Using space cameras to study big bits of ice and snow (and also other things)

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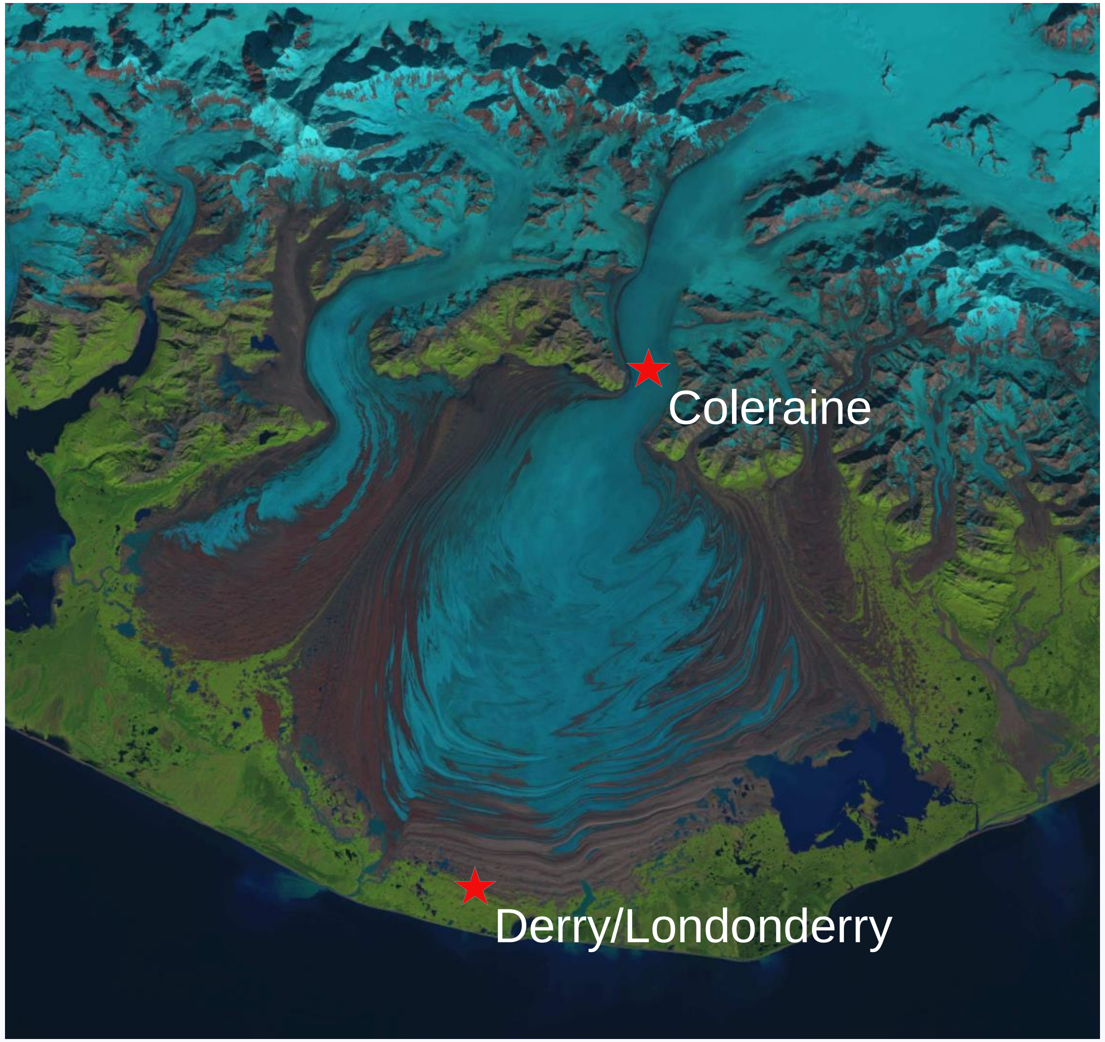
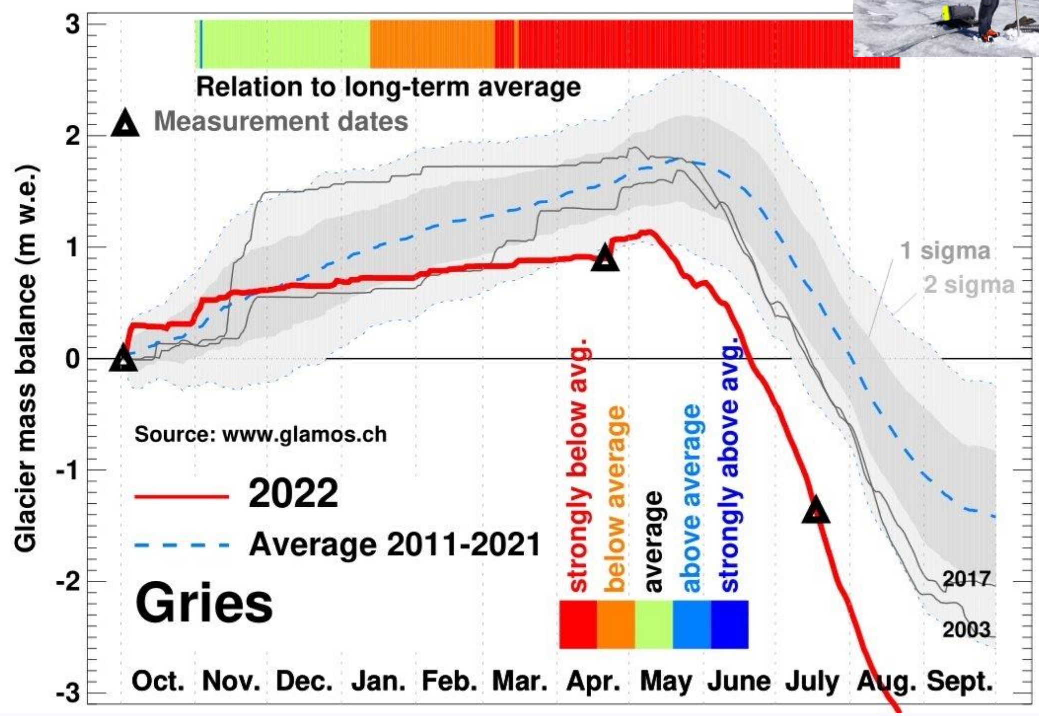
Big bits of ice and snow

- Glacier: a mass of snow and ice that moves under its own weight
  - Globally: ~25 cm SLE
- Ice Sheet: a continental-scale glacier (>50,000 km^2)
  - Antarctic: ~65 m SLE
  - Greenland: ~7 m SLE



Climate impacts on glaciers

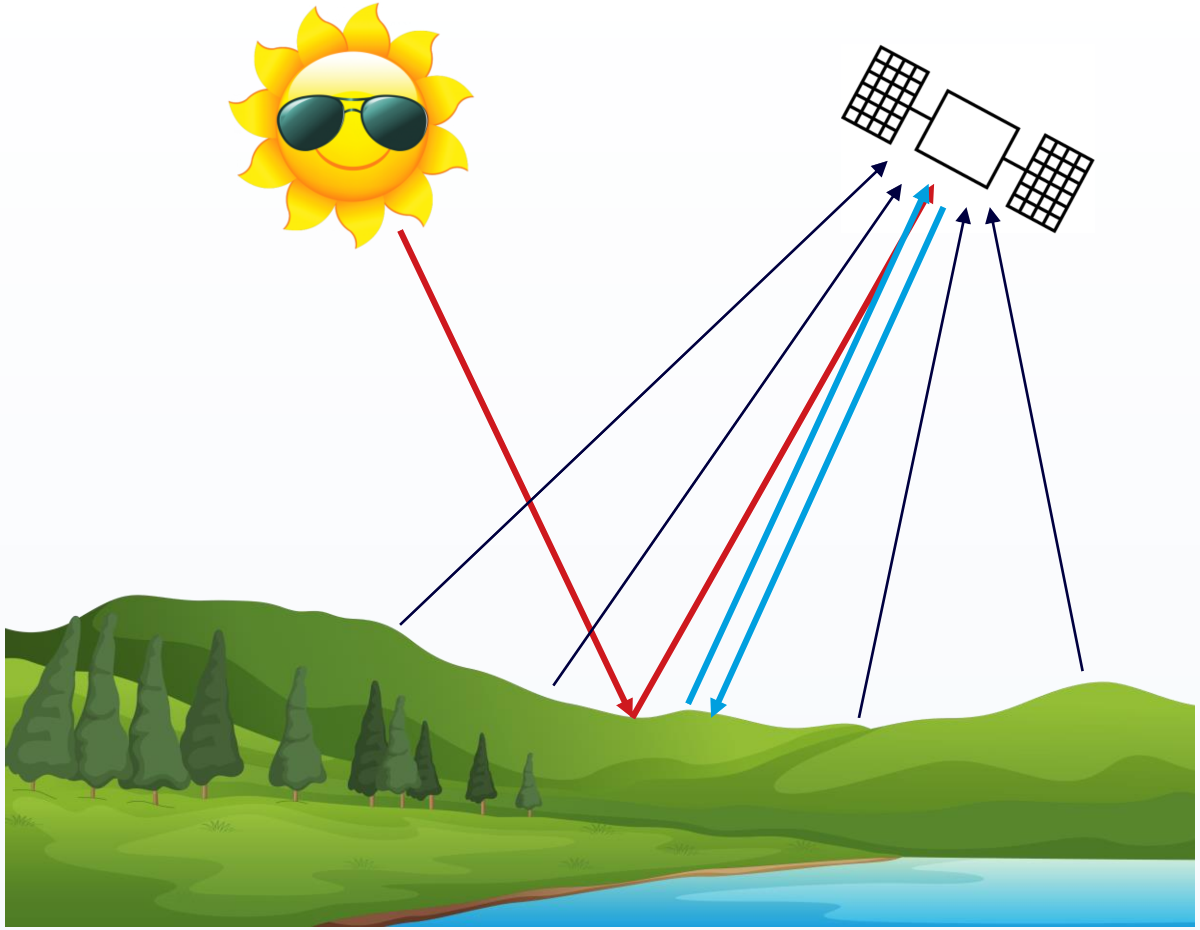
- Measure melt using mass balance stakes
  - Traditionally, measured 1-2 times/year
  - Now: automated instruments
- Example: Gries Gletscher (CH)
- Problem: glaciers are really big.
  - Globally: ~700,000 km^2
  - Size range: < 1 km^2 up to 1000s of km^2



Space+ Cameras*

- Remote sensing: studying an object without touching it
- Most often: measuring electromagnetic radiation (light)
- Source:
  - Sun
  - Object
  - Sensor (active)

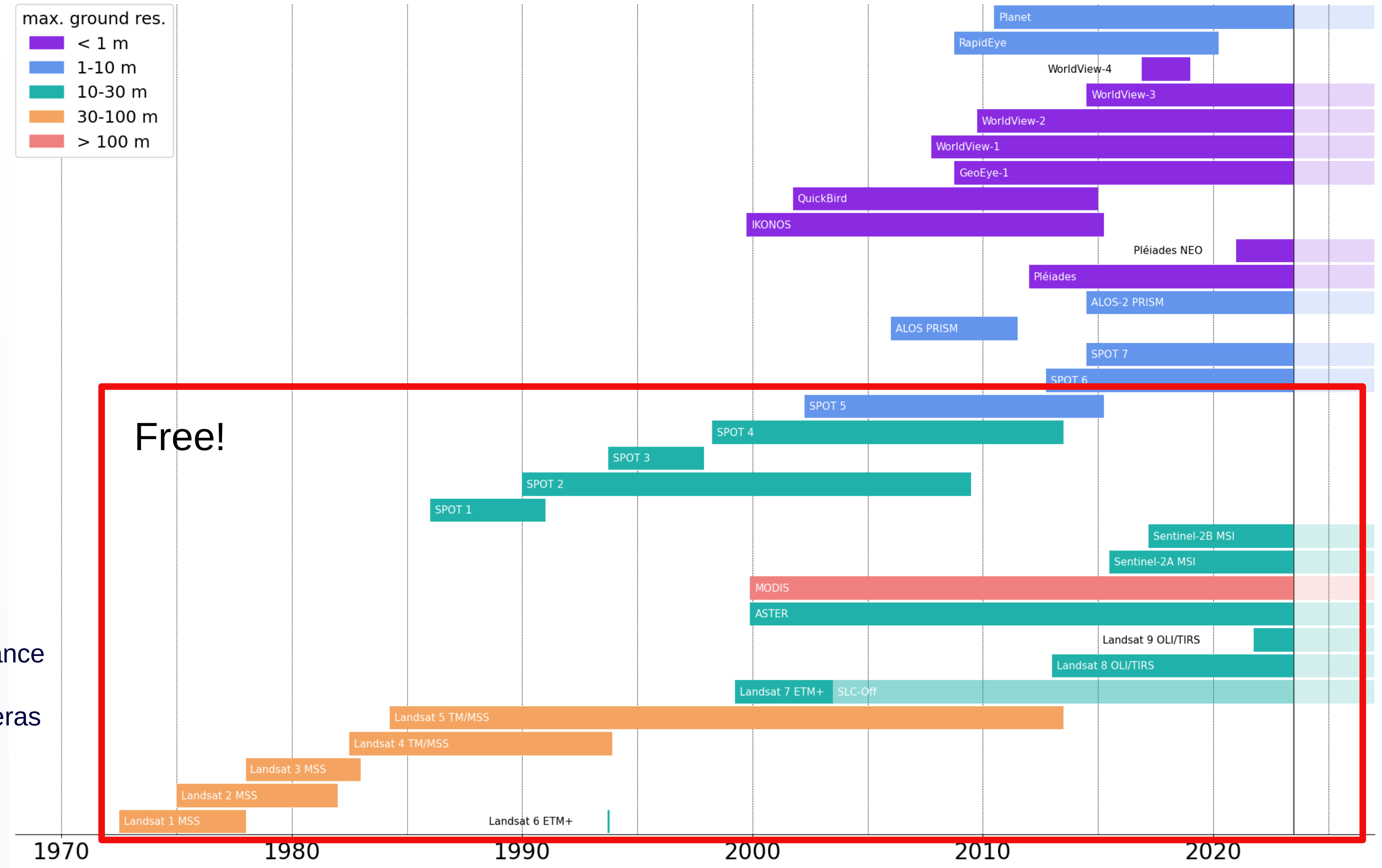
} passive



+not always in space!

*not always cameras!

A golden age

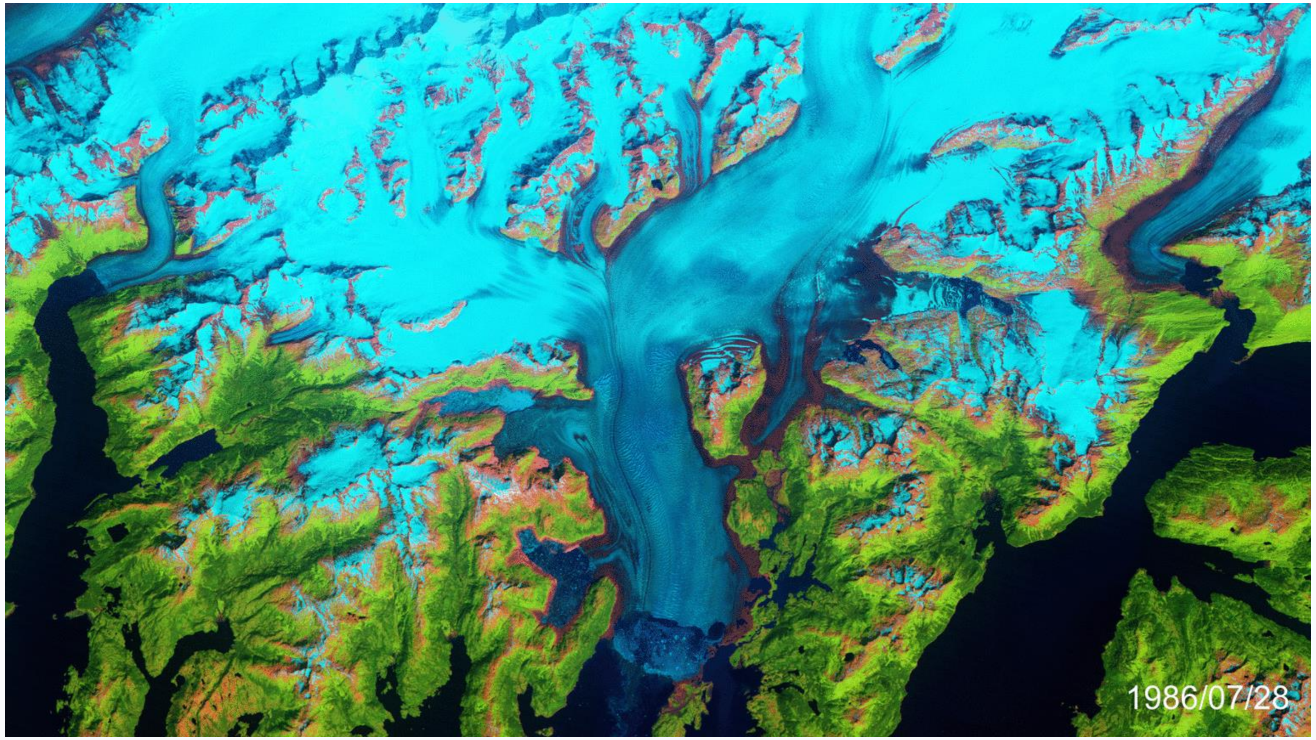


Not pictured:

- Declassified reconnaissance imagery
- Sensors that aren’t cameras
- Aerial photographs

50+ years of change from space

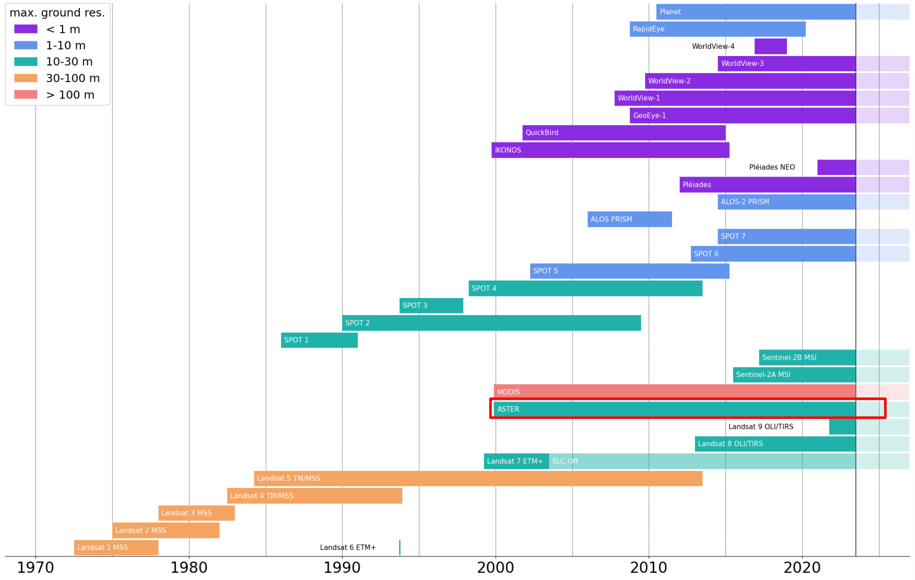
- Example: Columbia Glacier, AK
  - Marine-terminating glacier
- Since c.1980:
  - > 20 km retreat
  - Lost >50% of its volume (>160 km^3)
  - Split into several branches
  - Contributed several mm to global sea level rise

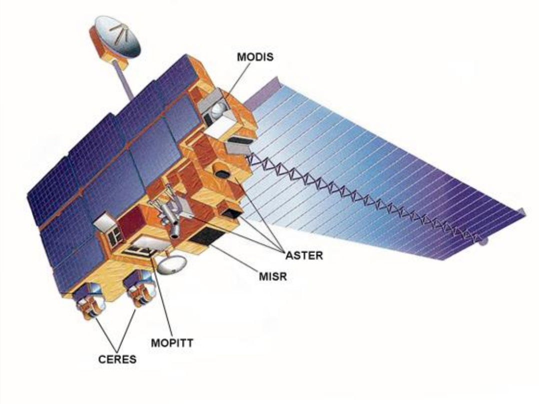


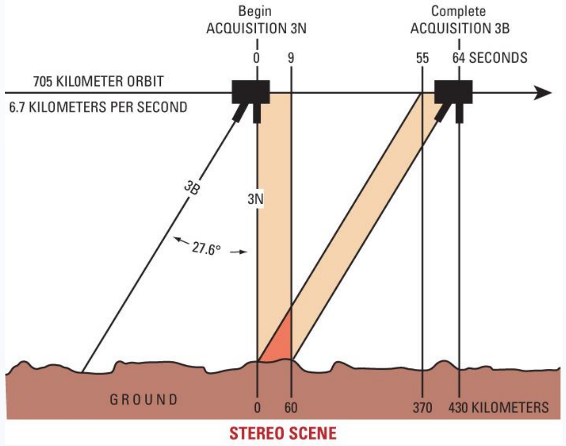
NASA/USGS

ASTER

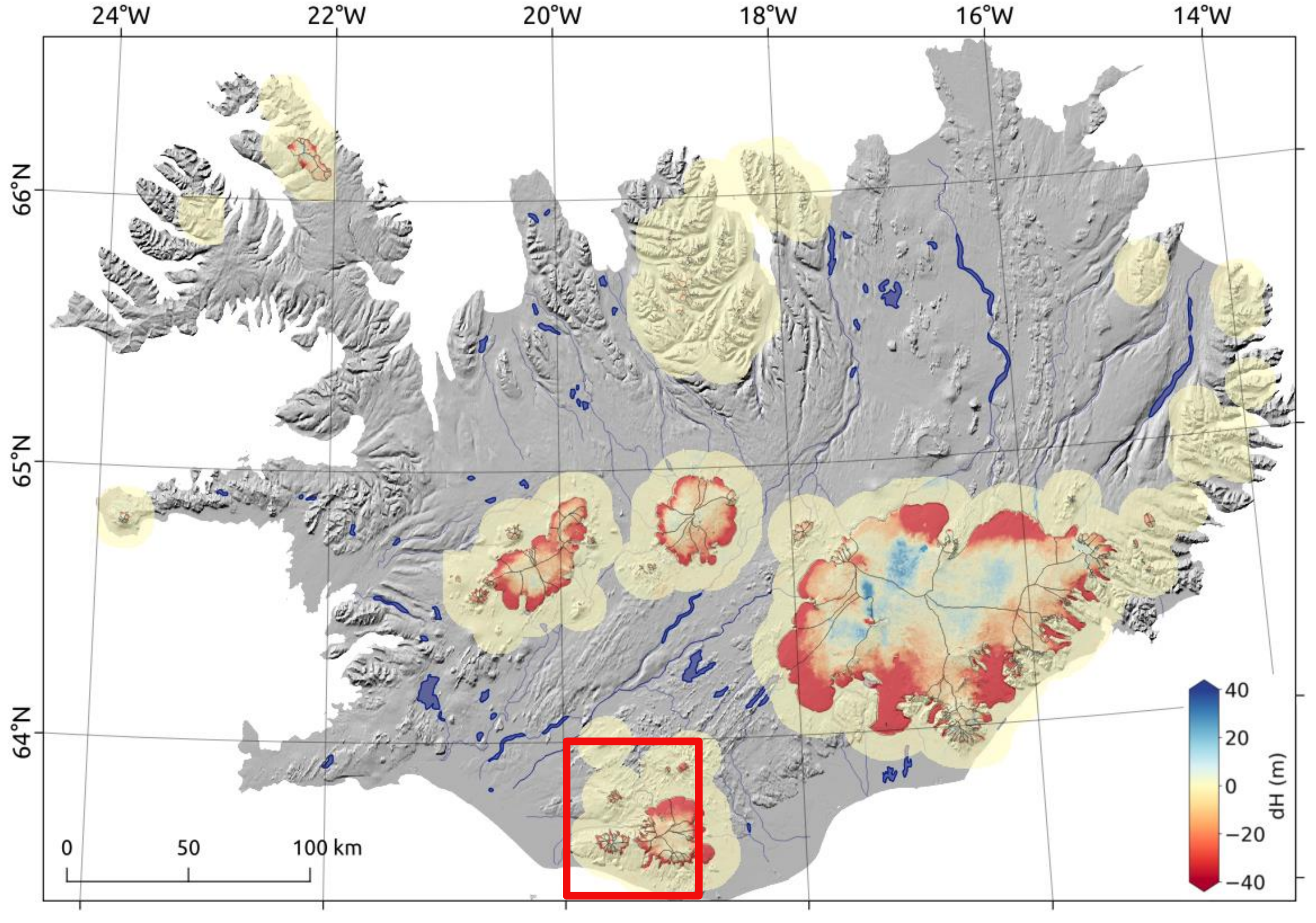
- Joint NASA/Japanese Space Agency (JAXA)
- Launched December 1999 aboard *Terra* satellite
- Stereo images: can measure elevation/topography
- From April 2016, entire ASTER archive freely available
  - > 20 year time series of global elevation (and change!)

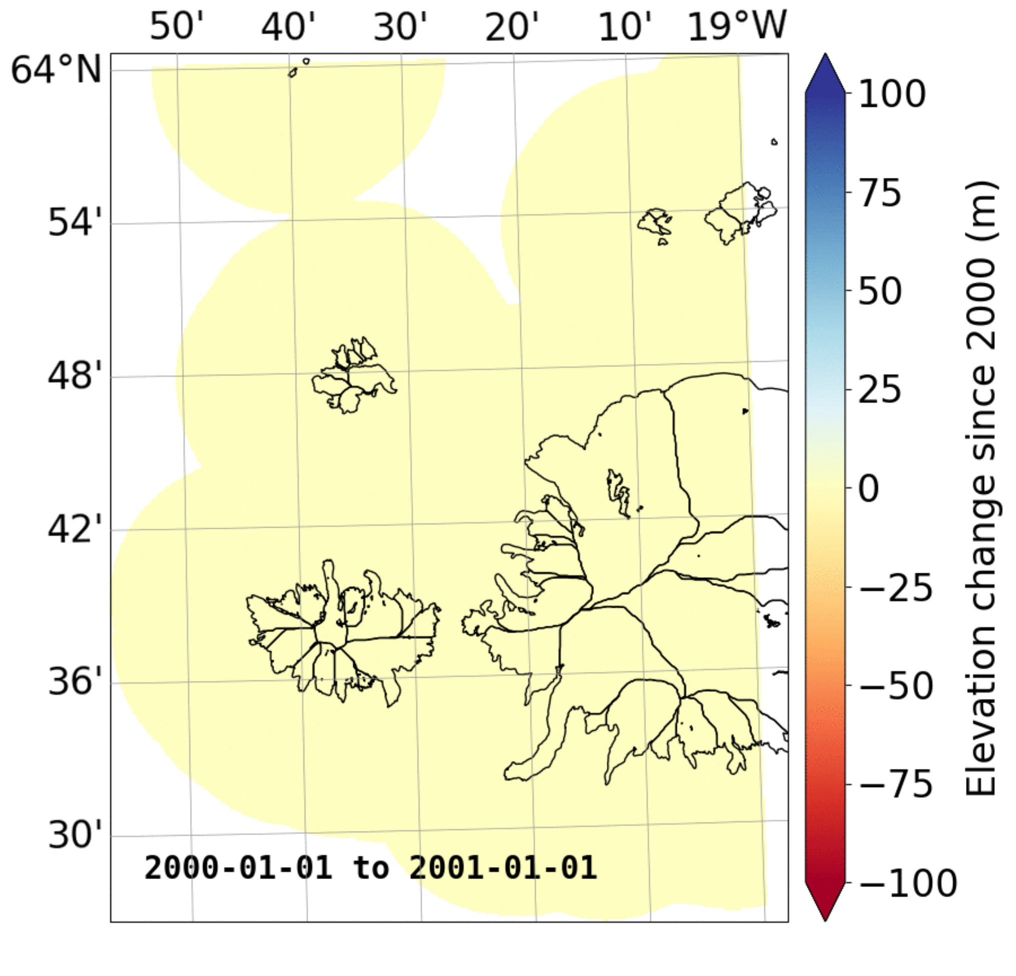






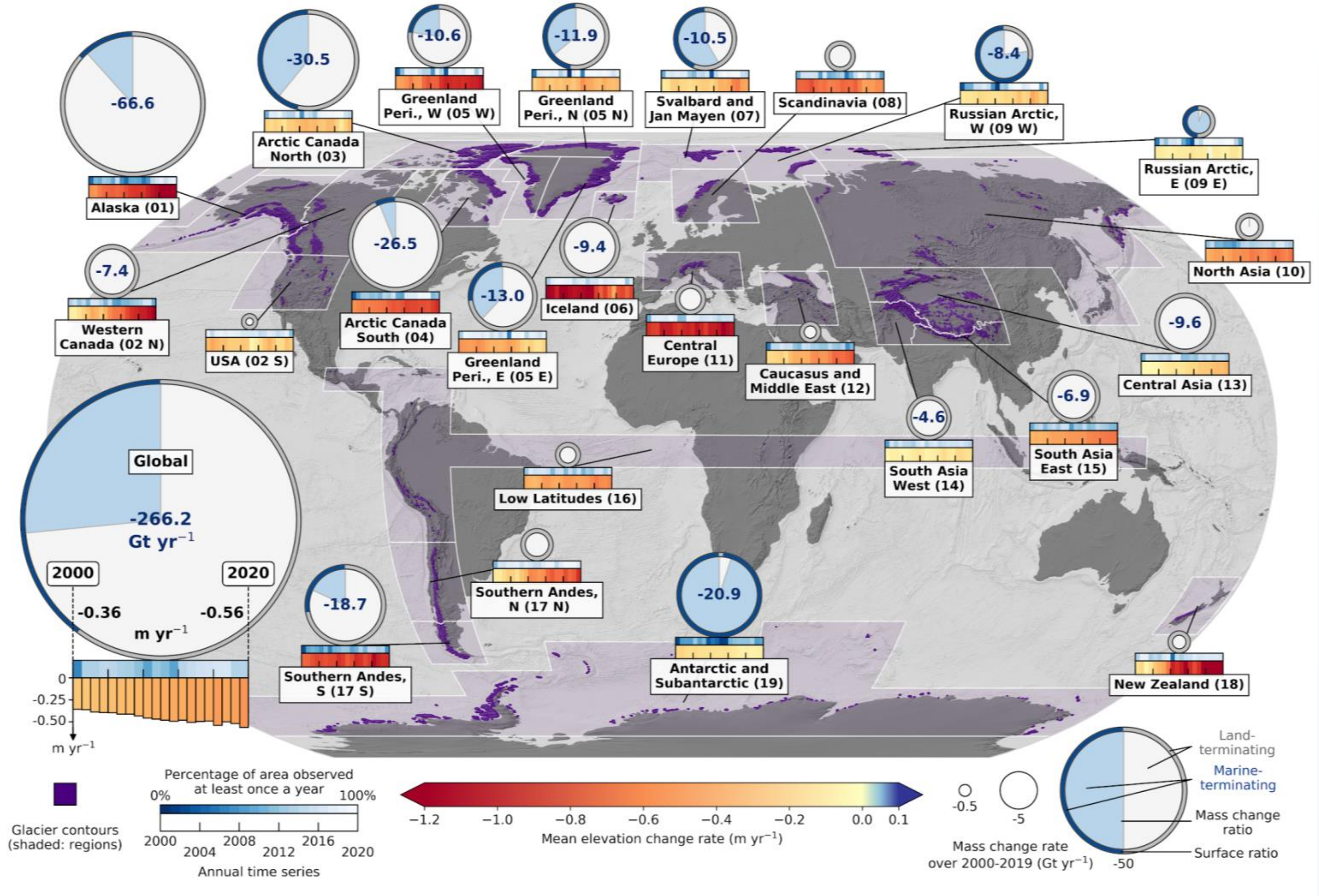
Spatiotemporally resolved elevation change





Global glacier mass changes, 2000-2019

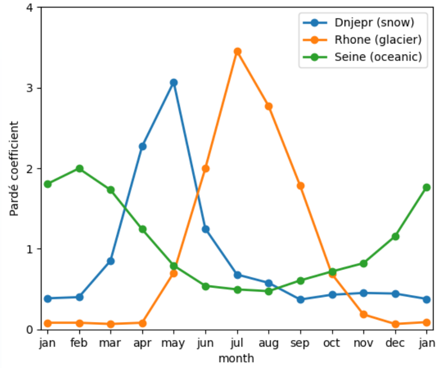
- Global mass loss:
  266 ± 16 Gt yr^{-1}
  - 1 Gt = 1 km^3 water
  - ~76 Lough(s) Neagh
  - Would cover Ireland in ~3 m of water
- 21 ± 3% of observed sea level rise
- Accelerated by
  48 ± 16 Gt yr^{-1} per decade

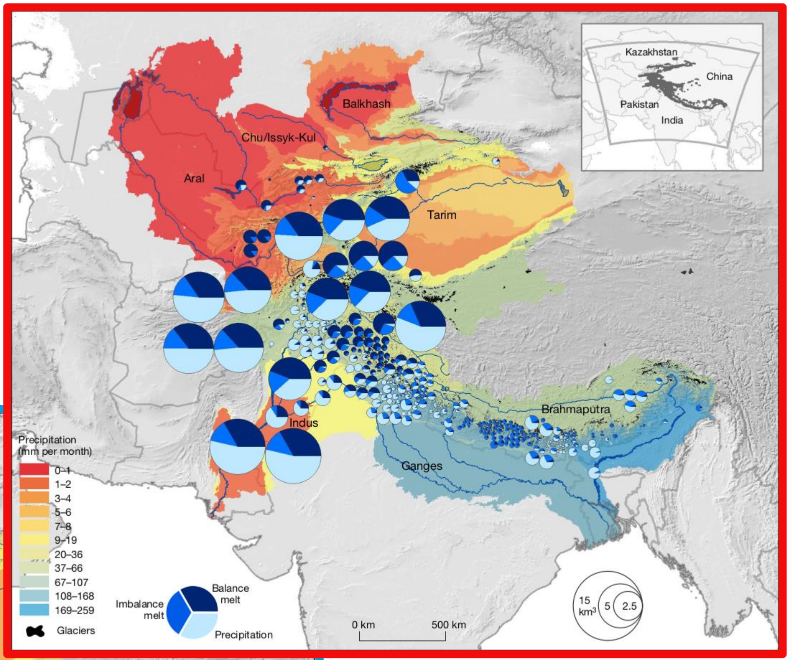


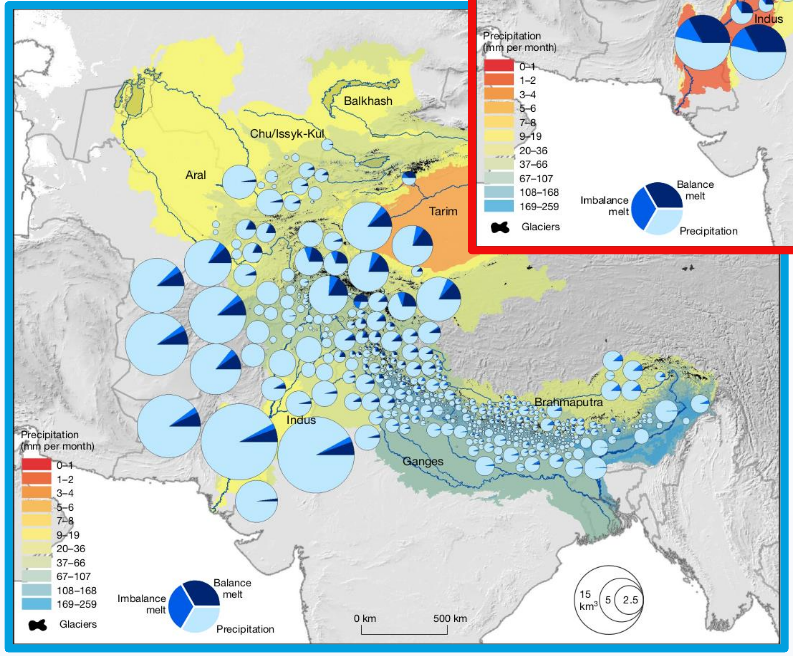
Hugonnet et al., 2021

Glaciers are important water resources

- Glacier melt:
  - Helps “delay” annual runoff peak
  - Provides water later in melt season
- Example: Central Asia
  - c.800M depend on glacier meltwater
  - Normal years: precipitation dominates
  - Drought years: glacier melt helps reduce drought stress



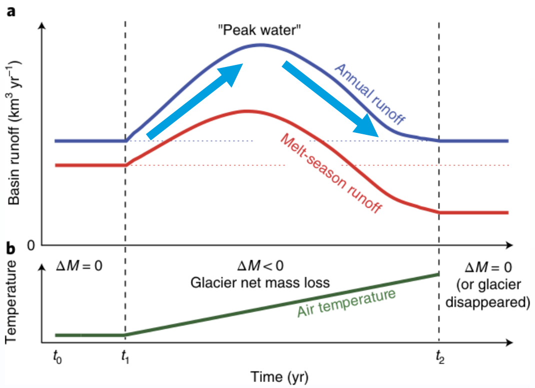


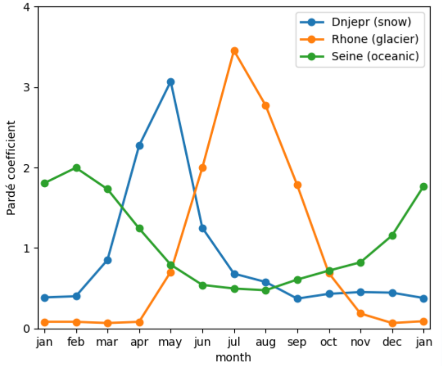


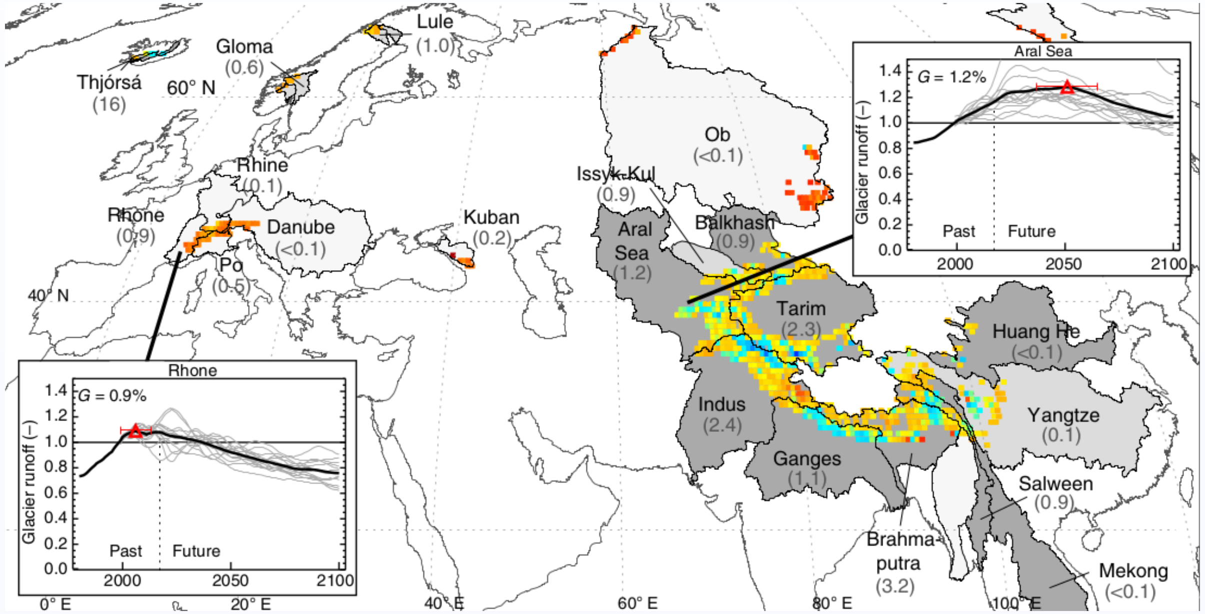
Pritchard, 2019

What happens in a warming climate?

- At first:
  - More glacier melt means more runoff
- Eventually:
  - “Peak water” passes
  - Less water available
- 56 “macroscale” (>5000 km²) drainage basins:
  - 45% have already reached “peak water”
  - Remaining 55%: “peak water” expected before 2100





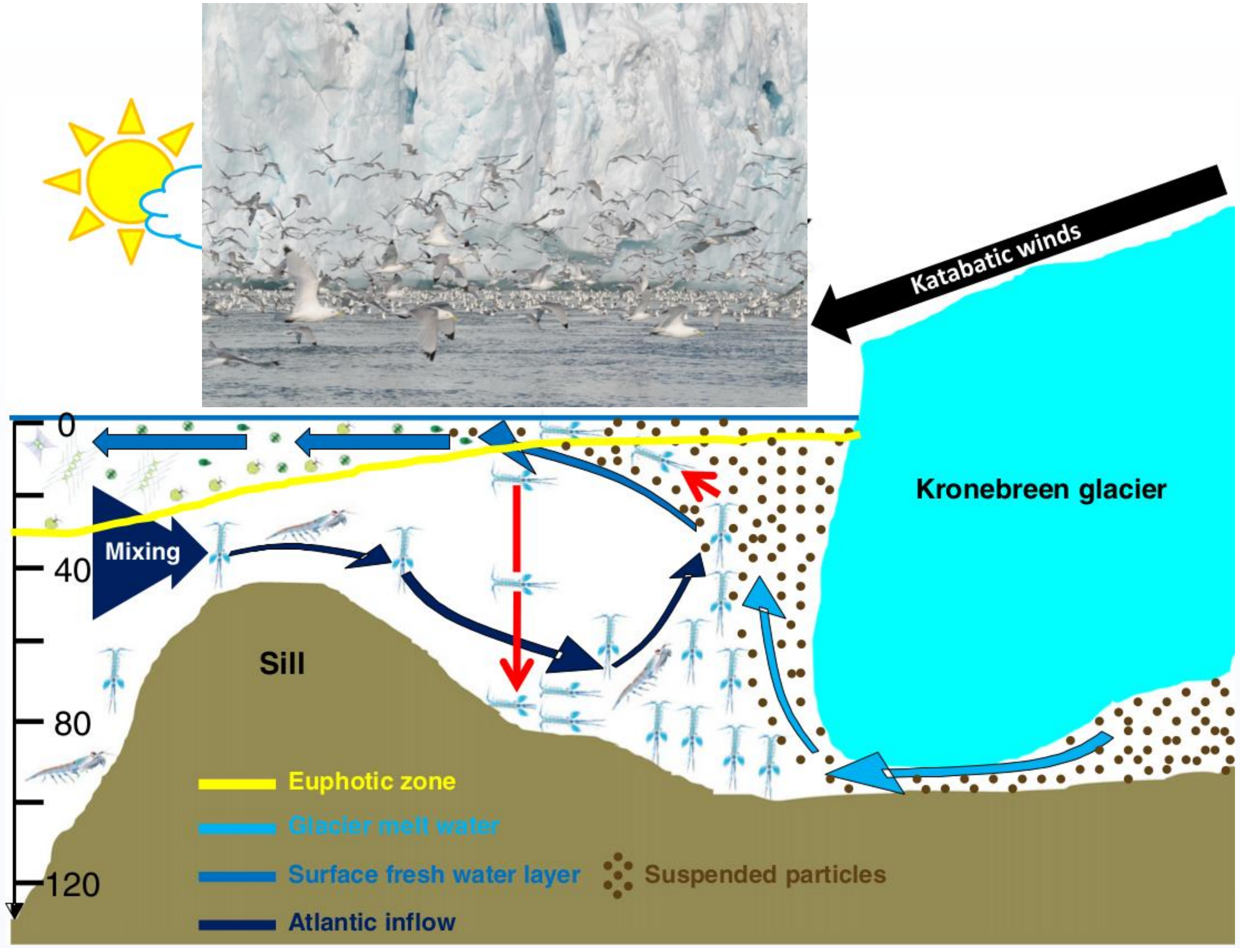


Huss and Hock, 2018

Glaciers are important habitat!

Glaciers provide important nutrients!

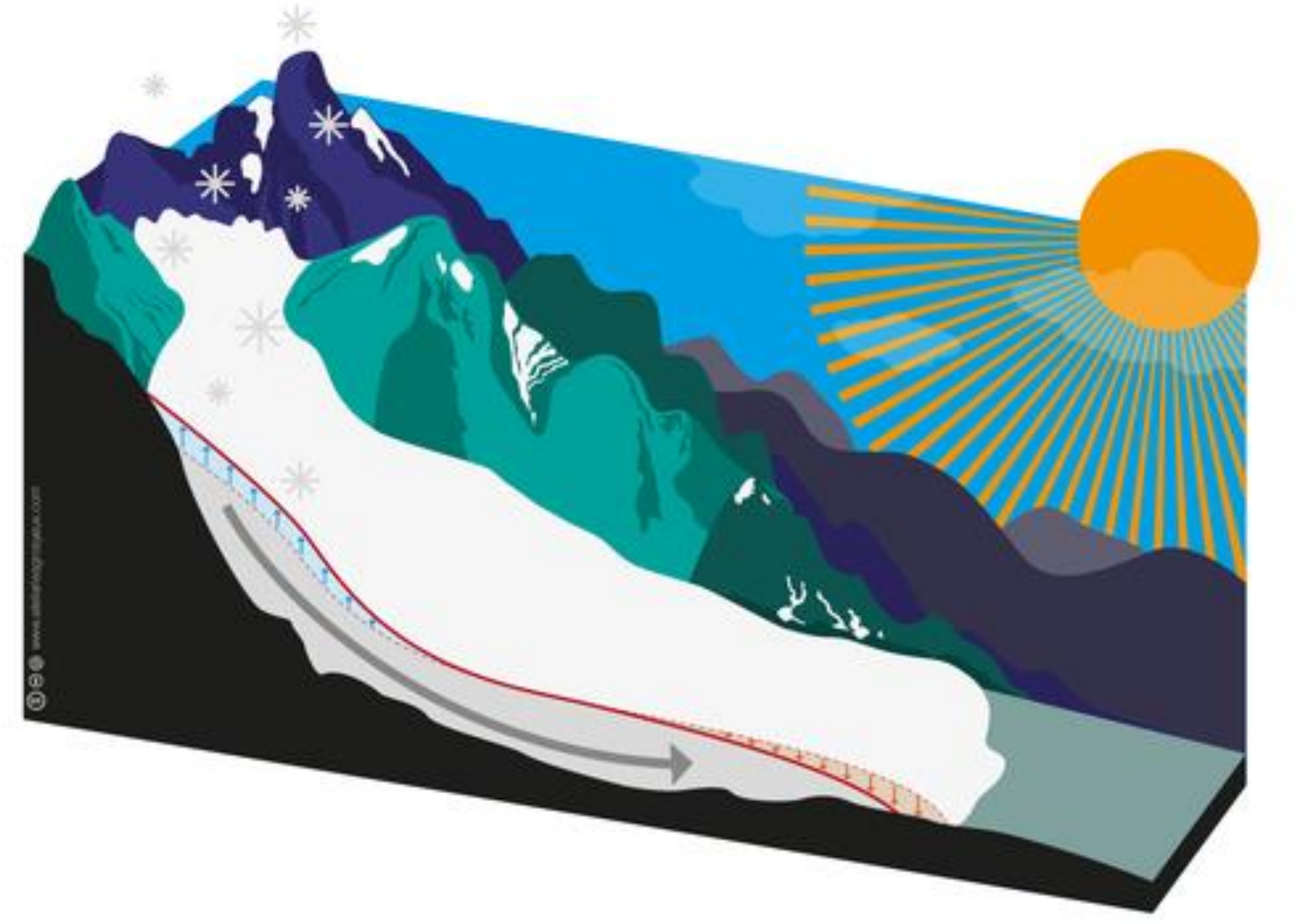
- Example: Kronebreen, Svalbard
- Meltwater enters the fjord from under the glacier (subglacial)
  - Contains sediments
  - Cold, fresh water
  - Causes upwelling as it exits the glacier
- Zooplankton are caught in meltwater plumes, brought to surface



Lydersen et al. 2014

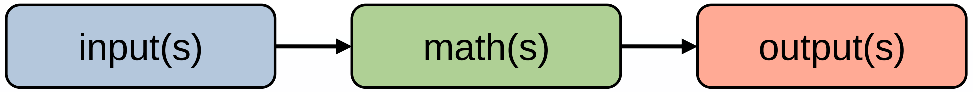
Reminder: how glaciers work

- Accumulation: mass gain
  - Snowfall
  - Snow transport (avalanches, wind)
- Ablation: mass loss
  - Melt (surface, base)
  - Calving (marine/lake-terminating)
  - Sublimation (some places)
- Mass “balance”: sum of gain and loss
  - Equilibrium Line Altitude (ELA): where mass balance is 0
- Remember: glaciers flow
  - Redistributes mass



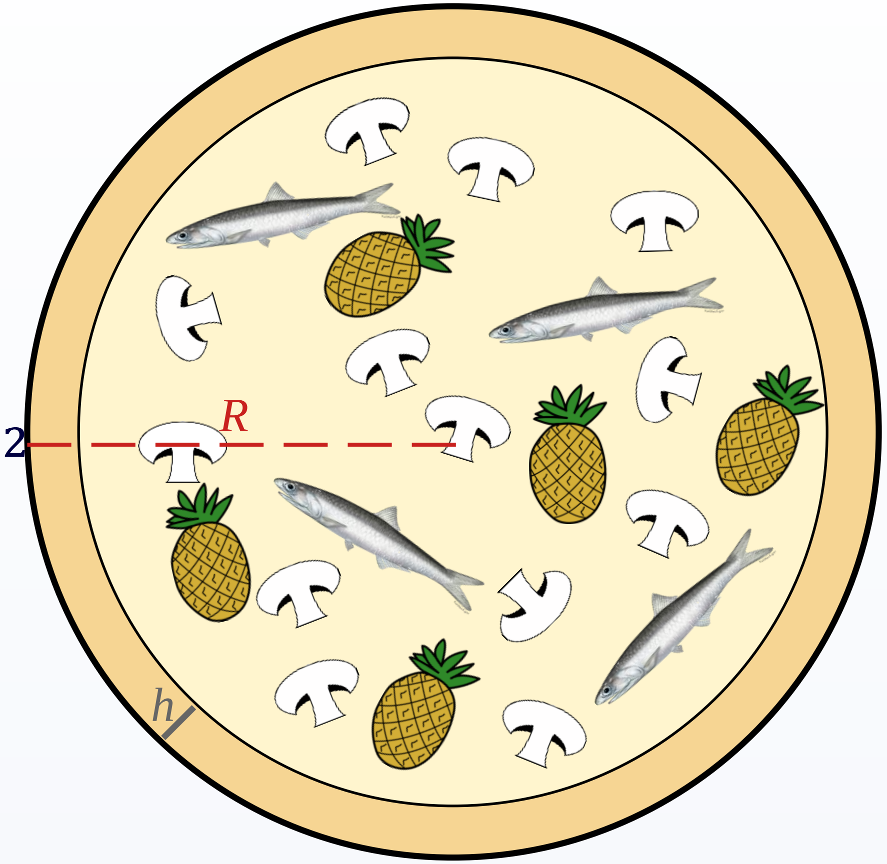
Refresher: mathematical models

- In science, seek to:
  - Understand (explain)
  - Make credible predictions
- One tool: mathematical models
- Example: surface area (A) of pizza
  - Simple!
  - But: what about crust?
  - But: crusts aren’t even thickness, pizza isn’t perfectly round, …
- Ultimately: “all models are wrong, but some are useful” (G. E. P. Box)



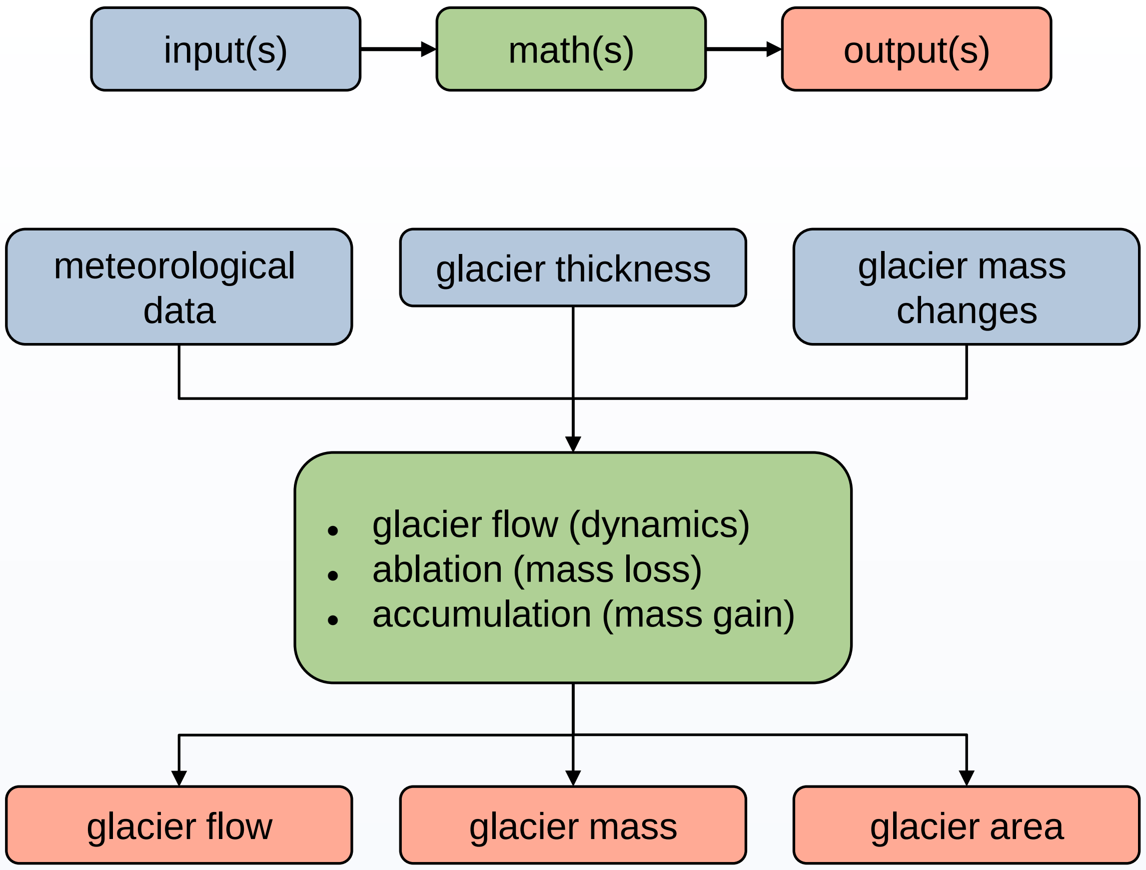
~~$A = \pi R^2$~~

~~$A = \pi(R - h)^2$~~

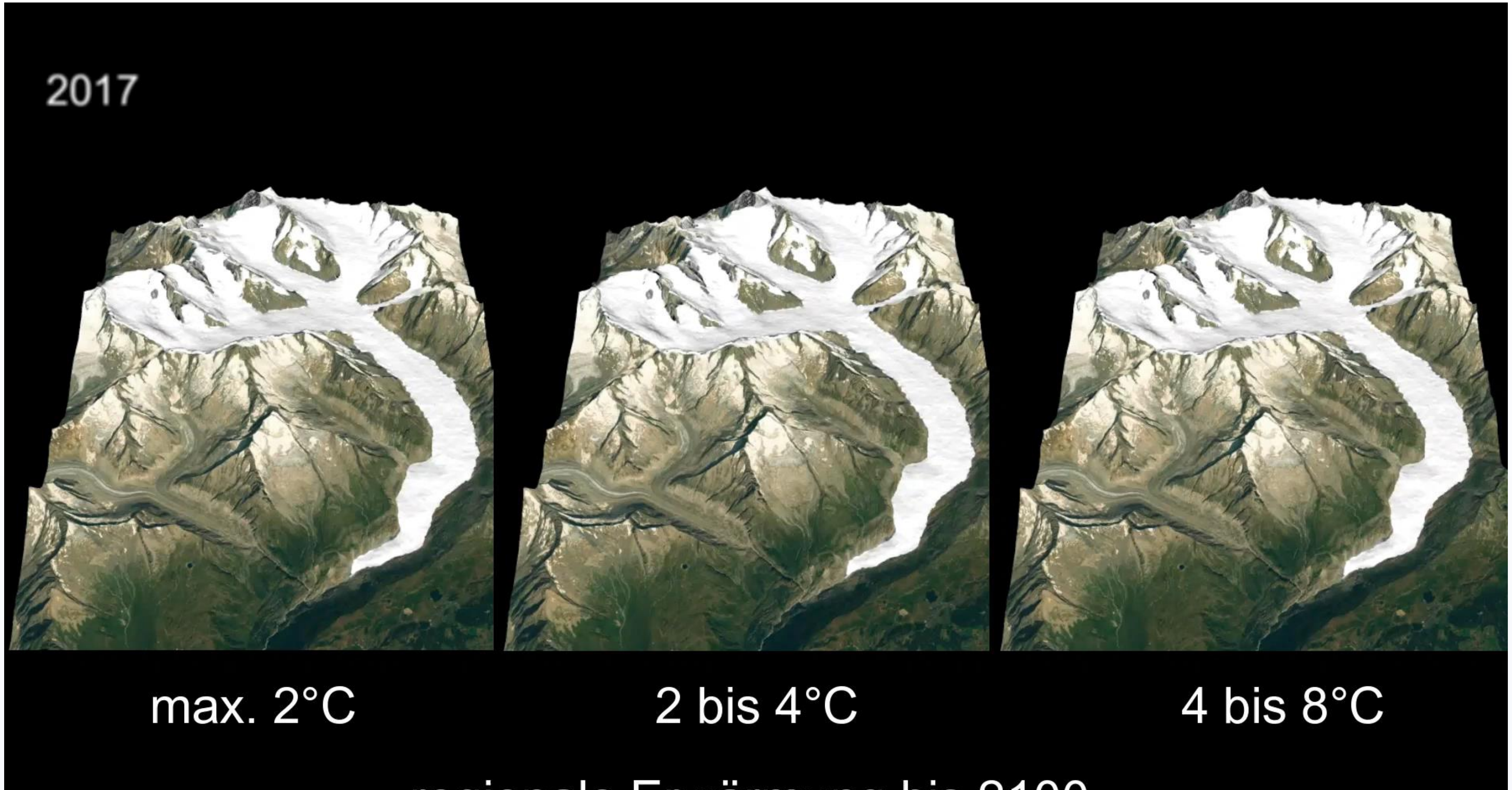


Glacier modelling: a primer

- Inputs:
  - Meteorological data (temperature, precipitation, …)
  - Glacier thickness
  - Observations of glacier mass changes*
- Math(s):
  - Some way of modelling how glaciers flow
  - Some way of modelling mass loss
  - Some way of modelling mass gain
- Output(s):
  - Glacier mass at time *t*
  - Glacier area*
  - Glacier flow*



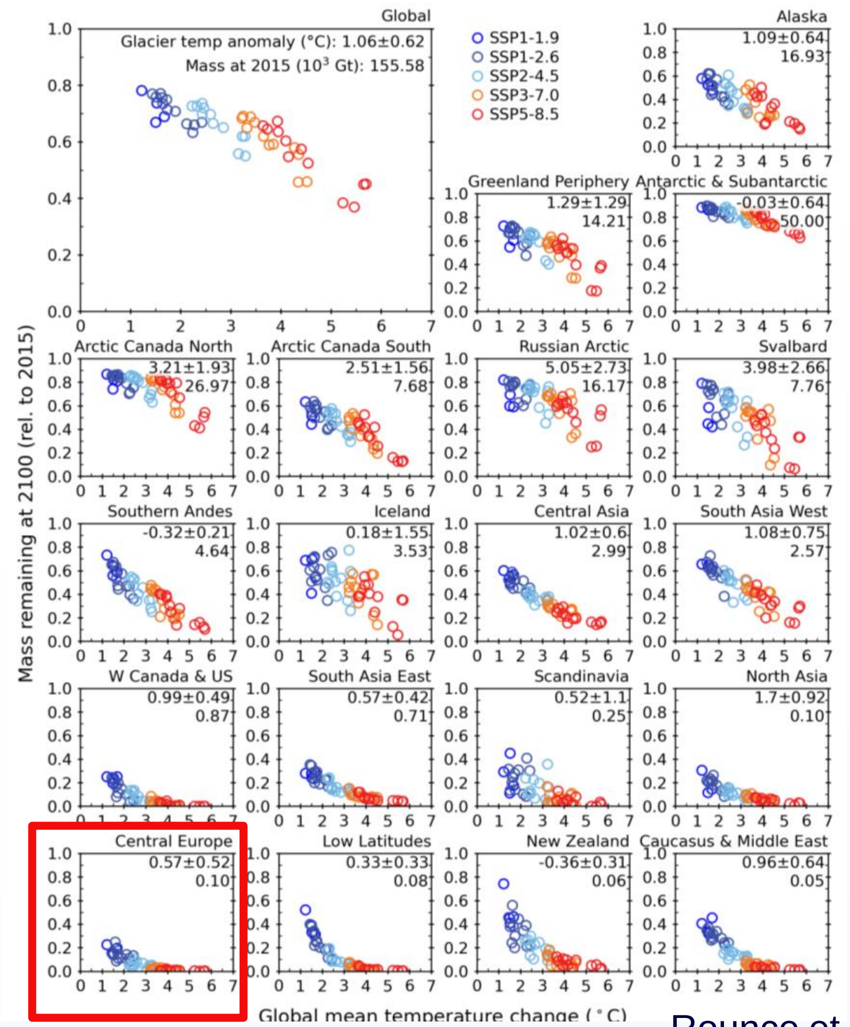
Projecting future changes



Jouvet and Huss, 2019

Every 0.1 degree matters

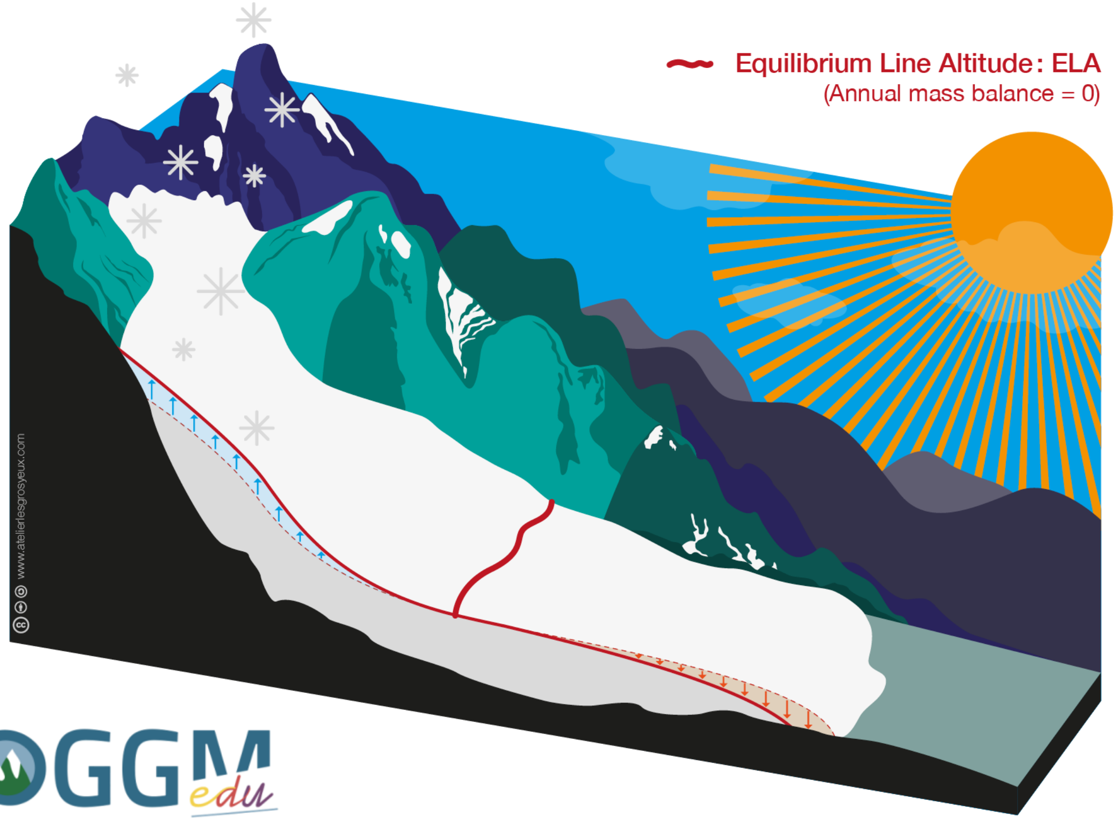
- Globally, glaciers projected to lose between 26 ± 6% (+1.5°C) and 41 ± 11% (+4°C) of mass by 2100
  - Up to 154 mm SLE
  - Between 49 ± 9% and 83 ± 7% of glaciers disappear completely
- Using COP26 pledges:
  - 2.7°C of warming by 2100
  - SLE: 115 ± 40 mm
- European Alps: only ~20% of glacier mass remaining, even under best-case scenarios



Rounce et al., 2023

OGGM-Edu

- Open Global Glacier Model (OGGM)
- OGGM-Edu: resources for educators
  - Glacier Gallery
  - Glacier simulator
  - Mass balance simulator
  - Future evolution of glaciers
  - … and more!



Other Resources

- AntarcticGlaciers.org
- VR Glaciers and Glaciated Landscapes
- SwissEduc Glaciers Online
- IQUA Shaping the Landscape
- World Glacier Monitoring Service
- Sentinel Playground (Example)

Questions?

References

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