Ice$_2$O

Capturing change in the icefield-to-ocean ecosystem of southcentral Alaska

Shad O'Neel

Jamie Shanley, Daniel Otto, Anna Bergstrom, Josh Koch, Johnse Ostman, Emily Baker, Chris McNeil, Caitlyn Florentine, Louis Sass

USGS (AK, VT, MT) CU Boulder

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AK CASC

Wolverine Glacier: 2012- 2019

USGS Benchmark Glacier Program

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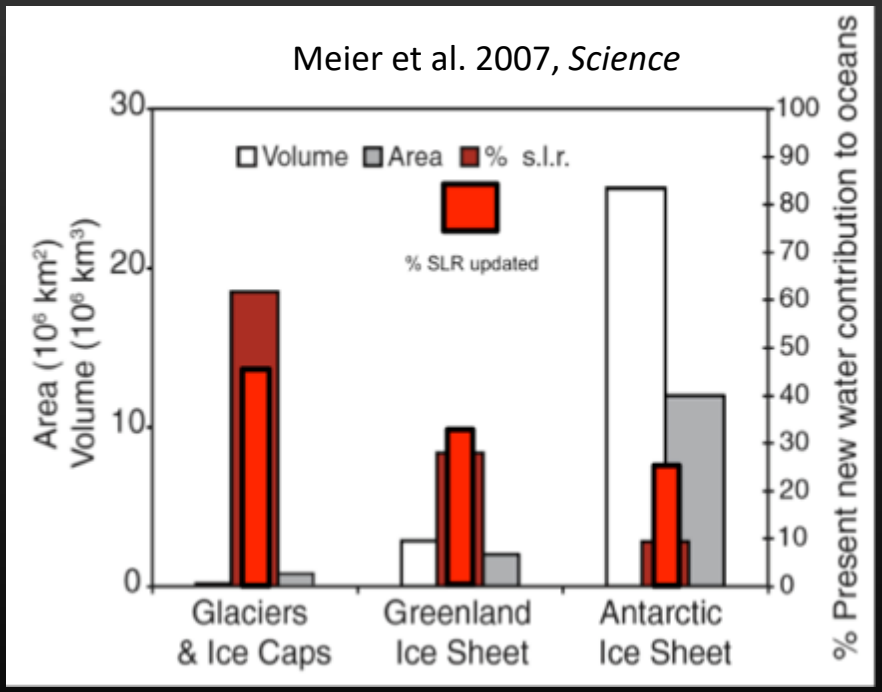
Motivation

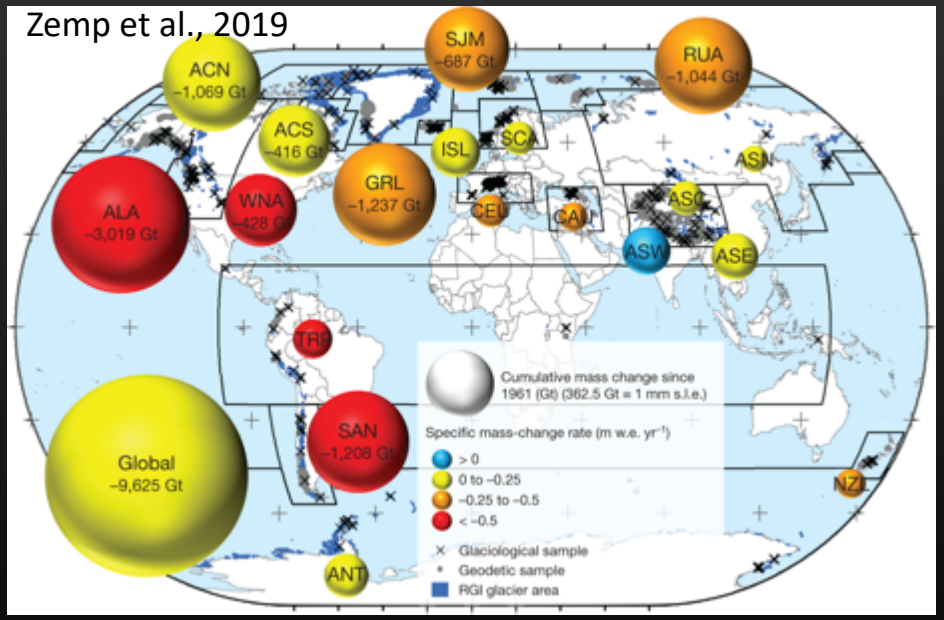
<u>Global- to local-scale motivators</u>

Climate, sea level, ecosystem function, infrastructure and tourism

Meier et al. 2007, *Science*



Zemp et al., 2019



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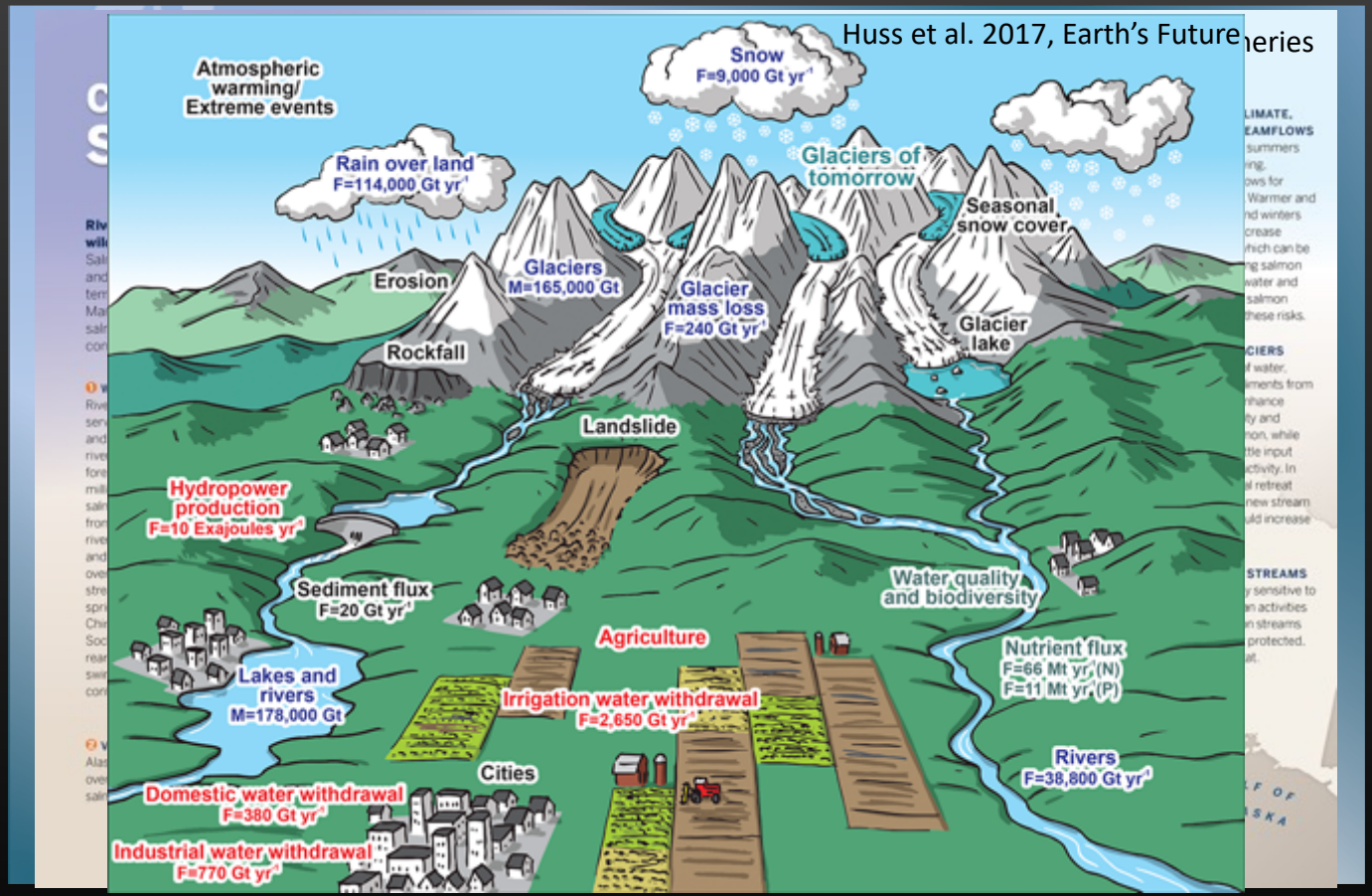
Connections

Emerging science topic: Glaciers are connected to ecosystems, but observations to support/constrain existing conceptual models are scarce



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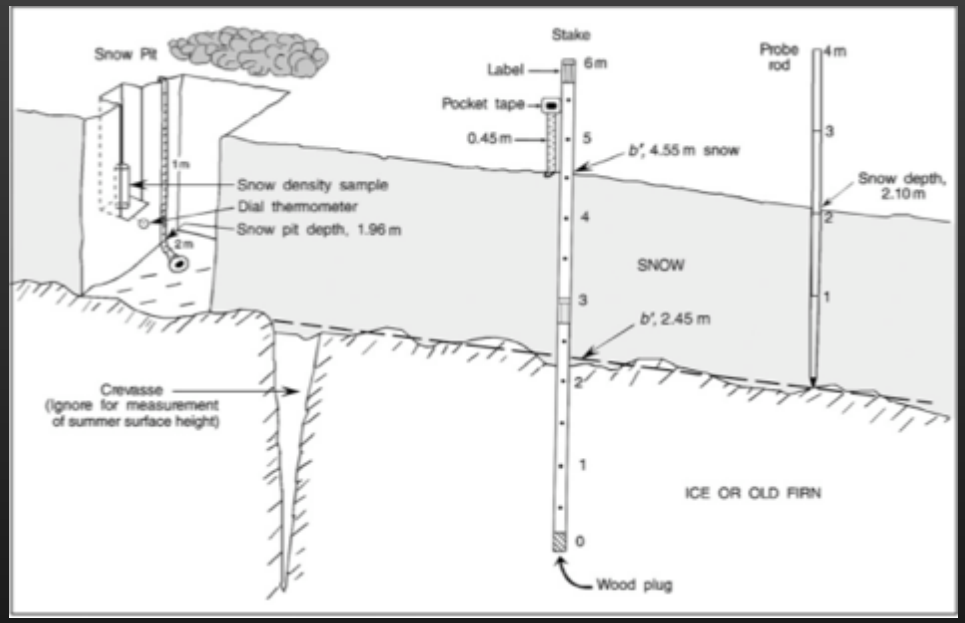
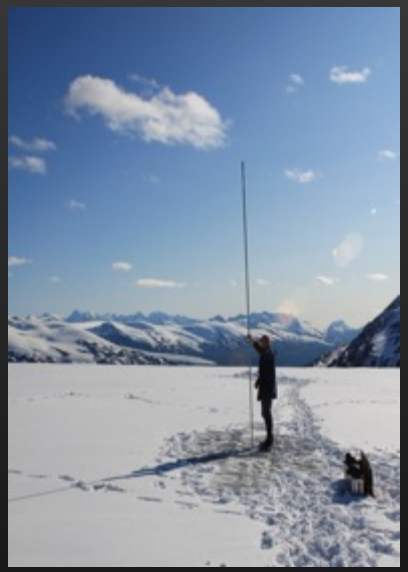
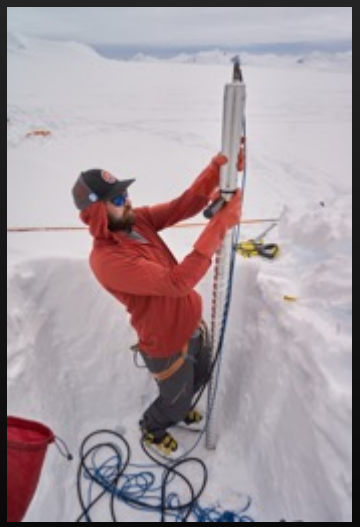
Measuring glacier change

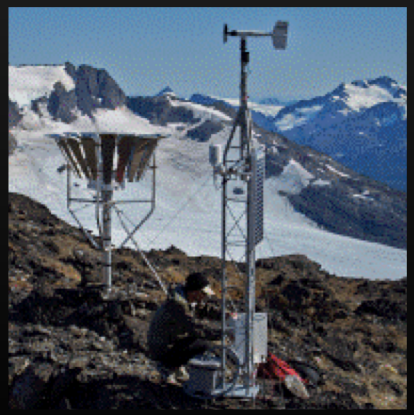
Mass balance: change in mass of a glacier over a stated span of time *Cogley et al., 2011*

Begin with point measurements









Local weather stations provide forcing for sub-seasonal modeling and long term climate evolution

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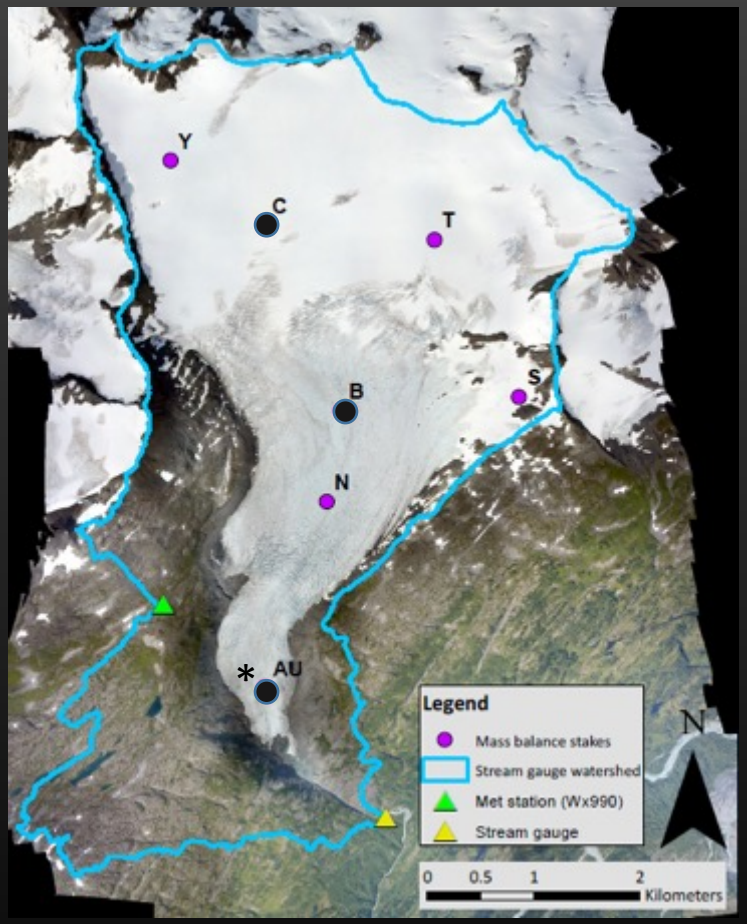
Measuring glacier change

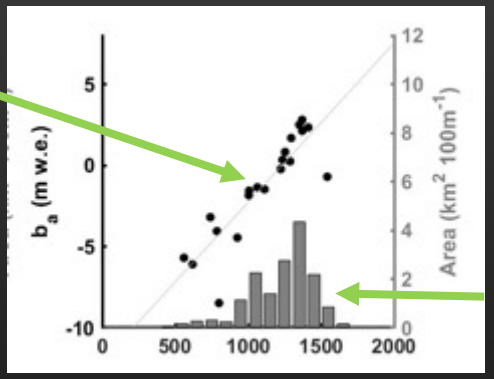


● – Long term sites
● – Established in 2009

First, parameterize with elevation.
Then, extrapolate over the glacier.

Balance profile

b(z)



area(z)

Point measurements of accumulation and melt are integrated over the glacier area.

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USGS Benchmark Glacier Project

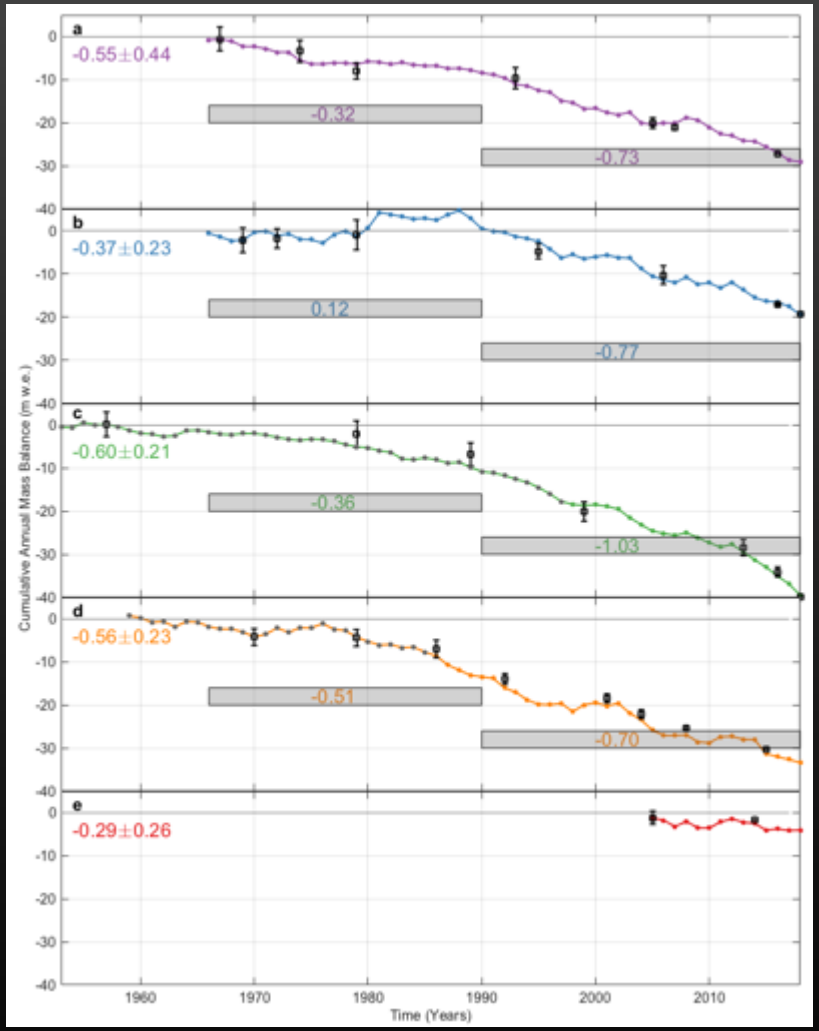
Gulkana, AK
- Interior/continental
- 1967- pres.
- 31 / 16 km^2 basin/glacier

Wolverine, AK
- Maritime/coastal
- 1967 – pres.
- 24 / 15.5 km^2

Lemon Creek, AK
- Maritime, southeast
- 1953 - pres.
- 32/ 9.5 km^2

South Cascade, WA
- Maritime
- 1957 – pres.
- 6.1/ 1.8 (ish) km^2

Sperry, MT
- transitional
- 2005 – pres.
- 4 / 0.8 km^2



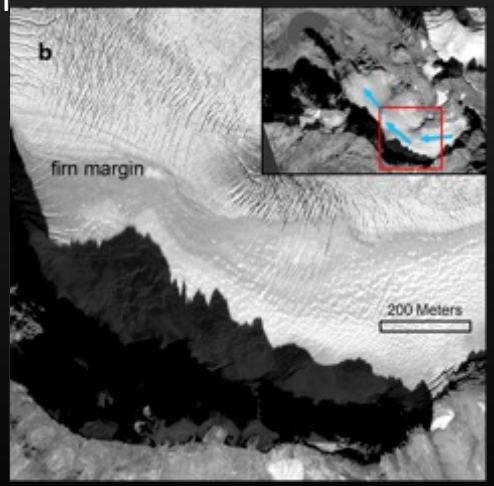
All glaciers lost mass, faster after 1990

Winter buffering for maritime less important today

Warmer summers explain the losses

Highest interannual variability at Wolverine (maritime) lowest at Lemon Creek (maritime)

Elevation-independent processes crucial



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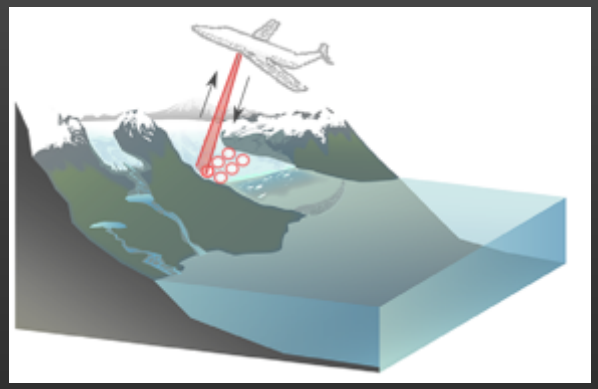
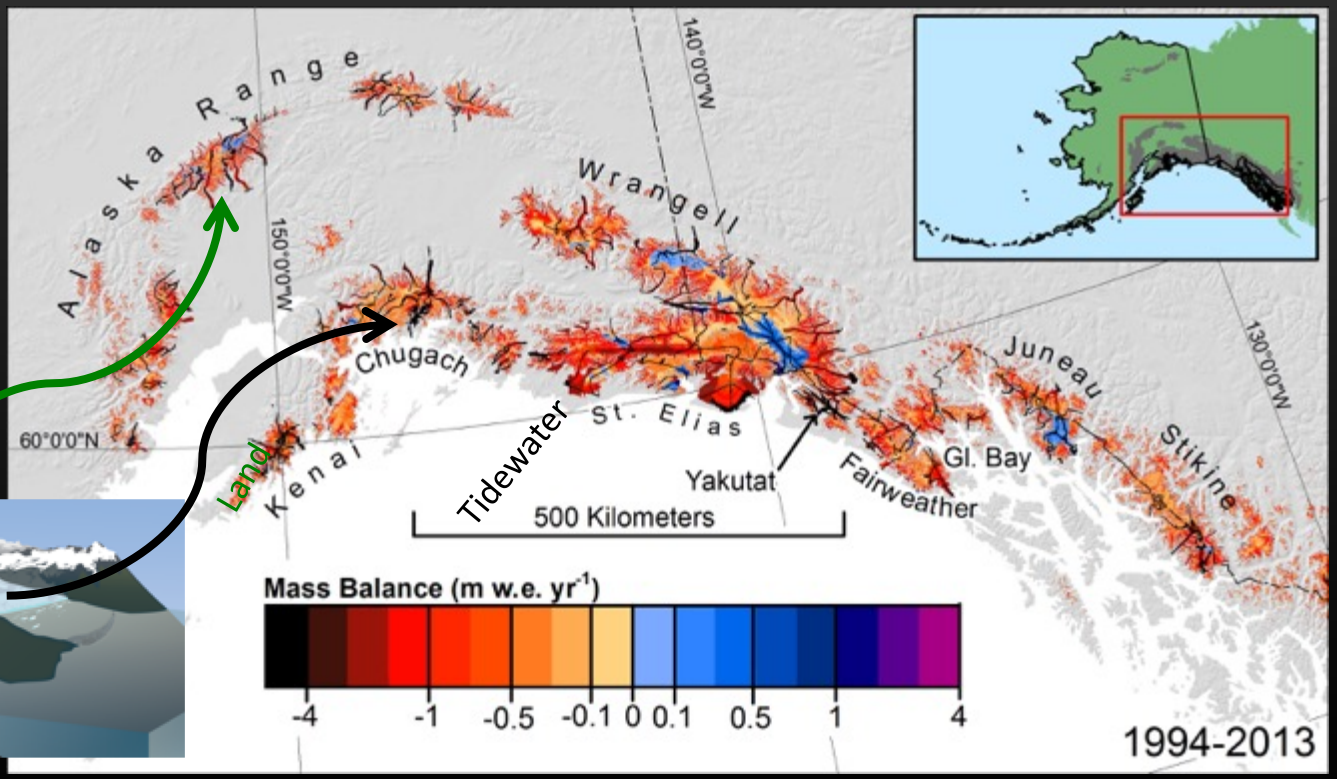
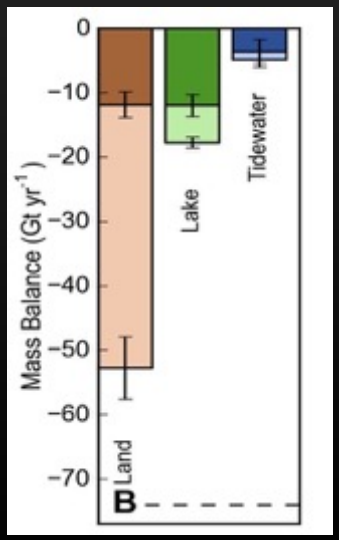
Alaska's changing ice



- Repeat glacier surface elevations measured using airborne laser altimetry (NASA IceBridge)
- ~40% directly measured, extrapolated to all 87,000 km^2 of ice in Alaska/northern Canada
- Dynamic partitioning by terminus type
- Nearly all glaciers were thinning and losing mass (red colors) during the 20 year period

Larsen et al 2015 GRL





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Connecting glaciers to the ecosystem

- What is the role of land ice in water and nutrient budgets as exported into the nearshore ocean?
- What are the important seasonal controls on water and solute fluxes?
- How will these budgets change as ice cover diminishes? Will changes be focused in magnitude, timing or both?

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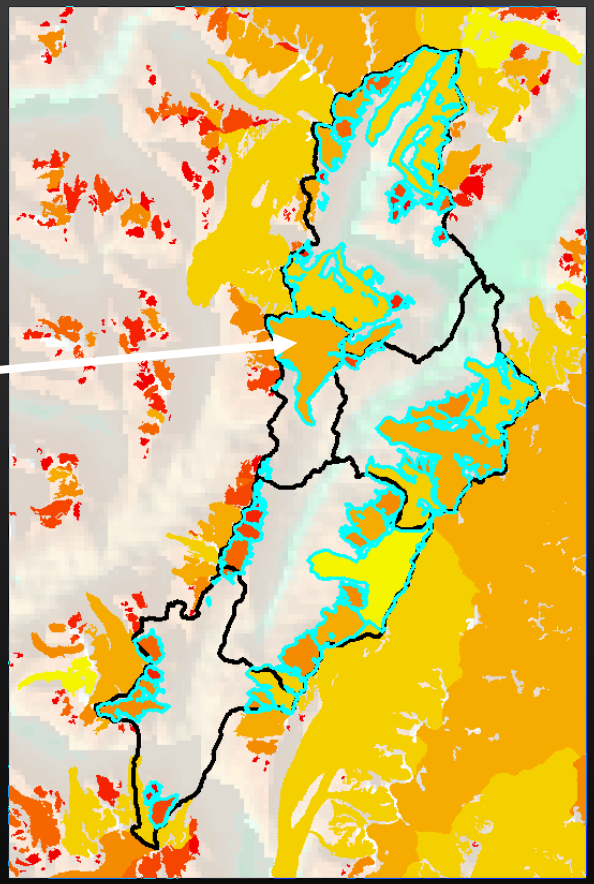
Ice_2O

Projections of change in Nellie Juan watershed

Wolverine Glacier

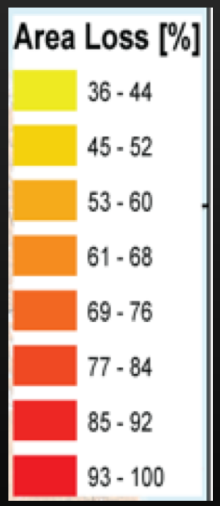


Most/all glaciers will undergo significant mass/ area loss by the end of the century

Changes in area and thickness

Small glaciers changing the fastest

2100



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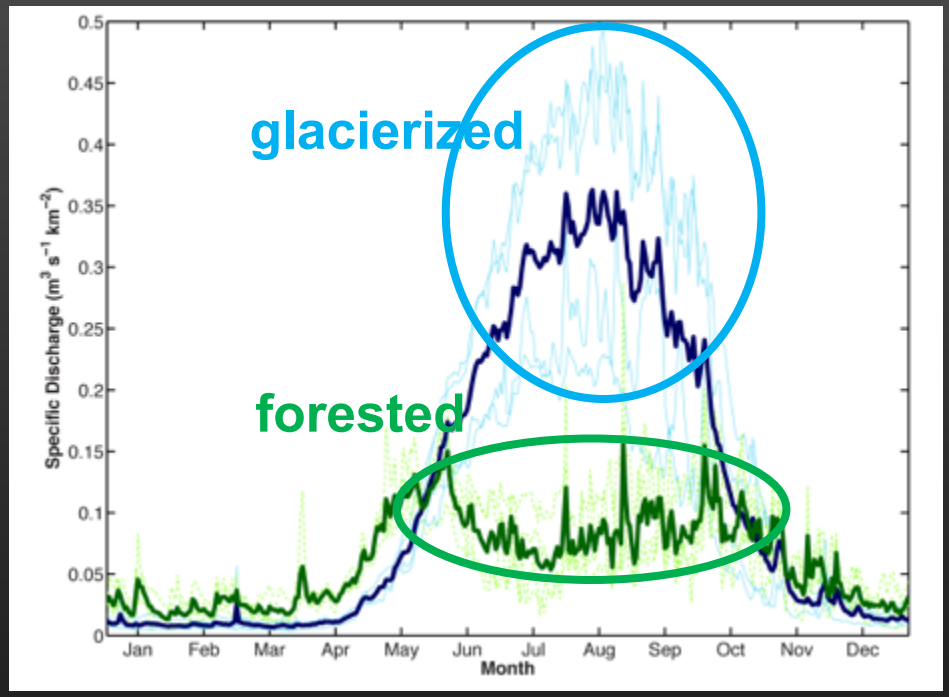
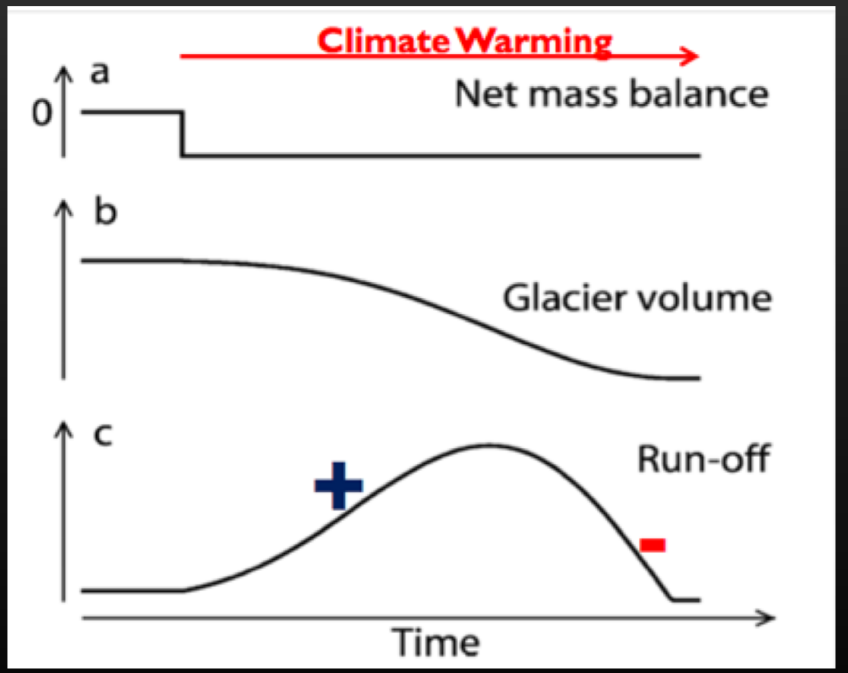
Its all about the water: Glacier hydrology



O'Neel et al, 2015, Bioscience

Runoff Timing
Physical properties of water
Chemical properties of water



Jansson et al. 2003

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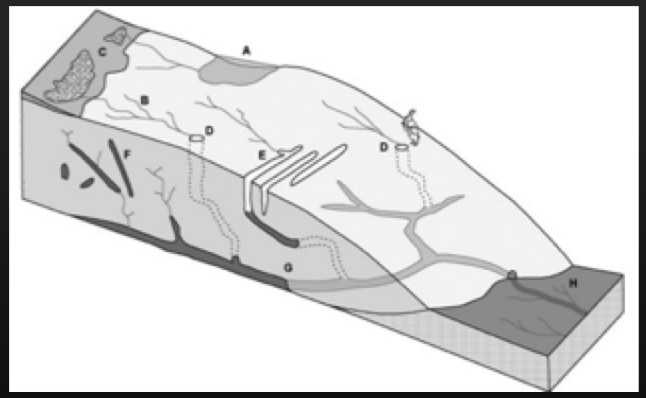
Water Cycle Viewpoints

Hydrologist view

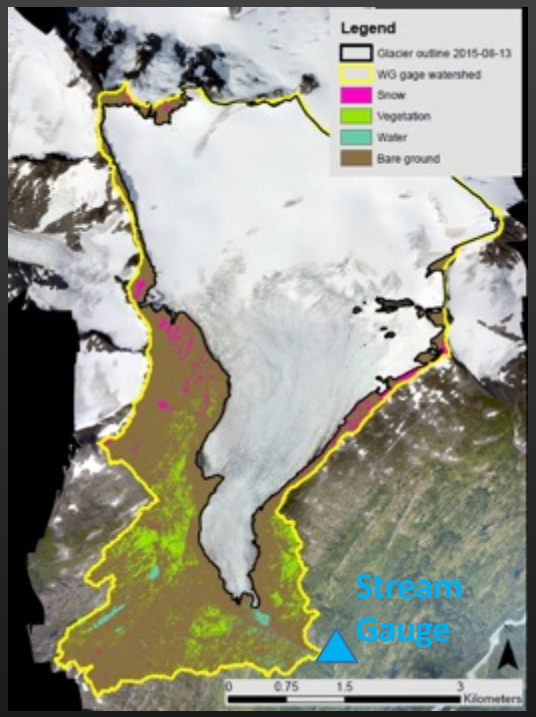
Ice disconnected

Glaciologist view



Water leaves glacier and is forgotten

How will basin yield evolve as the glacier disappears?



How will nutrient fluxes change?

Water Balance

$$\Delta S = P_{on} + P_{off} + B_a - Q - ET$$

S = storage
B = glacier volume change
ET = Evapotranpiration

P = precipitation
Q = river discharge

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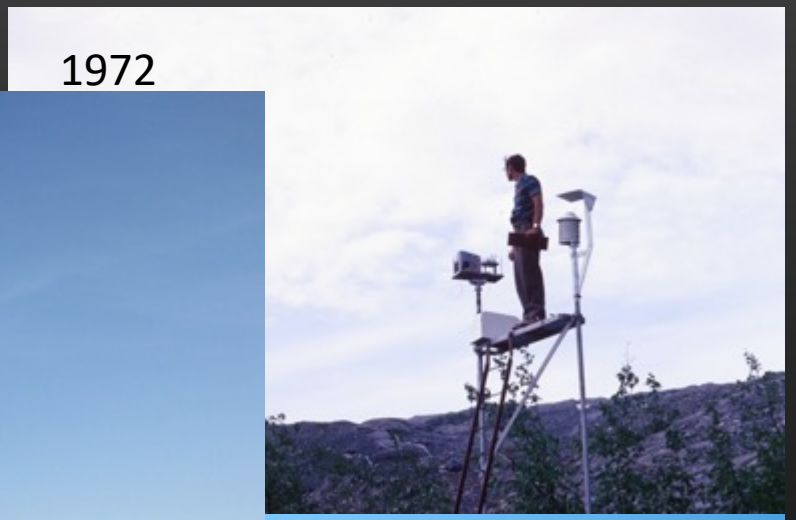
Lessons from the water budget

Precipitation is tough – instruments, point vs distributed; storm vs season; wind redistribution
Snow dominates rain, but less than it used to (more rain in winter).
Snow sticks to the glacier (75-80% snow) better than the ground (35% real estate)
Mass turnover exceeds volume change by x8-9
ET is non-negligible and increasing



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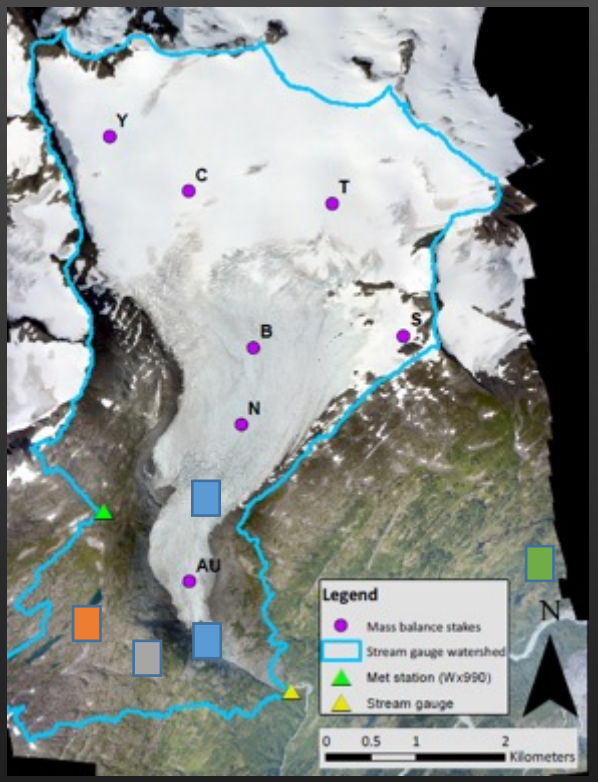
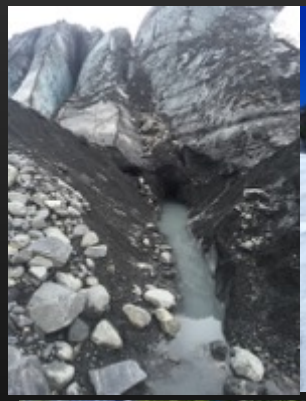
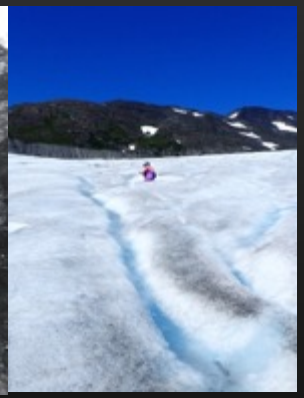
Spectrum of source waters

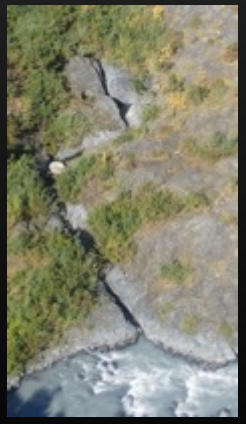
End-member ecosystems in close proximity but highly isolated

- Glacier
- Tundra
- Groundwater
- Forest
- Mixed









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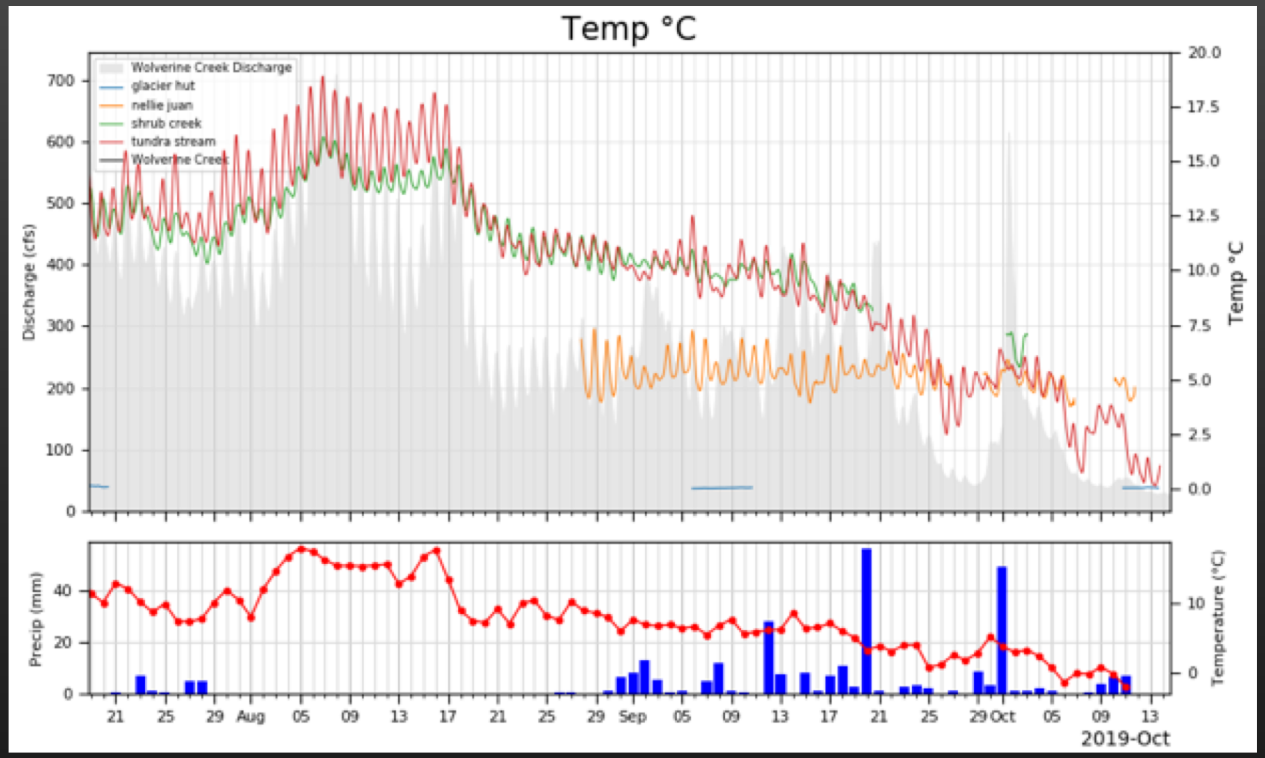
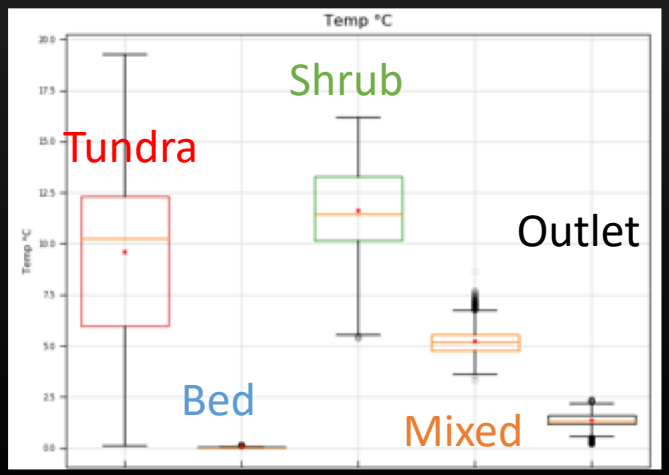
Example – Water Temperature



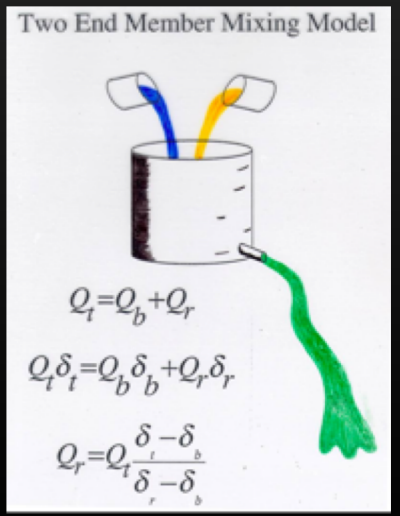


High flux, low concentration system

Strong source-dependent signatures

Microbial signature from glacier water

Allows for mixing model development (in prep) to constrain water budget partitioning efforts



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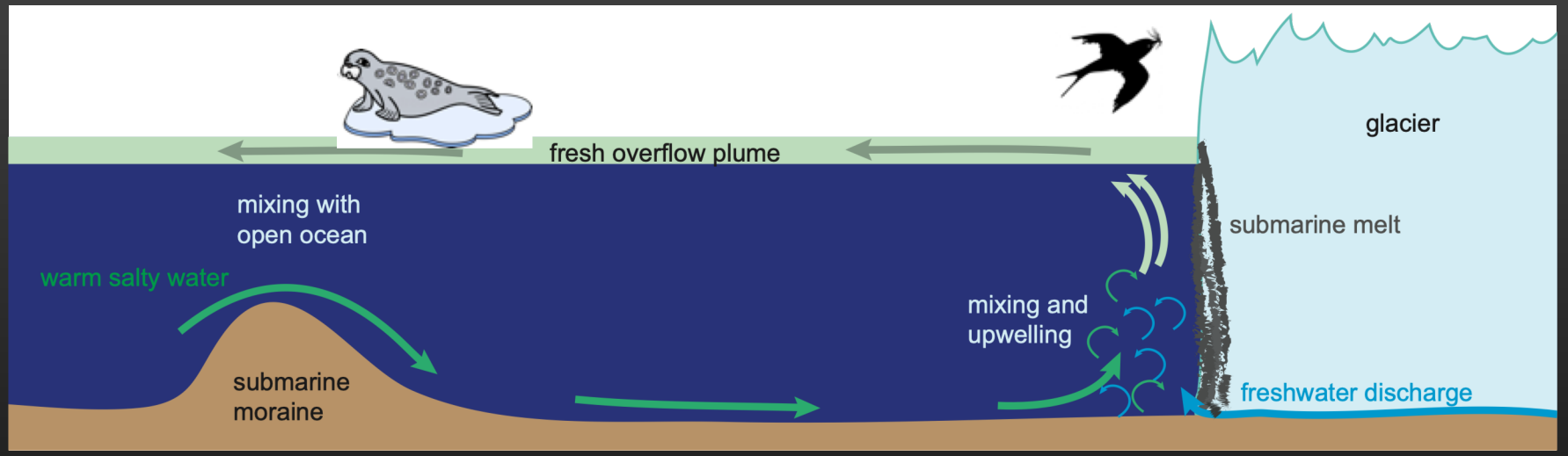
Columbia Glacier Retreat

Tidewater Glacier Biophysics

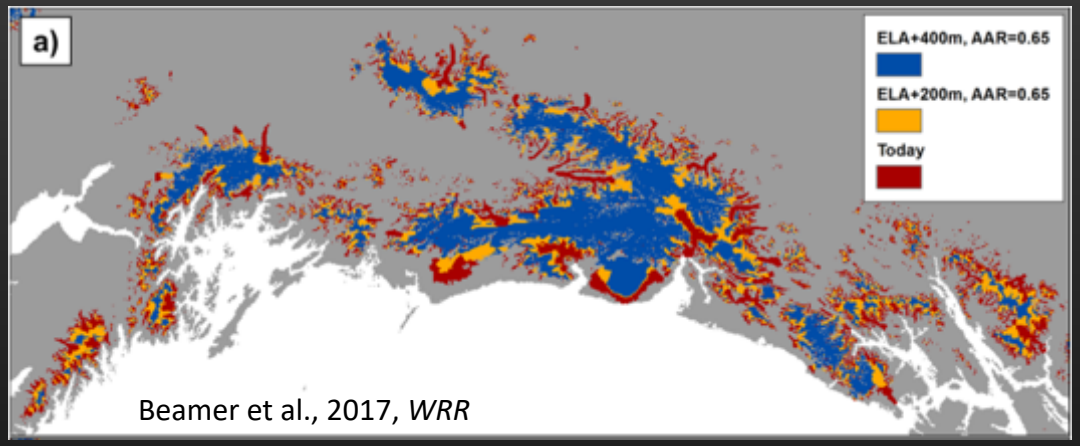


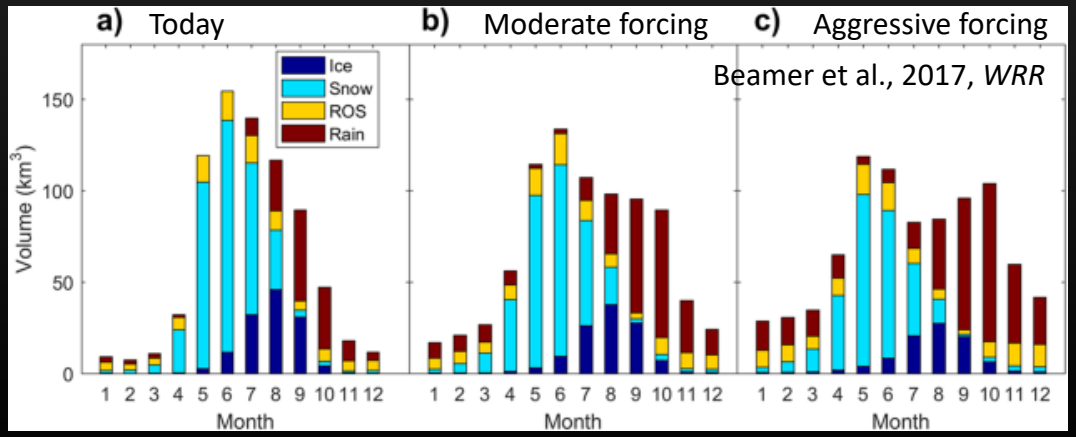
Basal freshwater discharge driver for fjord convection
Warm upwelling melts ice
Upwelling transports biota
Calving glaciers often biological hotspots

Retreat from tidewater removes all feedbacks.

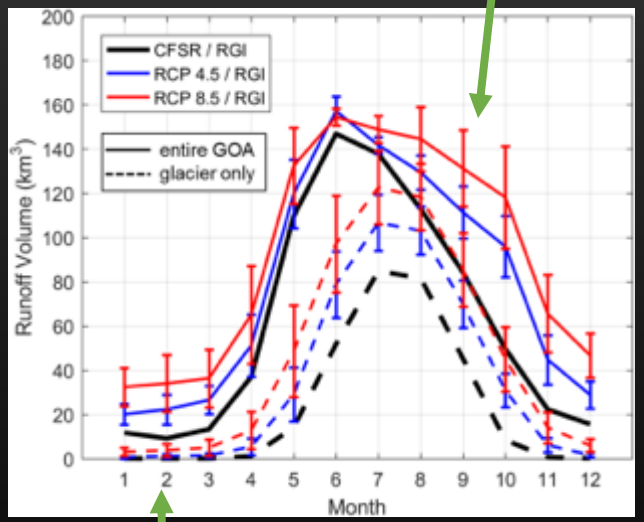
Integrated science

- Earth systems models emerging, but need for basin-scale constraints cannot be understated.





Increased fall flow & variability



Increased winter flow

Ecological implications

Freshwater/ riverine

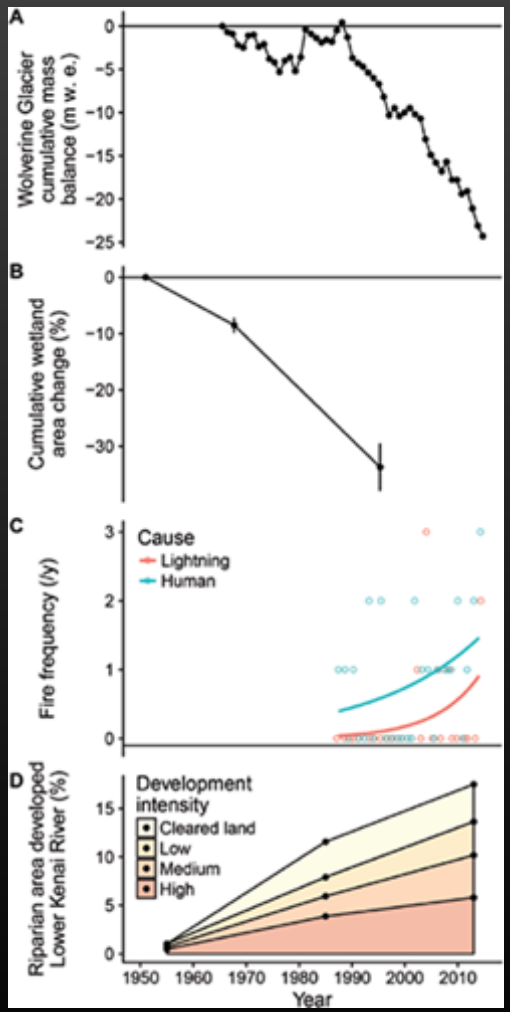
- Winter runoff scours spawning sites (e.g., Liljedahl et al. 2017)
- Decreased summer ice melt drives increased stream temperature, flashiness, changes to peak runoff (e.g., Moore et al. 2009)
- Changes + and – in fish habitat

Terrestrial

- Release of stored contaminants
- More proglacial lakes (potentially positive for salmon) (Bryant et al. 2009)
- Increased vegetation, change in species/ growth zones
- Changes to ET
- New outburst hazards

Ocean

- Acidification (Evans et al. 2014)
- Changes in food webs structured by physical gradients (e.g., Arimitsu et al. 2016)
- Baroclinic forcing (Weingartner, 2005)



Schoen et al., 2017

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Summary

- USGS benchmark glaciers have consistent analysis! Ubiquitous mass loss signal
- Ice_2O: Wolverine Glacier experiment captured physical and biological processes extensively and simultaneously.
- Changes in snow and ice are likely to significantly impact hydrographs, water quality and ecosystem processes.
- Model capacity emerging, but many open questions remain. Developing a robust predictive tool for glacier evolution represents a critical next step.