Simulating mountain glacier mass balance and dynamics with the Community Ice Sheet Model

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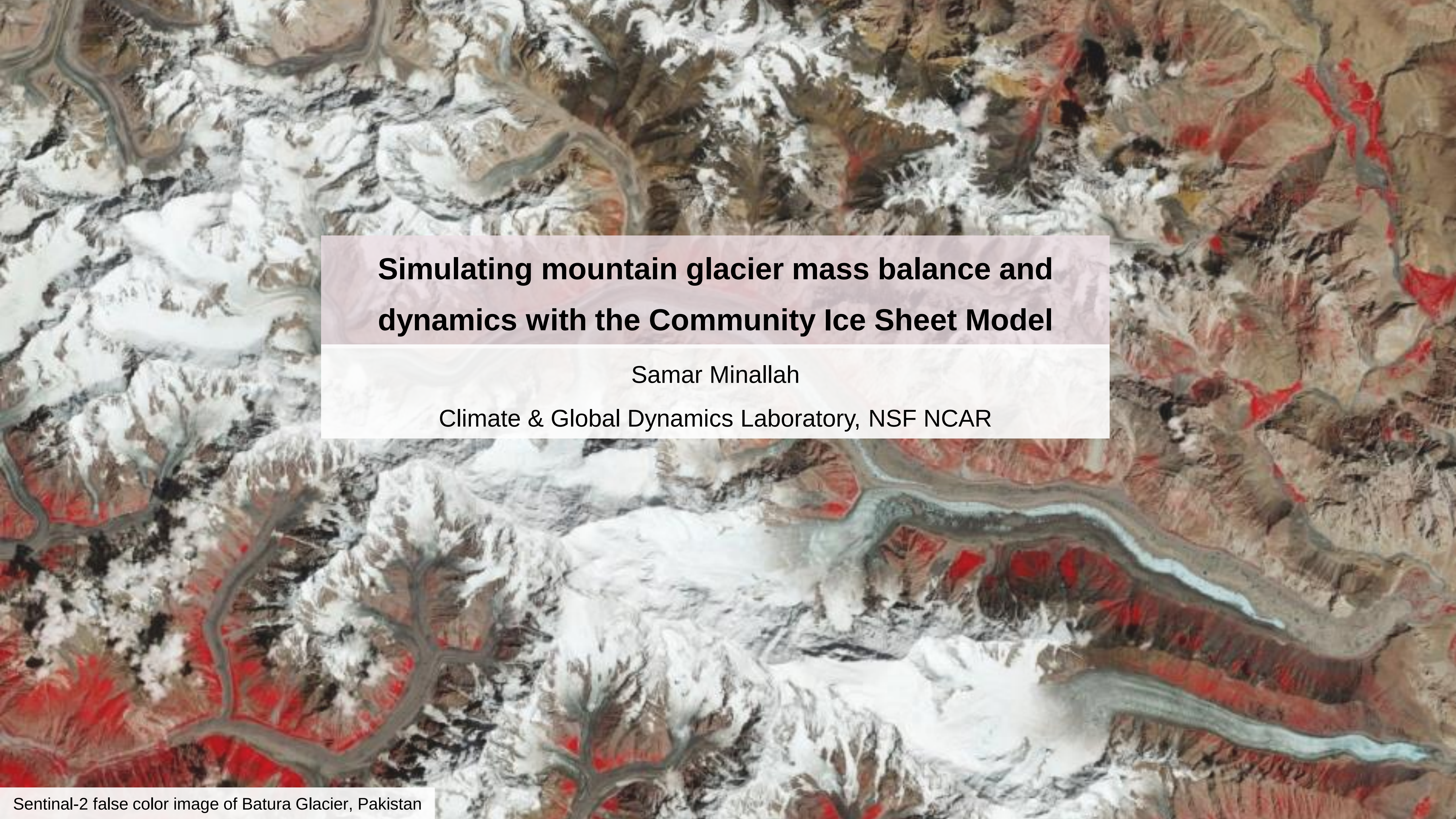
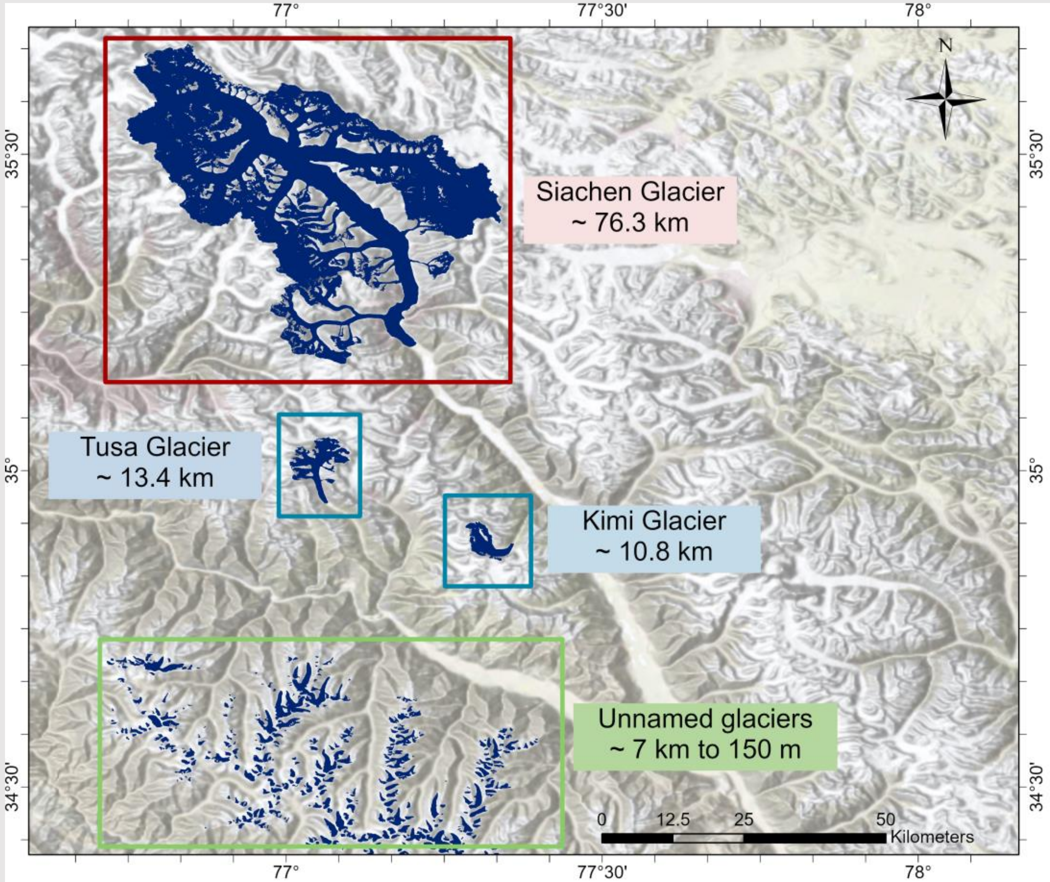


Sentinal-2 false color image of Batura Glacier, Pakistan

Mountain Glaciers

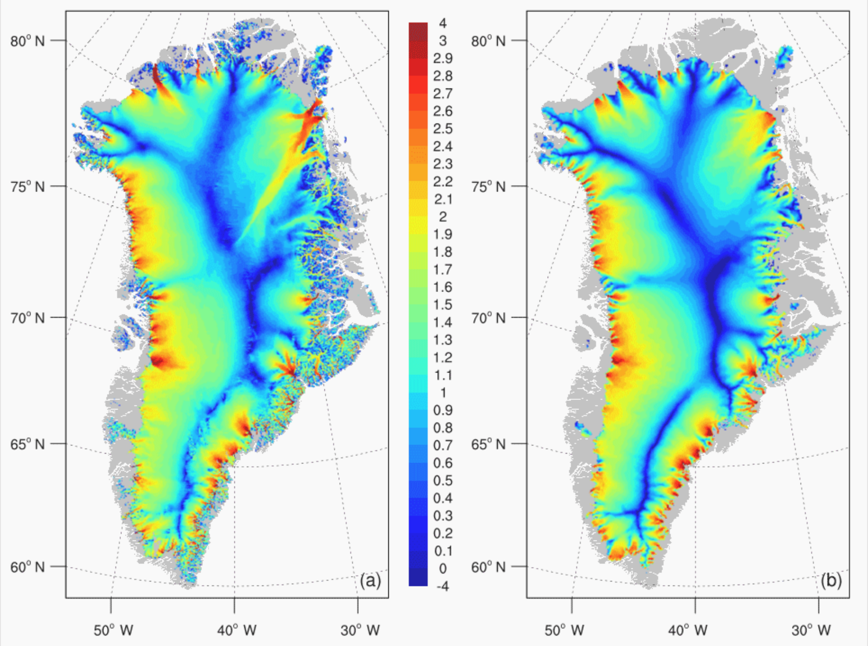
- **Polar ice sheets** (continental glaciers) and their peripheral glaciers
  - These are much larger and contribute to sea level rise

- **Mountain glaciers** are characterized by smaller size, sheer number, and spatial discontinuities in the ground ice coverage
  - ~98,000 glaciers in high-mountain Asia
  - ~4,000 glaciers in the Alps
  - Significance as a freshwater resource



Community Ice Sheet Model (CISM)

- The ice dynamics component of CESM
- Used for predicting ice sheet evolution (Greenland and Antarctica)
- Solves conservation equations for mass, momentum, and thermal energy to determine the ice geometry evolution, velocities (*figure*), and internal temperature, respectively
- Runs at regular mesh; horizontal resolution of ~4km for ice sheets



Observed (left) and simulated Greenland surface ice speed (m yr^{-1})

Lipscomb et. al. (2019). *Description and evaluation of the Community Ice Sheet Model (CISM) v2.1*. Geoscientific Model Development

Study objectives

- ➢ Introduce a new modeling framework within CISM for mountain glaciers
  - Mountain glaciers are not dynamically simulated in Earth System Models (ESMs) - knowledge and representational gap

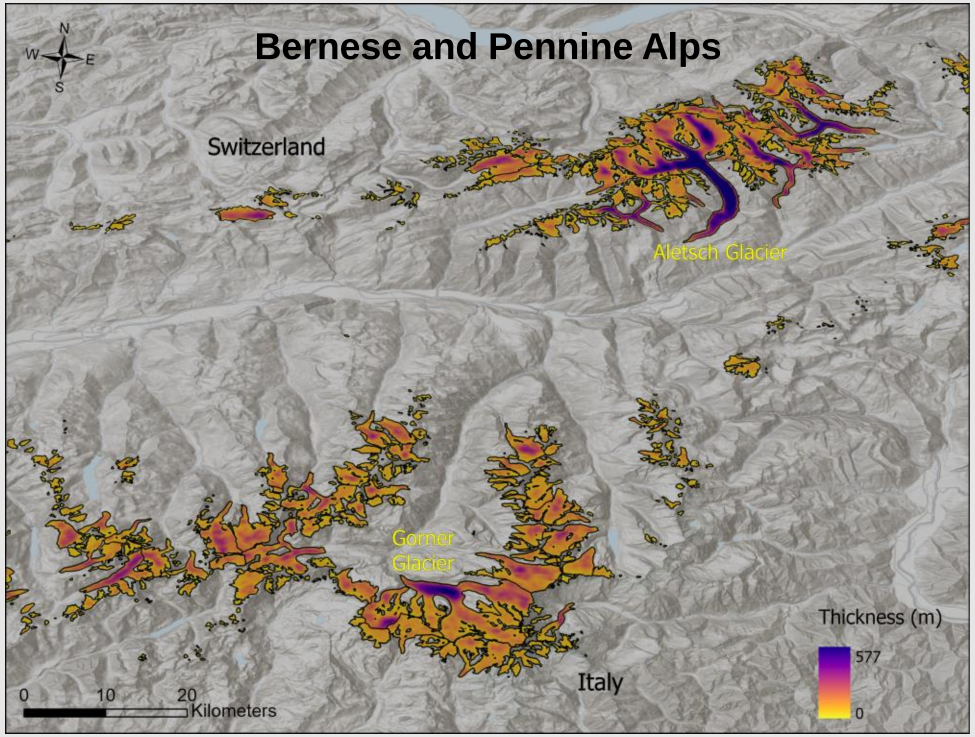
- ➢ Study the evolution of mountain glaciers under different climate scenarios

Adapted CISM to simulate the **mass balance** and **flow dynamics** of mountain glaciers

CISM as a Glacier Model

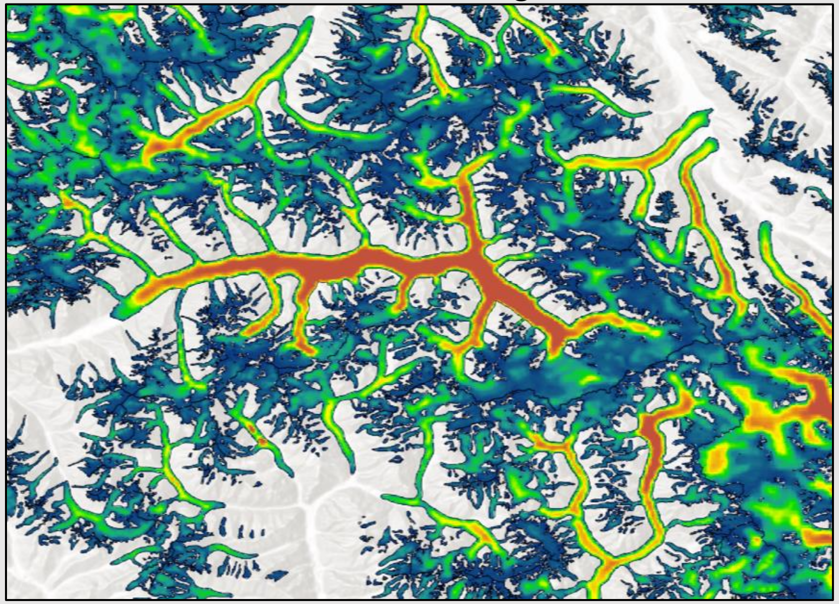
Input:

1. Glacier outlines:
    - RGIv6
2. Surface topography:
    - merged 3 arc-sec SRTM and *Farinotti et. al. 2019* surface elevation tiles
3. Glacier thickness:
    - *Farinotti et. al. 2019*
4. Climate forcing:
    - W5E5v2, CMIP6



Model grid

CISM 200-m grid



Traditional glacier model with flowlines

We ran CISM at **100-m** resolution for the Alps domain (RGI region 11)

Total glaciers in RGIv6: 3892

	100-m	200-m
Sub-grid	**6**	259
1 grid	**42**	782
2 grid	**182**	493

Mass-balance model

- As an ice sheet model, surface MB is an input coming from the land component of CESM
- For mountain glaciers, we introduce a positive degree day (PDD scheme)

Mass-balance model

$$\alpha P_i + \mu (T_i - T_{melt}) = 0 \qquad (1)$$

$$\alpha P_i' + \mu (T_i' - T_{melt}) = B_i \qquad (2)$$

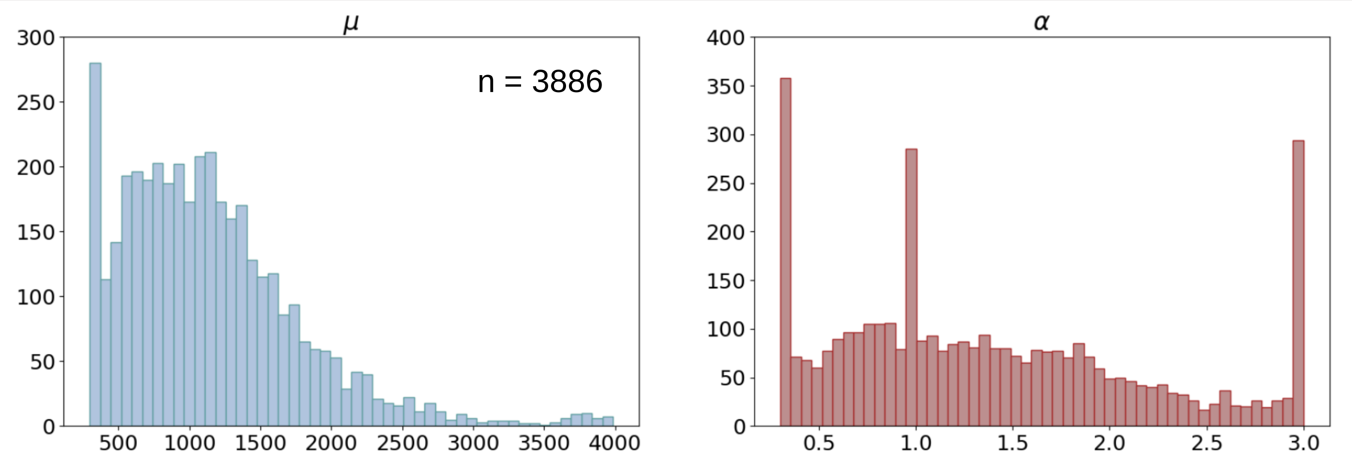
Eq. 1: Baseline climate, assumed to be at some "pre-industrial state" with a net zero mass balance

Eq. 2: Auxiliary climate is taken as 2000 – 2019 mean, matching the *Hugonnet et al. (2021)* period

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
T_i' and P_i' : Auxiliary climate

Tuning parameters

μ : temperature sensitivity parameter (mm w.e. K^{-1} $month^{-1}$)
α : Precipitation correction factor

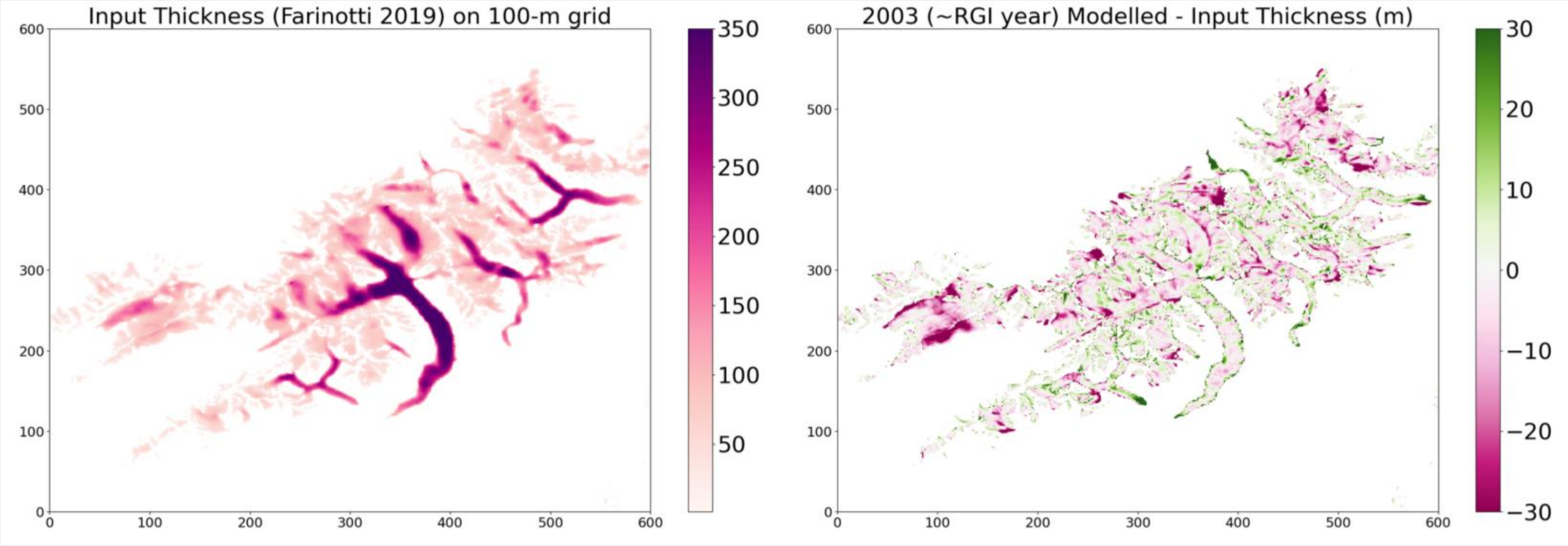


Inversion

- Depth-integrated viscosity approximation (DIVA) velocity solver
  - Stable at high resolutions (~100-m)
- Velocity depends on temperature-dependent ice flow factor (computed in the model empirically) and friction coefficient C_p

Basal friction power law: $\tau_b = C_p(x, y)\ u^{1/3}$

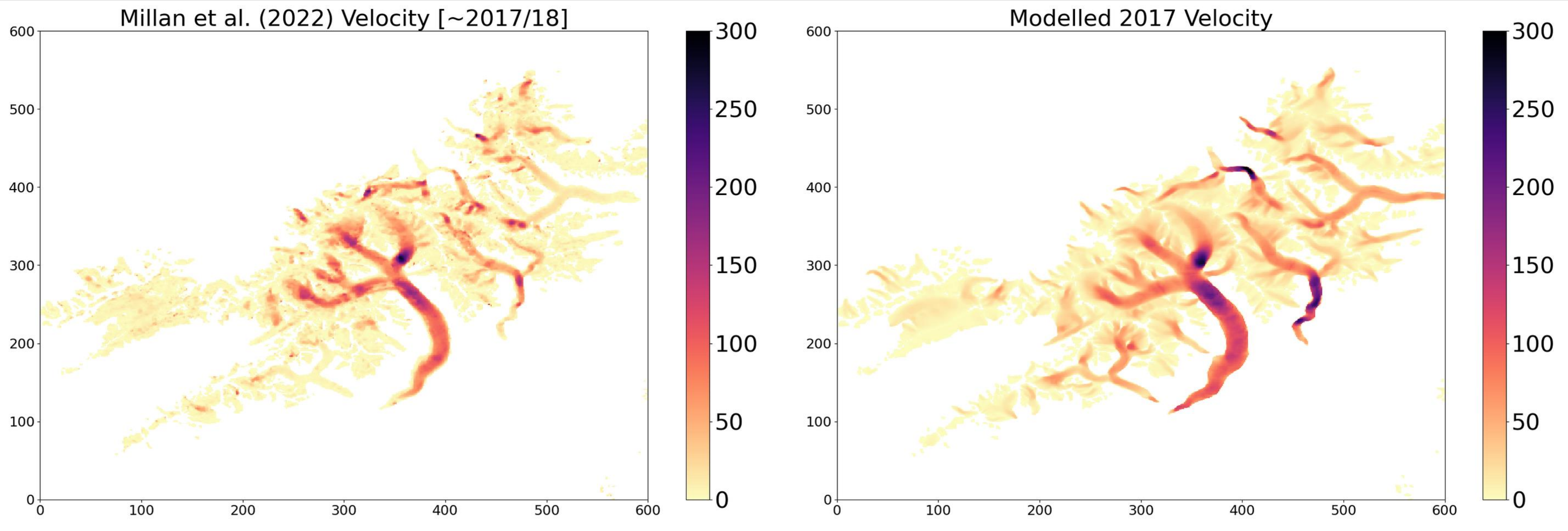
- C_p is tuned to nudge the modelled ice thickness towards the reference thickness (Farinotti et al. 2019).



Spin-up

➢ Spin-up the model for 10,000 year (8,000 with inversion and 2,000 without inversion).

Reference data | **CISM**



CISM participation in GlacierMIP3

- Coordinated intercomparison of global-scale glacier mass change models

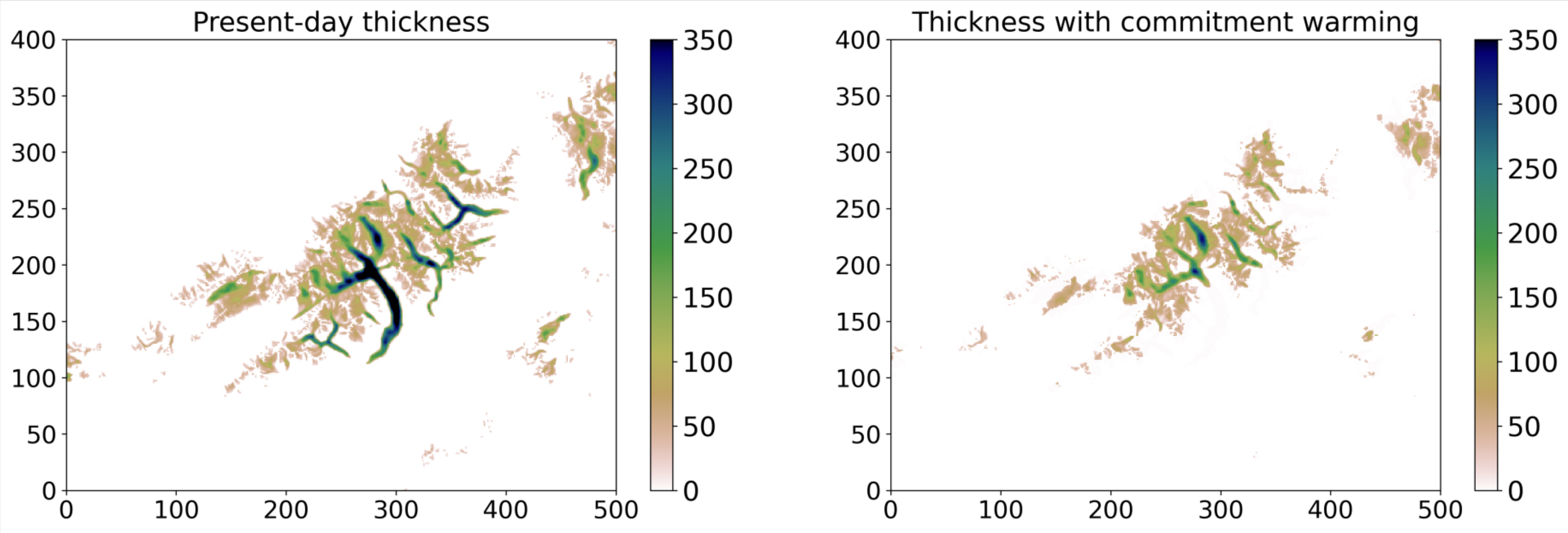
- The third phase (GlacierMIP3) is on equilibration of glaciers under different climate states

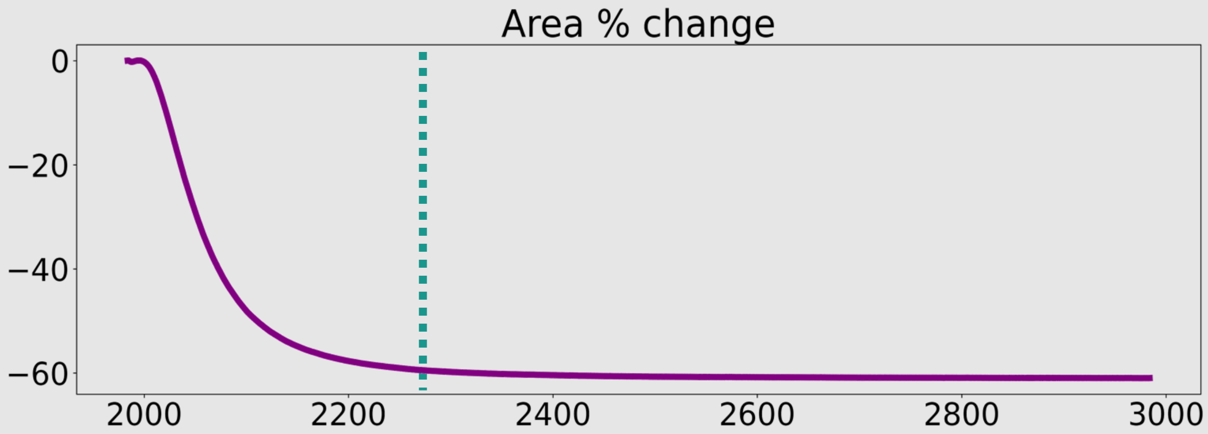
  What would be the equilibrium volume and area of all glaciers outside the ice sheets if global mean temperatures were to stabilize at:

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

- Team: Harry Zekollari (chair), Fabien Maussion, Lilian Schuster, Regine Hock and Ben Marzeion

Commitment loss

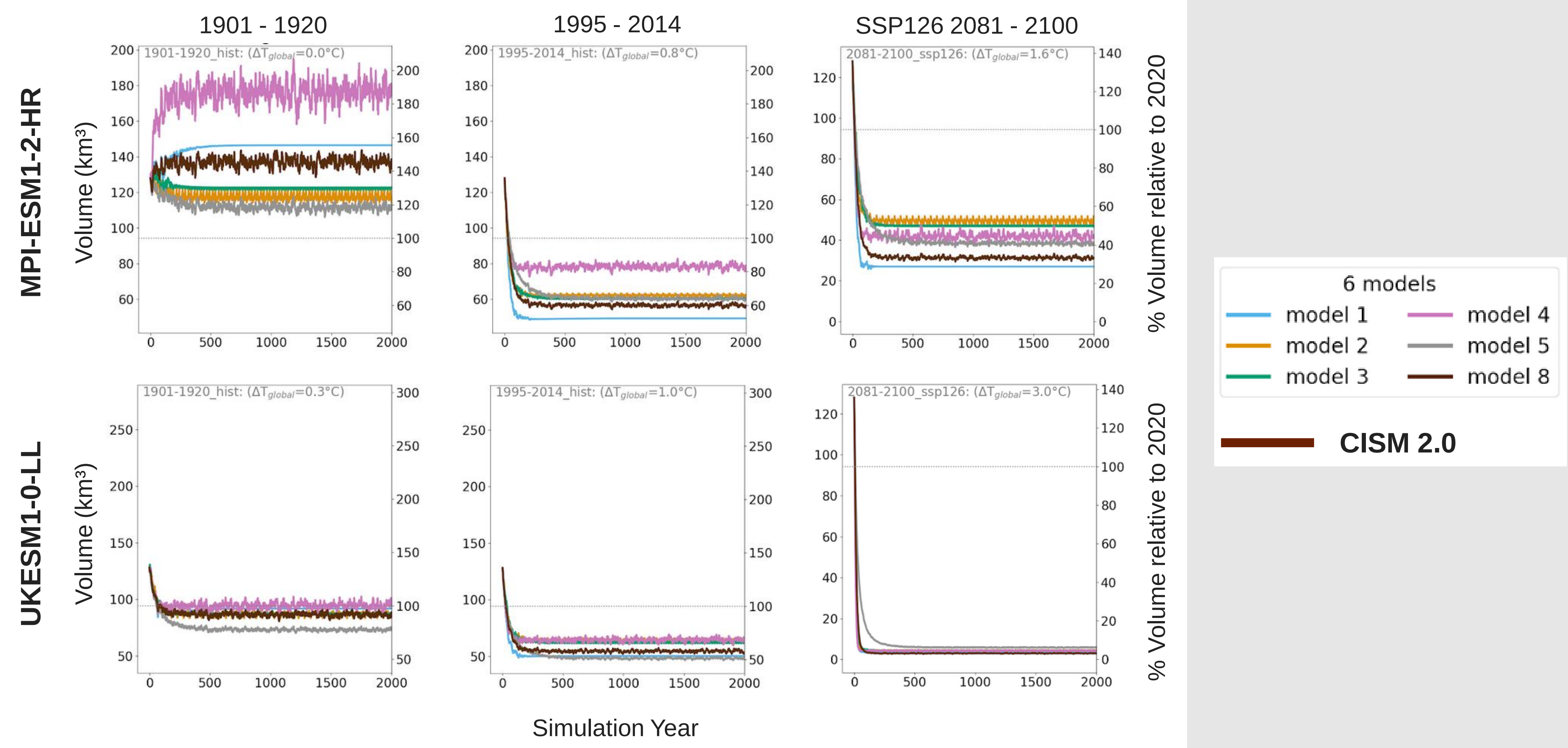




- In these runs, the total number of glaciers drop from 3633 to 1287 with the commitment warming
- It takes ~270 years to reach the new equilibrium state

CISM participation in GlacierMIP3 (RGI 11: Central Europe)

Analysis & Figures from Lilian Schuster



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GlacierMIP3 team:

Harry Zekollari, Lilian Schuster, and Fabien Maussion

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Questions

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Sentinal-2 false color image of Batura Glacier, Pakistan