as they hunt for fish. Up to 1,700 seals converge in Johns Hopkins Inlet each summer for pupping and mating. Ongoing research in the park indicates that the population in the inlet has declined 75 percent in the past decade.

References:

Womble, J. N., P. J. Williams, R. W. McNabb, A. Prakash, R. Gens, B. S. Sedinger, and C. R. Acevedo. 2021. Harbor seals as sentinels of ice dynamics in tidewater glacier fjords. Frontiers in Marine Science. Link

Womble, J. N., J. M. Ver Hoef, S. M. Gende, and E. A. Mathews. 2020. Calibrating and adjusting counts of harbor seals in a tidewater glacier fjord to estimate abundance and trends from 1992-2017. Ecosphere 11(4): e03111. Link

Sea Otter *Enhydra lutris*

The Glacier Bay sea otter population has rebounded from zero to almost 9,000 in the last 20 years. Voracious eaters of shellfish like crabs and clams, they exert a strong influence on their environment and scientists anticipate dramatic changes will take place in the underwater world of Glacier Bay. Sea otters perform many of their daily tasks such as eating, bathing, and sleeping while floating on their backs. Lacking a thick layer of blubber, otters instead have the densest fur of any mammal with up to one million hairs per square inch. Generally dark brown, their faces get whiter as they age.

References:

Lu, X., P. J. Williams, M. B. Hooten, J. A. Powell, J. N. Womble, and M. R. Bower. 2019. Nonlinear reaction–diffusion process models improve inference for population dynamics. Environmetrics e2604. Link

Williams, P. J., M. B. Hooten, G. G. Esslinger, J. N. Womble, J. L. Bodkin, and M. R. Bower. 2019. The rise of an apex predator following deglaciation. Diversity and Distributions 00: 1– 14. DOI: 10.1111/ddi.12908 Link

Williams, P. J., M. B. Hooten, J. N. Womble, and M. R. Bower. 2017. Estimating occupancy and abundance using aerial images with imperfect detection. Methods in Ecology and Evolution 2017;00:1-11. Link


Steller Sea Lion *Eumetopias jubatus*
Like all members of the eared seal family Otariidae, Steller sea lions can support themselves on their flippers while ashore, and their rear flippers pivot, allowing them to get around with surprising speed. In the water they become fluid, executing a seemingly endless series of underwater flips, turns, and rolls. Mature males can weigh almost 2,000 pounds, though females average only 600 pounds. During mating season, large bulls compete at established rookery sites on Glacier Bay's outer coast to collect harems of females. Unsuccessful and immature males often congregate at haul-out areas like South Marble Island. Though the number of sea lions is growing in Glacier Bay, the population in Western Alaska has decreased by 80 percent since the late-1970s leading to that portion of the population's current listing as endangered.
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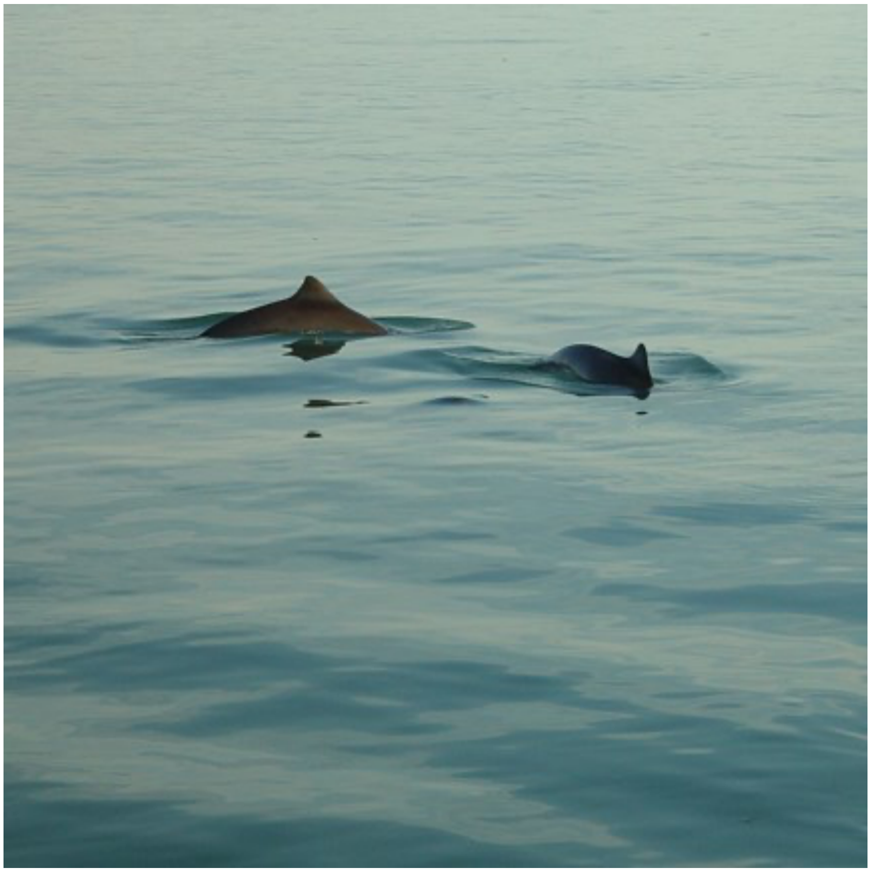

Harbor Porpoise *Phocoena phocoena*

At five feet long and about 120 pounds, harbor porpoise are the smallest cetaceans in Alaska waters. Often seen in groups of two to ten throughout the bay, they announce themselves by offering a brief glimpse of their small triangular dorsal fin cutting slowly through the water's surface when they come up to catch a breath. Harbor porpoise are generally dark gray with a slightly pointed face. They do not ride bow waves, like their relative the Dall's porpoise. Dall's porpoise are larger (6.4 feet and 300 pounds) and resemble small orcas in their black and white coloration. Though Dall's porpoise can be seen in the bay, they are more often seen near the entrance and in Icy Strait.

Humpback Whale *Megaptera novaeangliae*
Seeing a humpback whale in Glacier Bay is an unforgettable experience for many visitors. The true giants of Glacier Bay's waters, these endangered animals are 40-50 feet (12-16 m) long and weigh over 35 tons (32,000 kg). The humpback is a baleen whale that migrates seasonally. Most Glacier Bay whales swim to Hawaii each winter to mate and give birth, a 2,500-mile (4,000 km) journey that takes about a month each way. These whales do not eat while they are wintering in the tropics. All spring, summer, and fall in Alaska, they gorge themselves on high-calorie small schooling fish such as capelin and herring.
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Fish

Excerpt from https://www.nps.gov/glba/learn/nature/fish.htm
Glacier Bay National Park and Preserve protects million acres of rugged mountains, temperate rainforest, bountiful coastline, deep fjords, open ocean, rich estuaries, wild rivers, lakes, streams and ponds, and a plethora of fish! This complex and dynamic, temperate ecosystem has nearly 1200 miles of coastline, including 950 square miles of ocean habitat and greater than 1000 freshwater systems of available fish habitat for over 200 fish species. From the smallest forage fish like Pacific herring and sandlance to deepwater giants such as 500 pound Pacific halibut and 14-foot sleeper sharks, fish play critical roles in Glacier Bay's rich ecosystems.

Pacific sandlance (top), Pacific herring (middle), capelin (bottom) M. Arimitsu

Small schooling forage fishes include capelin, sand lance, herring, juvenile walleye pollock, juvenile salmonids and myctophids (lanternfish). Though individually small, these fishes are unbelievably numerous, often swimming in large, dense schools. As a key food source, they serve as a critical link between marine primary and secondary producers (phytoplankton and zooplankton) and are prey for fishes, birds, harbor seals, Steller sea lions and even humpback whales.

Numerous studies have documented capelin as important forage species for many sea birds and marine mammals in the Gulf of Alaska. Capelin were extremely abundant and widespread in the Gulf of Alaska until the late 1970's when they became almost absent. Increased water temperature and predation are implicated in the mass decline of this important species. Recent research in Glacier Bay suggests that glacial fjords may serve as critical refuges for capelin during warmer temperature cycles in the Gulf of Alaska. Research suggests that these important fish are strongly associated with the tidewater glacier ecosystem in Glacier Bay and could help to replenish the Gulf of Alaska if water temperatures again decrease.

East Alsek sockeye salmon in full spawning color. NPS / C. Murdoch

Adult salmon are unparalleled contributors to Glacier Bay National Park's ecosystems. Much like small schooling fishes, salmon feed a diversity of other animals and are particularly unique because they link marine, freshwater and terrestrial habitats. Salmon are anadromous, which means they migrate upriver from the sea to spawn in their birth streams after spending 1 to 5 years maturing in the marine environment. Some salmon increase their body weight 1000 times at sea. When they return to their natal stream to spawn and die, salmon bring all the marine derived nutrients they consumed in the ocean back to their freshwater streams. These nutrients feed and fertilize aquatic plants, insects, and other organisms, and ultimately provide food for their own offspring. Salmon fertilize the forest too. Bears, otters, mink, eagles, and other forest animals feast on adult salmon, often leaving their carcasses half eaten and decomposing...bathing the forest with ocean nutrients.

Glacier Bay National Park was expressly established for the study the successional ecological processes following rapid deglaciation. Researcher Dr. Sandy Milner is doing just that with his 35 year study of stream succession and fish colonization in Glacier Bay. His research is not only the longest running study in the park but also the longest continuous study of primary succession in streams anywhere. Dr. Milner's important work has elucidated the incredible changes that streams undergo after they are born from retreating glaciers. One of many important findings is that Dolly Varden and straying pink salmon may colonize a new stream in just 10 years!

Land animals

Moose *Alces alces*

The largest member of the deer family is a recent newcomer to Glacier Bay. The first moose was spotted here in the late 1960s. Despite their tremendous size (bulls can weigh 1,600 pounds and cows 1,300 pounds), they can appear and disappear in thick brush with surprising stealth. Moose are usually solitary, except for cows with calves and during the fall rutting season. Cows give birth in the spring to one or two small, reddish calves. A calf will stay with its mother for two years before the cow drives it off as she prepares to have more young. Their diet includes willow leaves, grasses, herbs, and aquatic vegetation. Only bulls grow antlers.

Porcupine *Erethizon dorsatum*

You may find this prickly member of the community high up in a cottonwood tree nibbling tasty tender leaves. Except for their footpads and nose, porcupines are completely covered with yellowish fur and quills, which are actually modified hairs tipped with barbs. A threatened porcupine will turn its back-end toward the source of trouble to present an intimidating display of quills that firmly suggests the would-be predator reconsider its dinner plans. This large rodent (second largest in North America behind the beaver) performs a broad repertoire of grunts, whimpers, and screams. Listen for them in the evenings "talking" to no one in particular.

Mountain Goats *Oreamnos americanus*

Mountain goats have thick white coats of hollow hairs that help to keep them warm in extreme weather. Goats may have been among the first land animals to recolonize Glacier Bay after the ice retreated, coming over the mountains from Lynn Canal to the east. They are at home on the steep rocky cliffs in the mid-to-upper bay. The special shape and design of their hooves allows them to leap nimbly from ledge to ledge in search of grasses, herbs, and low-growing shrubs. Seen at a distance, they can be mistaken for Dall sheep, which are found in interior Alaska, rather than Glacier Bay.

Red Squirrel *Tamiasciurus hudsonicus*

If you see a little red flash zipping up a tree trunk or leaping nimbly among the branches, chances are it is a red squirrel. These agile rodents spend their summer preparing for winter by collecting and storing green spruce cones in their middens, mounds of cones at the base of a tree. A red squirrel can harvest 12,000 to 16,000 spruce cones a year. Other favorite foods include mushrooms and seeds. Like forest alarms, they chatter unrelentingly when a threat—like you—is near.

Glacier Bay Bears

Glacier Bay National Park is home to both brown bears, Ursus arctos, and black bears, Ursus americanus. Black bears are primarily creatures of woodlands and are found among the forested areas of the lower bay, including Bartlett Cove. In contrast, park biologists have recently discovered that brown bears inhabit virtually every part of Glacier Bay, from the barren glaciated areas to lush old-growth forests.

Although it is not always a given that a visitor will see a bear in Glacier Bay, there are very few beaches on the bay's 1,100 miles of coastline where sign of bear activity is not visible. Bears thrive in a variety of habitats, and their strategy for survival is to constantly explore their surroundings for new food sources. Most of the islands in the bay are visited routinely by bears, and one can expect to find them almost anywhere. They are always a thrilling sight when spotted on their mostly solitary rambles along Glacier Bay's beaches.

References:

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Plants and post-glacial succession

Excerpt from https://www.nps.gov/glba/learn/nature/plant-life.htm
With pictures from https://www.nps.gov/glba/learn/nature/succession.htm
Glacier Bay provides the premier example in the world of how vegetation returns to a landscape following deglaciation. There, on moist lowland surfaces for example, post-glacial barrens succeed from tundra, through shrub land to young forest in about 250 years. Forests of ages 400-1800 years on moraines delimiting Lituya, Yakutat and Dundas Bays provide insights into later stages of forest development.

Mature vegetation of the Glacier Bay region can be subdivided into eight categories. At the shore, a few salt-tolerant species form productive salt marshes. At and above extreme high water, a lush, diverse beach meadow dominated by grasses and large umbels such as cow parsnip is often present. Beach meadow are a distinctive feature of the Glacier Bay region, where high rates of post-glacial rebound have caused the sea to recede faster than the forest can come forward. These biotically important meadows are often backed by a narrow band of alder and then the forest.

Lowland forests are dominated by Sitka spruce and western hemlock, plus cedar near the outer coast and toward the south. Moss, ferns, evergreen herbs and shrub species such as blueberry, menziesia and devils club cloak the ground, except where an even-aged forest canopy admits too little light to support undergrowth. With increasing elevation, mountain hemlock supplants western hemlock.

Forested lands generally form an unbroken cloak on southeast Alaska landscapes unless interrupted by disturbance, wetness or altitude. Disturbance can take many forms, such as avalanche, snow creep, flooding, disease, insect infestation, glacial advance, wind throw and logging. Infrequent or small scale disturbance does not erase the forest. In fact, it increases diversity by creating a mosaic of different ages, admitting light to the forest floor, making some of the region's best wildlife habitat.

Most trees take a long time to reestablish, however, so forest cannot persist if disturbance is too frequent or severe. It is replaced by shrub land, which can generally stand more punishment and bounces back faster if erased. Alder, salmonberry and copper bush withstand the deep snows of the sub alpine, and can extend far downhill in avalanche chutes, where they are joined by elderberry, devils club and currants. Willow and alder are prominent in river valleys frequently disturbed by flooding.

Forest habitat also gives way in places too wet to sustain good tree growth. Such conditions are encouraged by relatively level topography or impervious sediments such as silty glacial sediments or raised marine deposits. Wetness due to topography may be further exacerbated by soil hardpans and acidic, spongy peatmoss, resulting in a bog community. Here stunted trees and sparse heath shrubs eke out a sparse living on an-ever-thickening mantle of mossy peat which insulates the plants from access to minerals in the underlying rocks and sediments. At peat land edges where groundwater has contact with the substrate, or in young wetlands where the processes of bog formation are in their infancy, more productive sedge-dominated fens may form.

With increasing altitude, tree growth is first impeded, then halted by low summer temperatures, wind, and damage from snow creep or avalanche. Often a zone of brush interposes, but sometimes forest gives way directly to lush sub-alpine meadows much like those just above the tide. Farther up, where summers are brief indeed and winter winds tend to blow away protective mantles of snow, tundra mats of prostrate shrubs, tiny herbs, mosses and lichens predominate among the permanent snowbirds. Even higher, bare rock and ice reign supreme.