Glacier-Human Interactions

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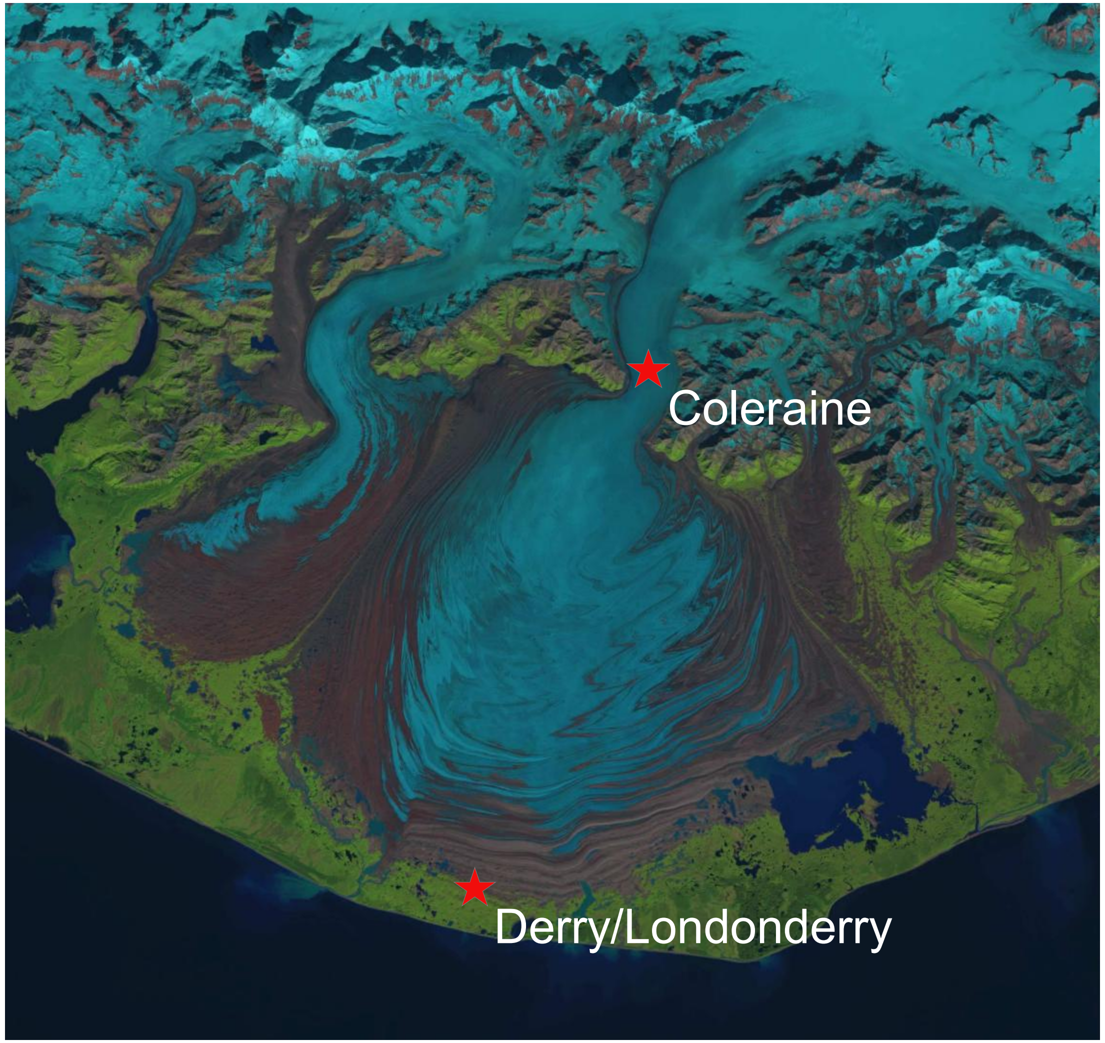
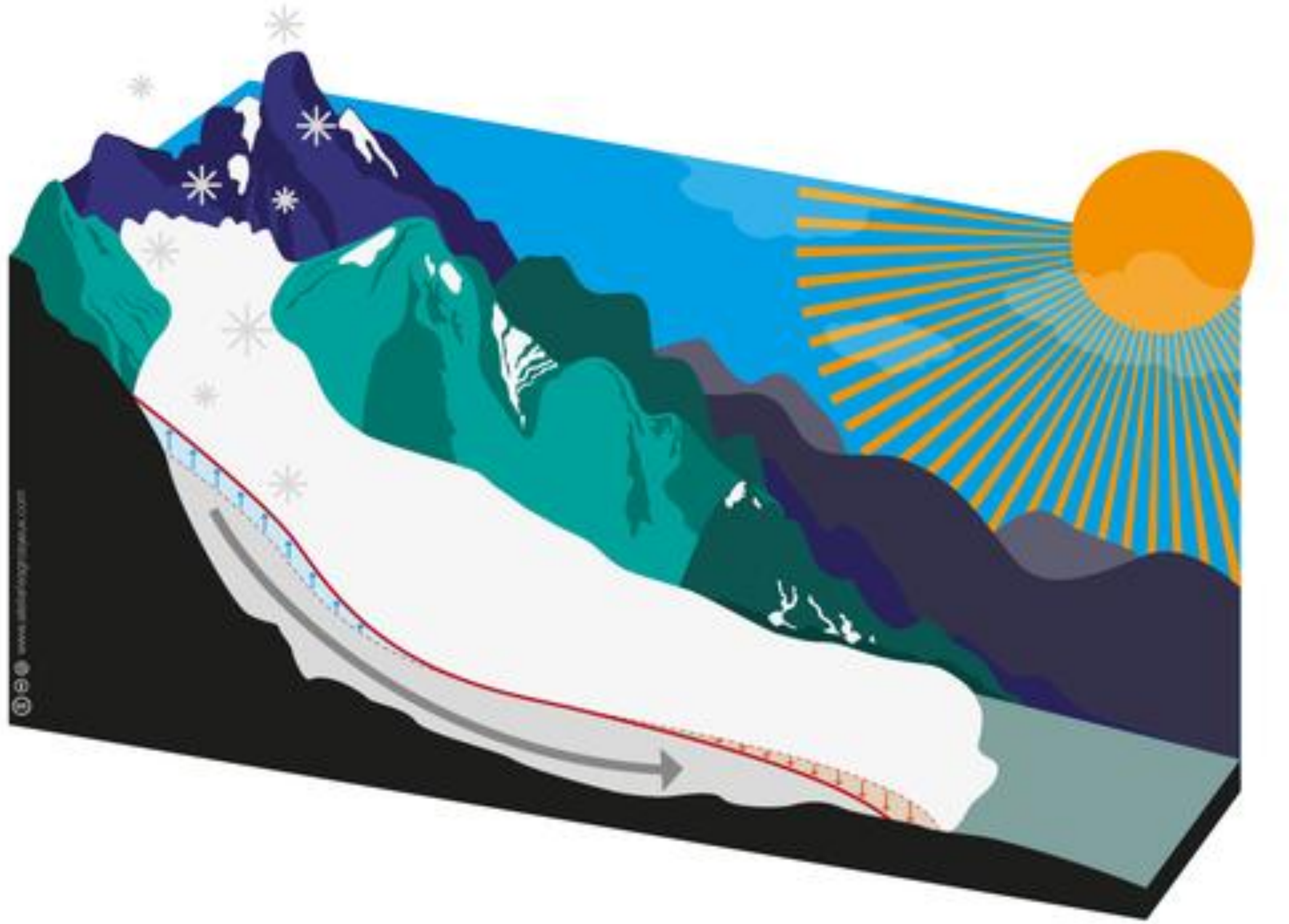
Big bits of ice and snow

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



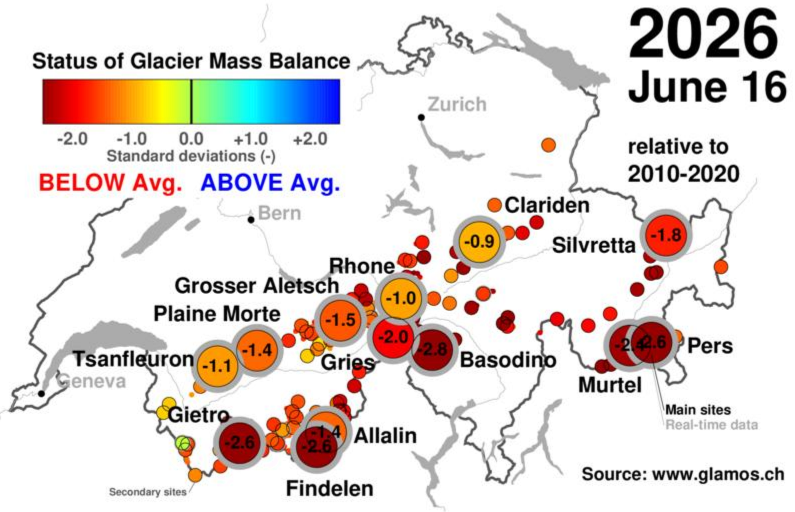
Reminder: how glaciers work

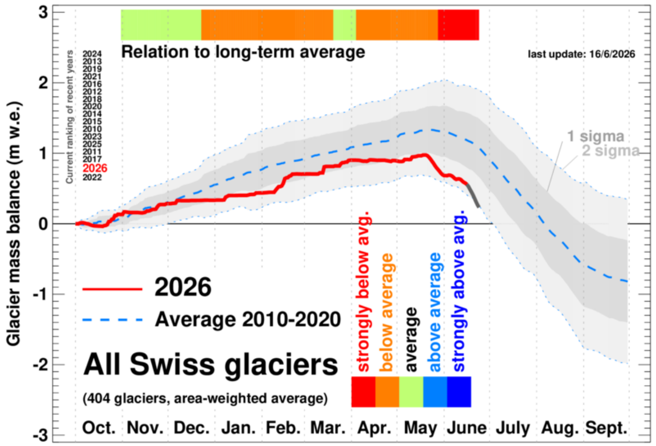
- Accumulation: mass gain
  - Snowfall
  - Snow transport (avalanches, wind
- Ablation: mass loss
  - Melt (surface, base)
  - Calving (marine/lake-terminating)
  - Sublimation (some places)
- Mass “balance”: sum of gain an loss
  - Equilibrium Line Altitude (ELA): where mass balance is 0
- Remember: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



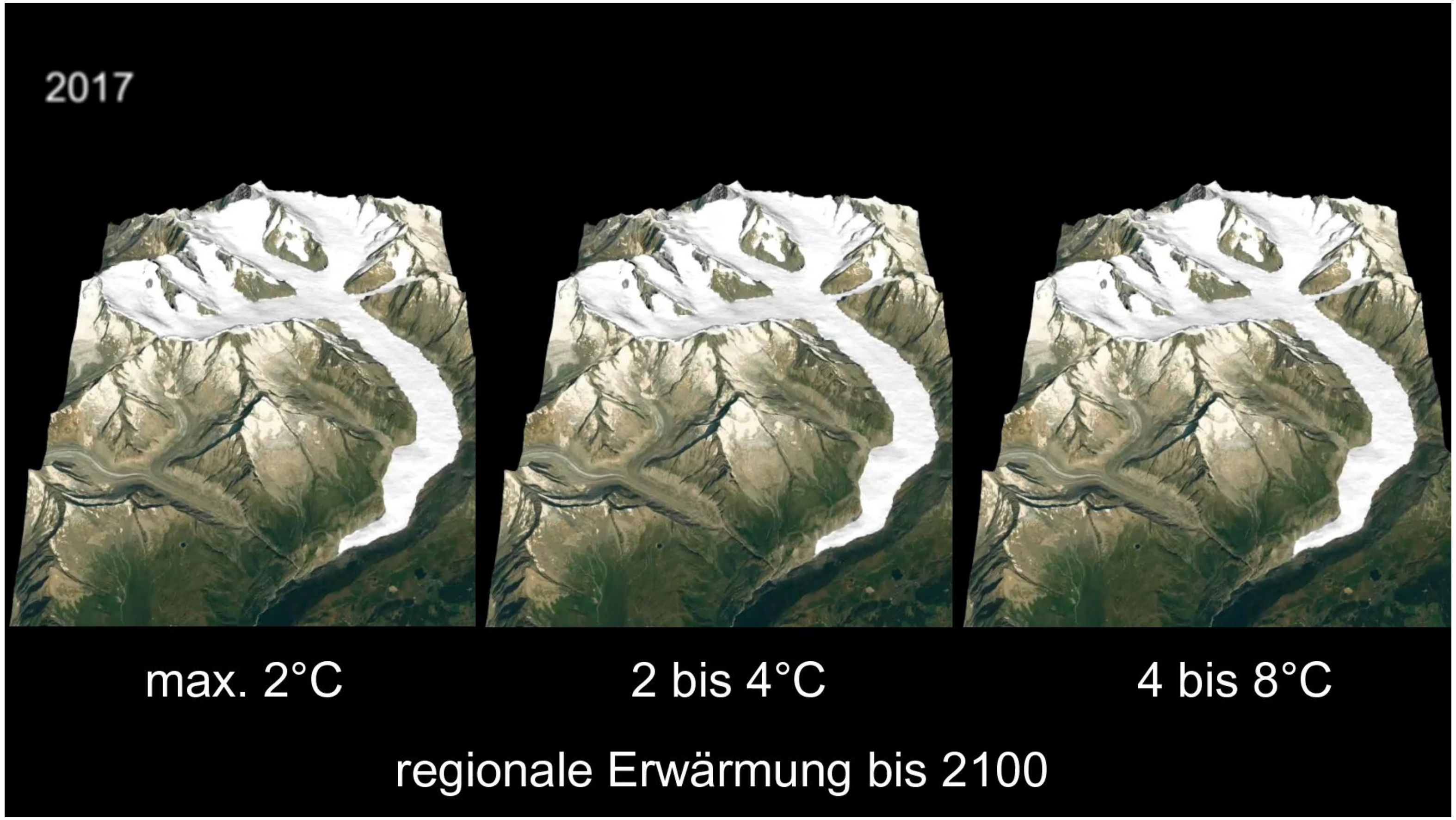
Climate impacts on glaciers

- Measure mass balance using mass balance stakes
  - Traditionally, measures 1-2 times/year
  - Now: automated observations
- Example: Glacier Monitoring Switzerland (GLAMOS)
  - Daily updates for glaciers across Switzerland





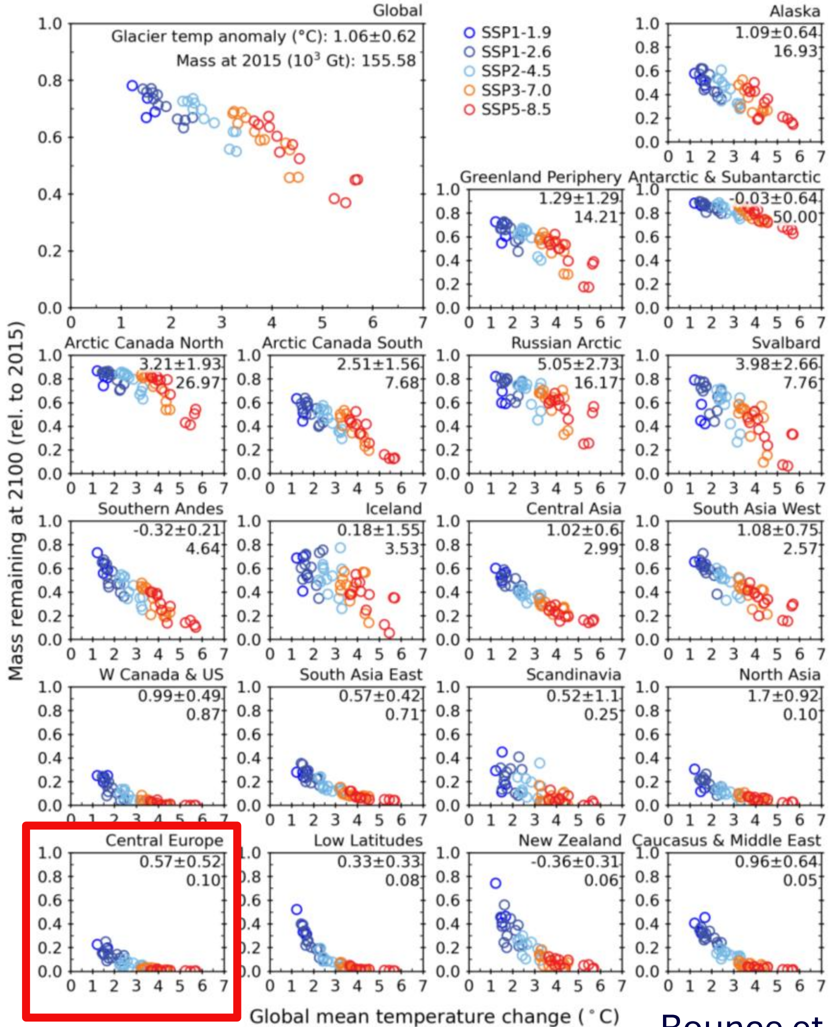
Projecting future changes



Jouvet and Huss, 2019

Every 0.1 degree matters

- By 2100, glaciers projected to lose between 26 ± 6% (+1.5°C) and 41 ± 11% (+4°C) of mass
  - 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

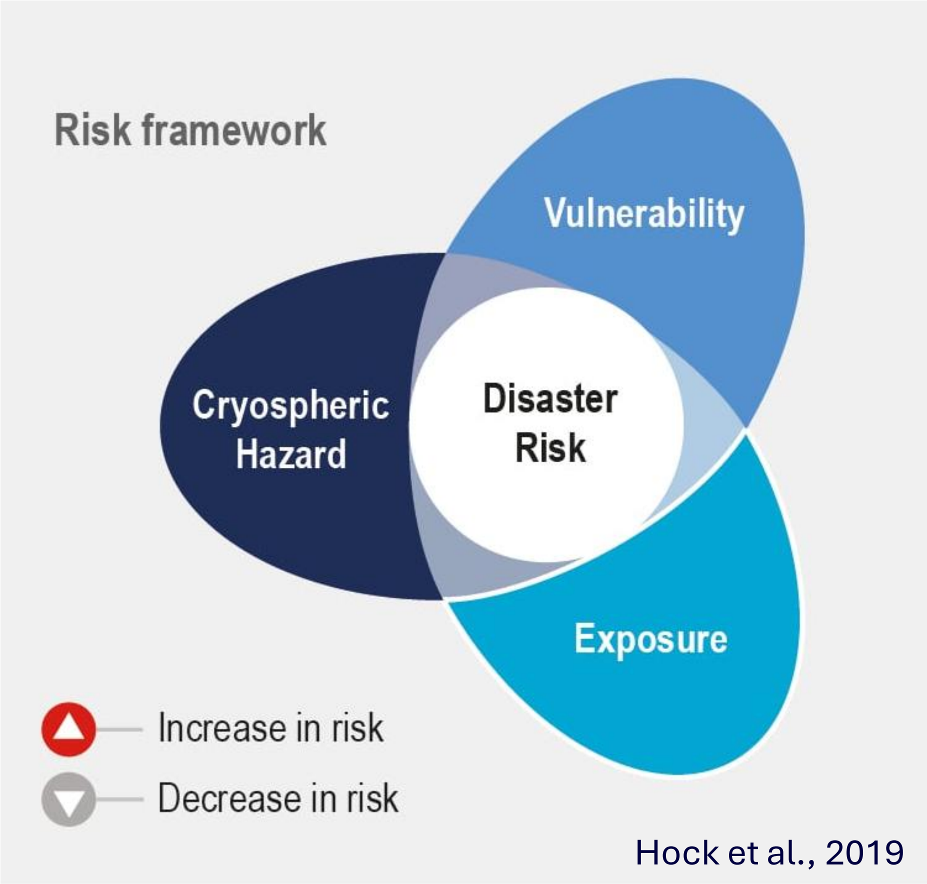
The times, they are a-changin’

- Even under the most optimistic climate scenarios, a lot of glacier change is “baked in”
  - (sorry)
- What are the different ways that:
  - Glacier changes are currently impacting humans?
  - Future changes will impact humans?

Columbia Glacier, Alaska
Oct. 2014

Hazard and Risk

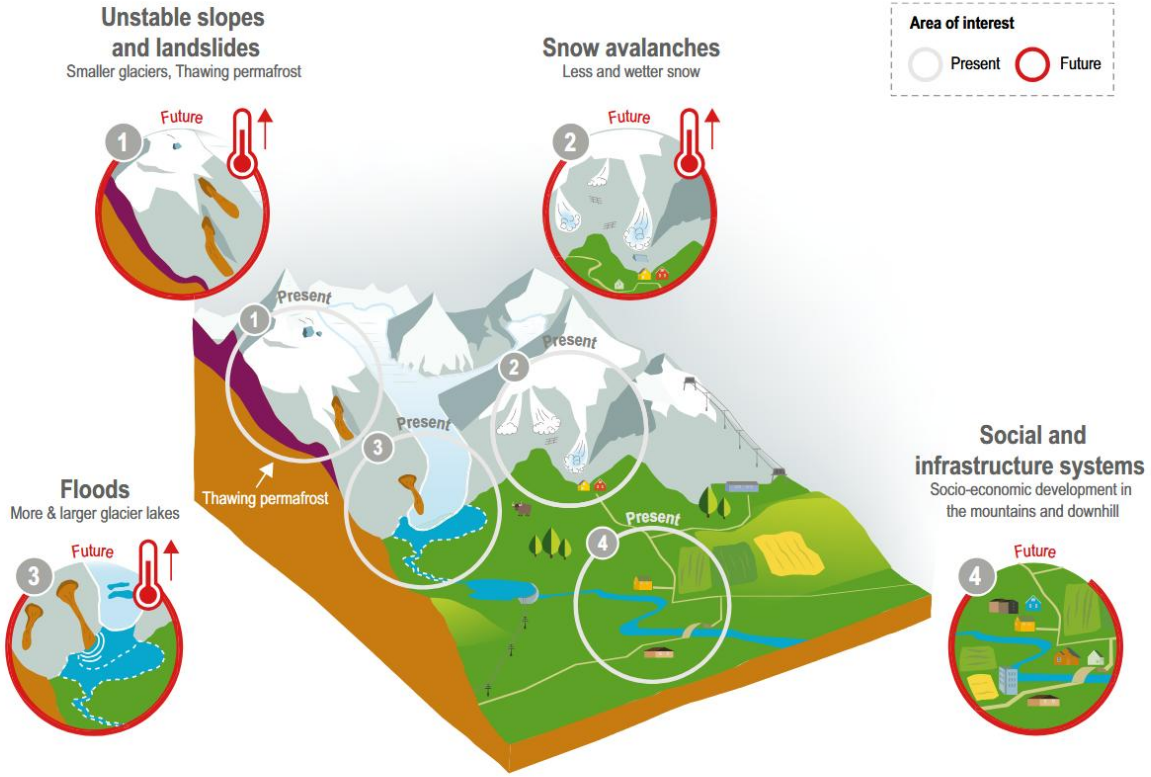
- **Hazard**: Probability/magnitude of a potential harmful event
- **Vulnerability**: Capacity to cope/recover from event
- **Exposure**: amount of people, resources, infrastructure likely to be impacted
- **Risk**: combination of each of these factors



Hock et al., 2019

Glacier impacts on humans: Hazards

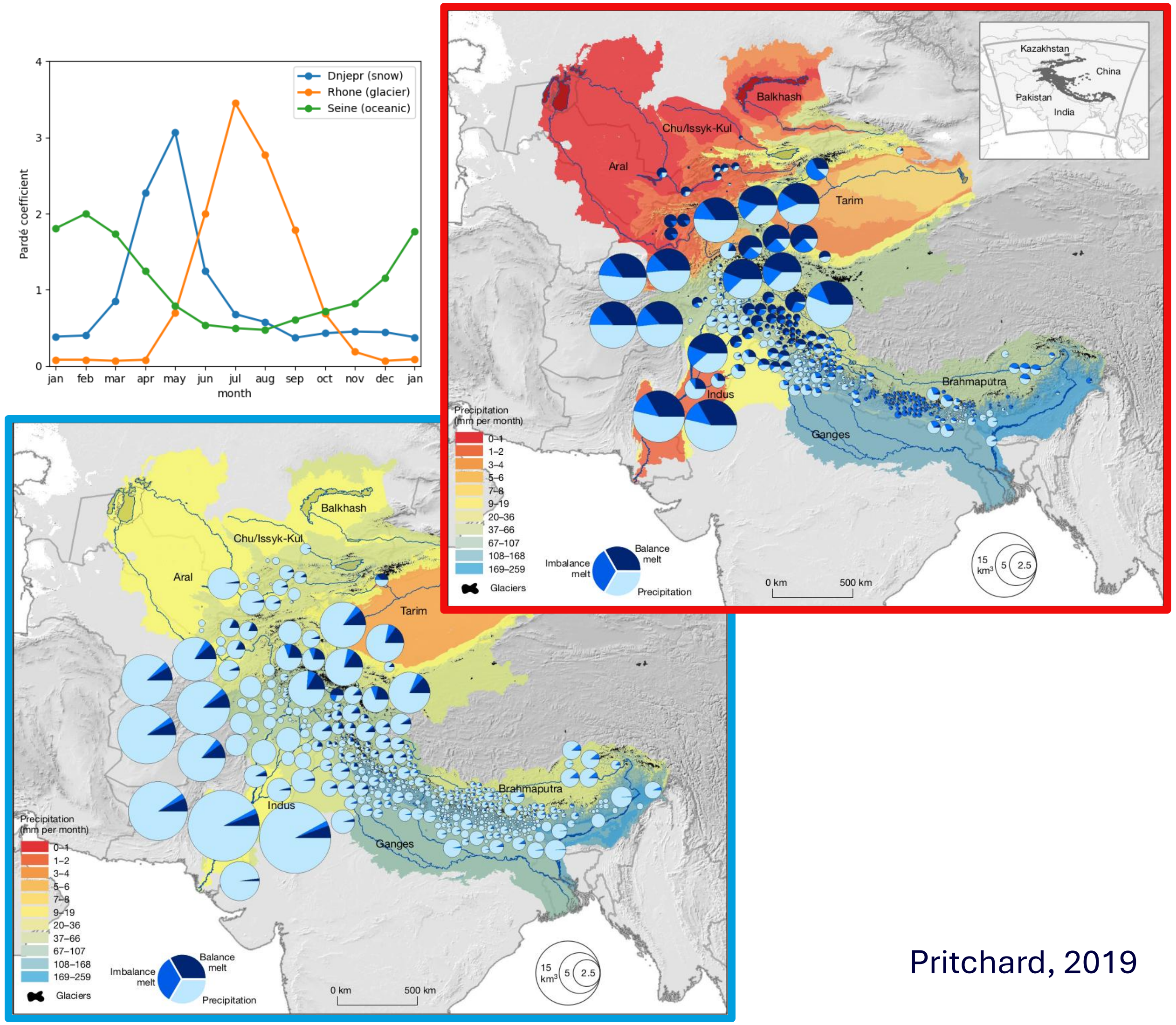
1. Unstable slopes and landslides
   - Glacier retreat, permafrost thaw lead to increased slope instability
2. Snow avalanches
   - More wet-snow avalanches (most dangerous)
3. Floods
   - More, larger glacier lakes
   - More high-elevation rain-on-snow floods
4. Social and infrastructure systems
   - Increased population, infrastructure



Hock et al., 2019

Glaciers are important water resources

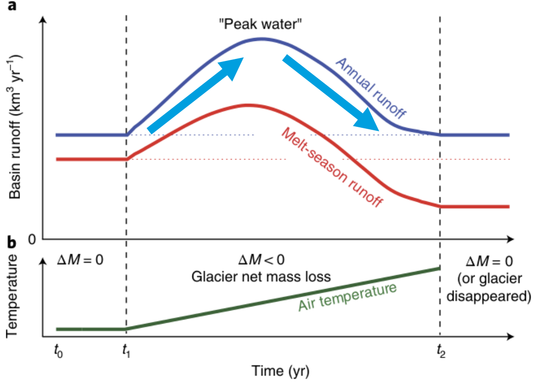
- Glacier melt:
  - Helps “delay” annual runoff peak
  - Provides water later in melt season
- Example: Central Asia
  - ~800M depend on glacier meltwater
  - Normal years: precipitation dominates
  - Drought years: glacier melt helps reduce drought stress

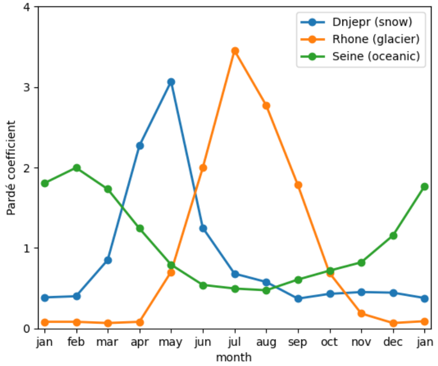


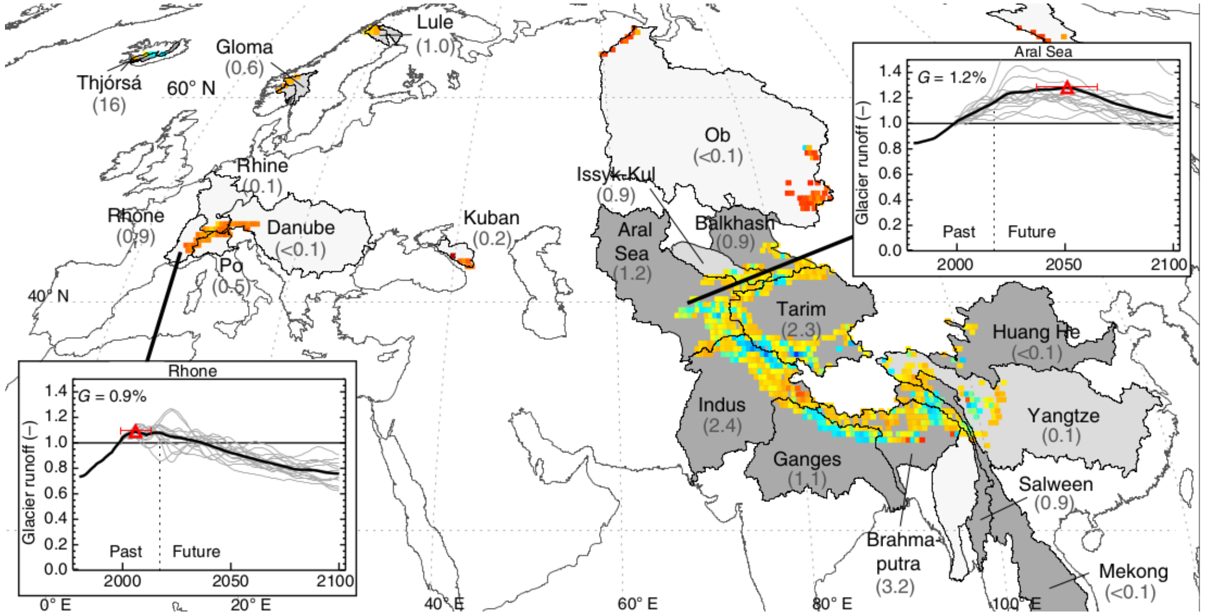
Pritchard, 2019

What happens in a warming climate?

- At first:
  - More glacier melt means more runoff
- Eventually:
  - “Peak water” passes
  - Less water available
- 56 “macroscale” (> 5000 km^2) drainage basins:
  - 45% have already reached “peak water”
  - Remaining 55%: “peak water” expected before 2100



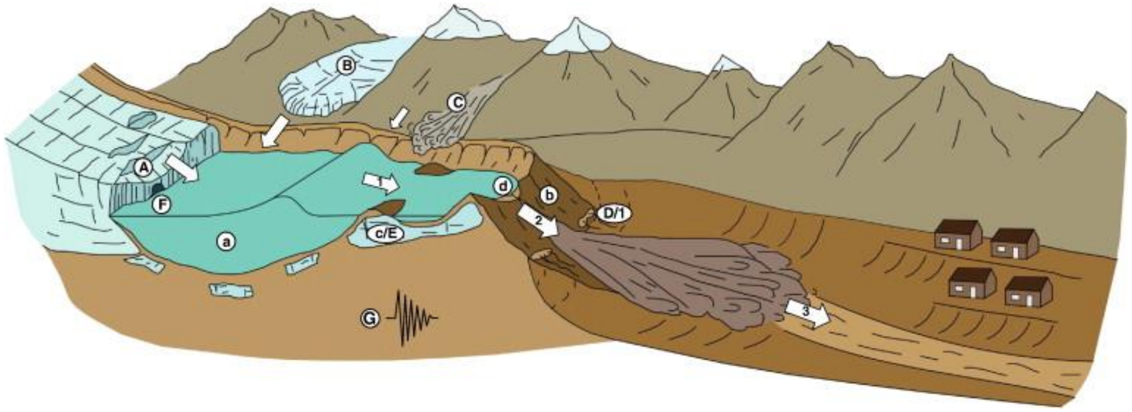




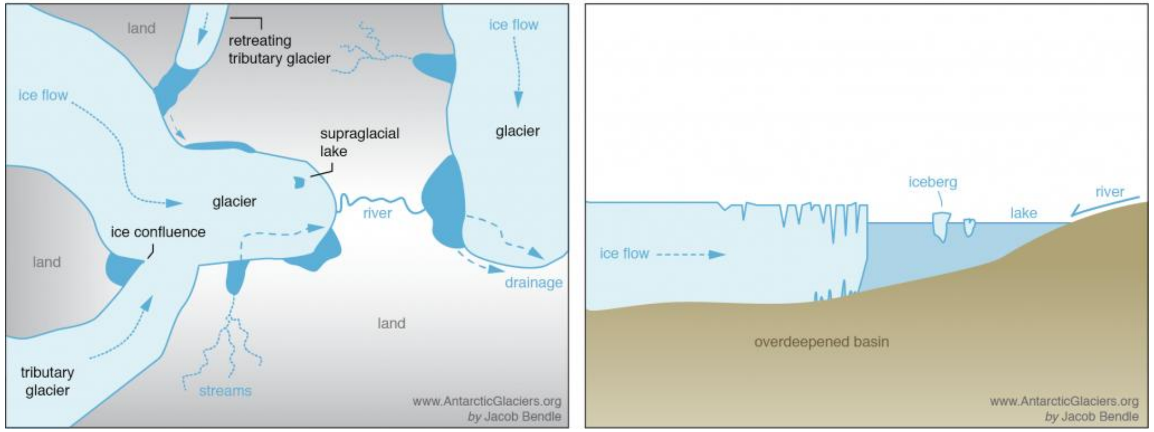
Huss and Hock, 2018

Glacial lake outburst floods (GLOFs)

- Moraine-dammed
  - Drains after lake overtops/breaches a sediment-based dam
  - Typically form in front of glacier
- Ice-dammed
  - Drains once lake is deep enough to lift the glacier
  - Typically form next to glacier



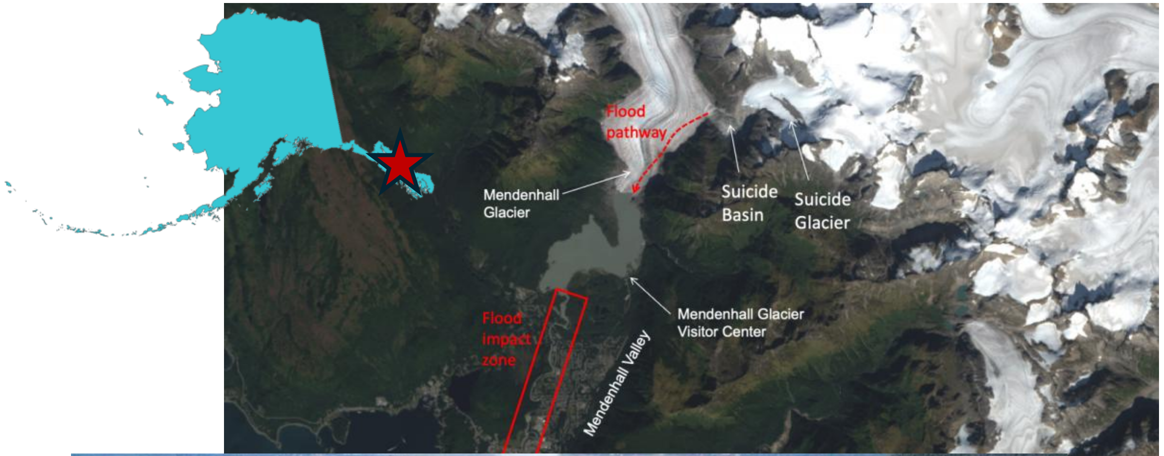
Westoby et al., 2014



J. Bendle / AntarcticGlaciers.org

Case study: Mendenhall Glacier, Alaska

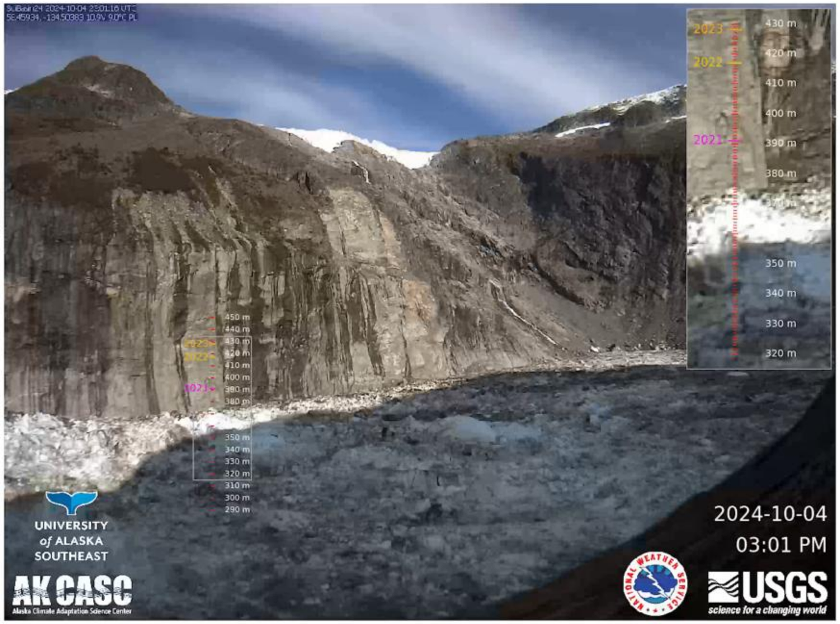
- Mendenhall Glacier (Juneau Icefield)
  - (formerly) lake-terminating outlet of Juneau Icefield
  - Drains into Mendenhall Lake/River
  - Since 2011, **annual** ice-dammed glacial lake outburst flood
- Mendenhall Valley, Juneau
  - Population: ~10,000




Alaska National Guard

Case study: Mendenhall Glacier, Alaska

- Suicide Basin: created as tributary glacier thinned, retreated
- Ice-dammed basin: drains once water is deep enough
- Mendenhall Lake/River floods:
  - 2023: peak lake level of 4.6 m (15 ft)
  - 2024: 4.9 m (16 ft)
    - 25% more flow than 2023
  - 2025: 5.1 m (16.65 ft)
    - 20% more flow than 2024
- About 40 hours between start to peak flood in Mendenhall Valley
- Eventually, glacier will thin enough to remove hazard



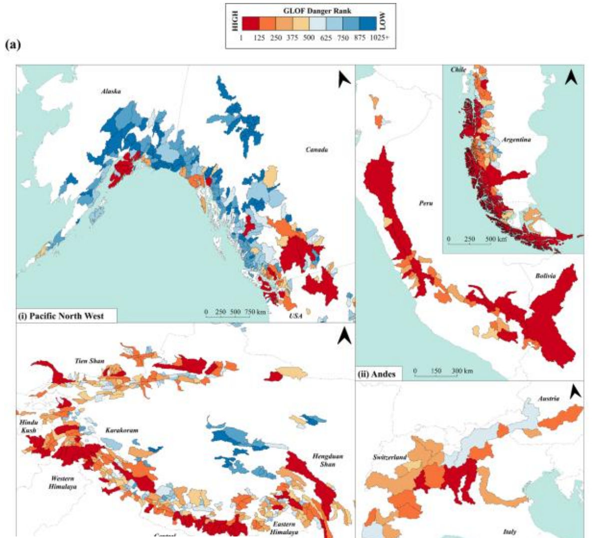
Case study: Mendenhall Glacier, Alaska

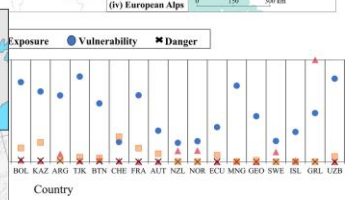
How do we monitor these hazards?

- “On the ground”:
    - Uncrewed Aerial Vehicles (UAVs)
    - Laser range finders / LiDAR
    - Timelapse Camera stations
    - Drawback: difficult/expensive to install/maintain
    - Some floods/hazards happen more rapidly
- Satellite Remote Sensing
    - Global-scale
    - Remote Areas
    - Longer-term
    - Drawback: more difficult to use for early warning

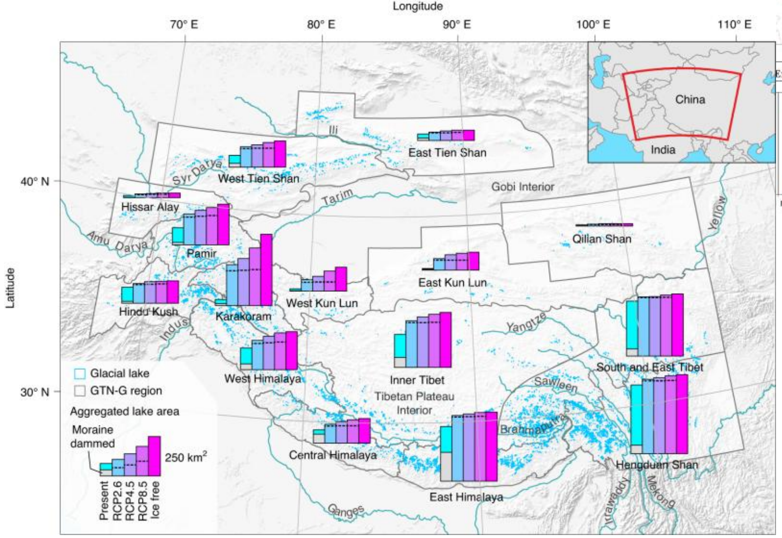
Global GLOF Risk/Danger

- Estimated 15M exposed to potential GLOF impacts
  - ~ 1M in High Mountain Asia (HMA) alone
  - Most in HMA, South America
- Effects can reach hundreds of km downstream
- Hazard may increase with glacier retreat / lake expansion





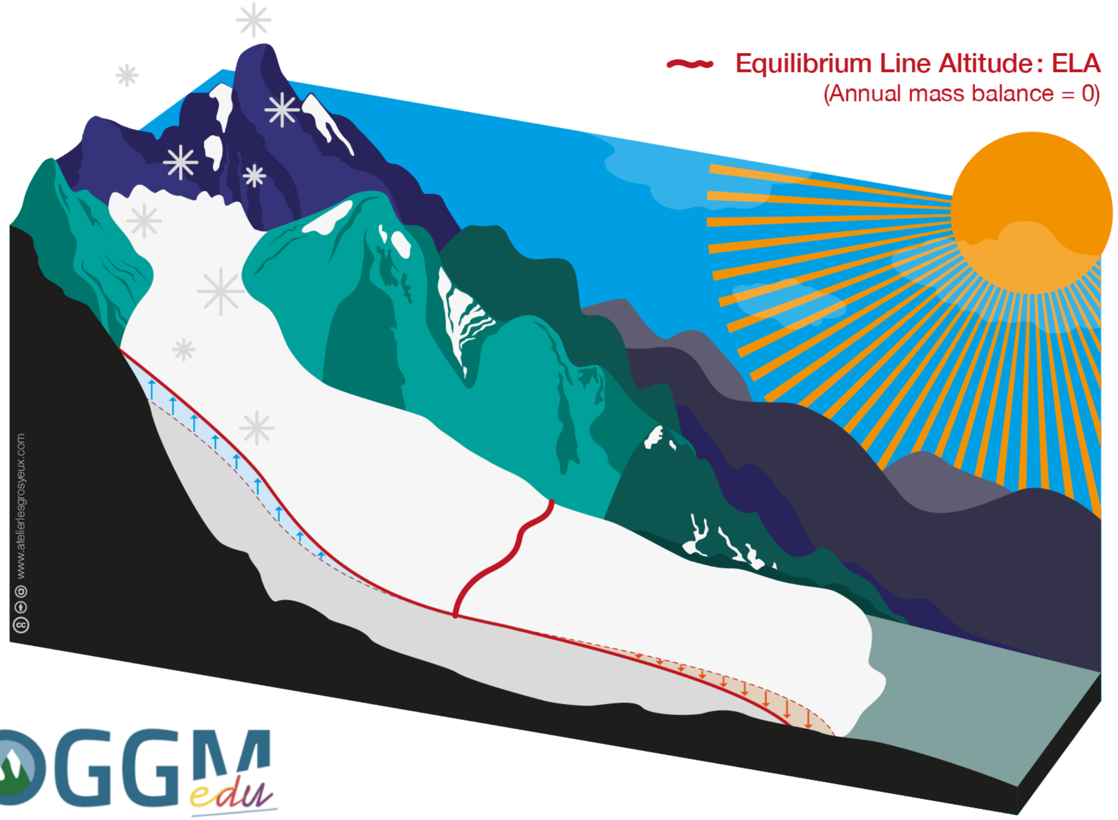
Taylor et al., 2023



Zheng et al., 2021

OGGM-Edu

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



OGGM edu
Open Global Glacier Model

Other resources

- AntarcticGlaciers.org
- VR Glaciers and Glaciated Landscapes
- SwissEduc Glaciers Online
- IQUA Shaping the Landscape
- GLAMOS.ch
- World Glacier Monitoring Service
- Glacier Outburst Floods: Mendenhall Glacier
- Monitoring Glacial Changes: Tools and Techniques

Questions?

References

- Hock, R. et al. (2019). High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. [H.-O. Pörtner et al., (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 131-202. doi: 10.1017/9781009157964.004
- Huss, M. and R. Hock (2018). Global-scale hydrological response to future glacier mass loss. *Nature Climate Change* 8, 135-140. doi: 10.1038/s41586-019-1240-1
- Jouvet, G. and M. Huss (2019). Future retreat of Great Aletsch Glacier. *Journal of Glaciology* 65, 869–872. doi: 10.1017/jog.2019.52
- Kienholz, C., et al. (2020). Deglacierization of a Marginal Basin and Implications for Outburst Floods, Mendenhall Glacier, Alaska. *Frontiers in Earth Science* 8, 137. doi: 10.3389/feart.2020.00137
- Pritchard, H.D. (2019). Asia’s shrinking glaciers protect large populations from drought stress. *Nature* 569, 649–654. doi: 10.1038/s41586-019-1240-1
- Rounce, D. R., et al. (2023). Global glacier change in the 21st century: Every increase in temperature matters. *Science* 379(6627), 78–83. doi: 10.1126/science.abo1324
- Taylor, C., et al. (2023). Glacial lake outburst floods threaten millions globally. *Nature Communications* 14, 487. doi: 10.1038/s41467-023-36033-x
- Westoby, M. J., et al. (2014). Modelling outburst floods from moraine-dammed glacial lakes. *Earth-Science Reviews* 134, 137–159. doi: 10.1016/j.earscirev.2014.03.009
- Zheng, G., et al. (2021). Increasing risk of glacial lake outburst floods from future Third Pole deglaciation. *Nature Climate Change* 1–7. doi: 10.1038/s41558-021-01028-3