Glaciers in CISM:

Current Capabilities and Future Directions

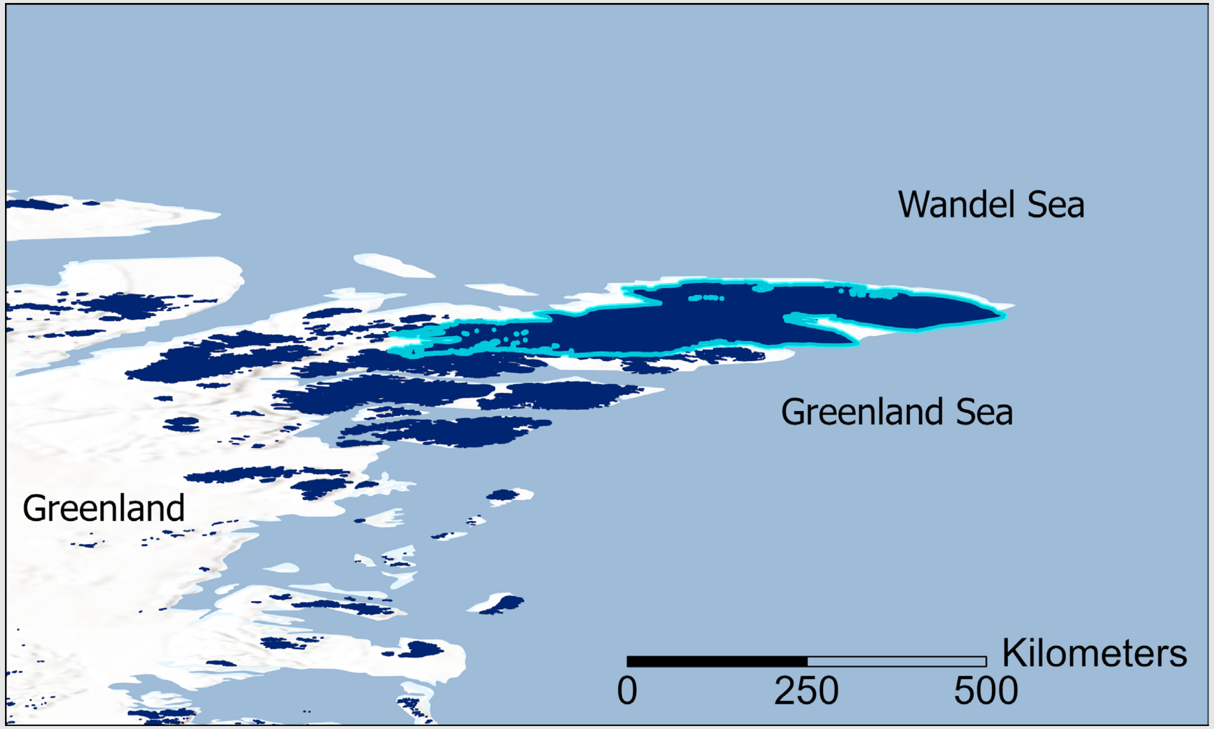
Samar Minallah, LIWG

CESM Workshop, June 2025

Baltoro Glacier, Pakistan

Glacier geometries

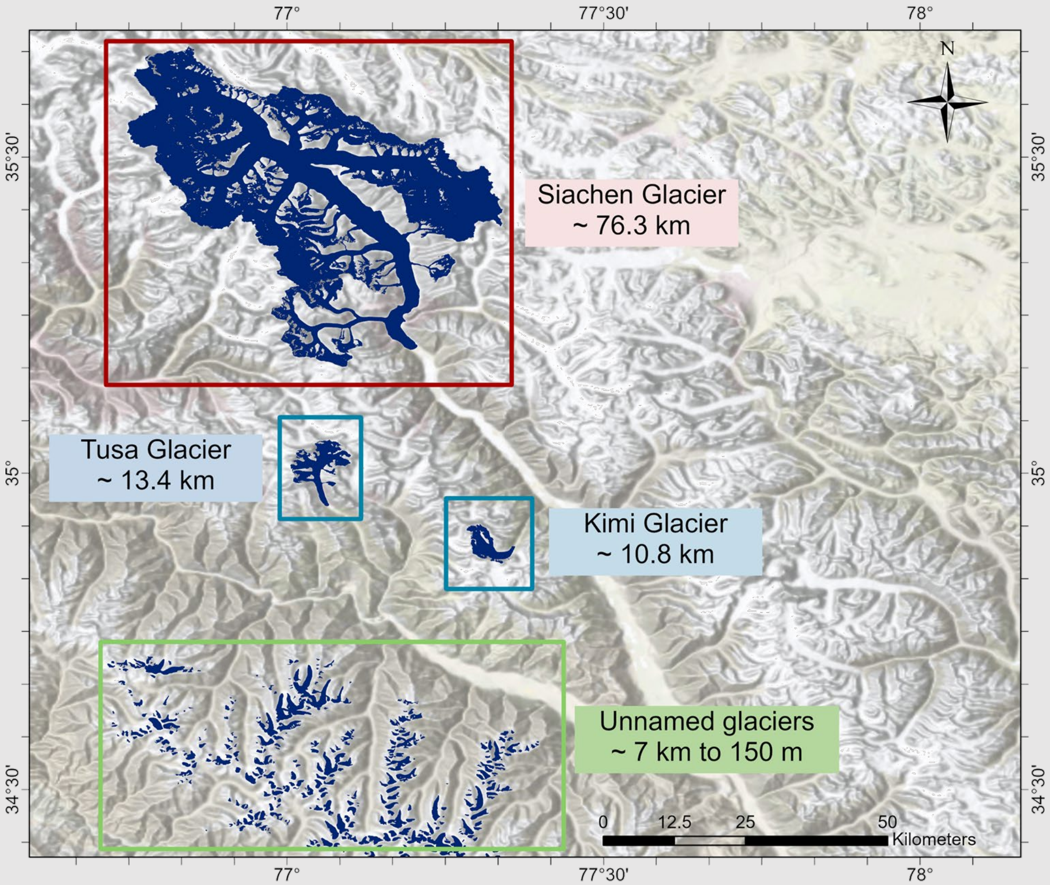
Polar glaciers in Greenland



Largest glacier in the Randolph Glacier Inventory (RGI) v6

Area ~7500 km²

Mountain glaciers in Karakoram



Largest glacier outside polar regions

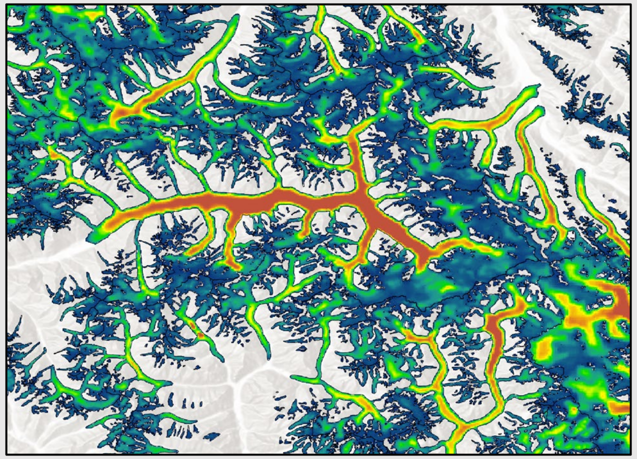
Area ~1077 km²

Glacier modeling with CISM

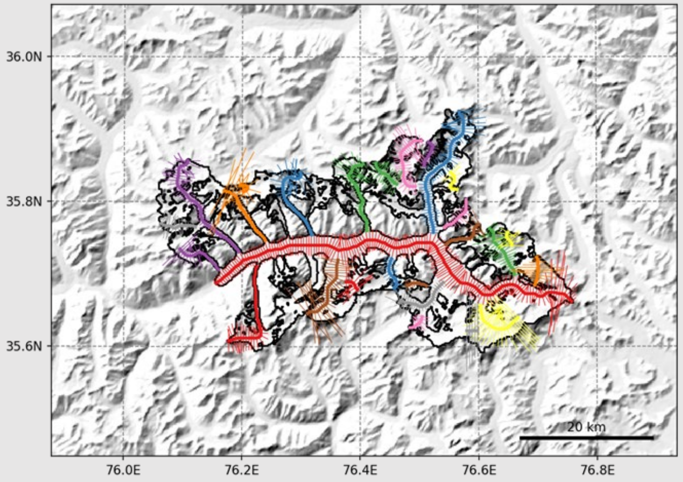
Introduced a new modeling framework in the Community Ice Sheet Model to study **glacier dynamics**, **geometry changes**, and **impacts.**

- First ESM to include dynamic simulation of mountain glaciers
- CISM is a 3D, higher-order ice-flow model for regional-scale glacier modeling
    - Depth-integrated viscosity approximation (DIVA)
    - Blatter-Pattyn approximation

Distributed thickness, 3D geometry

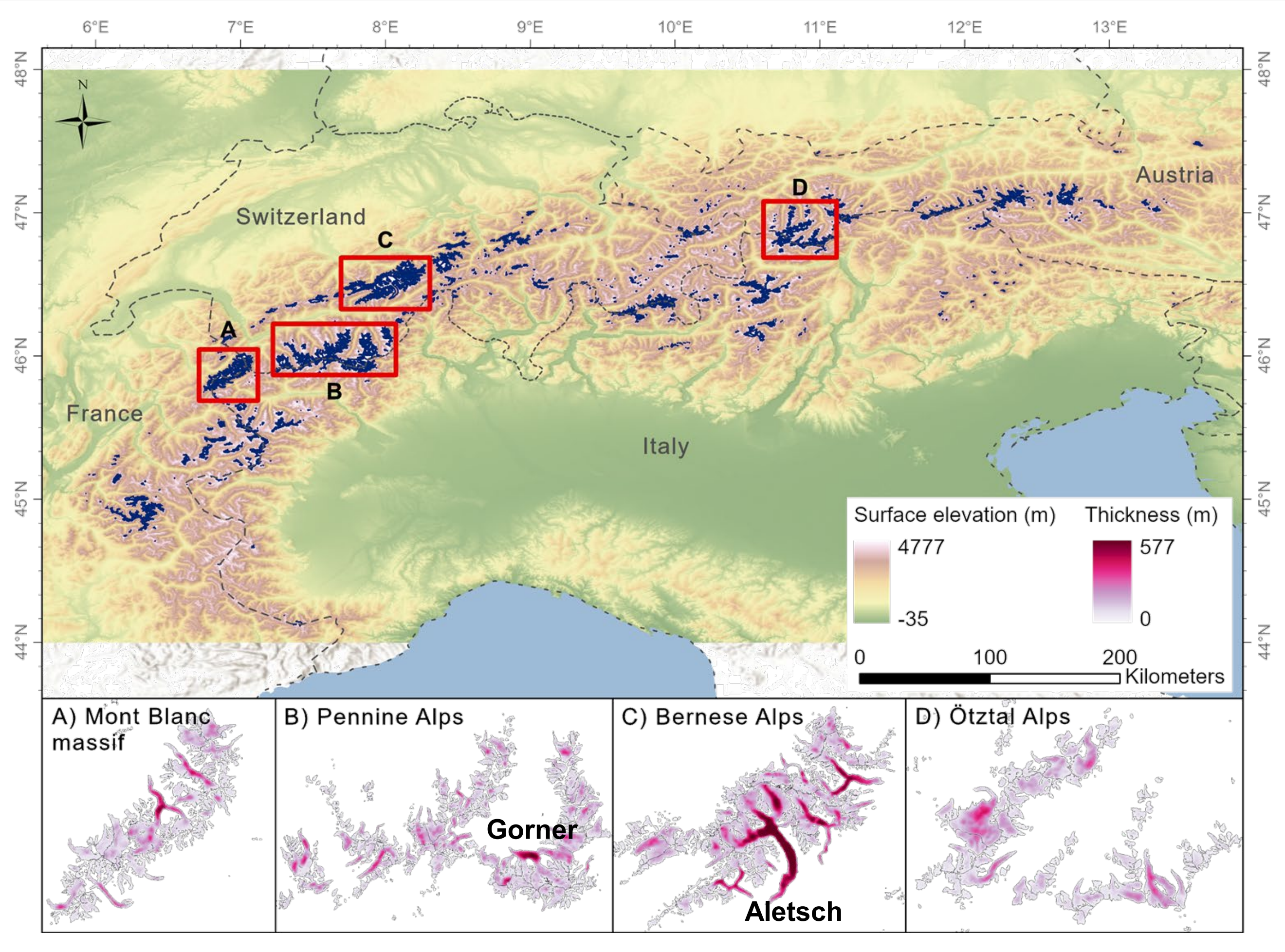


A flowline model (OGGM)



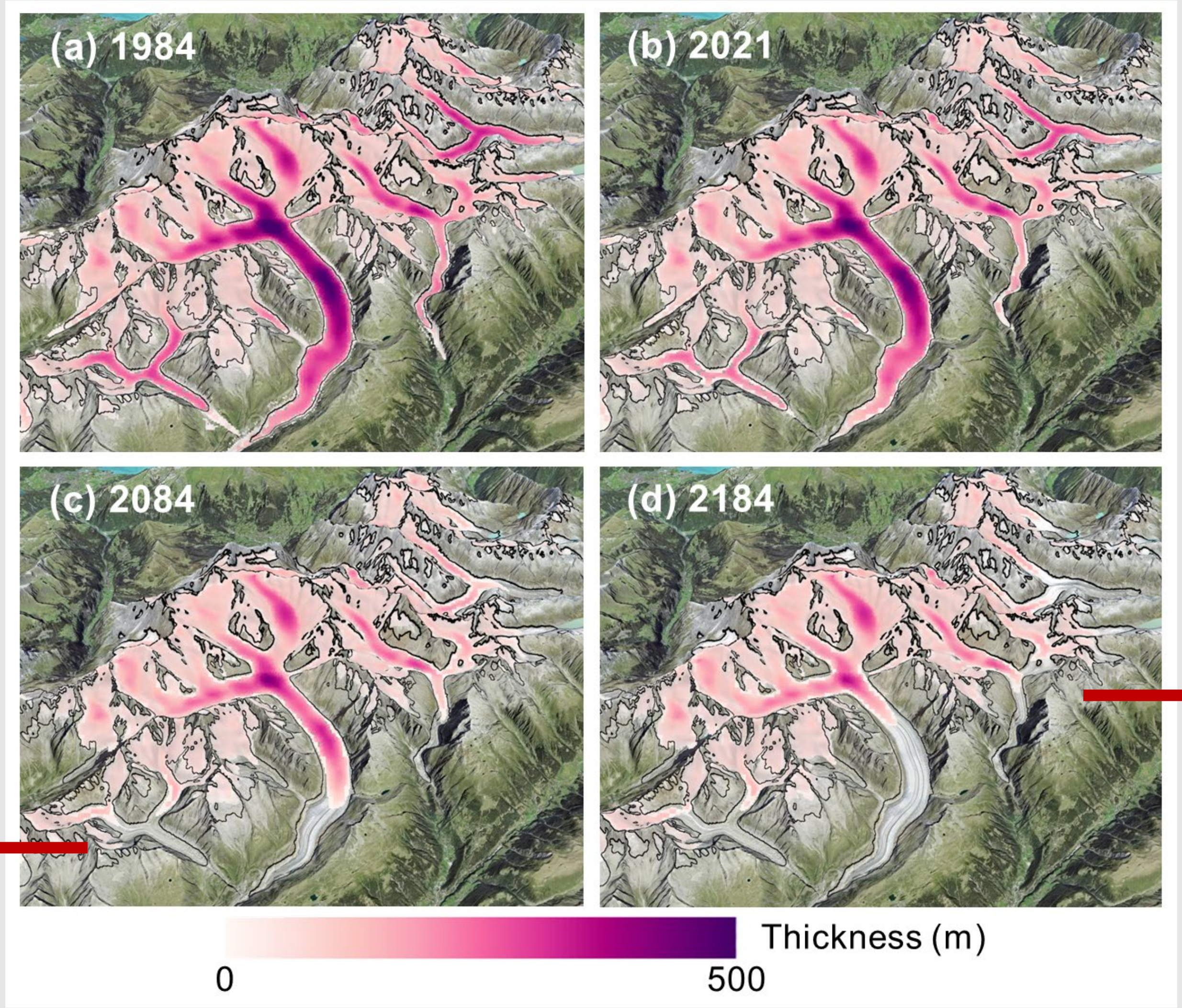
CISM application to the Alpine Glaciers

- Simulations over the European Alps
- 3892 individual glaciers
- Aletsch (~82 km²) and Gorner (~56 km²) are the largest glaciers
- Smaller glaciers are ~0.01 km²
- **100-m grid resolution** (6 glaciers are sub-grid)



CISM application to the Alpine Glaciers

Committed ice loss for the Aletsch Glacier



Glaciers splitting

Around time when these glaciers finally equilibrate

CISM application to the Alpine Glaciers

- Input data and atmospheric forcing requirements
- Mass balance scheme
- Initialization, spin-up, and inversion
- Calibration and validation

European Geosciences Union

Geoscientific Model Development

In review

A framework for three-dimensional dynamic modeling of mountain glaciers in the Community Ice Sheet Model (CISM v2.2)

Samar Minallah, William Lipscomb, Gunter Leguy, and Harry Zekollari

Glacier Model Intercomparison Project (GlacierMIP3)

What would be the equilibrium volume and area of all glaciers outside the ice sheets if global mean temperatures were to stabilize at:

- present-day levels
- different temperature levels (e.g. +1.5°C, +2°C, etc. relative to pre-industrial)

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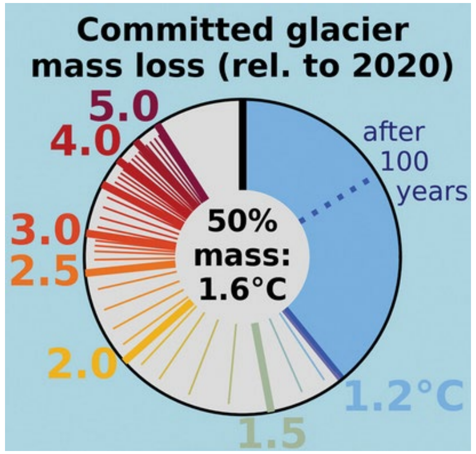


Multi-model ensemble median

- At 1.6˚C warming, relative to pre-industrial, global glaciers lose 50% of their mass
- At 2.7˚C warming, we will lose 75% of the global glacial mass
- For Alps: 0.9˚C to lose 50% mass - we have already crossed that!

Science

Glacier preservation doubled by limiting warming to 1.5°C versus 2.7°C

Zekollari*, Schuster*, et al. (2025)

Ongoing developments

Mass balance scheme in CISM

Glacial mass balance is currently computed internally with a simple parameterization (a temperature-index scheme):

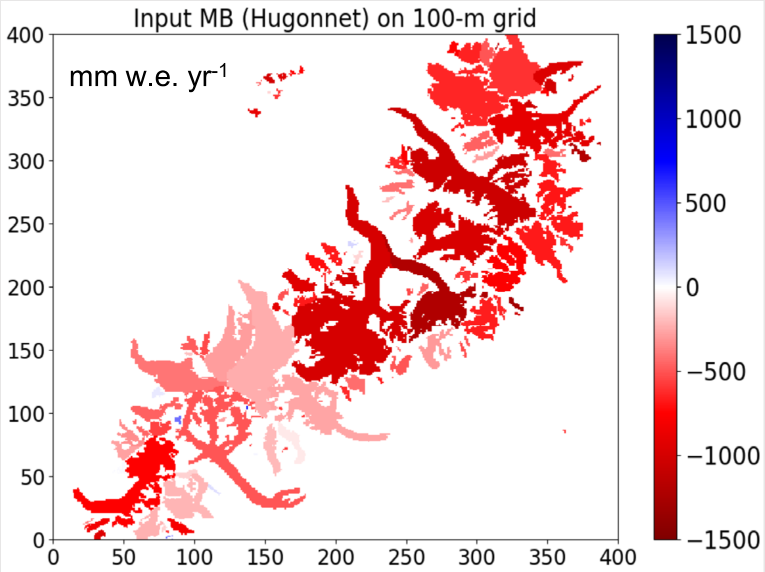
$$\alpha P_i + \mu\,(T_i - T_{melt}) = B_i$$

T_i : monthly mean temperature (K)
P_i : monthly total precipitation (mm w.e.)
T_{melt} : taken as -1˚C
B_i : monthly climatic mass balance (mm w.e.) at each grid cell

Tuning parameters

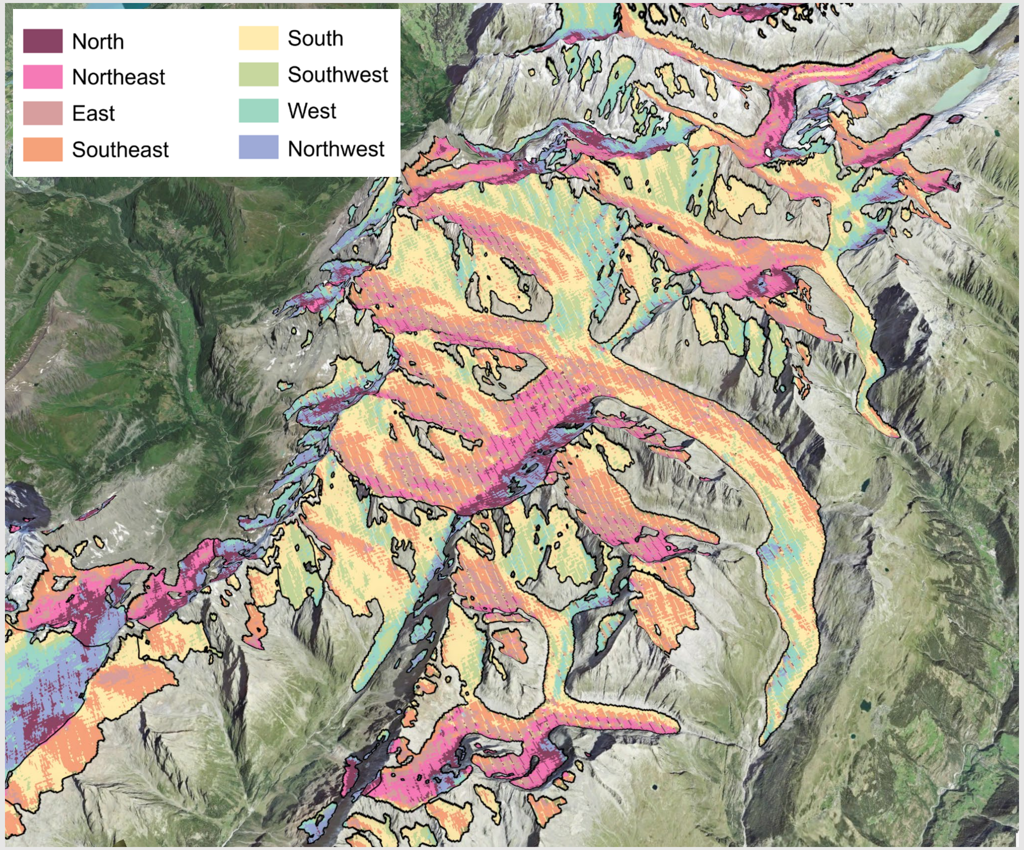
- μ : Temperature sensitivity parameter (mm w.e. K^{-1} $month^{-1}$) – for each glacier
- α : Precipitation correction factor

These are tuned to match a target MB (input) →



Terrain effects on mass balance

Aspect



Aletsch glacier, Bernese Alps

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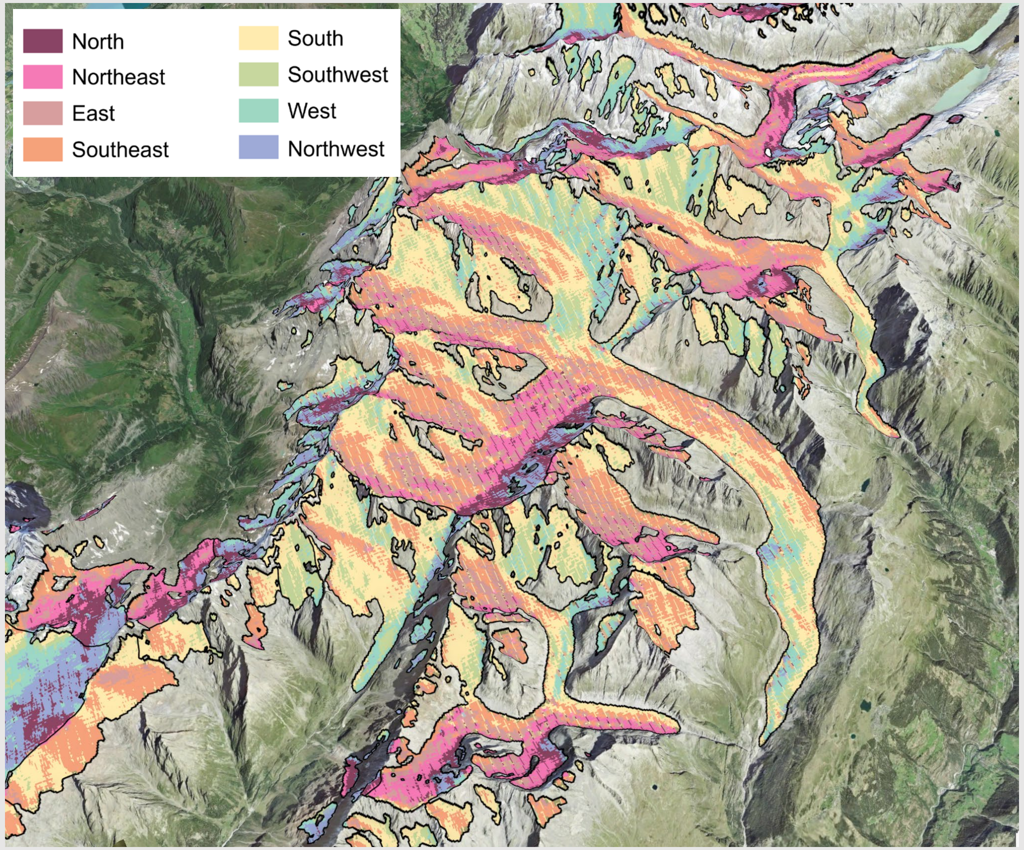

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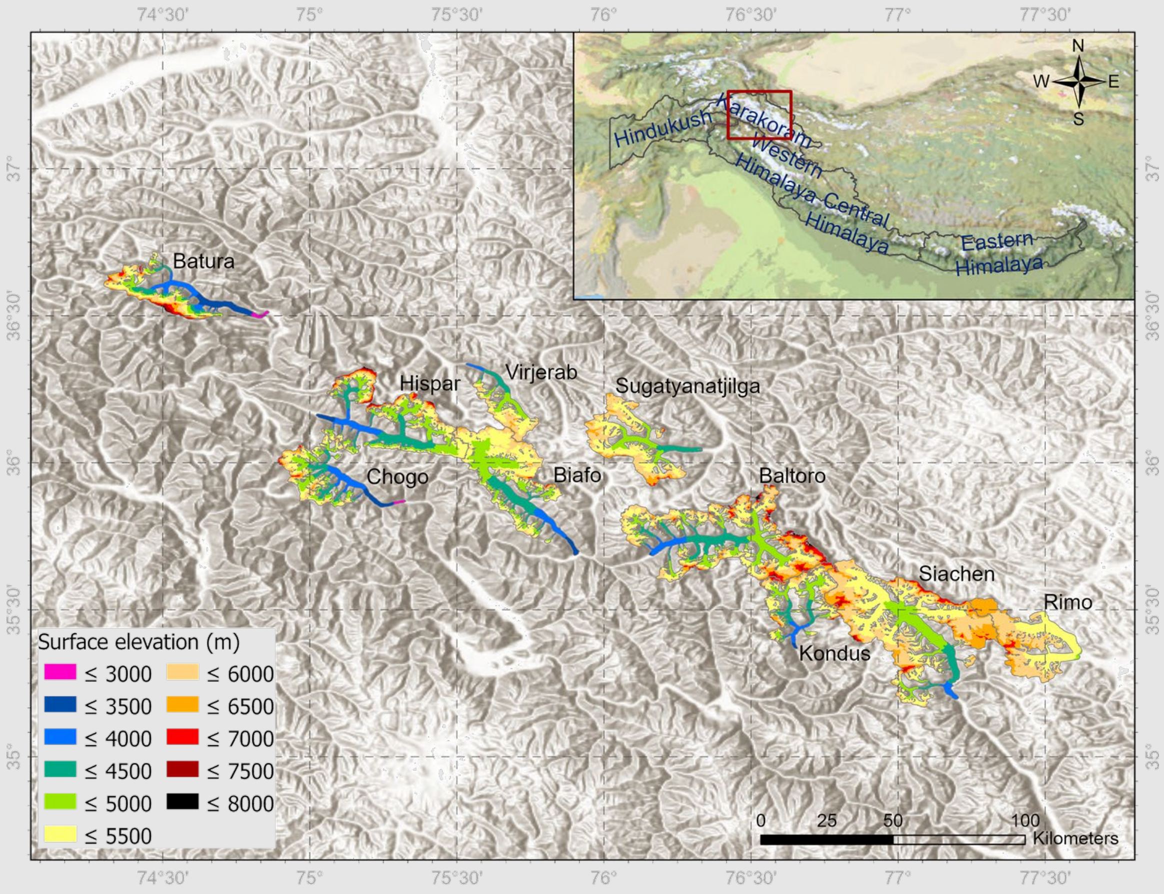
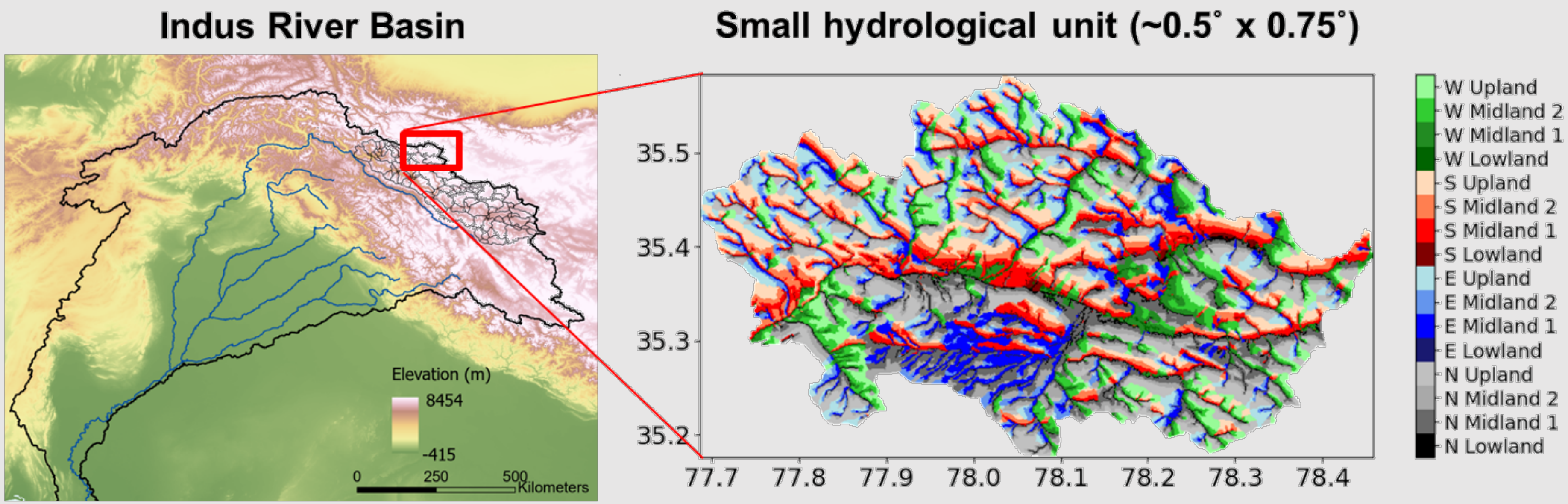
Elevation



Ten largest glaciers in the Karakoram

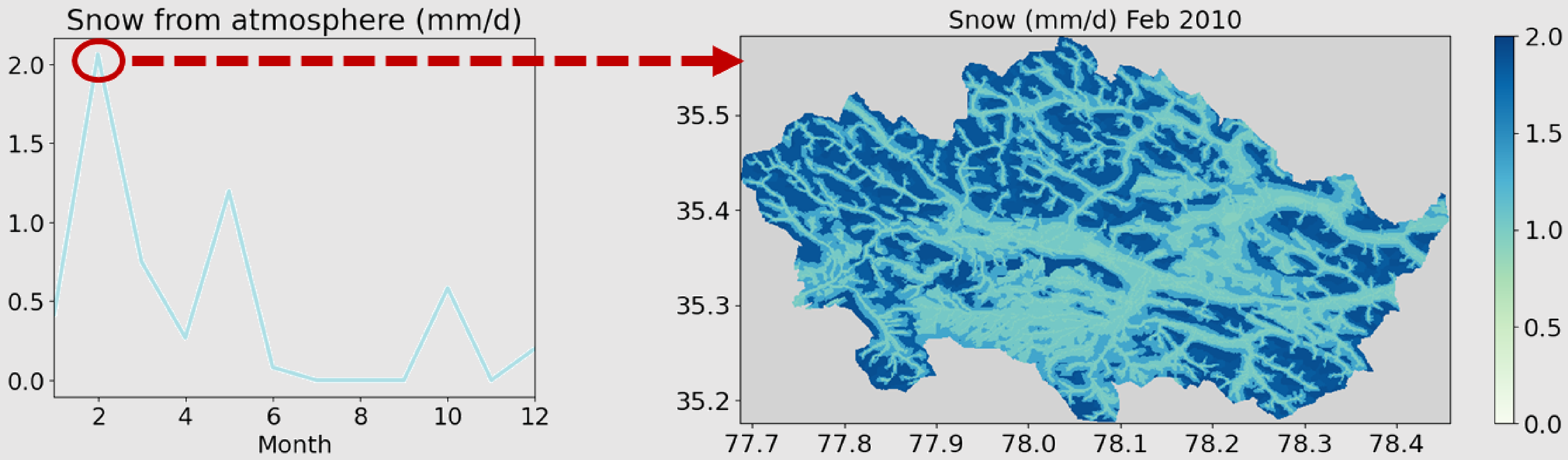
Accounting for terrain characteristics

MB computations with the **Hillslope Hydrology** configuration in the **Community Terrestrial Systems Model (CTSM)**



- Use High-resolution DEM to classify each cell into multiple hillslopes
- Capture simplified topography at sub-grid level

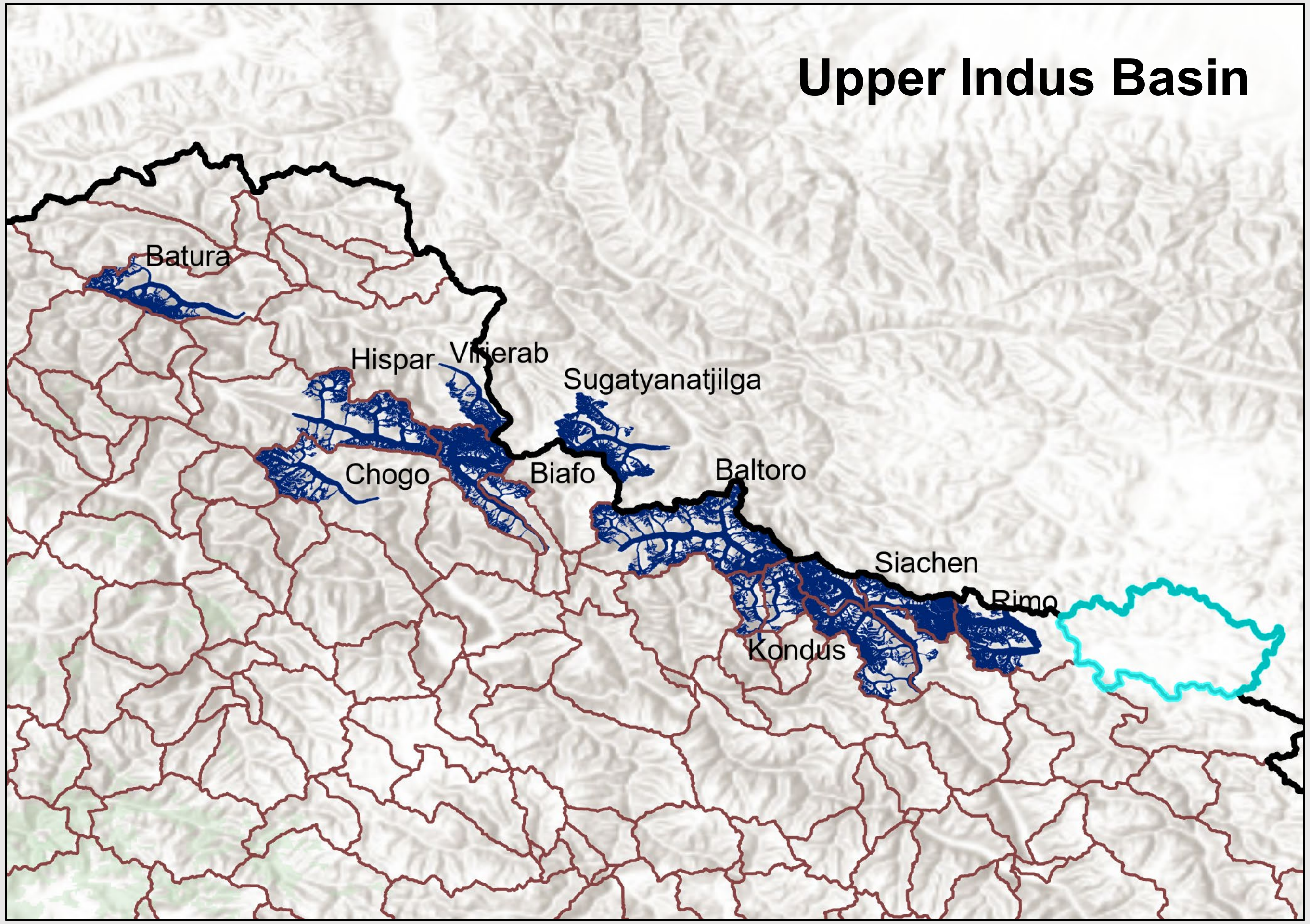
Downscaling with hillslopes



Use hillslopes to downscale quantities based on:

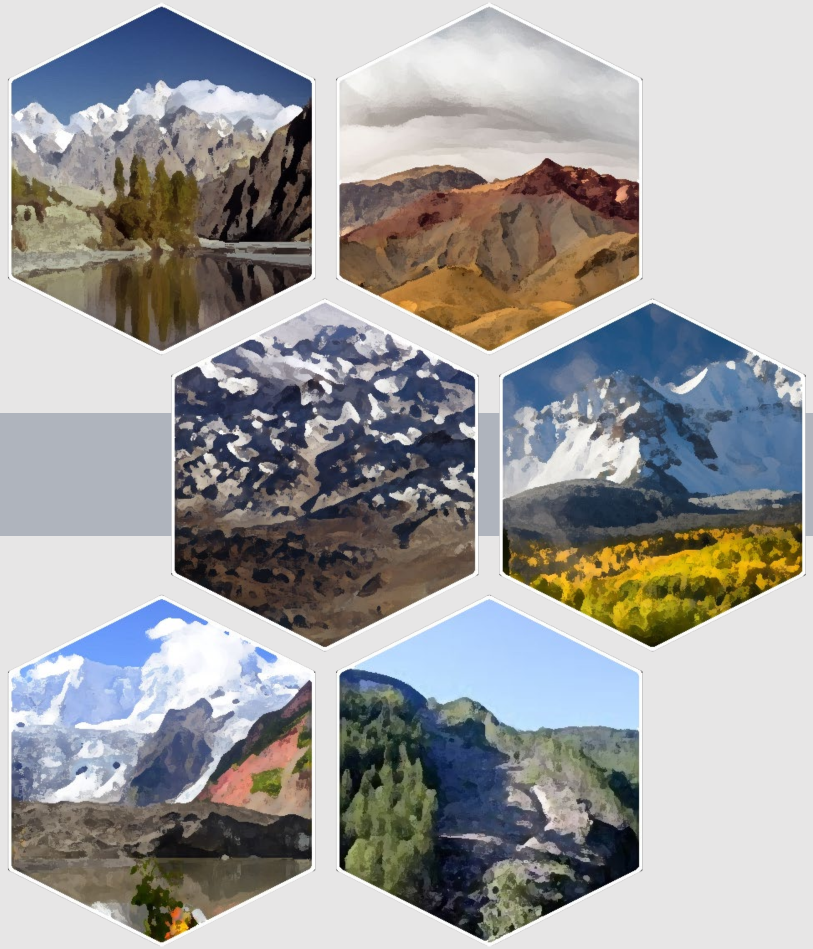
- Solar zenith angle
- Lapse rates
- Height anomalies

Application to glacial MB computations



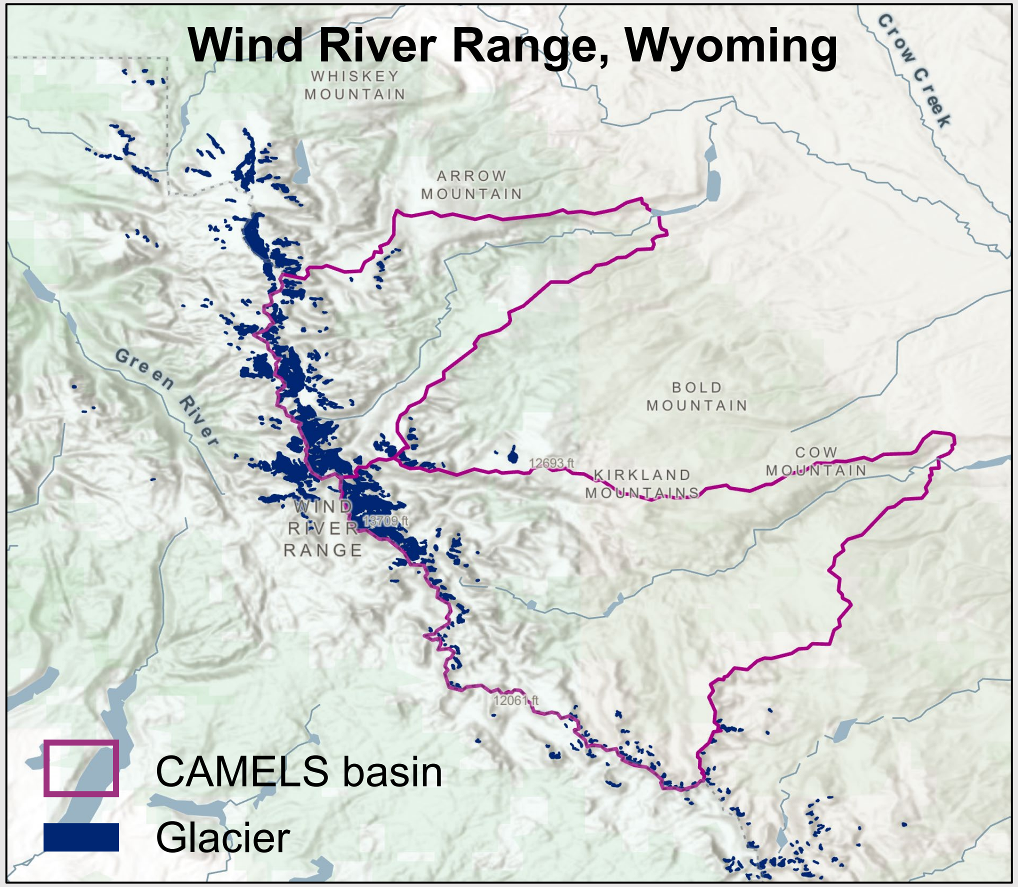
With Sean Swenson, Terrestrial Sciences Section

Research applications



(1) Water resources

CTSM – CISM application to cryosphere-hydrology assessments



Glaciers of the Rocky Mountains

Partitioning between glacial-melt, snow-melt, and baseflows for mountain watersheds

- Contribution from glaciers in sustaining summer baseflows in headwater streams

Historical variability and future impacts

Similar assessments for the Himalaya-Karakoram watersheds

(2) Glaciers and geohazards

As glaciers advance or retreat, they profoundly alter terrains

- Slope stability
- Moraine deposition
- Permafrost insulation
- Formation of glacial lakes
- Altering drainage patterns
- …

Birch glacier collapse, Switzerland

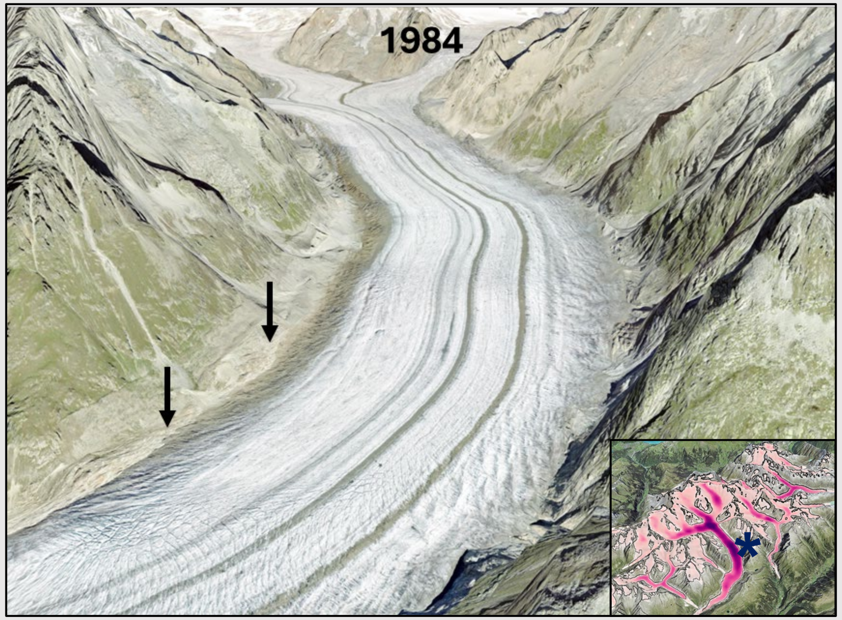
May 28, 2025

Ice and debris landslide

Images from Wikimedia

(2) Glaciers and geohazards

Simulated projections of terrain changes



(2) Glaciers and geohazards

Simulated projections of terrain changes

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Simulated projections of terrain changes

(1) Steepening and debuttressing of the valley walls >> Slope instability and failure

(2) Exposure of lose sediments and moraines >> Increased landslide and rockfall activity

(2) Glaciers and geohazards

Bridging **ice dynamics modeling** with **slope stability analysis** to study glacier-driven **geohazards**

- Time evolving terrain changes fed to slope stability model (Rocscience Slide)
- Assessments on debuttressing effects >> mechanical unloading of valley walls due to ice thinning >> stress fields from CISM

Questions

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