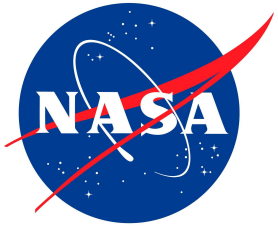
EARTH Workshop
"Understanding Rapid Glacier Change"

Ellyn M. Enderlin

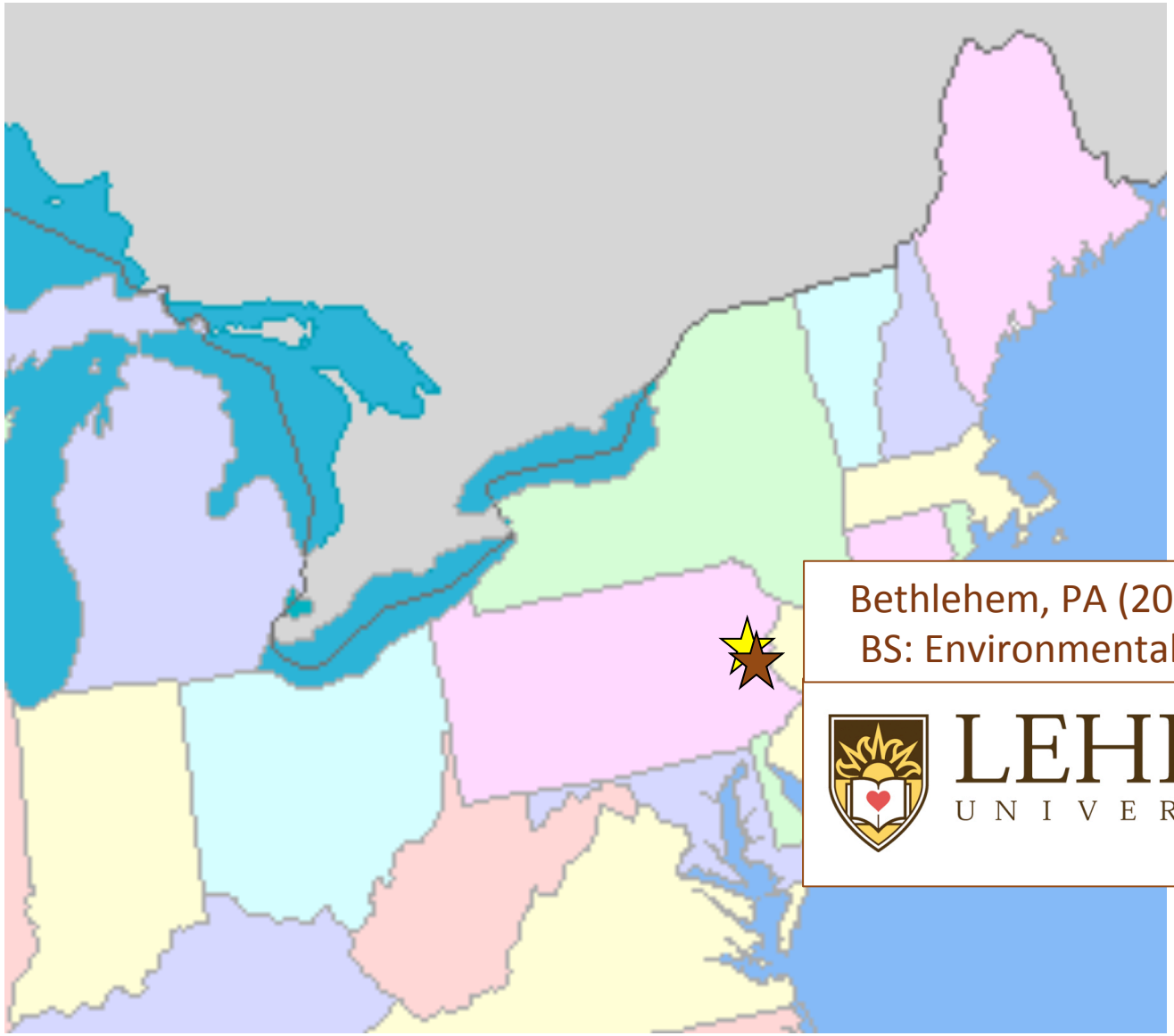
Research Assistant Professor

University of Maine



About Me

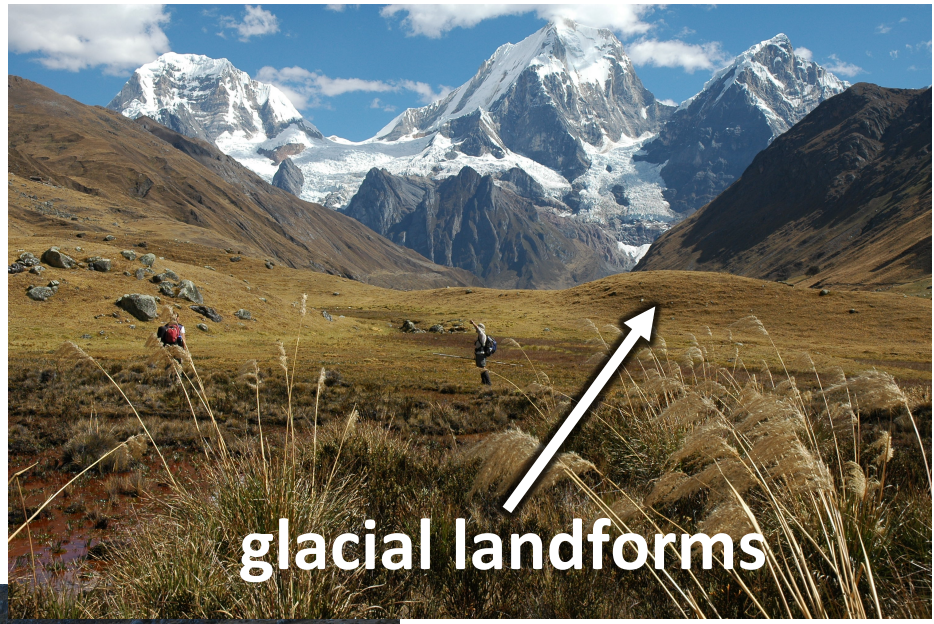
About Me



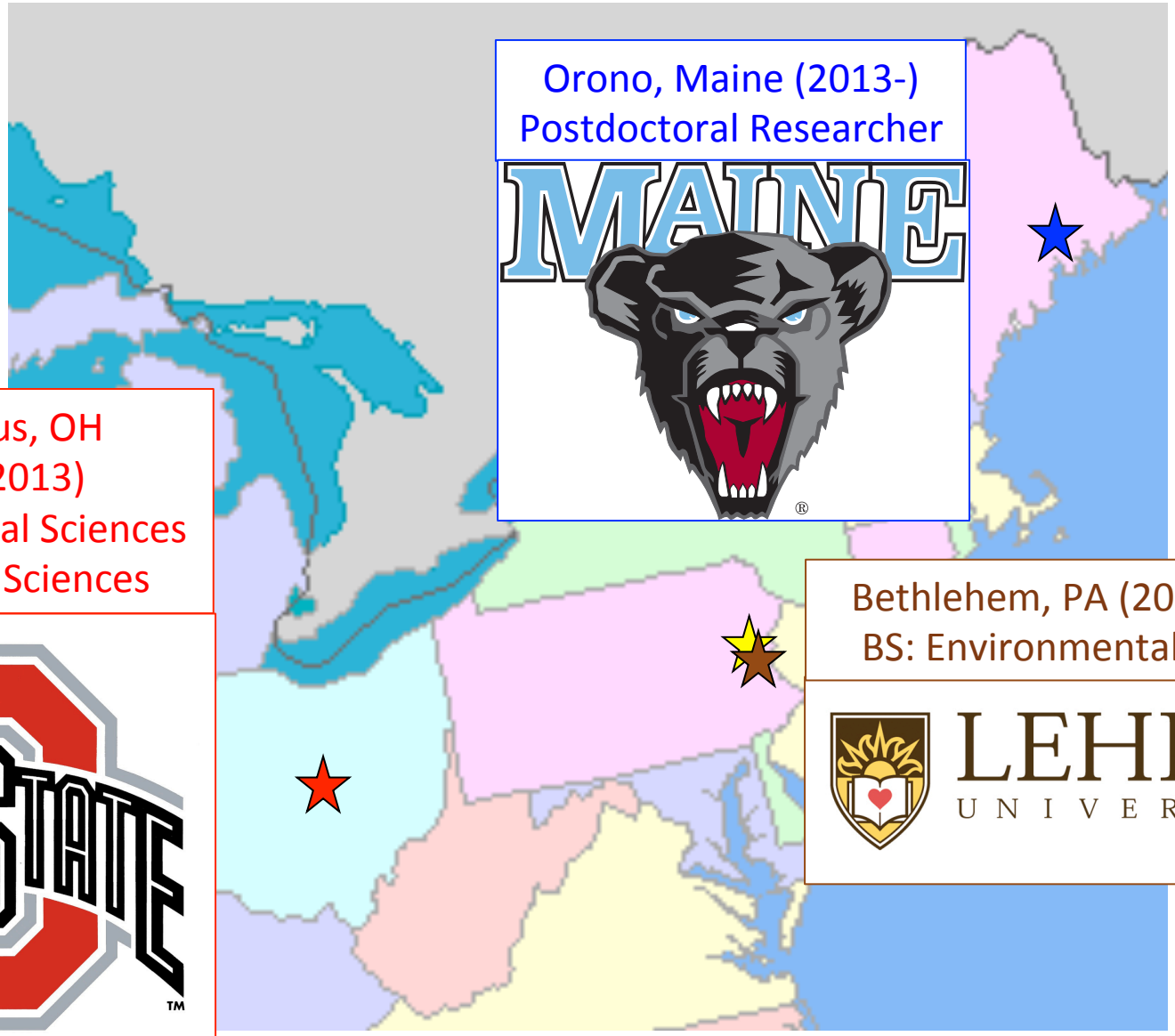
Bethlehem, PA (2004-2008)
BS: Environmental Science

LEHIGH UNIVERSITY

My First Glacier Experience



About Me



Orono, Maine (2013-)
Postdoctoral Researcher

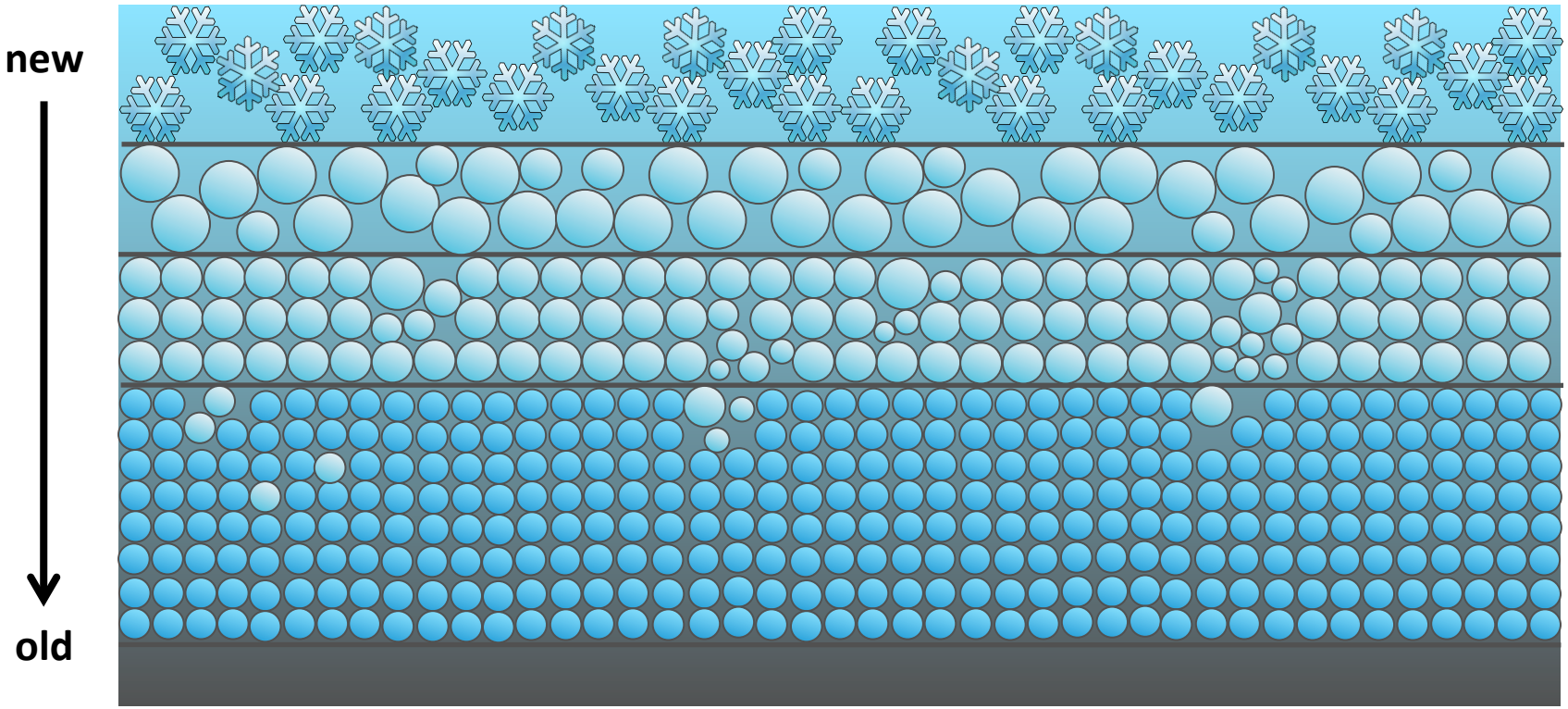
Columbus, OH
(2008-2013)
MS: Geological Sciences
PhD: Earth Sciences

Bethlehem, PA (2004-2008)
BS: Environmental Science

How do glaciers form?

Glaciers form where annual snowfall > melt

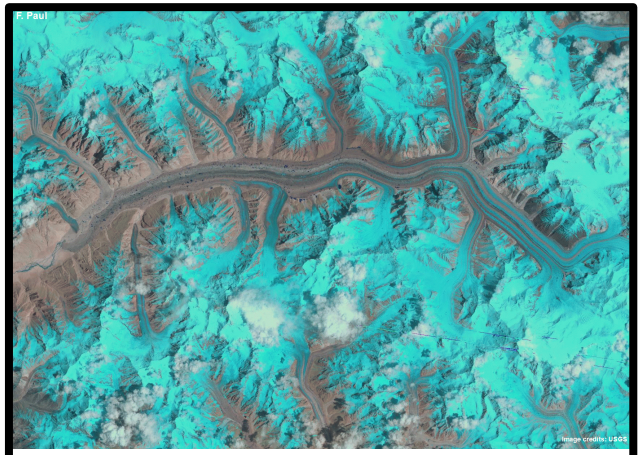
- Layers of snow accumulate
- Over time, the snow gets compressed by its own weight
- Compression increases the snow density -> ice forms!



Glacier Flow

Glacier Flow

- Snow accumulates at high elevations
- Gravity drives snow compression & glacier flow
- Snow & ice melt-away at lower elevations
- Icebergs break-off in the ocean

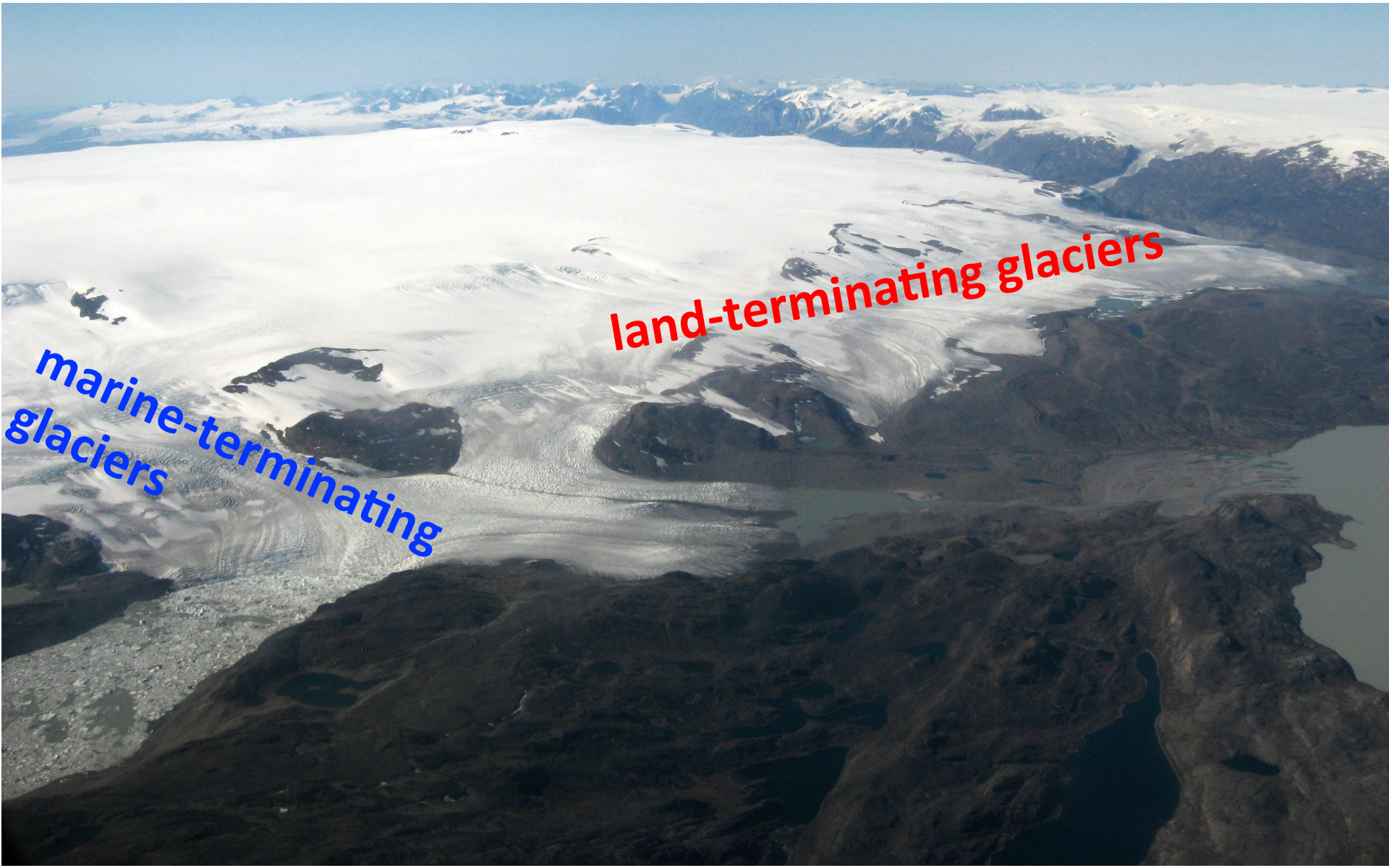


Snow accumulates & ice flows down-hill

Melt runs-off

Icebergs break off

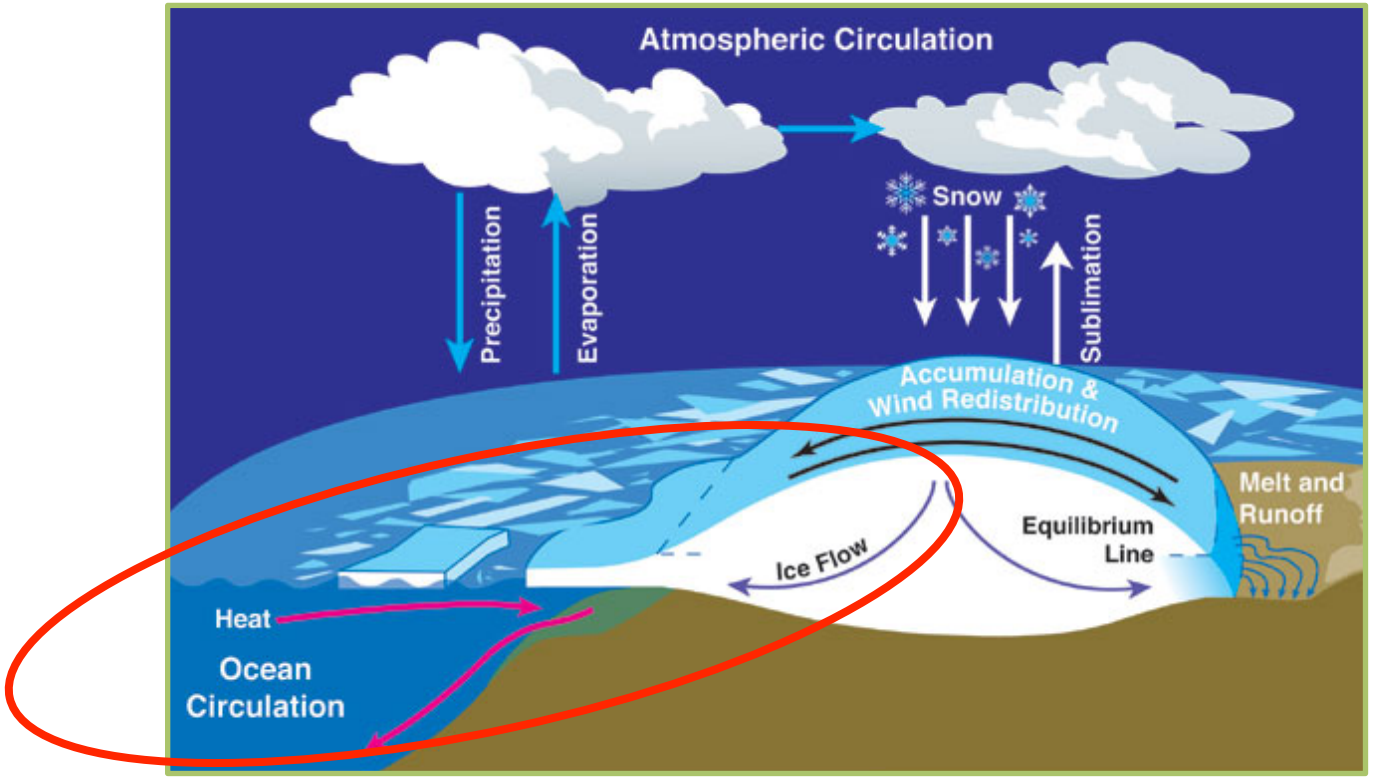
Two Types of Glaciers



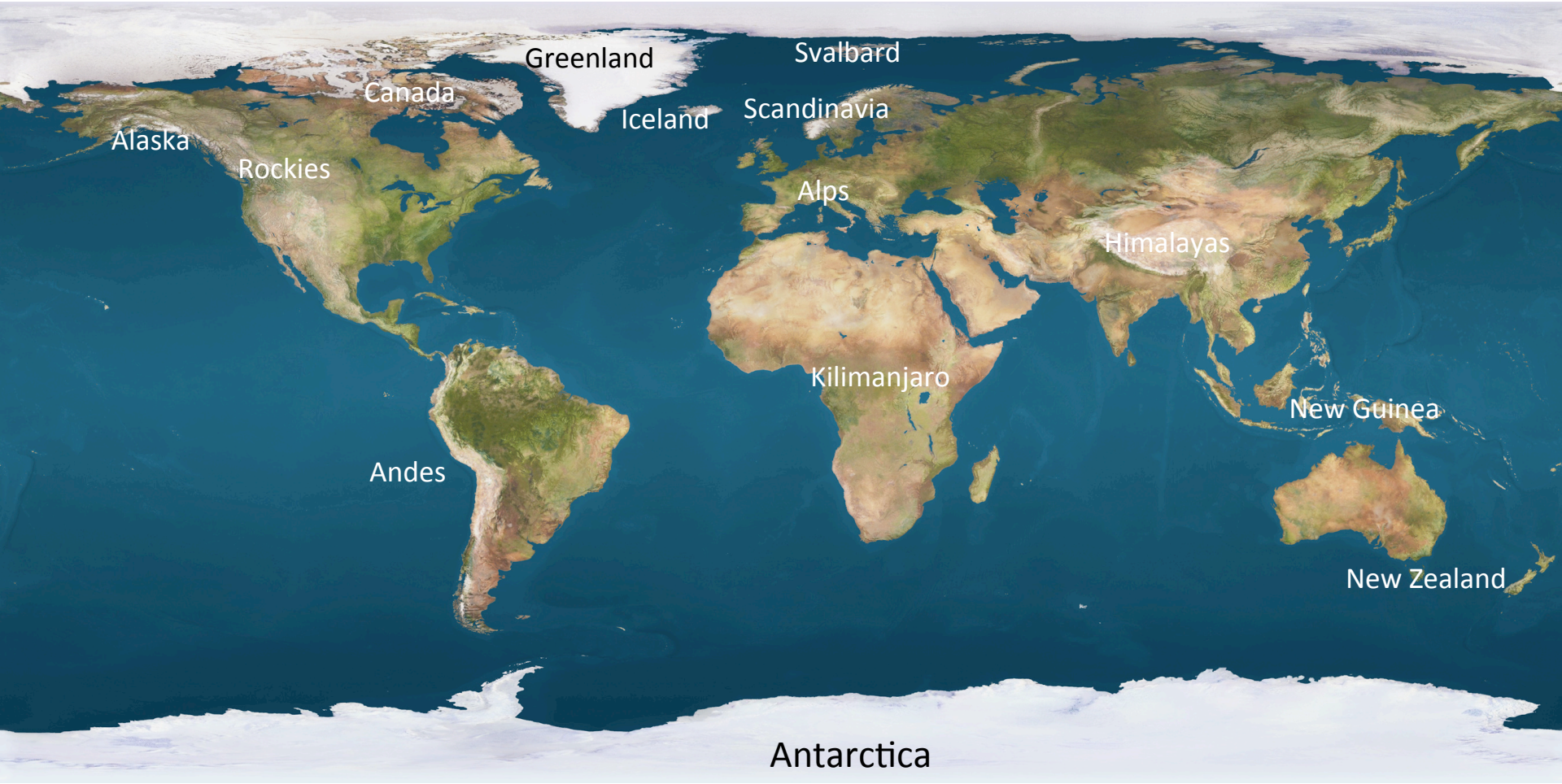
Glacier Mass Change

2 ways a glaciers can change mass:

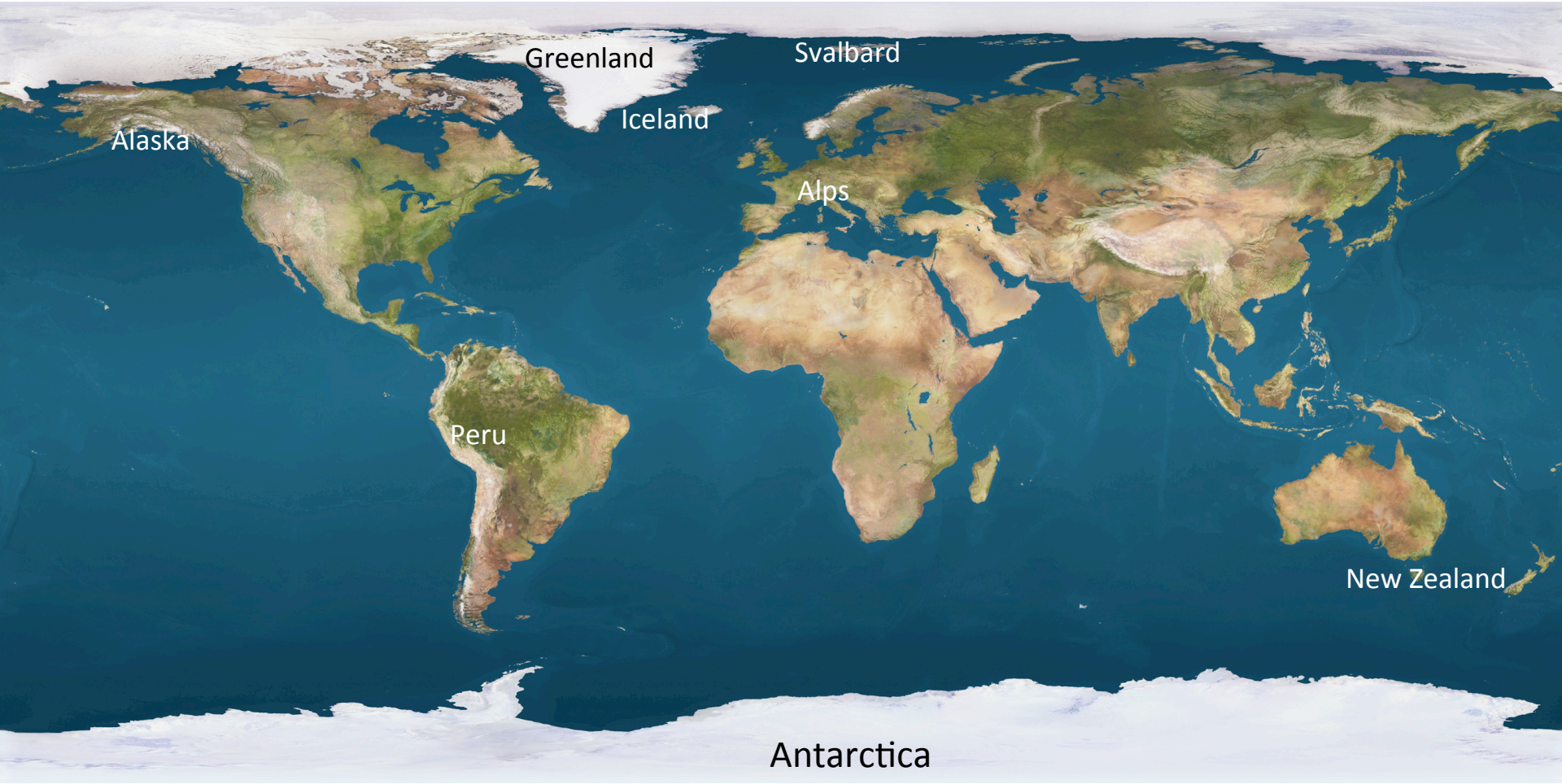
1. *Surface Mass Balance (land + marine-terminating glaciers)*: difference between snow accumulation & surface melt
2. *Dynamics (marine-terminating ONLY)*: loss of mass from interactions with the ocean



Where are glaciers located?



Where I've Gone



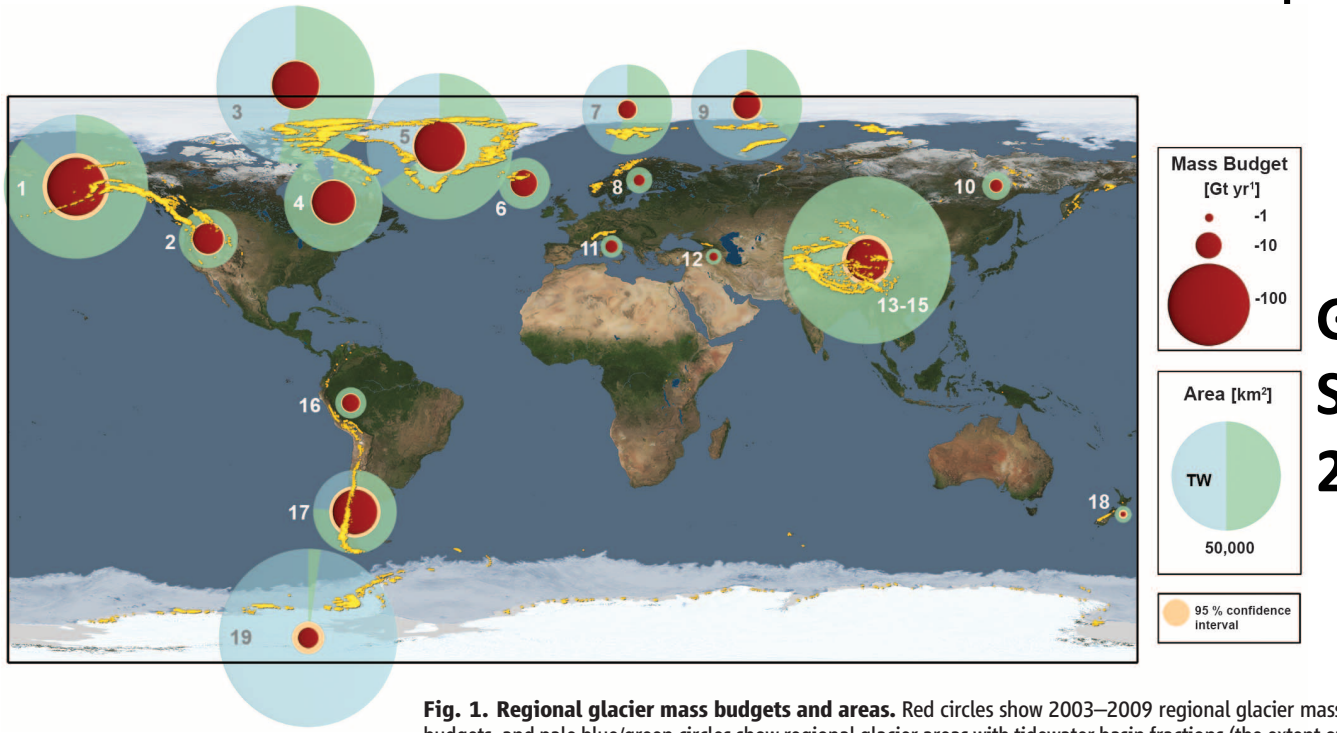
Northern Hemisphere

Southern Hemisphere

Why I Study Glaciers

Glaciers worldwide are shrinking

- glaciers outside of the Greenland & Antarctic ice sheets lose ~260 billion tons of ice per year
- the ice sheets lose ~600 billion tons of ice per year



Gardner et al., Science, 2013

Fig. 1. Regional glacier mass budgets and areas. Red circles show 2003–2009 regional glacier mass budgets, and pale blue/green circles show regional glacier areas with tidewater basin fractions (the extent of ice flowing to termini in the ocean) in blue shading (Table 1). Peach-colored halos surrounding red circles show the 95% CI in mass change estimates, but can only be seen in regions that have large uncertainties.

Why I Study Glaciers

Glaciers worldwide are shrinking

- glaciers & ice sheets lose ~850 billion tons of ice per year

Why does ice loss matter?

- ~375 billion tons of ice = 1 mm global sea level rise
  - total melt of glaciers & ice sheets would raise sea level by ~80 meters (~250ft)
  - 1/10th of people live within 30ft of modern sea level
- loss of ice cover decreases planetary albedo
  - a less reflective Earth surface = a warmer planet
- melt water can alter ocean circulation

Why I Study Glaciers

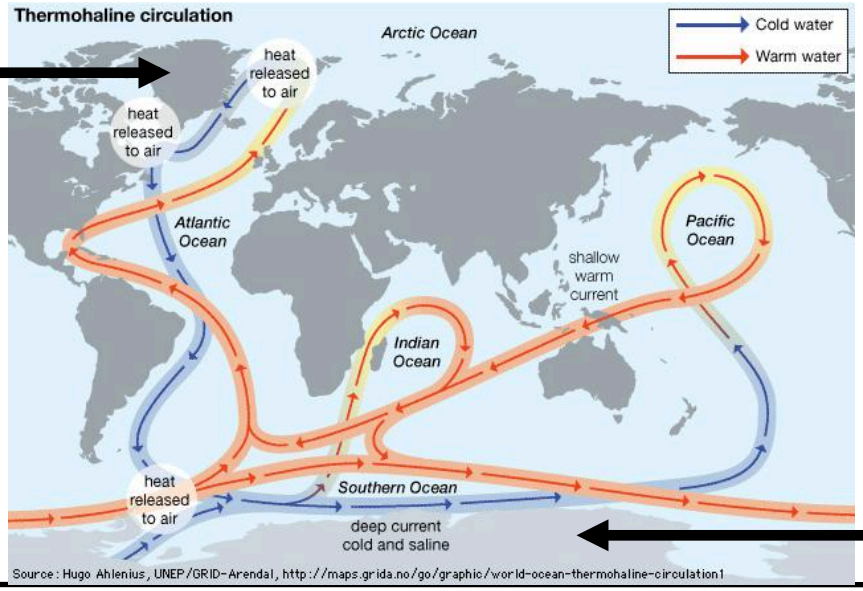
Glaciers worldwide are shrinking

- glaciers & ice sheets lose ~850 billion tons of ice per year

Why does ice loss matter?

- ~375 billion tons of ice = 1 mm global sea level rise
- loss of ice cover decreases planetary albedo
- melt water can alter ocean circulation

Greenland



Antarctica

Why I Study Glaciers

Glaciers worldwide are shrinking

- glaciers & ice sheets lose ~850 billion tons of ice per year

Why does ice loss matter?

- ~375 billion tons of ice = 1 mm global sea level rise
- loss of ice cover decreases planetary albedo
- melt water can alter ocean circulation

✧ local impacts matter too!

- decreased fresh water during the dry season in mountain regions
- modification of ecosystem structures near glacier margins

Mapping Glacier Length Change

- USGS & NASA's Landsat project is the world's longest continuously-operating satellite program to monitor the Earth's surface

- Landsat satellites record electromagnetic radiation reflected and emitted by the Earth

- observations spanning the visible and infrared portions of the electromagnetic spectrum going back to 1972

- all data are 100% FREE! https://earthexplorer.usgs.gov/

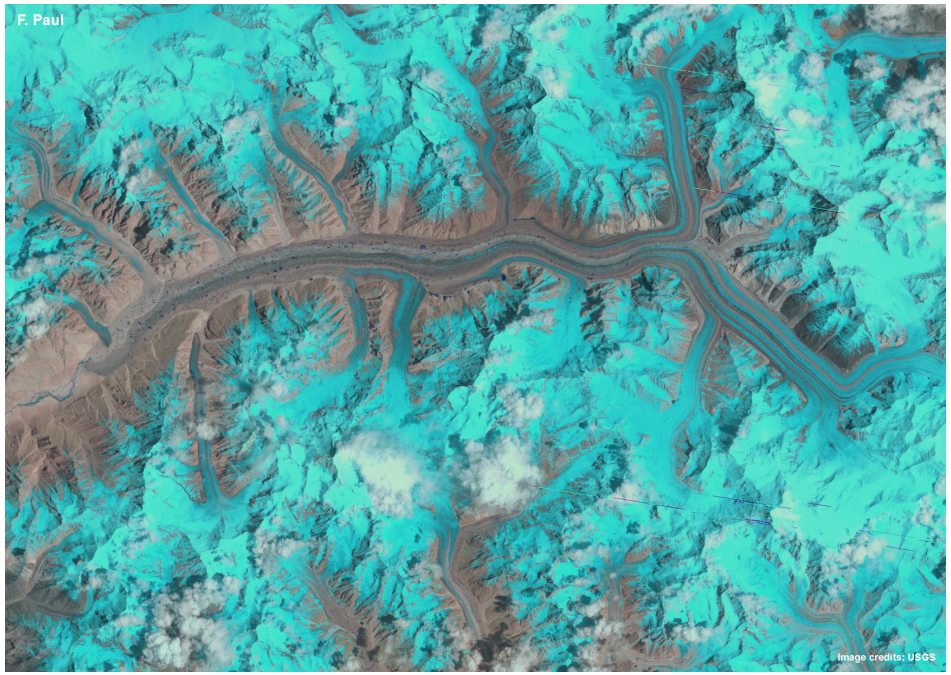
Glacier Monitoring

Mapping Glacier Length, Area, & Speed Change

- focus on the visible portion of the electromagnetic spectrum because glaciers stand-out relative to rock, vegetation, & water

- look at changes from summer-to-summer when snow on land cannot be confused as a glacier

- movement of distinct features can be used to estimate speed



Predicting Glacier Change

We can reasonably predict future mass change for land-terminating glaciers

- can map rates of retreat & extrapolate
- changes in area can be modeled if air temperature & snow accumulation data are available: https://phet.colorado.edu/en/simulation/glaciers

Predicting Glacier Change

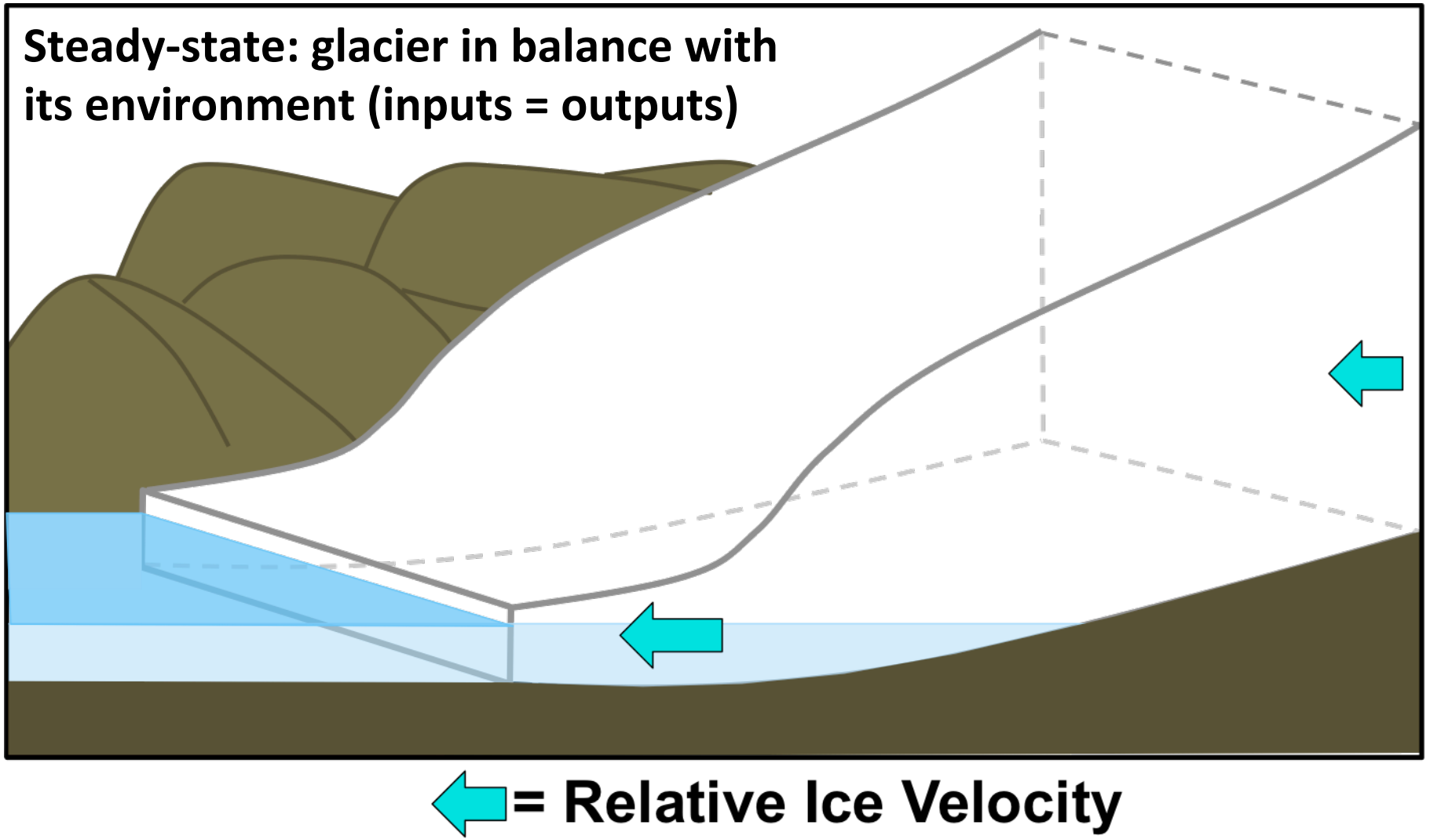
We can reasonably predict future mass change for land-terminating glaciers

- can map rates of retreat & extrapolate
- changes in area can be modeled if air temperature & snow accumulation data are available: https://phet.colorado.edu/en/simulation/glaciers

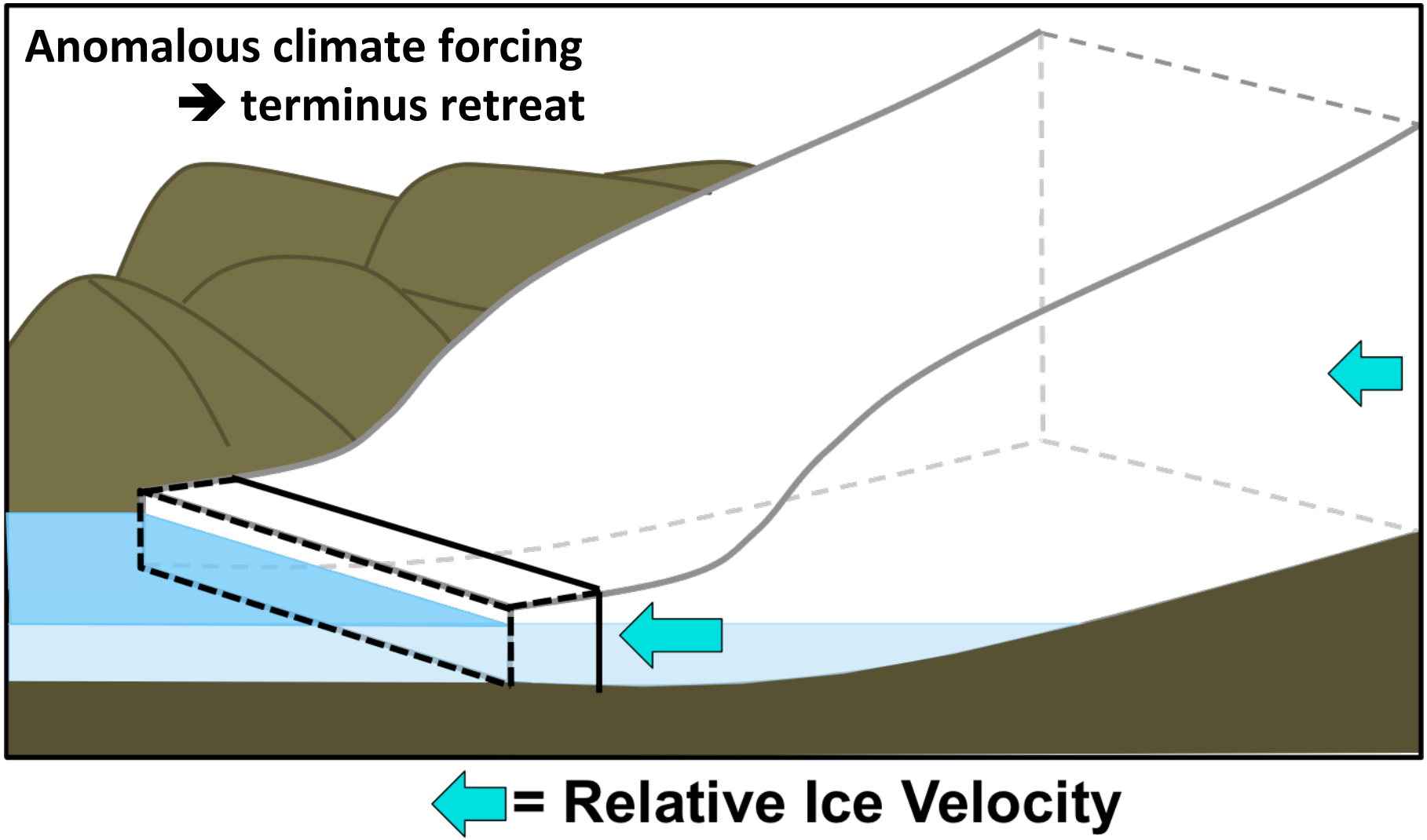
Marine-terminating glaciers are more tricky

- changes in snow accumulation, air temperature, AND ocean temperature all influence mass
- there are lots of potential feedbacks in the system

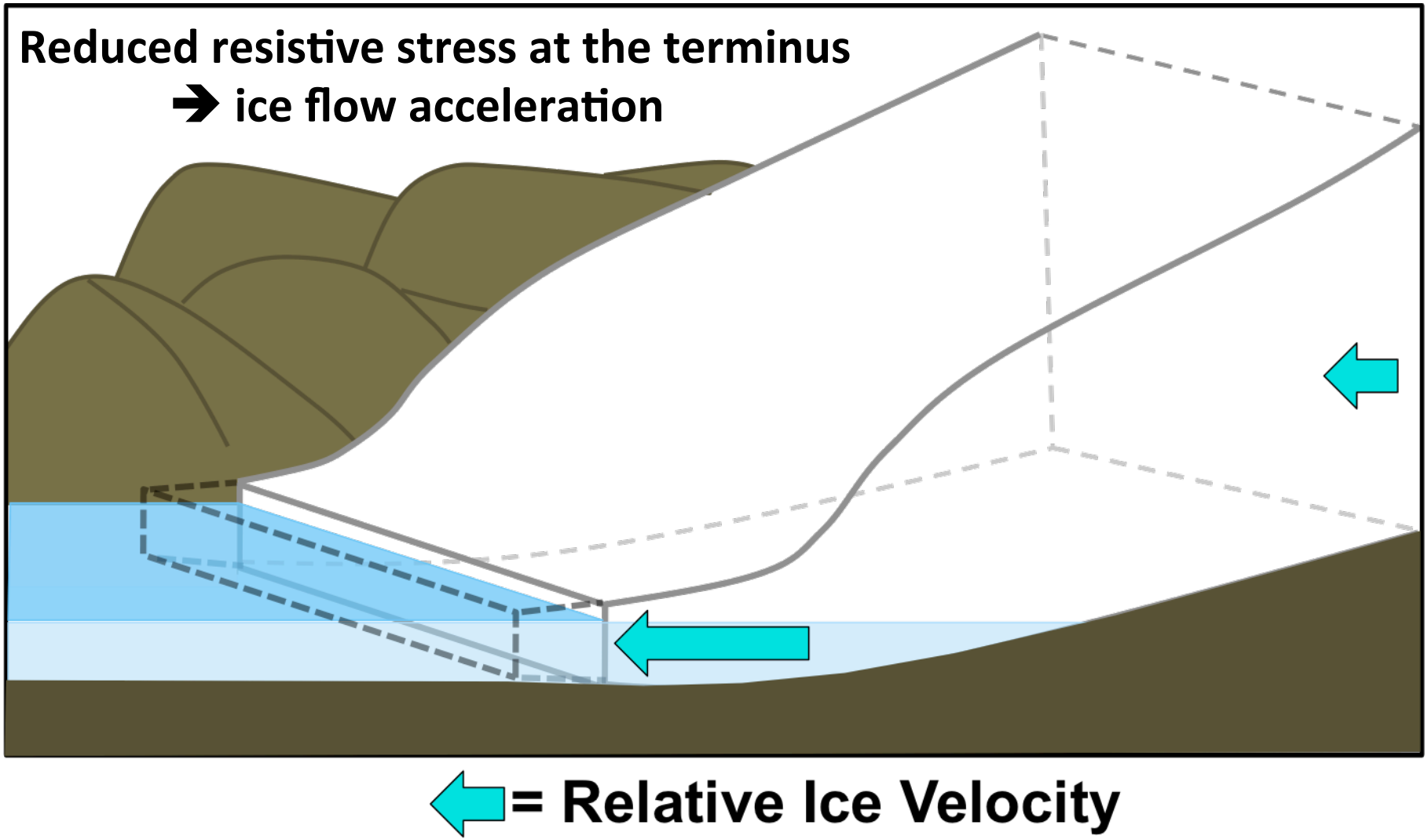
Mass Loss via Dynamic Change



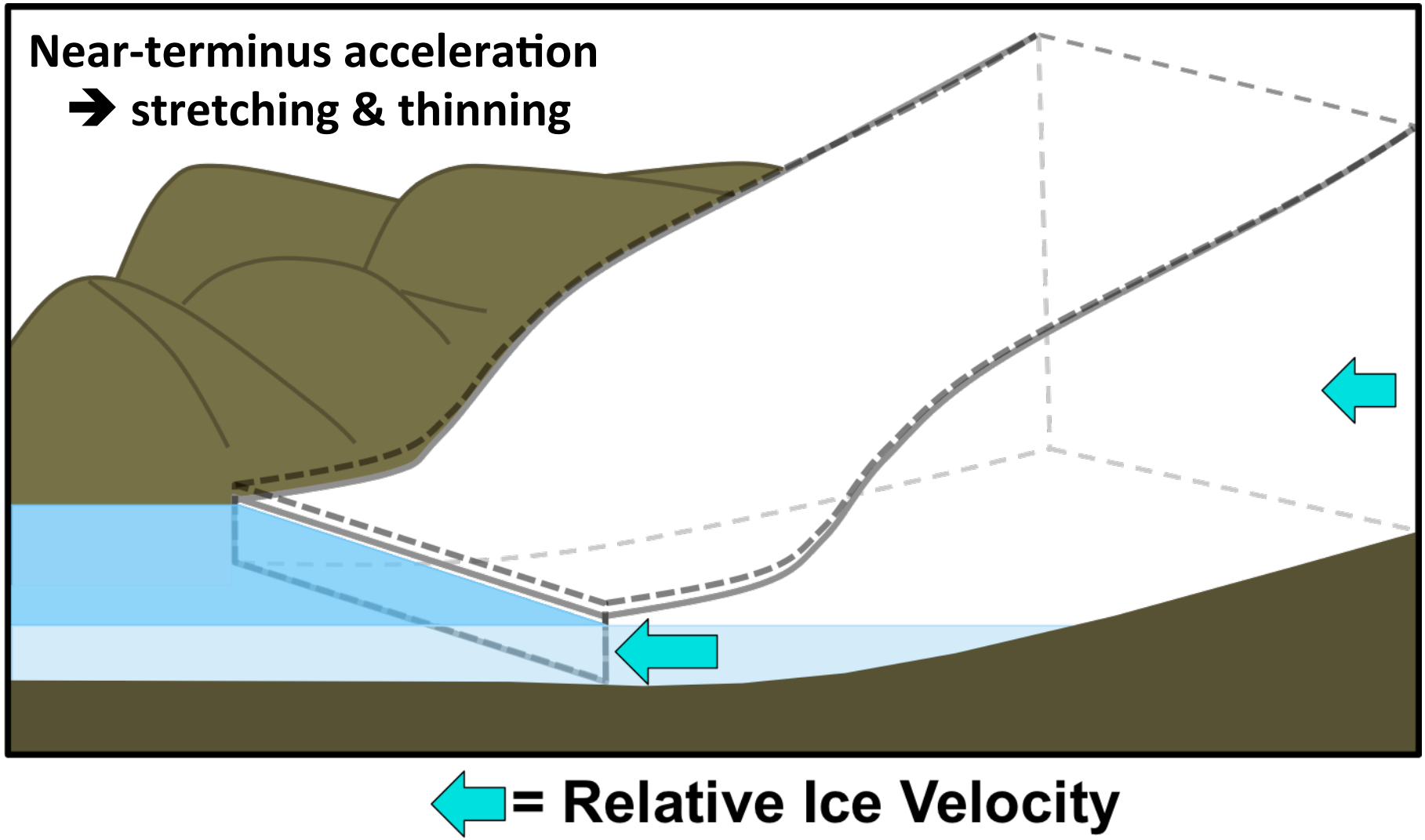
Dynamic Change: Opening the Floodgates



Dynamic Change: Opening the Floodgates



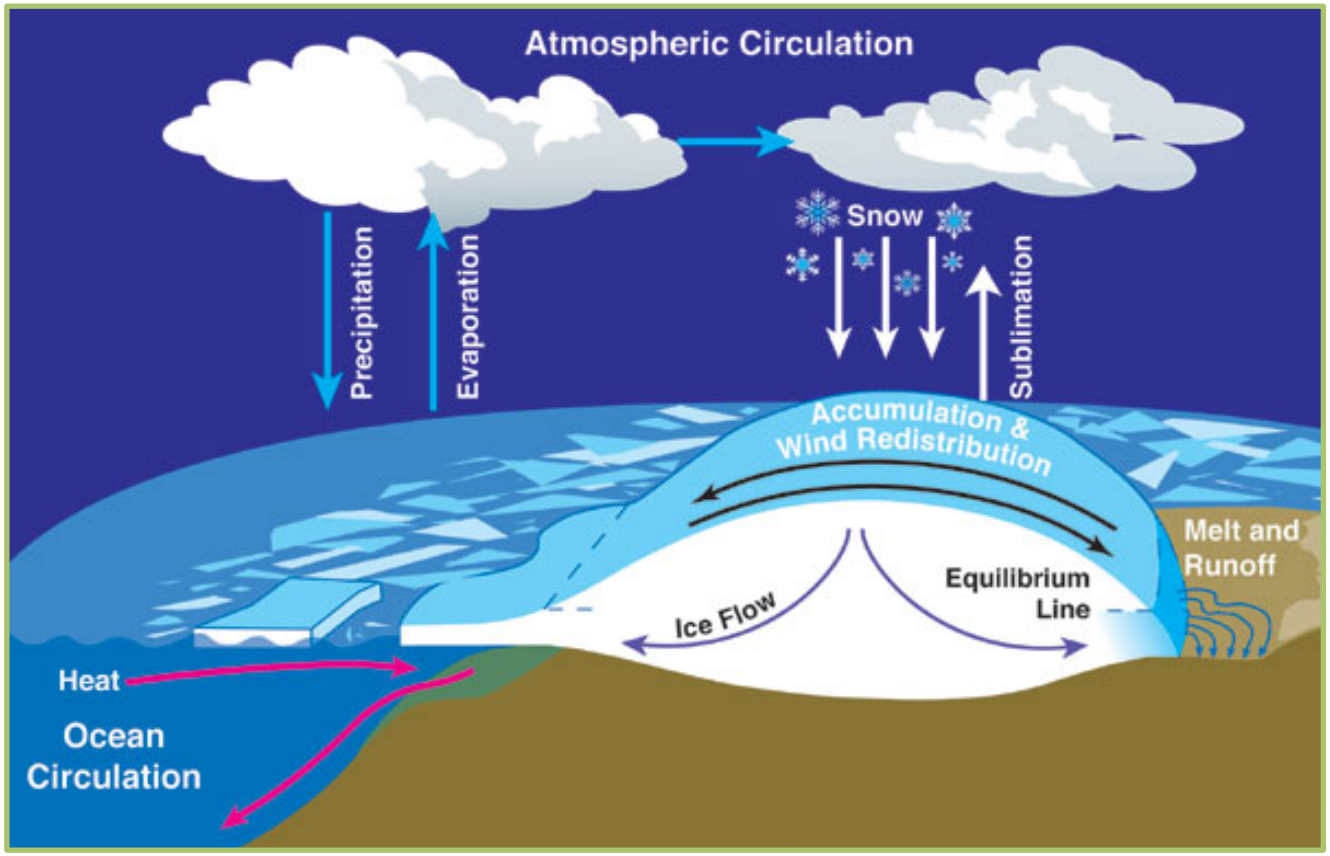
Dynamic Change: Opening the Floodgates



Marine-Terminating Glacier Change

Feedback between dynamics & surface melt:

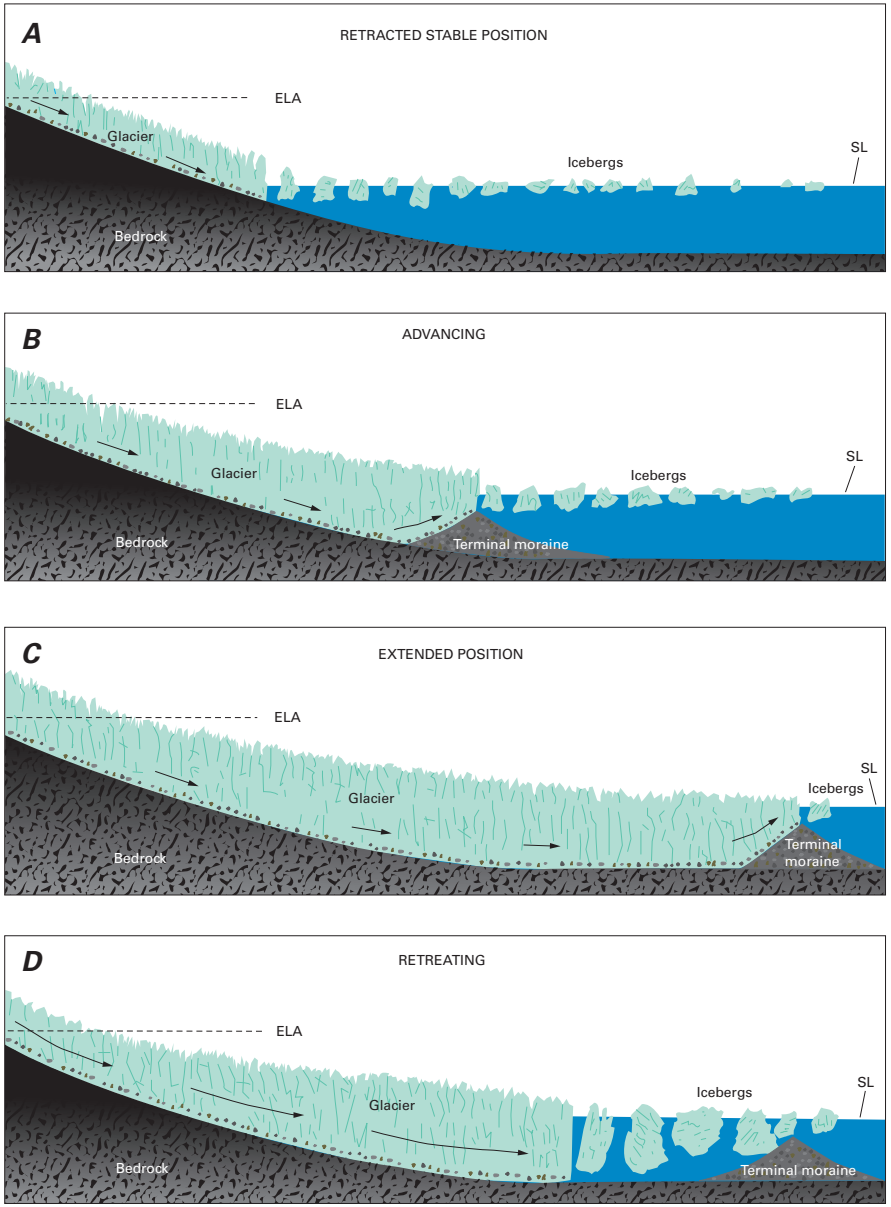
- dynamic thinning brings ice to lower surface elevations
- more melting occurs at lower surface elevations
- more melting leads to faster ice flow (slip-n-slide effect)



Marine-Terminating Glacier Change

Dependence on Geometry:

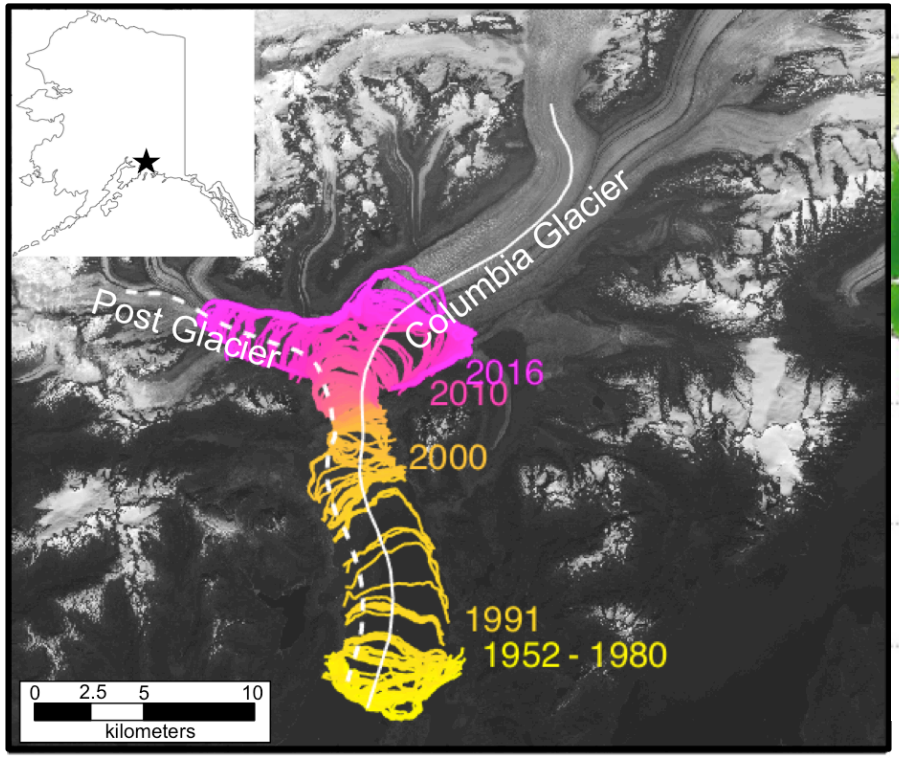
- glaciers are relatively stable when they terminate in shallow water
- if the terminus retreats from shallow water into deeper water, a positive feedback occurs
  - less friction holding the glacier back
  - larger cross-sectional area for ice to pass through

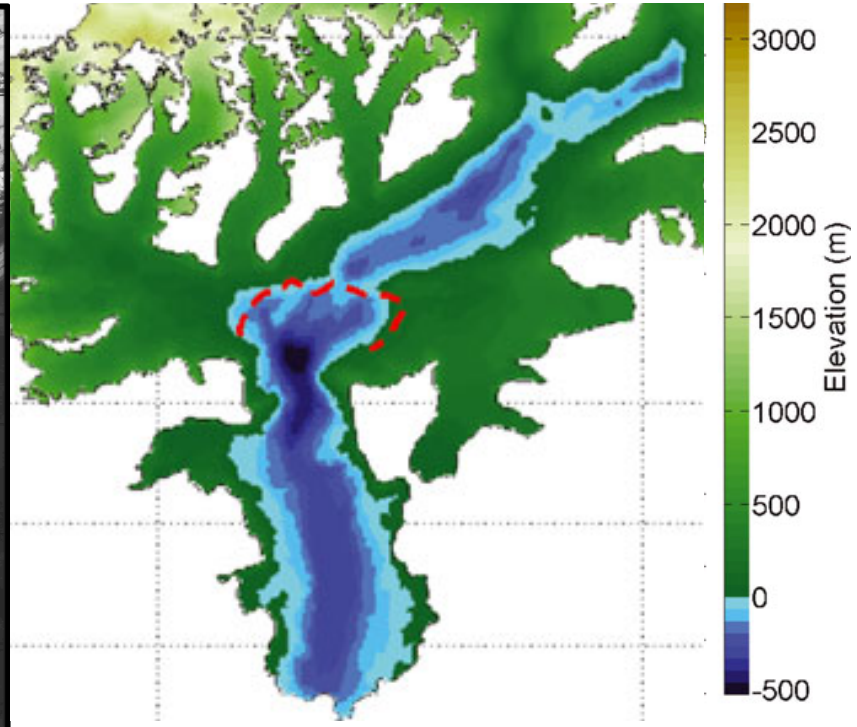


Marine-Terminating Glacier Change

Dependence on Geometry:

- geometric dependence makes some marine-terminating glaciers more sensitive to climate change than others
- geometry variability also complicates interpretation of the glacier change signal

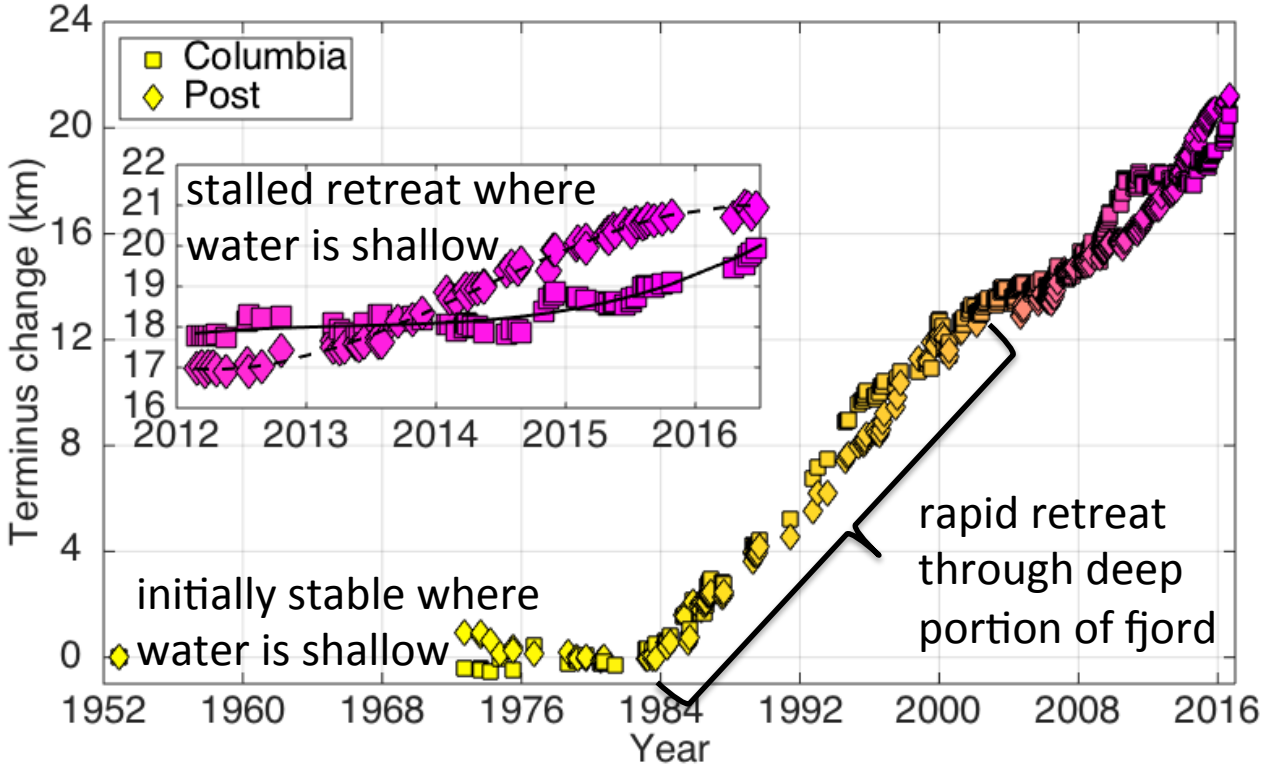




Marine-Terminating Glacier Change

Dependence on Geometry:

- geometric dependence makes some marine-terminating glaciers more sensitive to climate change than others
- geometry variability also complicates interpretation of the glacier change signal



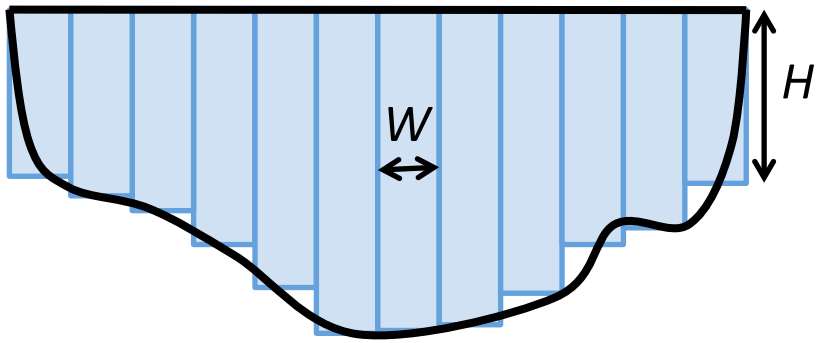
Greenland Marine-Terminating Glacier Change

Dynamic Mass Loss = Excess Iceberg Discharge

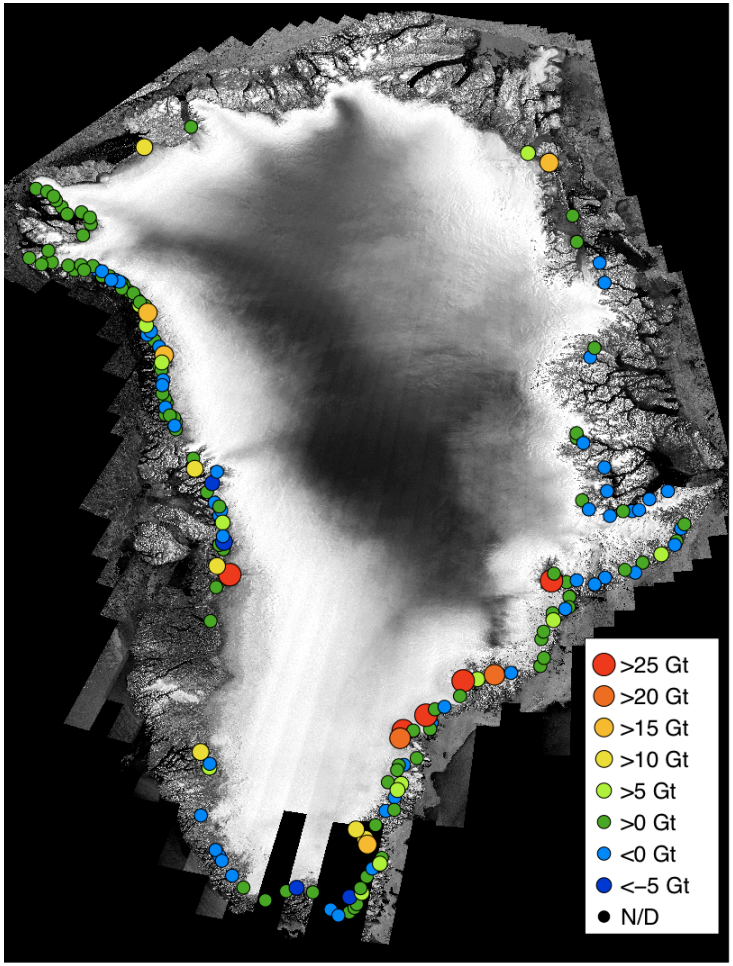
- Iceberg discharge

$$D = \rho_i \sum UHW$$

  - U = speed of ice flowing towards the terminus
  - H = ice thickness
  - W = width
  - ρ_i = density of ice



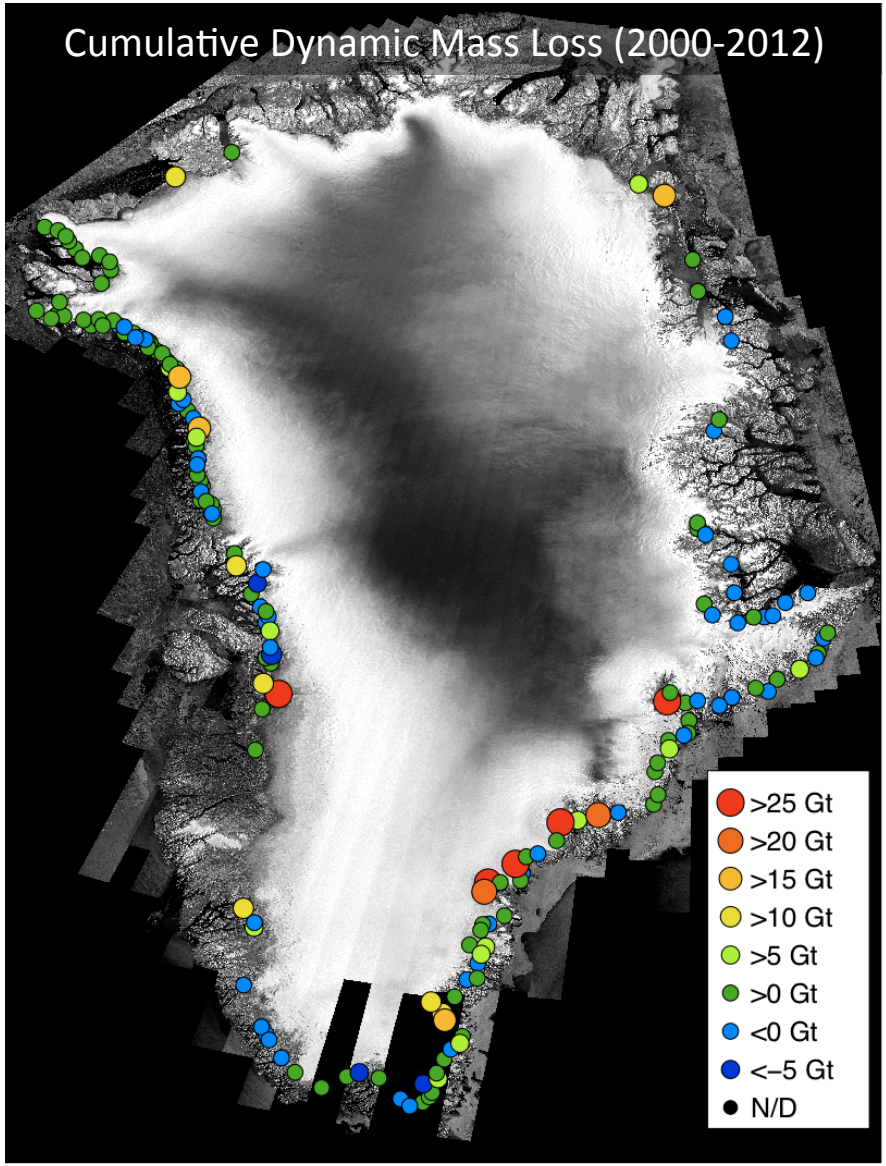
- Widths & speeds from satellite images
- Thickness from NASA airborne radar



Greenland Marine-Terminating Glacier Change

Dynamic Mass Loss from Greenland:

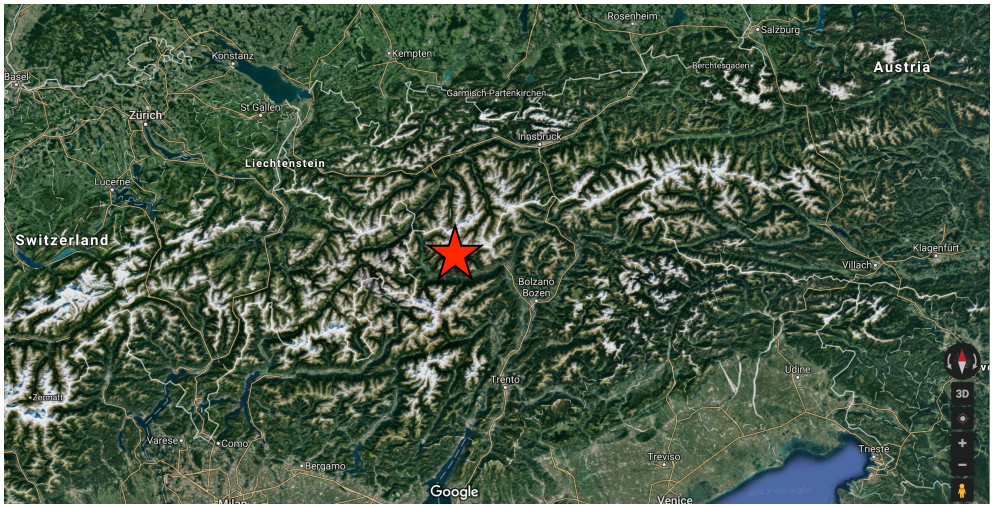
- almost all glaciers retreated, accelerated, & pumped-out extra icebergs
- a handful of glaciers disproportionately contributed to mass loss
- variability partially due to differences in geometry!

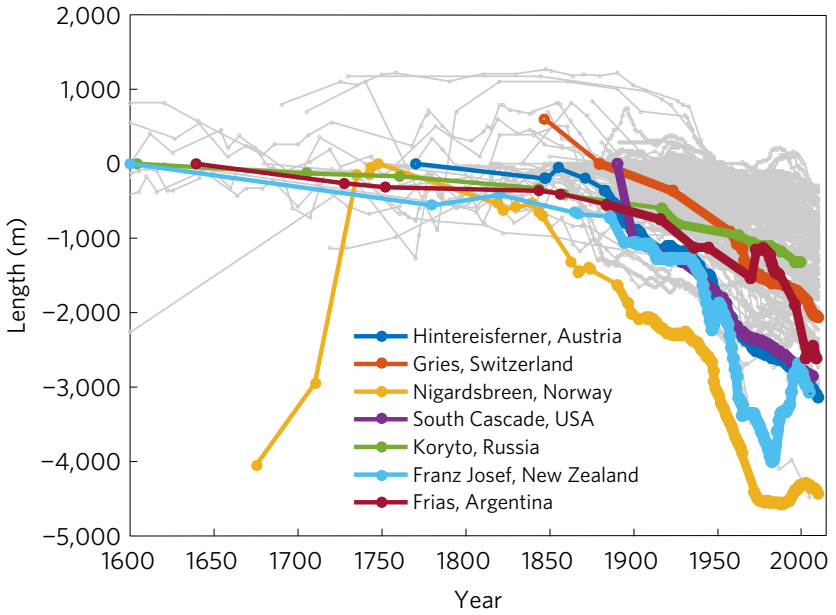


Glacier Data for the Classroom

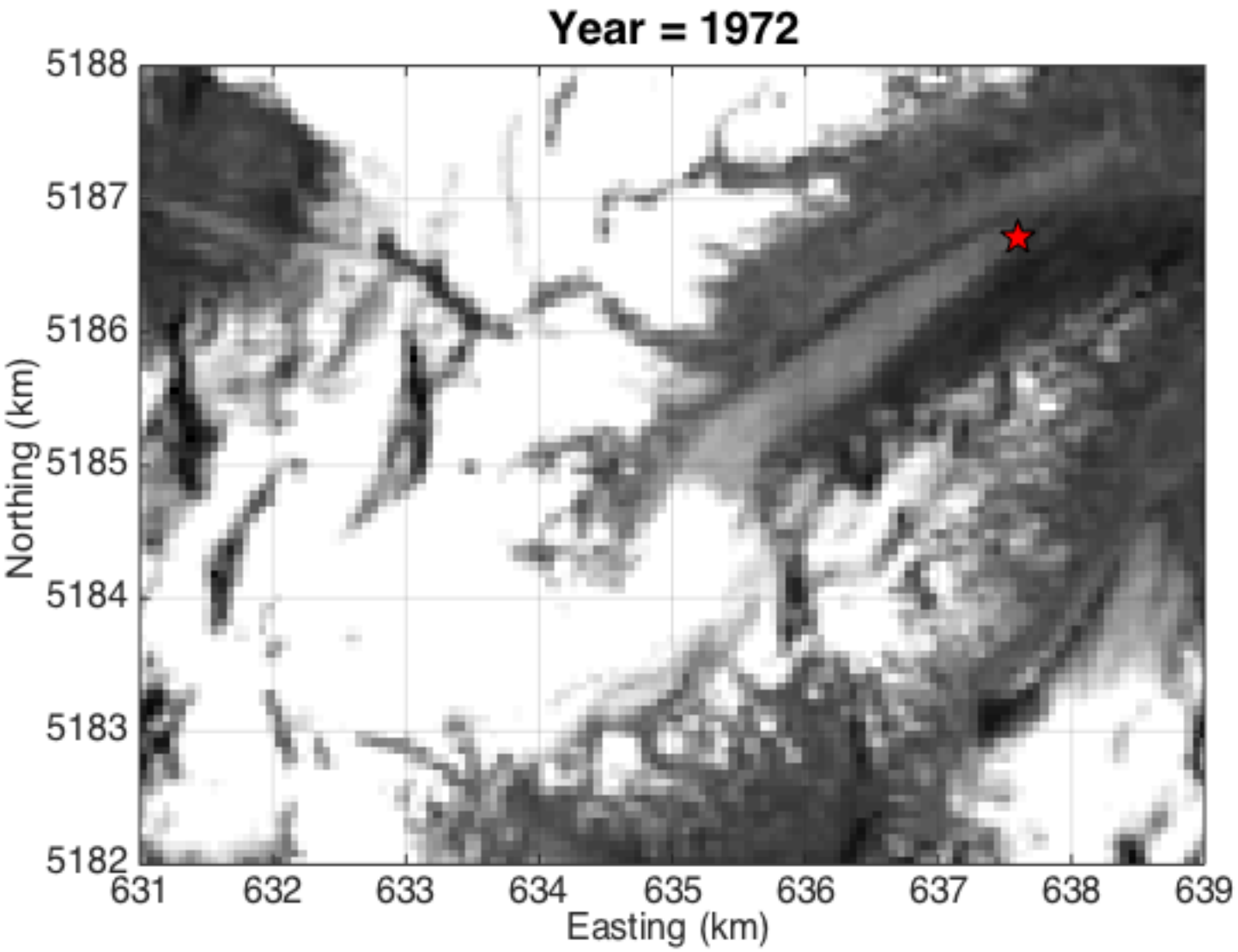
An Easier Glacier System: Hintereisferner, Austria

- one of the most rapidly-changing & best-studied glaciers in the Alps
- recently analyzed to show modern glacier retreat is unequivocally driven by anthropogenic climate change (Roe et al., Nature Geoscience, 2017)

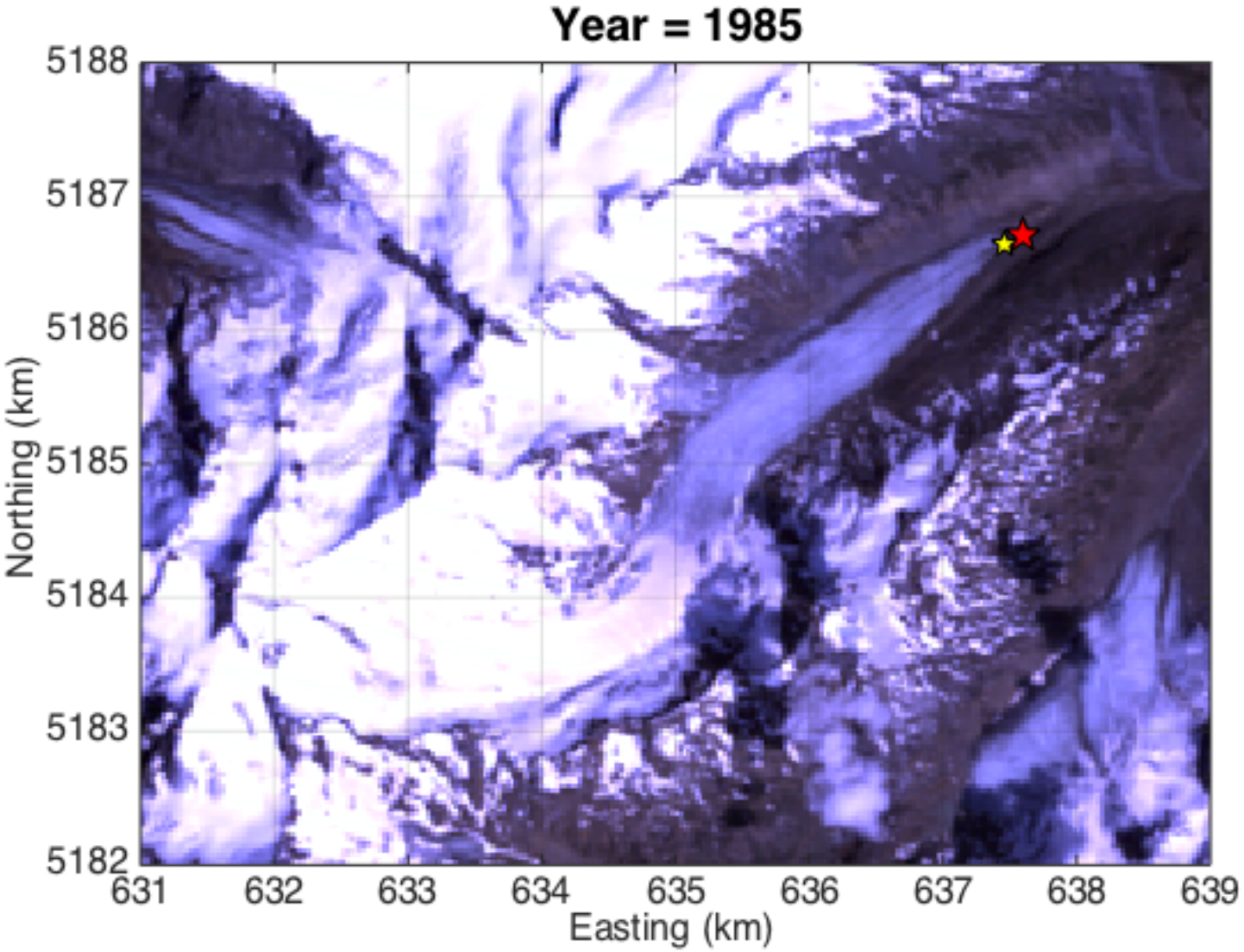




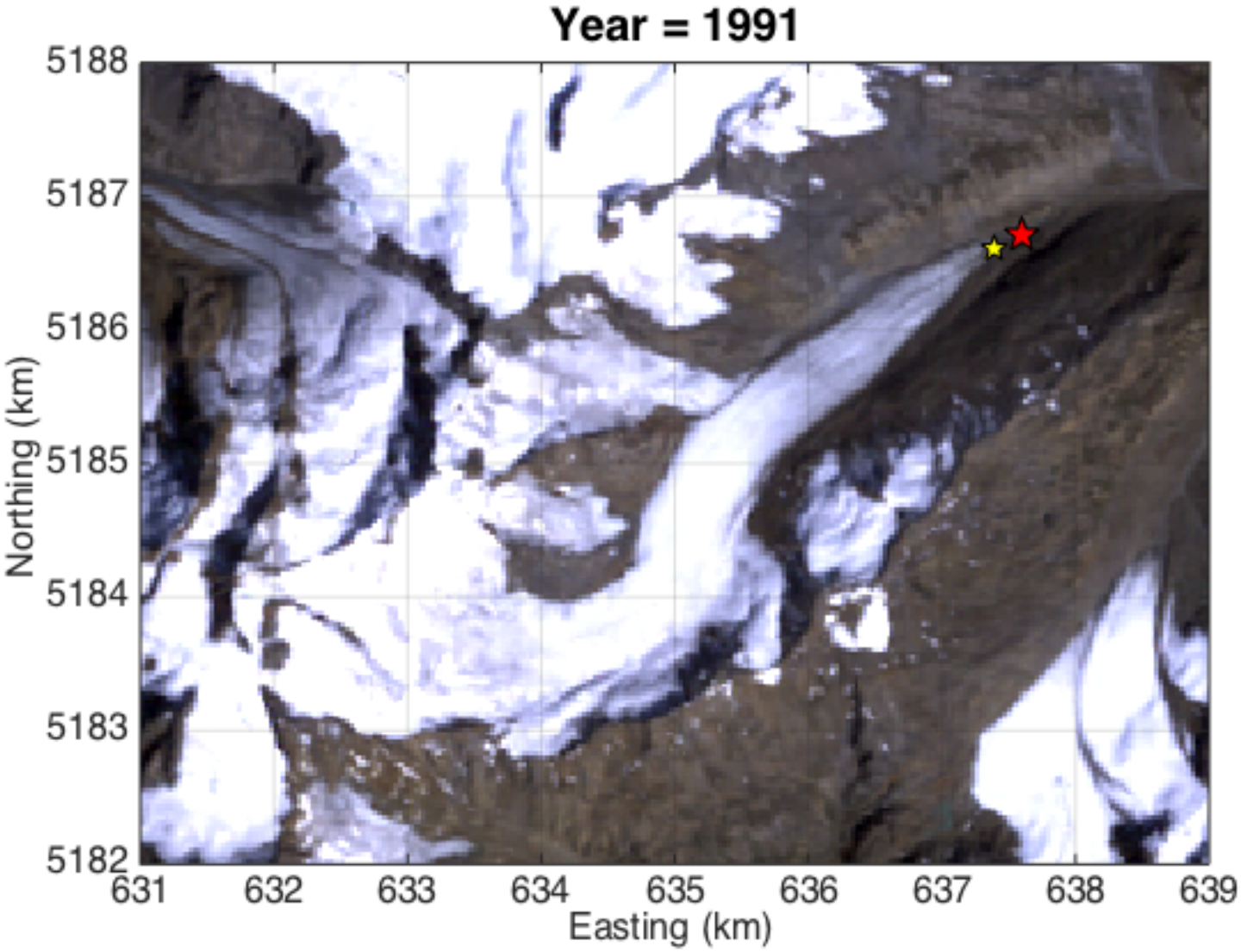
Glacier Data for the Classroom



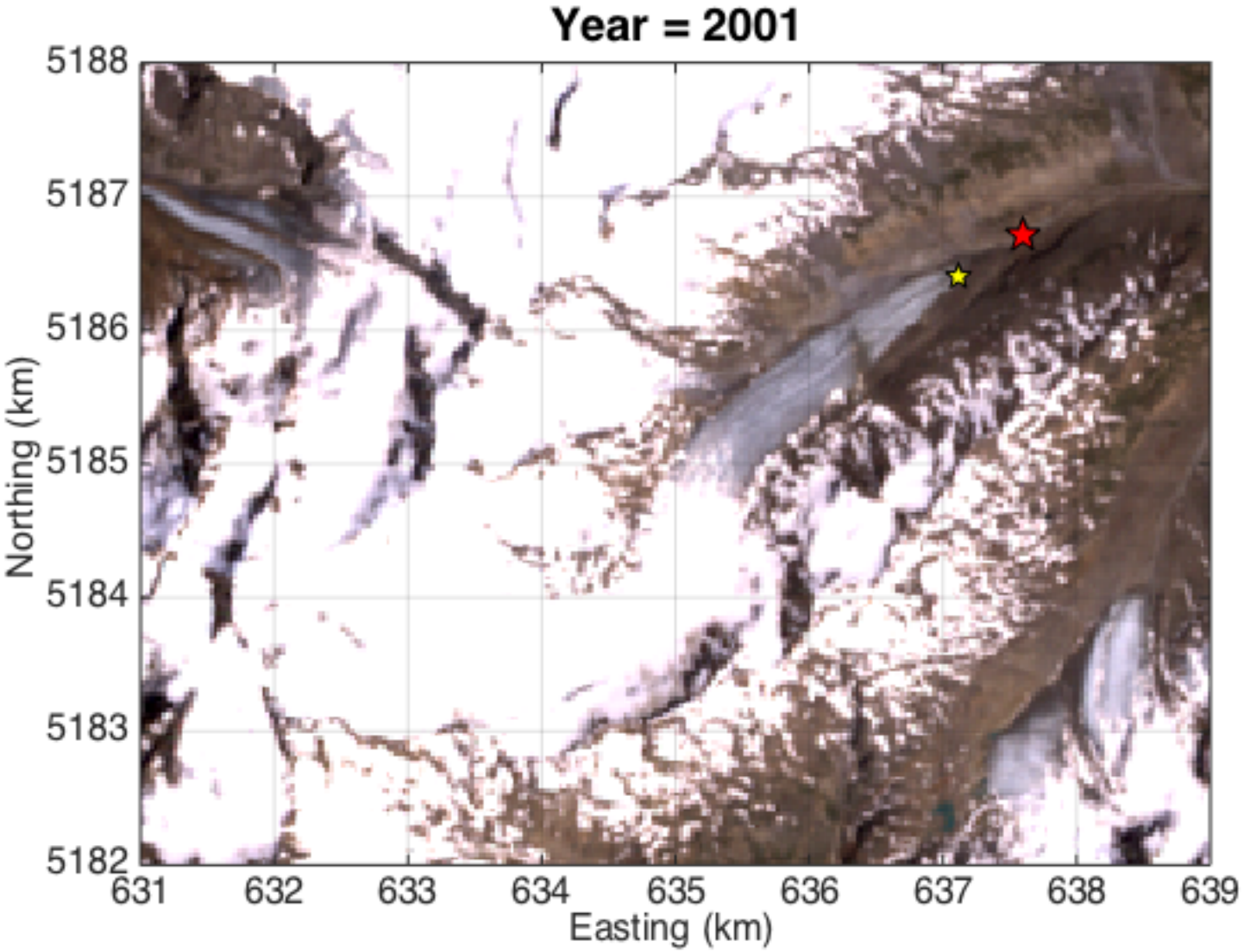
Glacier Data for the Classroom



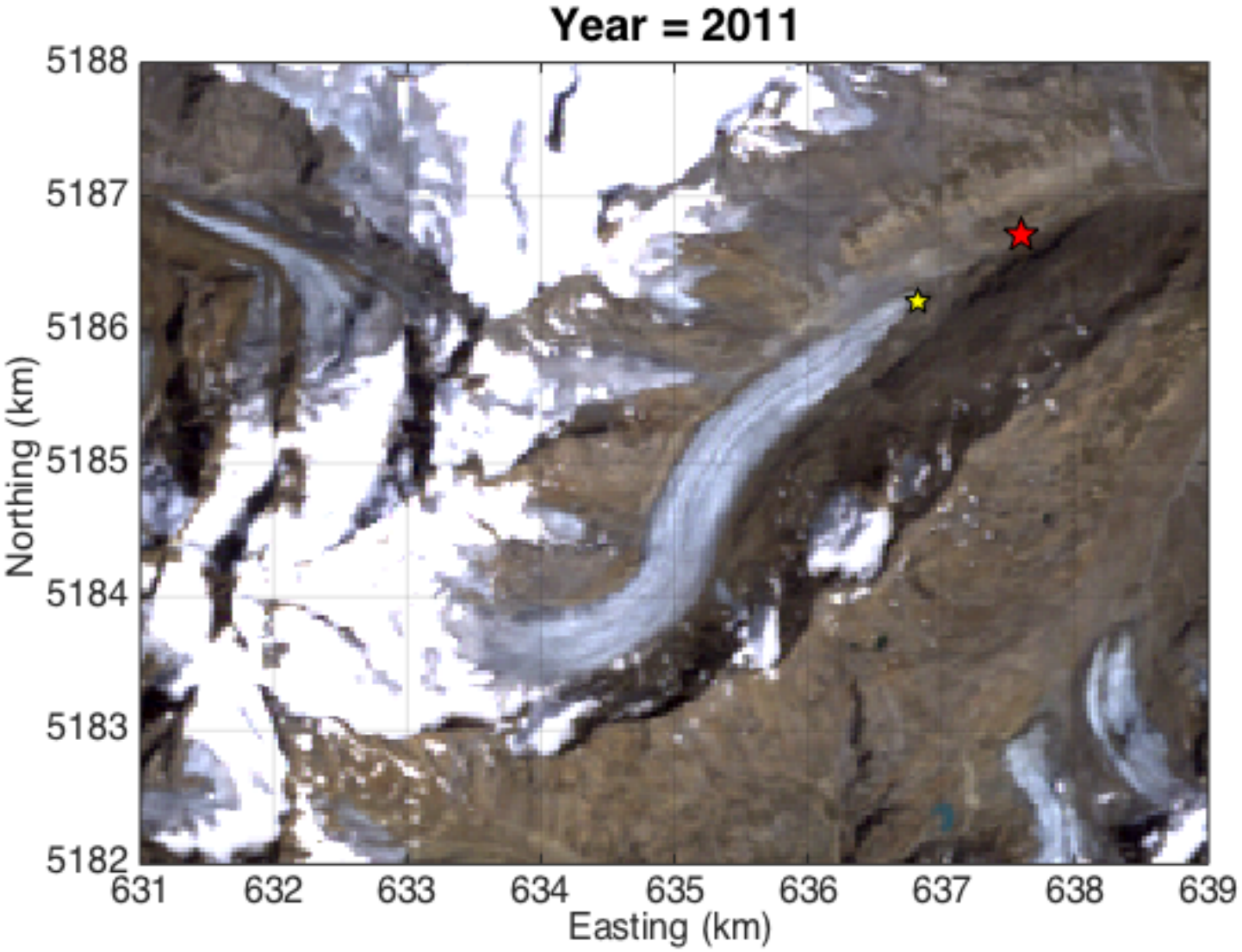
Glacier Data for the Classroom



Glacier Data for the Classroom



Glacier Data for the Classroom

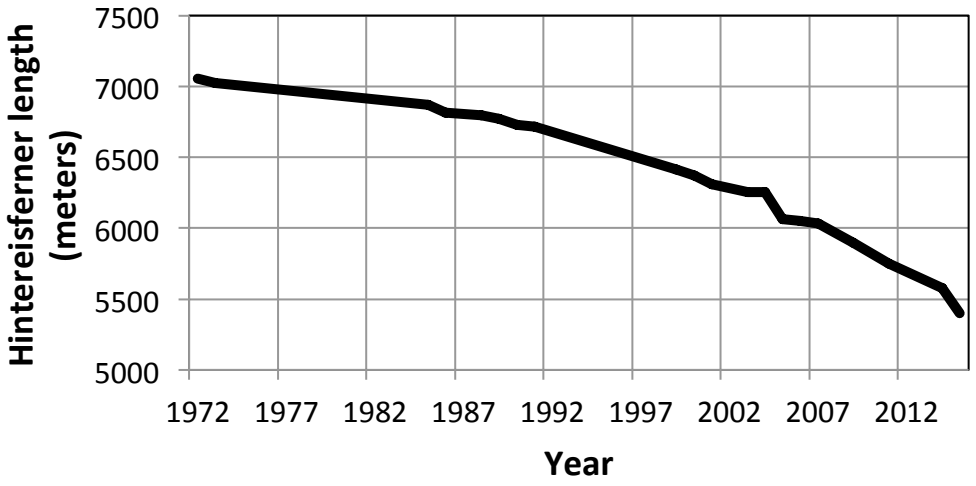


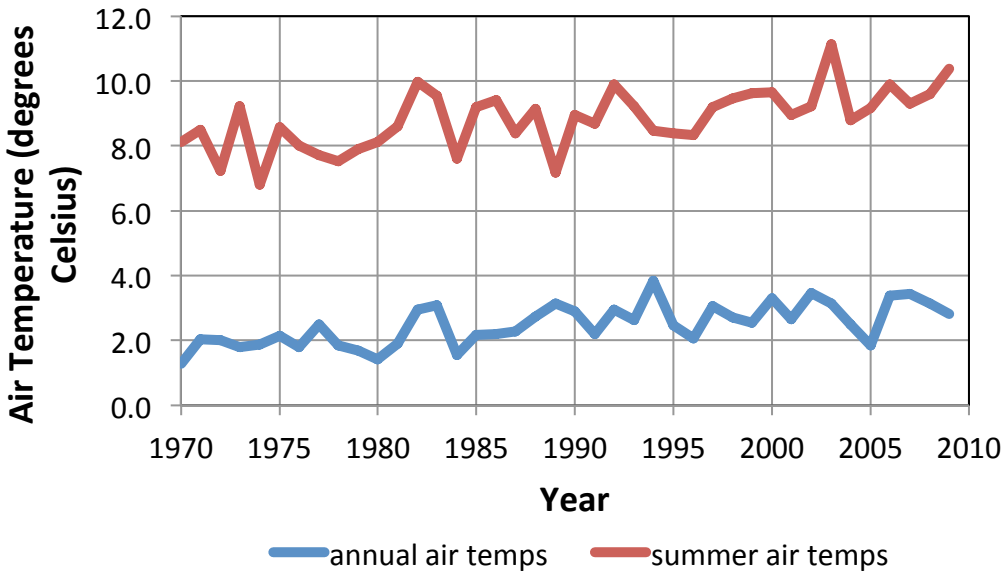
Glacier Data for the Classroom

PolarICE Data Story

- extract terminus change time series from satellite images

- compare terminus change, local air temperature, & global CO_2 records to demonstrate anthropogenic warming is driving glacier mass loss





Glacier Data for the Classroom

Other Interactive Activities

- use the UColorado glacier simulation tool https://phet.colorado.edu/en/simulation/glaciers to investigate glacier sensitivity to air temperate & snow accumulation change

- have students experiment with glacier "flubber" to see how ice flows

- collect time-lapse photos of flubber flow to get an idea of remote sensing of glaciers

Questions & Discussion

Questions?

email me:
ellyn.enderlin@gmail.com

check-out my website:
https://sites.google.com/site/ellynenderlin/

follow me on twitter:
@glacier_doc