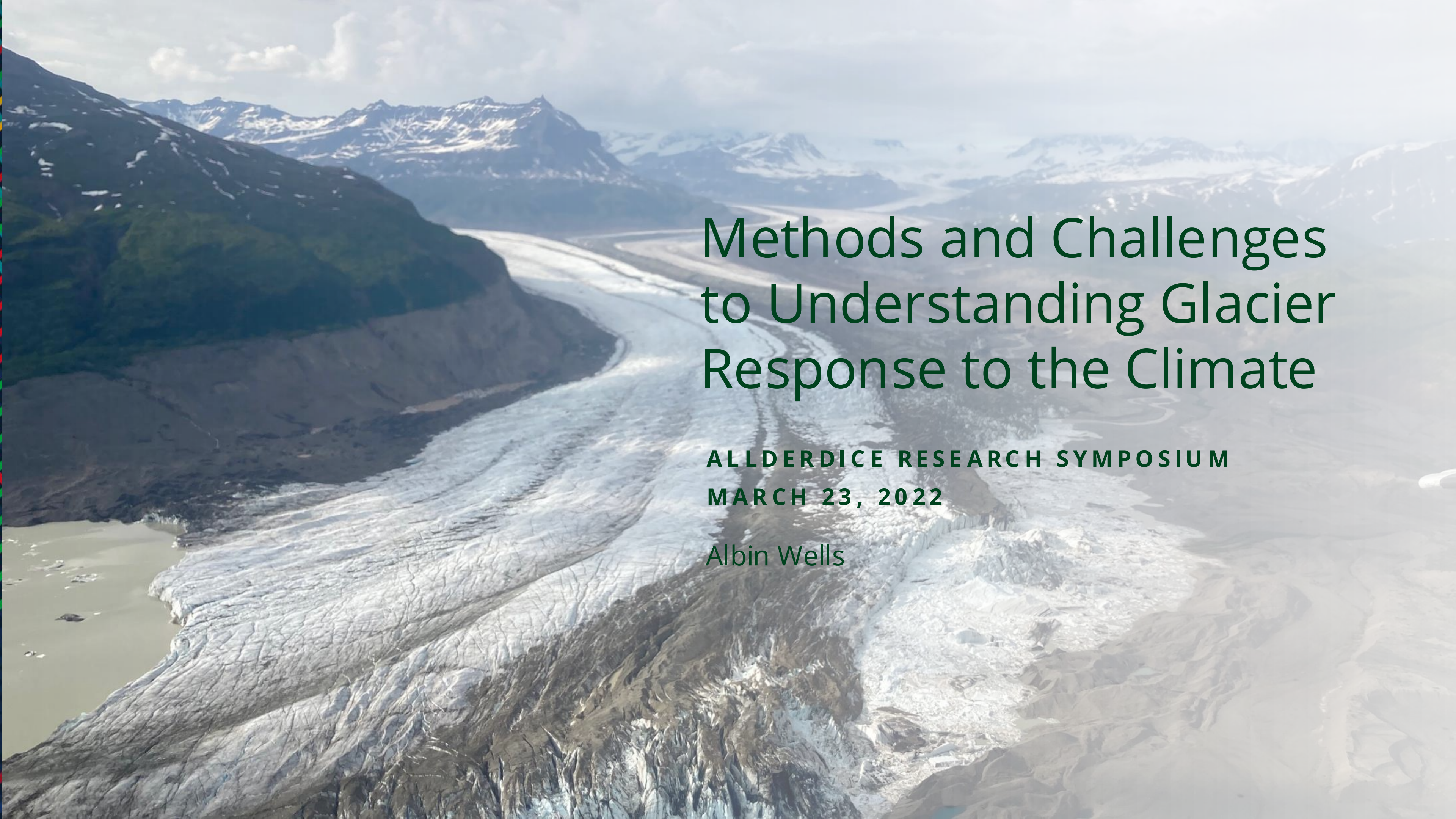


Methods and Challenges to Understanding Glacier Response to the Climate

ALLDERDICE RESEARCH SYMPOSIUM
MARCH 23, 2022

Albin Wells

A quick intro…

Allderdice c/o 2017

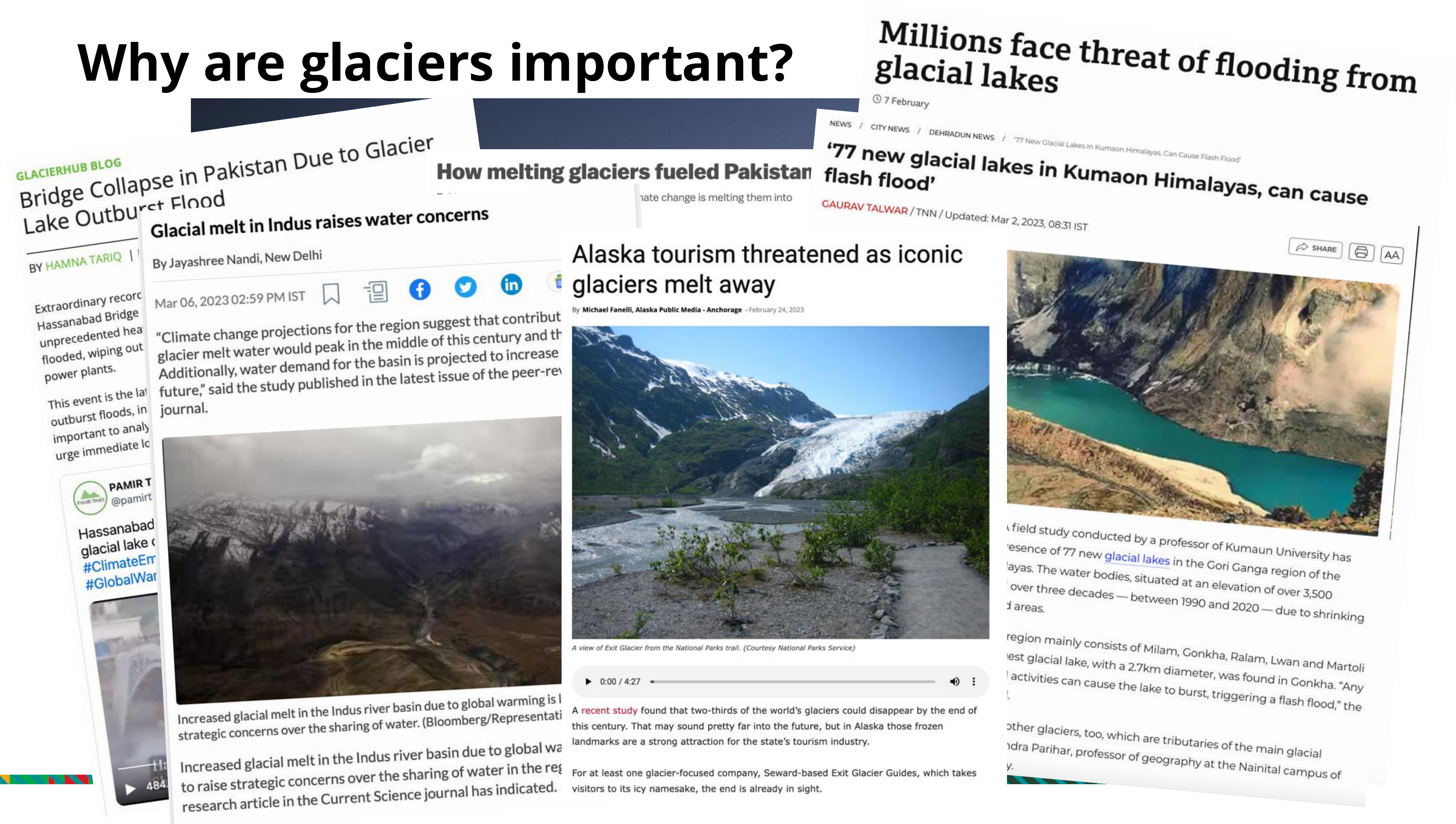
CMU !!

Brown University c/o 2021

Pursuing a Ph.D. in Civil and Environmental Engineering, studying glaciers

Received an Sc.B. in Mechanical Engineering

Why are glaciers important?



Glacier mass loss is occurring worldwide

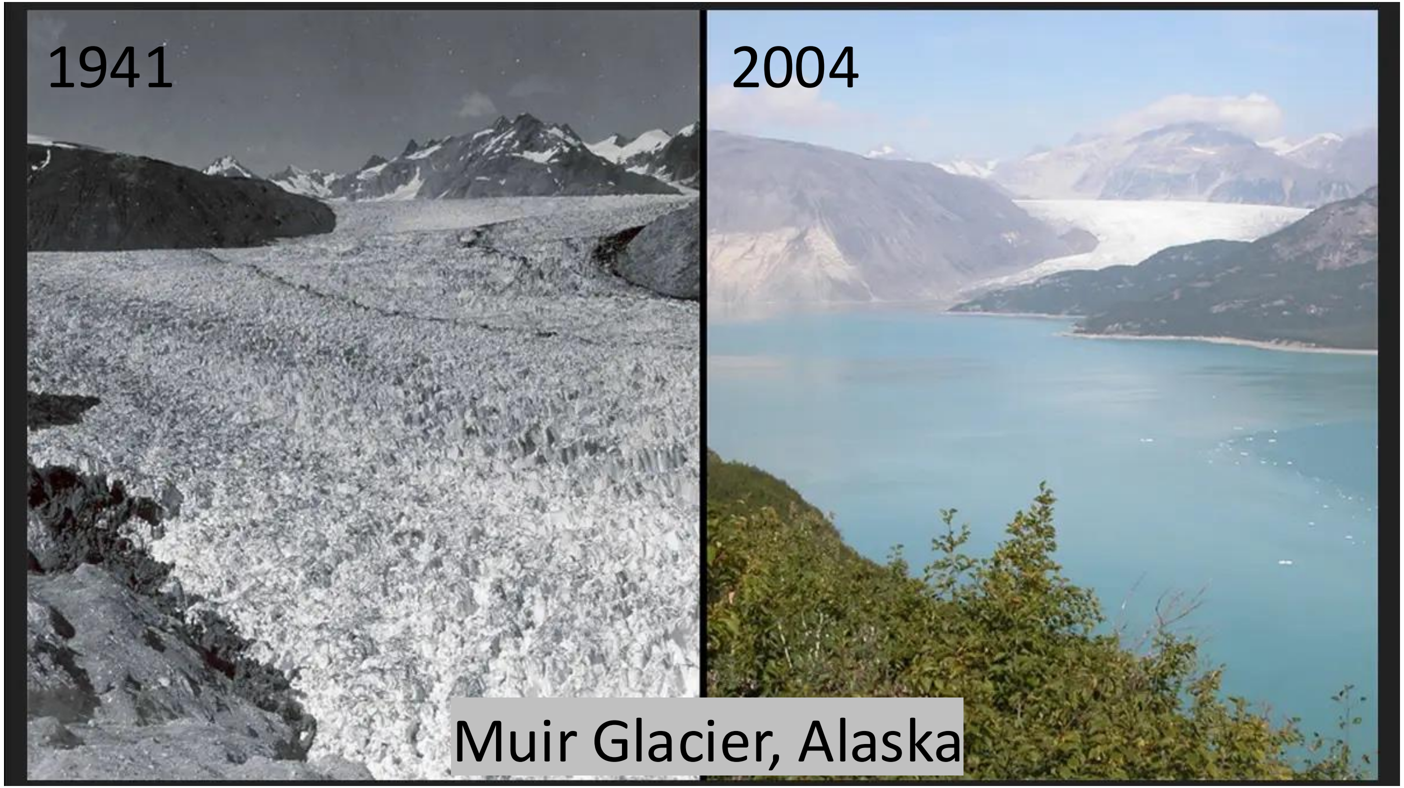


Image Credit: NSIDC

Waggonwaybreen, Svalbard

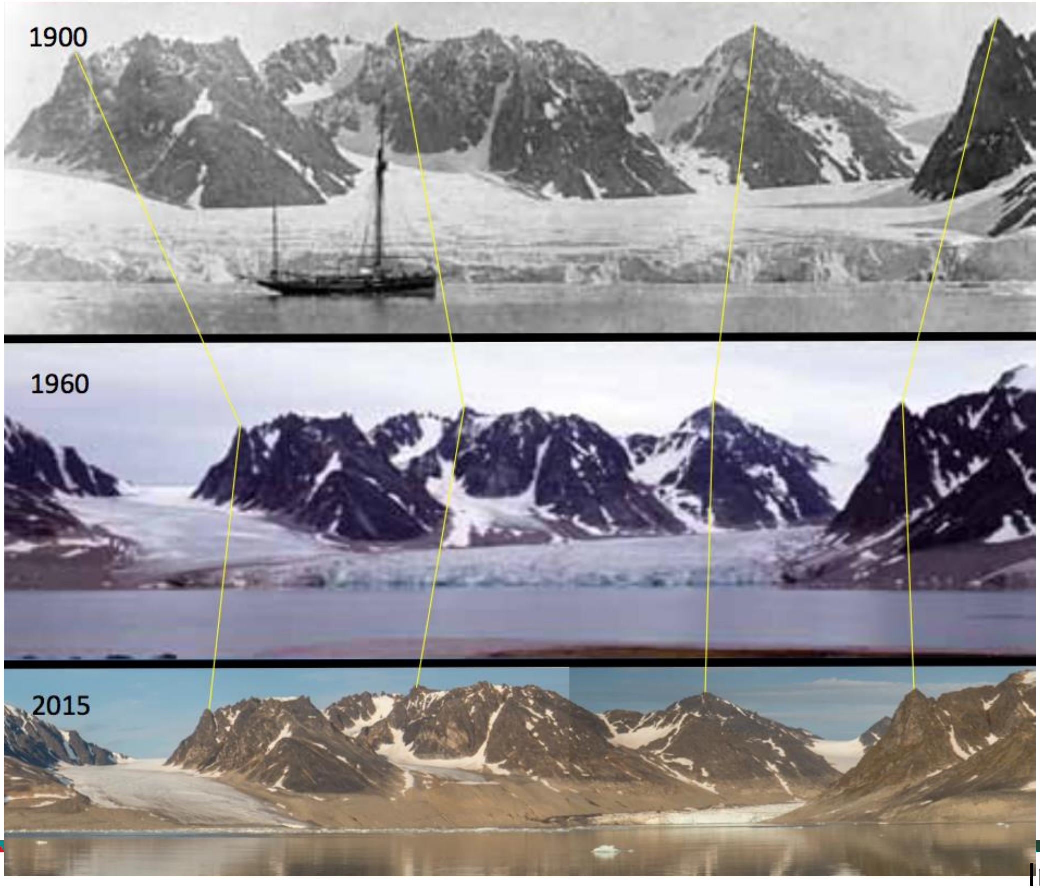


Image Credit: Andreas Weith

Kyetrak Glacier, Tibet

Image Credit: David Breashears/Royal Geographic Society

Extreme mass loss is also observed over the last few years

Bear Glacier, Alaska

Image Credit: NPS

Fox Glacier, New Zealand

Image Credit: Dr Ian Fuller

The most recent models project ~50-80% of global glaciers to melt by 2100

- Glaciers account for only **1% of global ice volume**
- Account for **1/4 to 1/3 of observed sea-level rise** in recent years
- Global average thinning rates of **0.85 m/yr** (2006-2015)

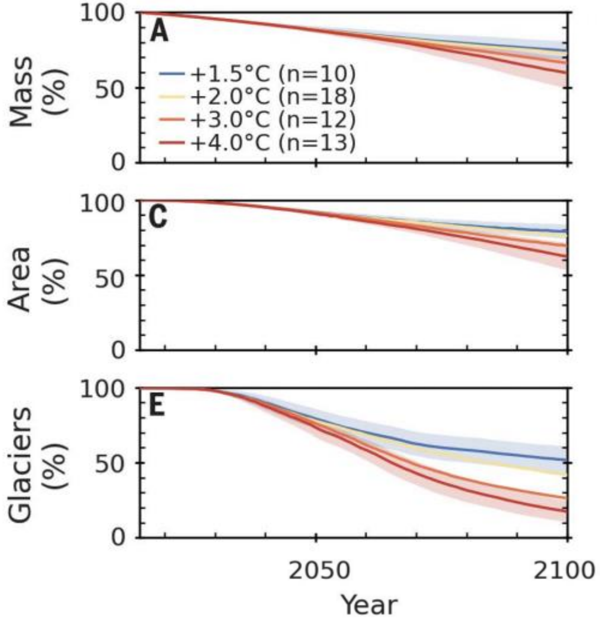


Figure from Rounce et al. 2023

What regions are losing the most mass?

Regional and global glacier thinning rates from 2000-2019

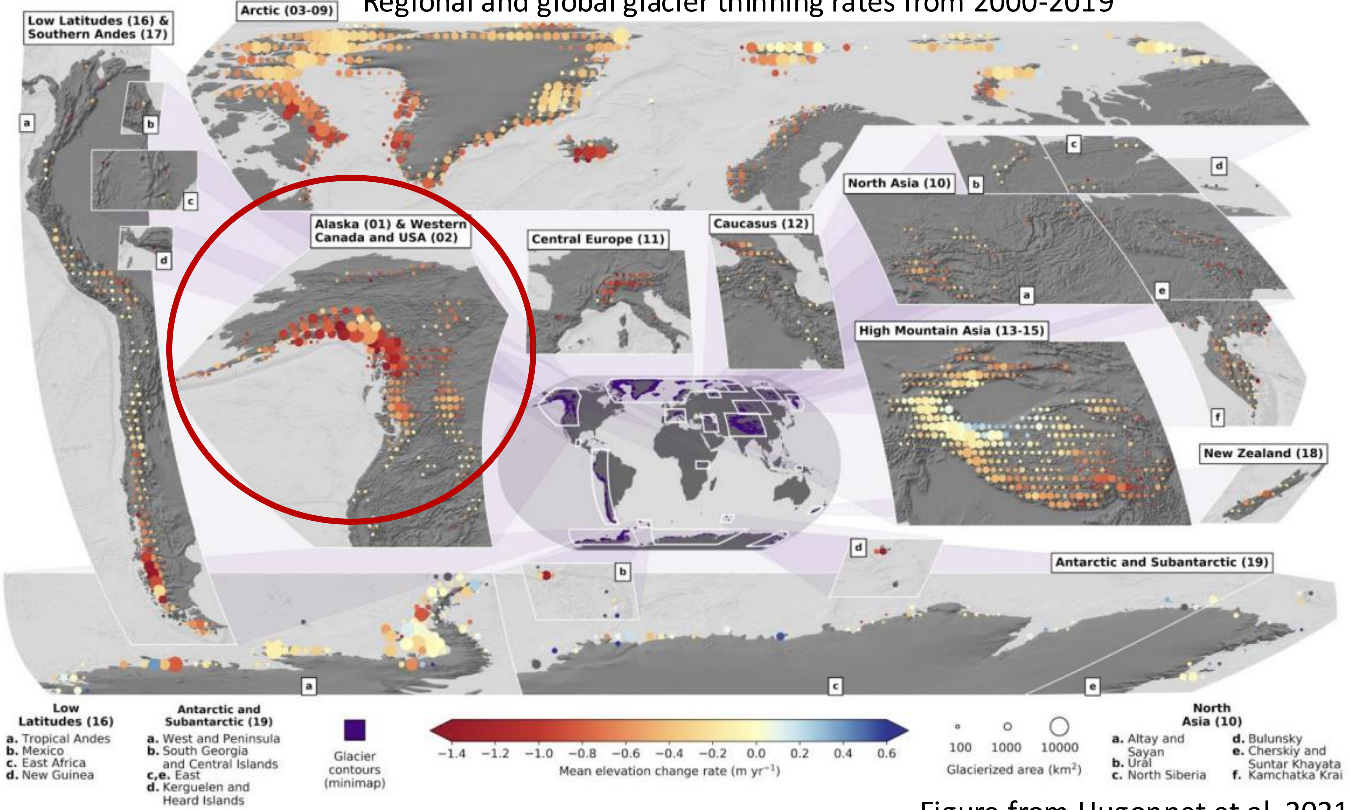


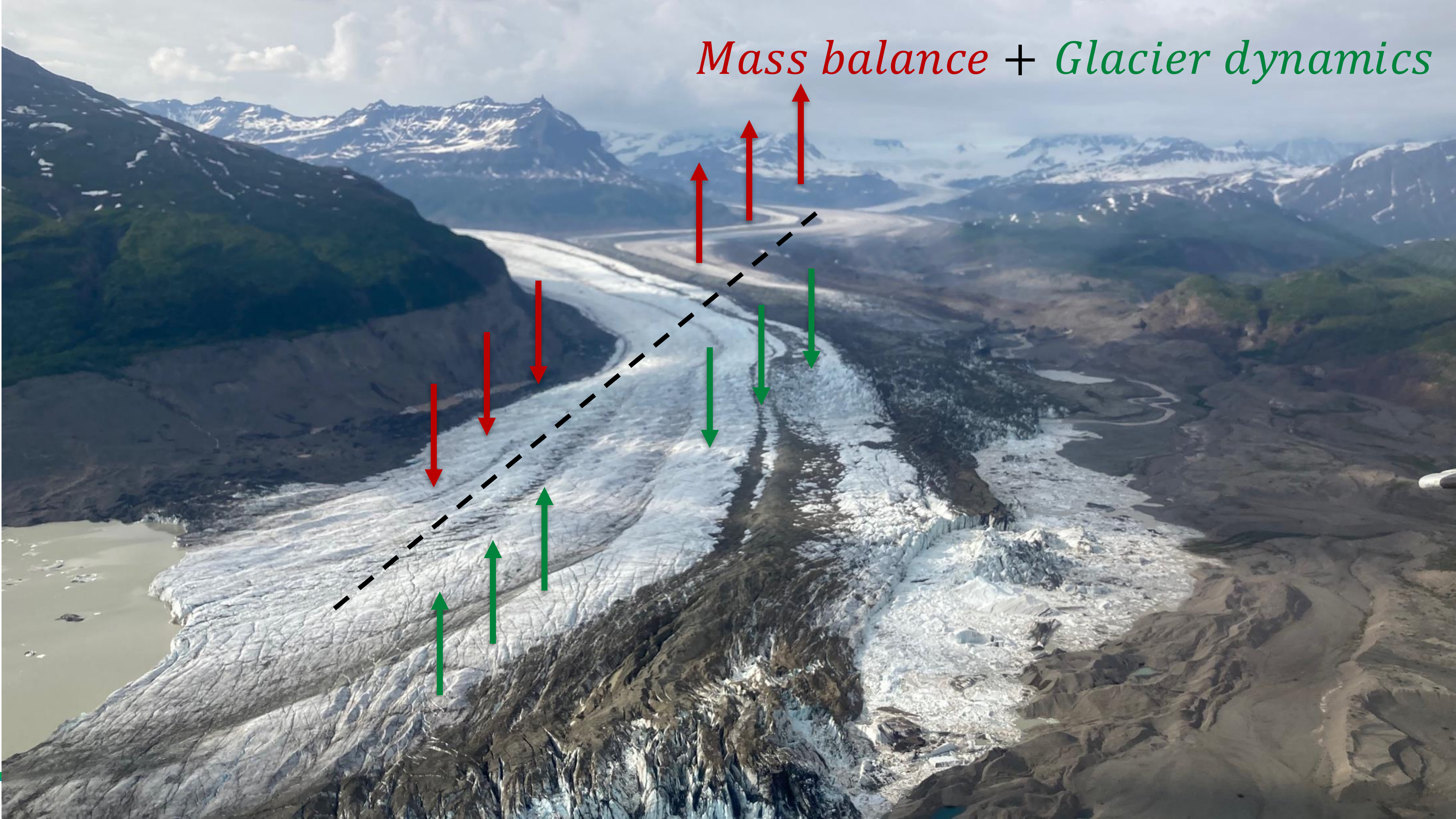
Figure from Hugonnet et al. 2021

So, how can we predict a glacier's response to the climate?

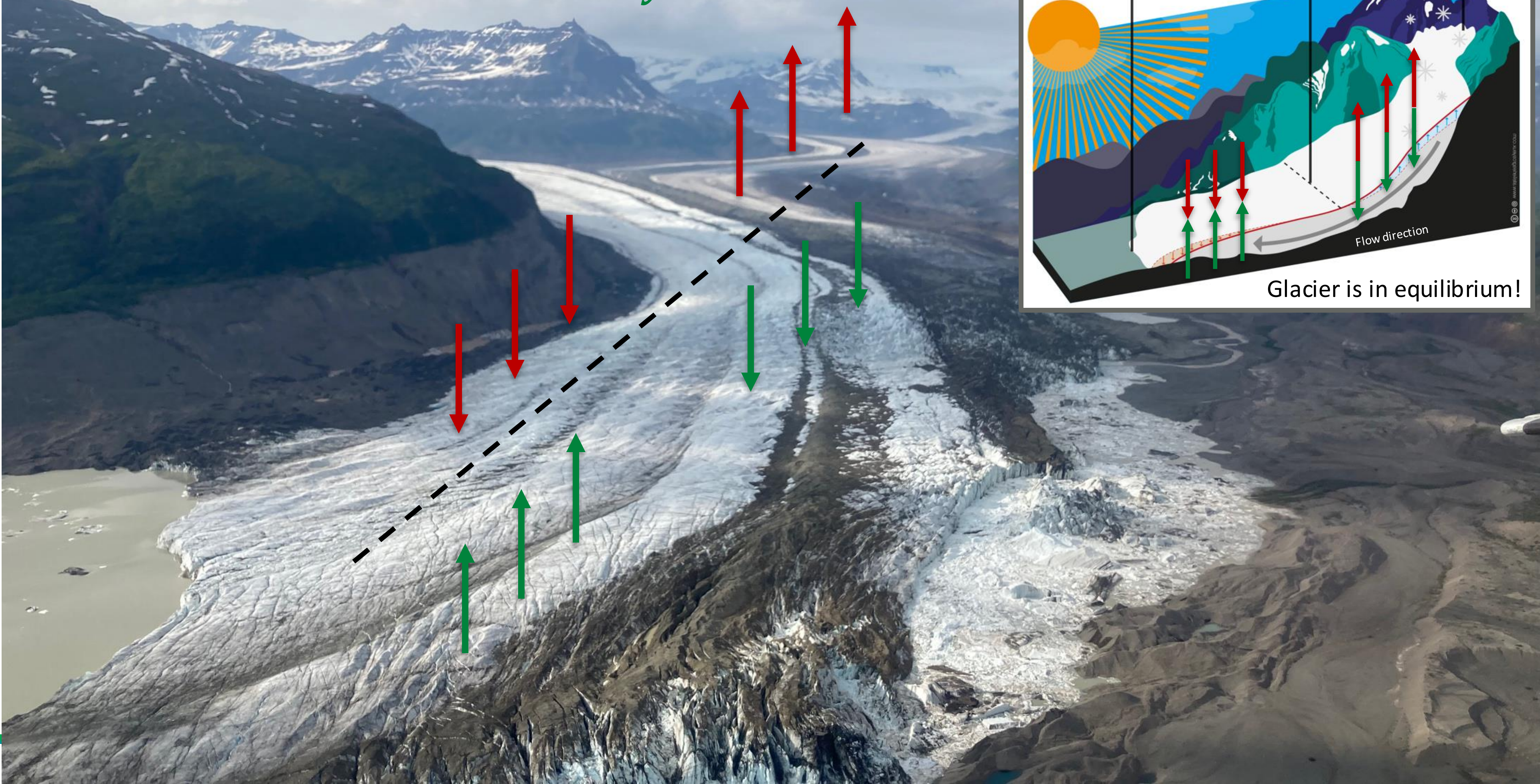
First, we need to understand how glaciers work!


$Climate + Gravity$

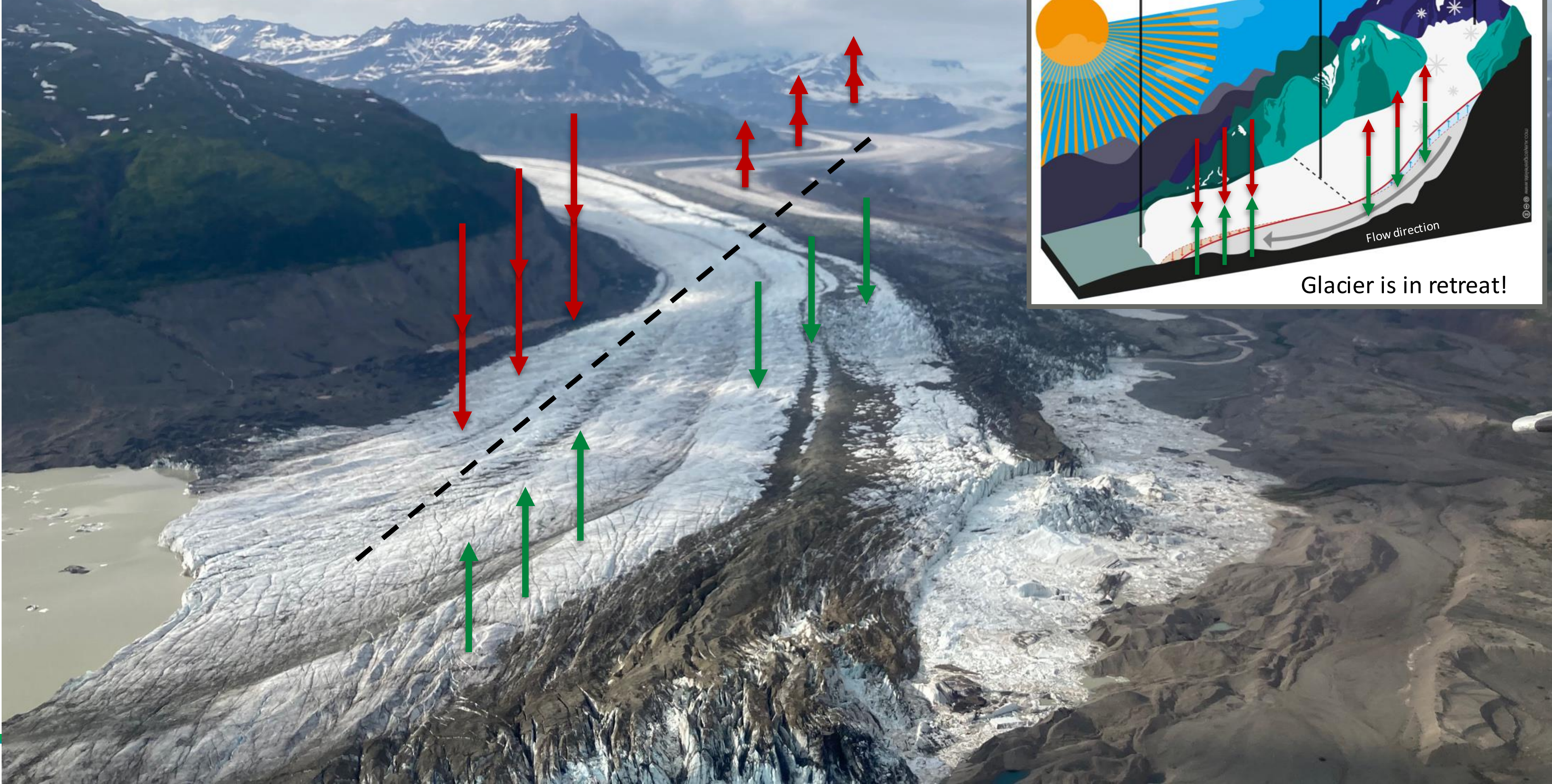
Mass balance + *Glacier dynamics*


Mass balance + Glacier dynamics

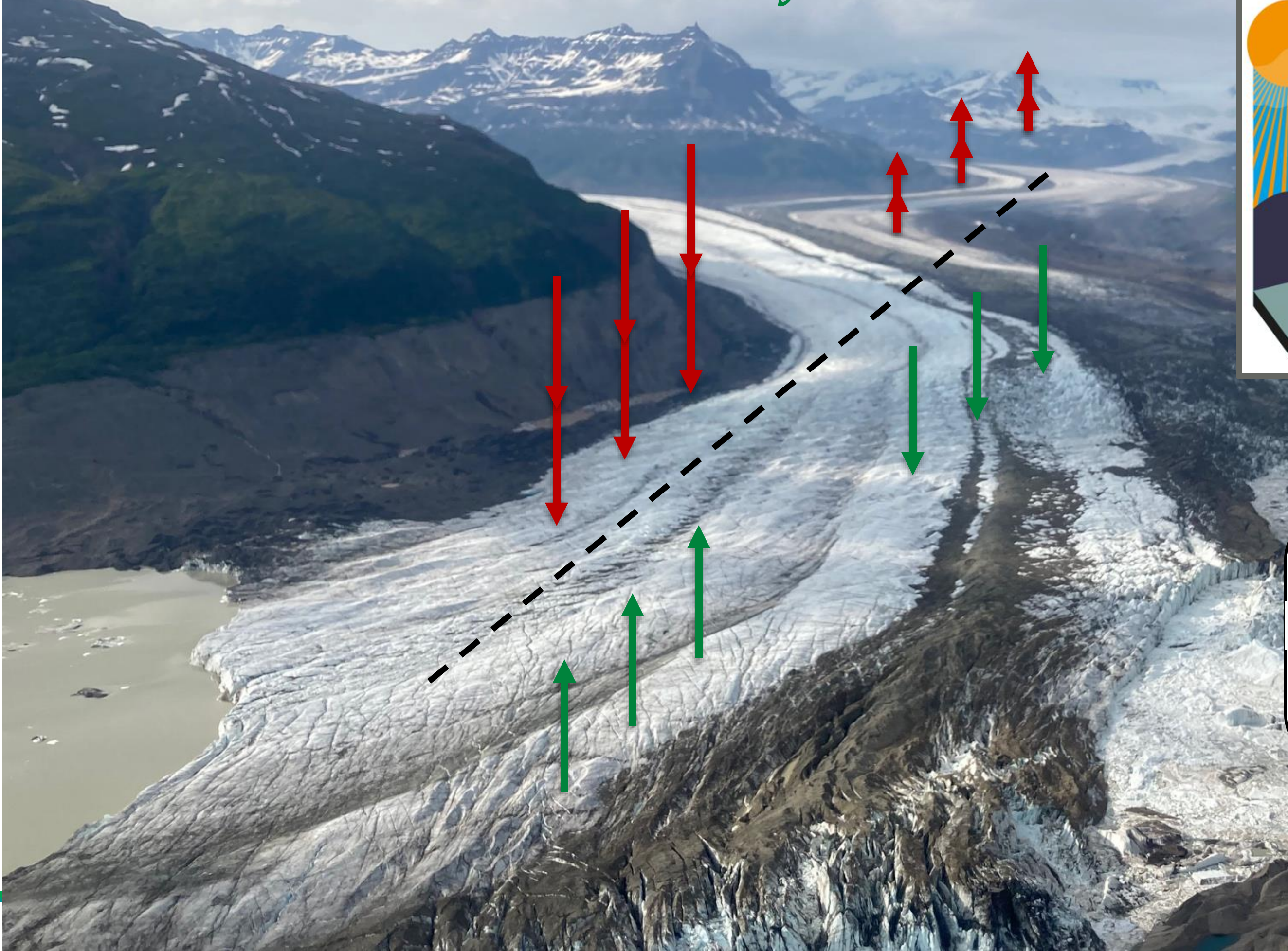
Mass balance + *Glacier dynamics*

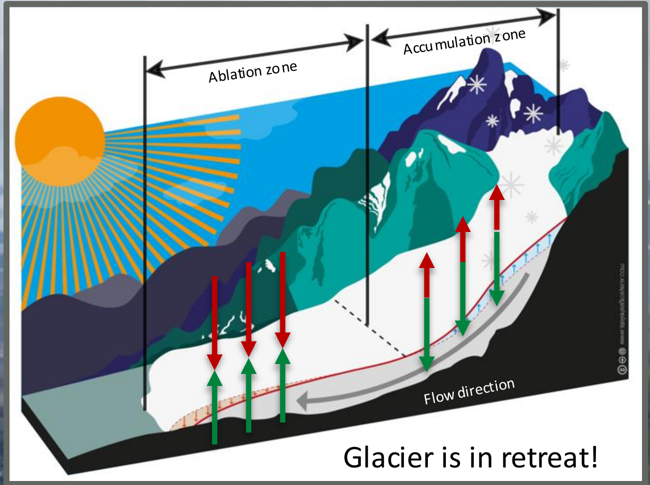


Mass balance + *Glacier dynamics*



Mass balance + *Glacier dynamics*





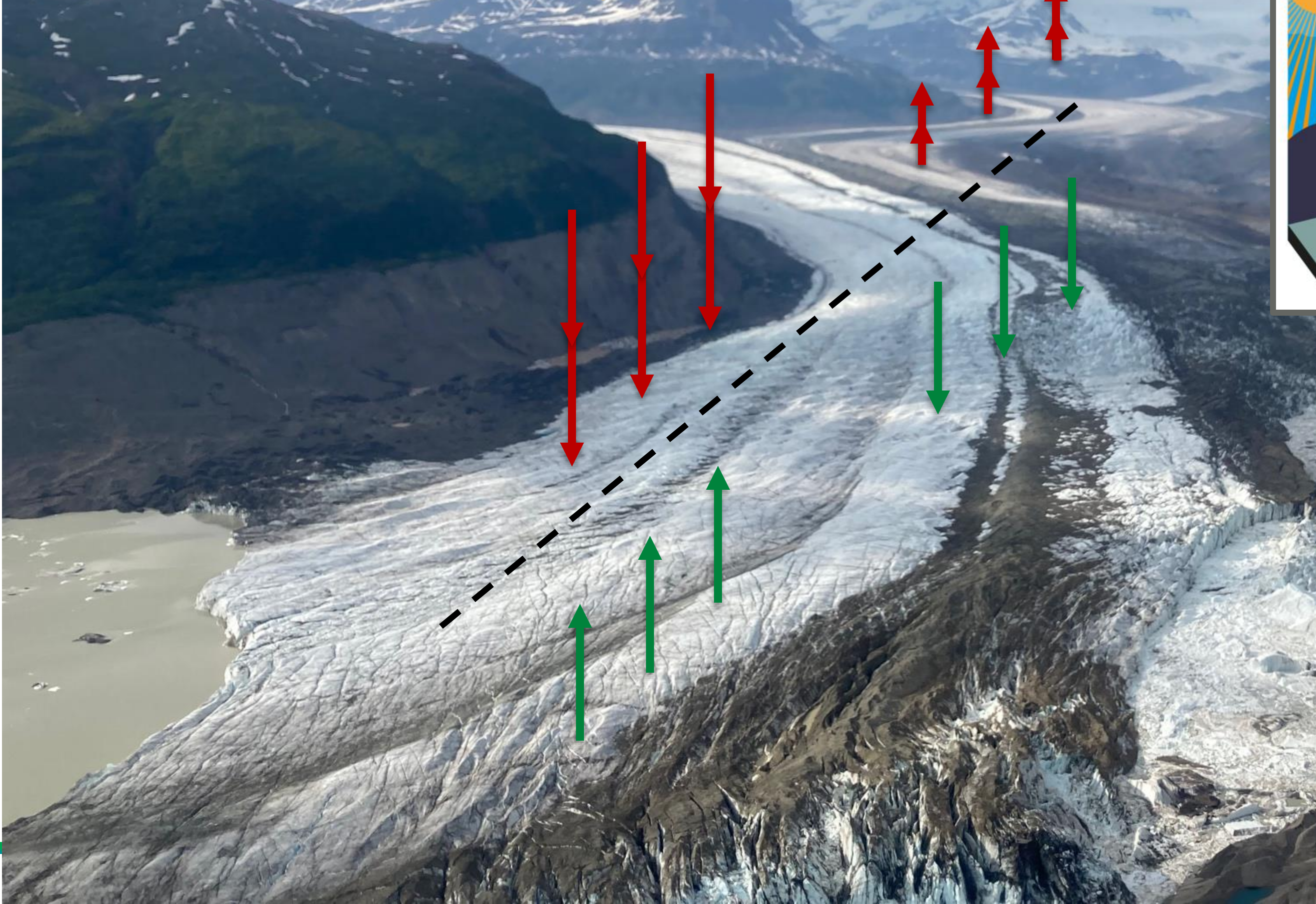
Total Mass Balance: $\dot{b}_{\text{tot}} = \frac{dh}{dt}$

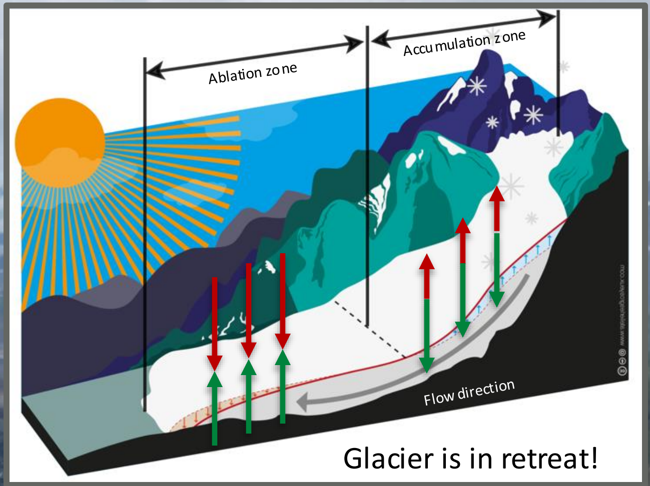
Climatic Mass Balance: $\dot{b}_{\text{clim}} = \frac{dh}{dt} + \nabla q$

where: $\nabla q = \nabla u \cdot h$

We need 3 primary data inputs:

- Digital Elevation Models (elevation change)
- Ice thickness
- Velocity





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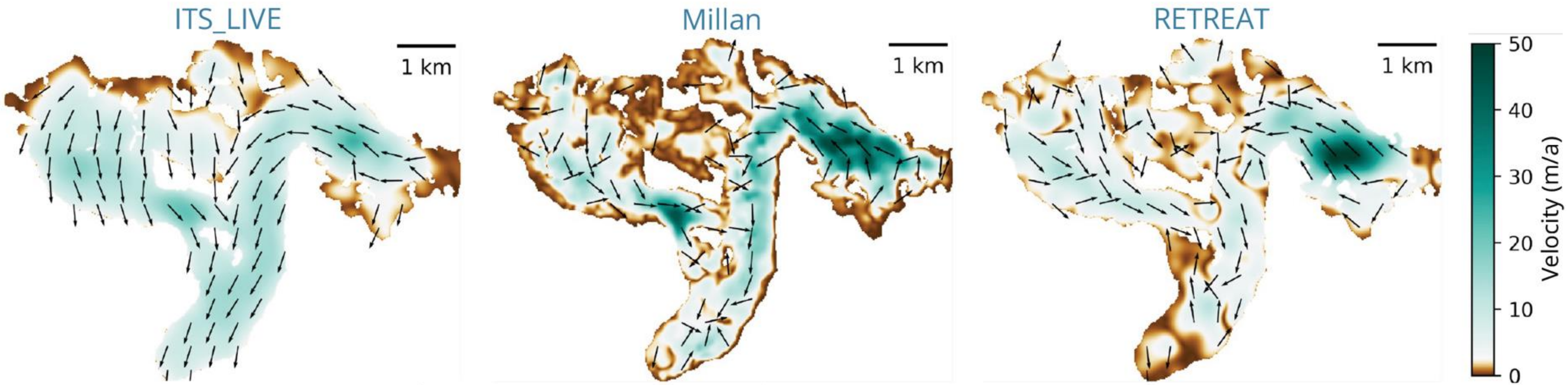
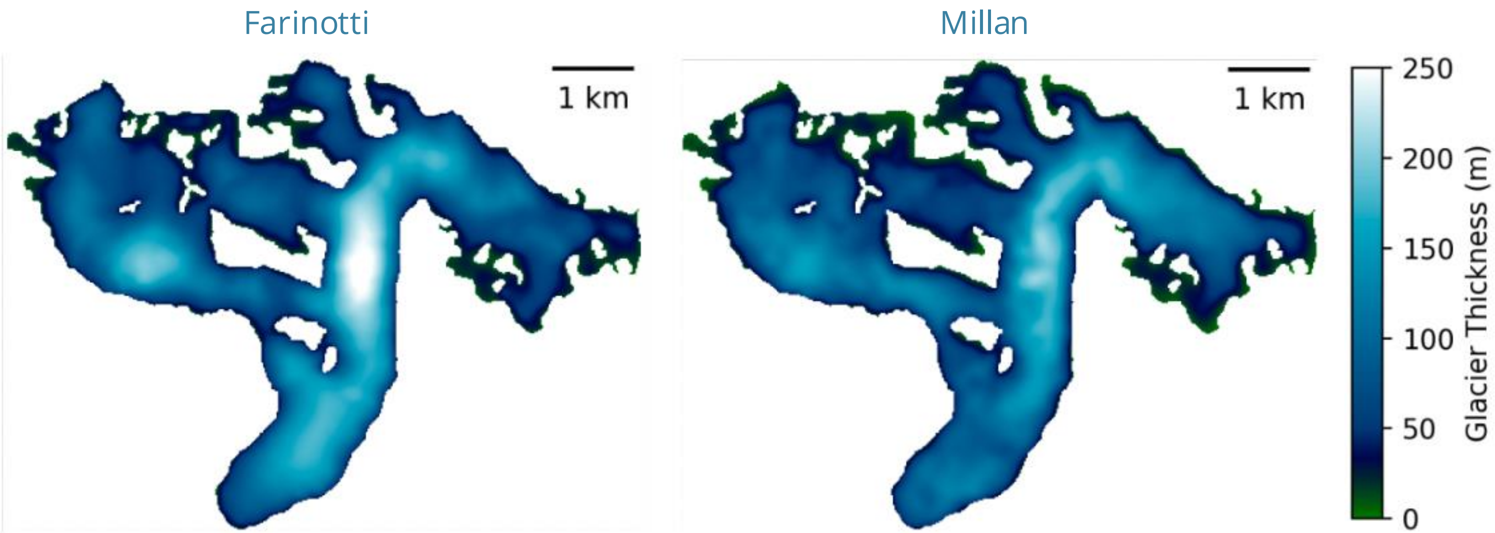
Large-scale, systematic remote sensing products have discrepancies

- Gulkana Glacier in Alaska is ~17.5 km^2
- Global velocity products show large deviations in magnitude and spatial distributions



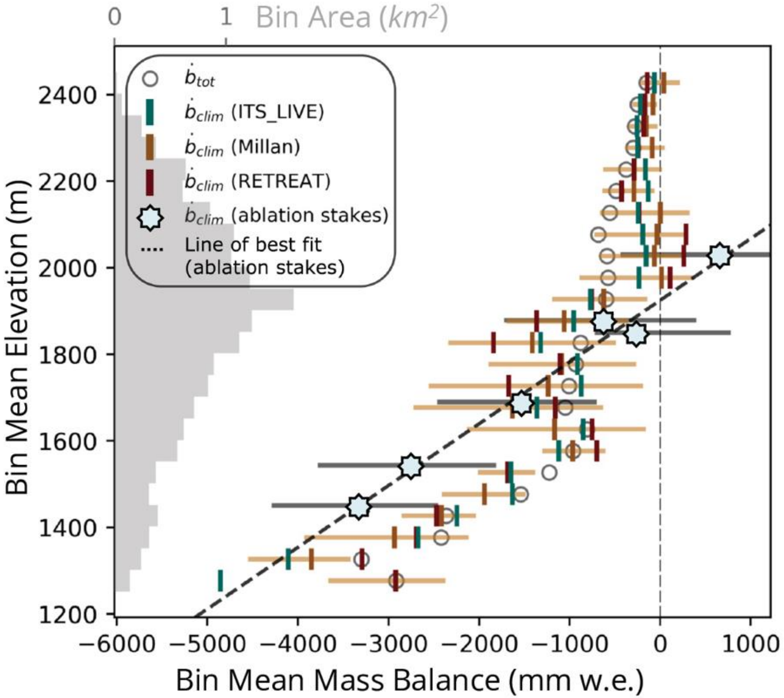
Modeled ice thickness products also differ



Our confidence in global datasets is limited by a paucity of validation data that address issues pertaining to noise, bias, and uncertainty!

Velocity and ice thickness impact our ability to calculate the climatic mass balance

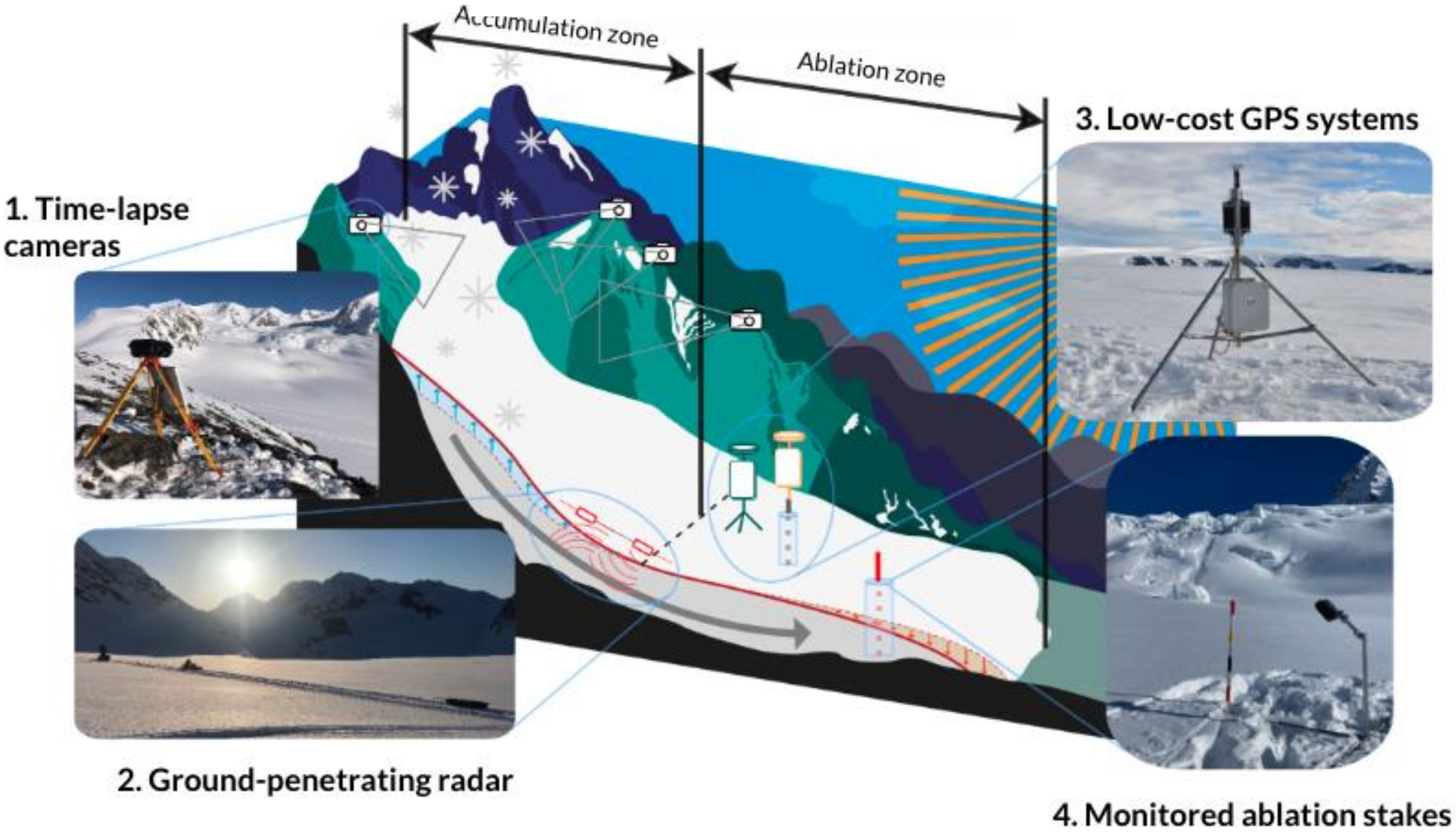
Gulkana Glacier climatic mass balance as a function of elevation



The climatic mass balance gradient is off by >50% compared to the observed stake data!

We can try to reconcile these discrepancies by leveraging field measurements and models

Field Measurements



Field Measurements

Total Mass Balance:

$$\dot{b}_{\text{tot}} = \frac{dh}{dt}$$

- Time-lapse cameras
- Low-cost GPS systems

Climatic Mass Balance:

$$\dot{b}_{\text{clim}} = \frac{dh}{dt} + \nabla q$$

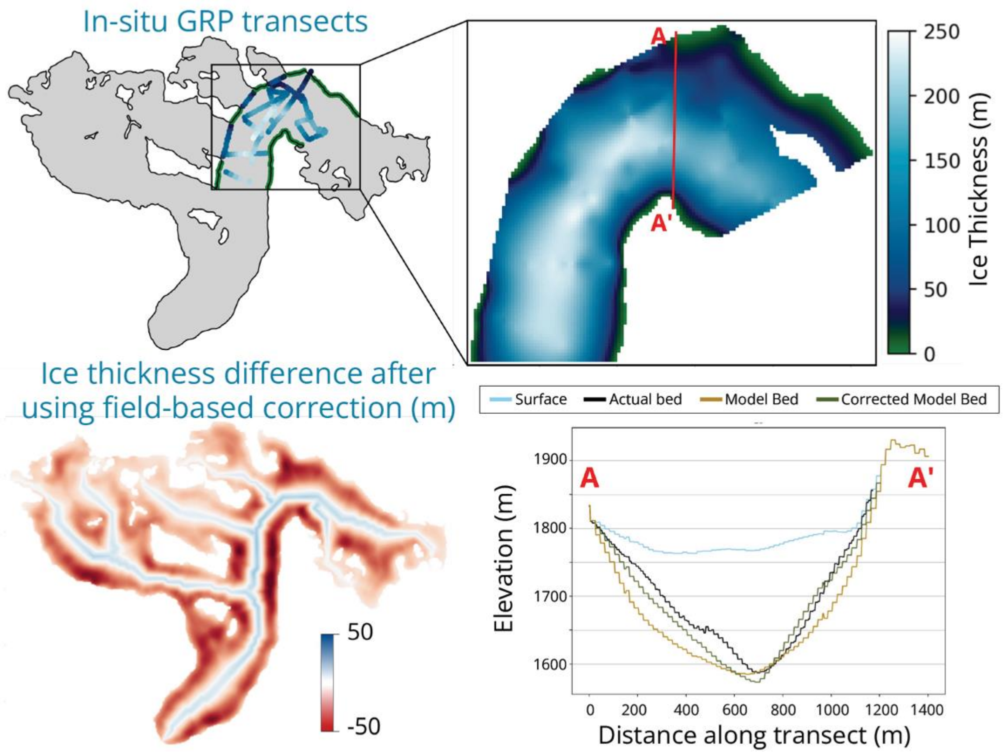
- Monitored ablation stakes
- Low-cost GPS systems

Flux Divergence:

$$\nabla q = \nabla (h \cdot u)$$

- Time-lapse cameras
- Ground-penetrating radar
- Low-cost GPS systems

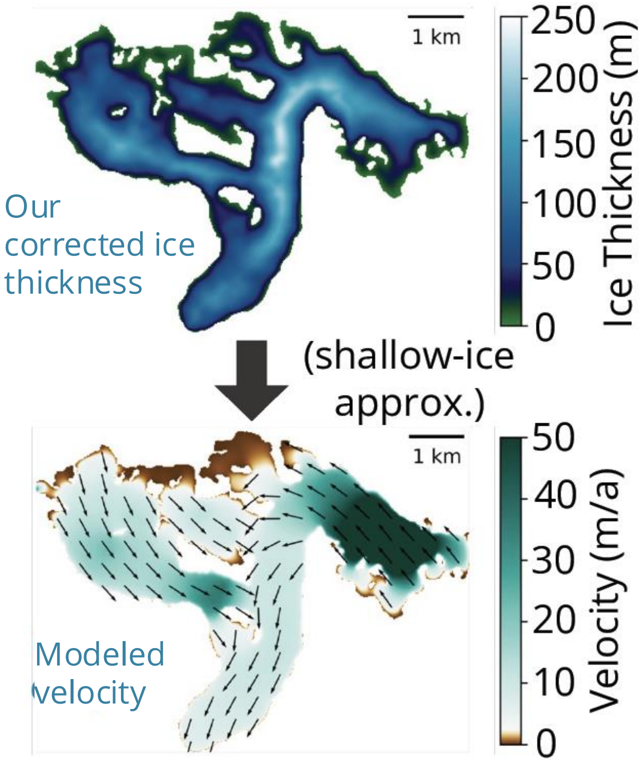
Integrating field measurements with existing data products: Ice thickness



- On Gulkana, ice thickness products…
  - underestimate thickness along the centerline
  - overestimate ice thickness along the margins

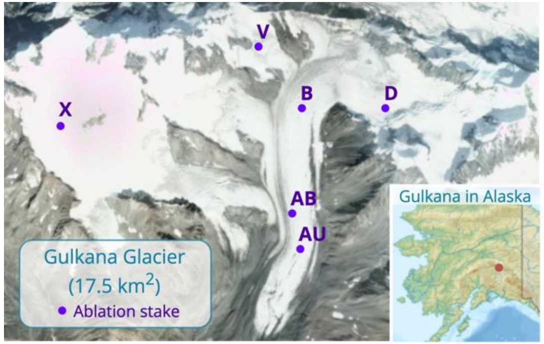
- Essentially, our data is used to correct the ice thickness product for the proper bed shape

Integrating models: Velocity



- Also deriving our own velocity products from high-resolution remote sensing
- Future steps to integrate models with observations using Bayesian inference
  - combine prior belief (model) with observations (remote sensing)

- Use our point data as validation

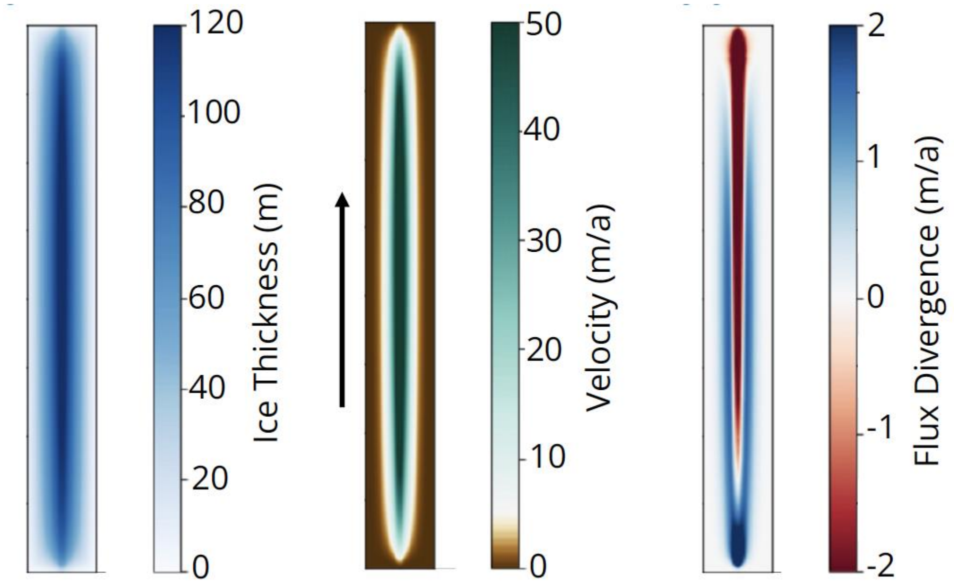


Velocity at Ablation Stake Locations (m/a)

		Location			
		AU	AB	B	D
Data Source	Stake	18.5	23.9	39.7	53.9
	Millan	15.9	5.3	26.3	46.7
	ITS_LIVE	14.7	13.8	13.0	20.5
	RETREAT	6.1	3.3	3.9	20.9
	Model	10.8	10.6	13.1	61.7

A theoretical approach to the climatic mass balance

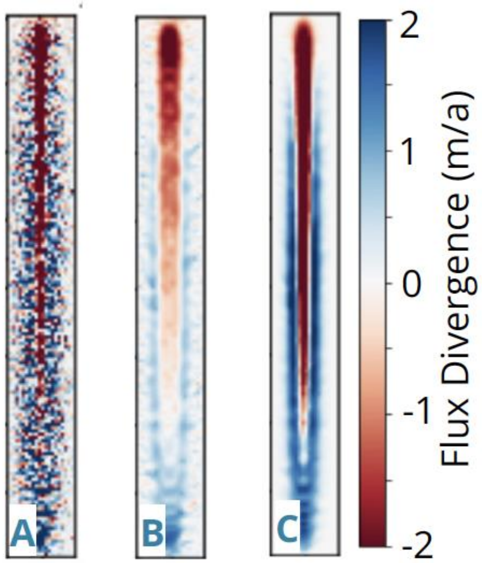
- ***How accurate do ice thickness and velocity need to be?***
- Start with idealized glacier and derive physically consistent ice thickness and velocity



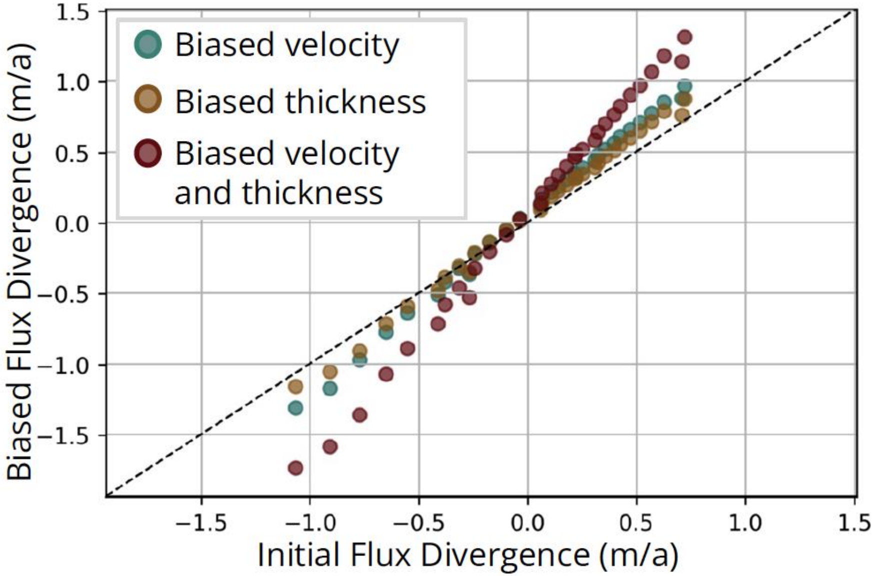
A theoretical approach to the climatic mass balance

- Then, introduce noise and/or bias into the data and see how it affects our results

Flux divergence from noisy (A), smoothed (B), and corrected (C) inputs



Overestimation bias effect on flux divergence



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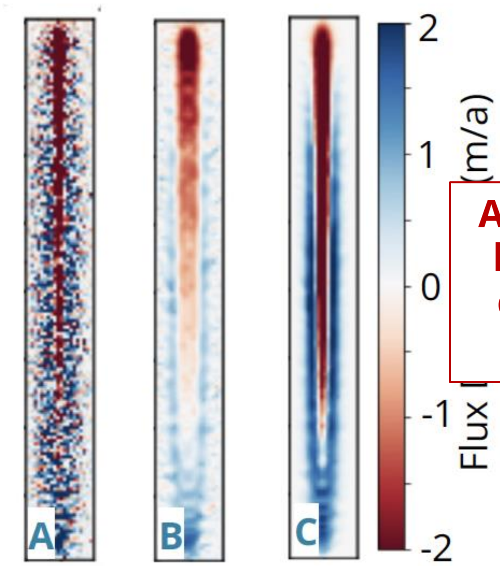

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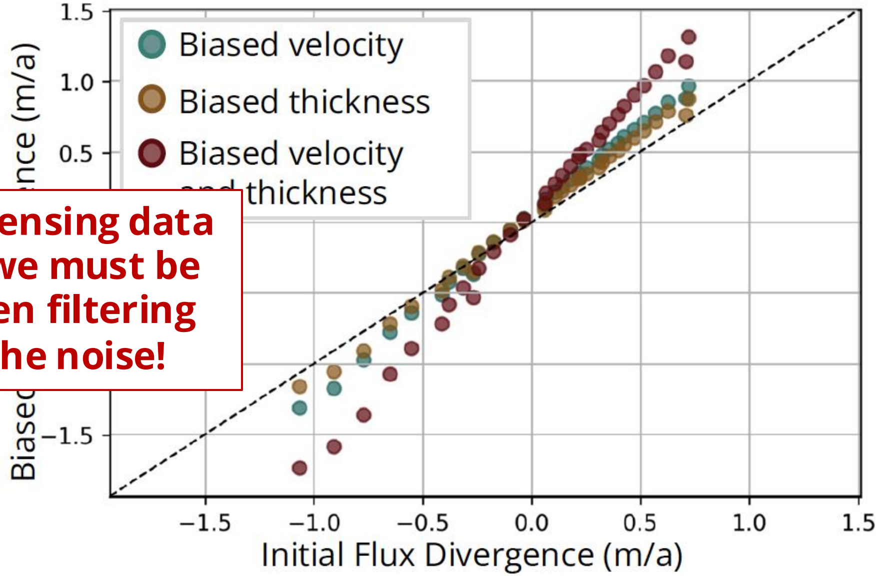

All remote sensing data has noise; we must be careful when filtering through the noise!

Takeaways and Conclusions

- The impacts of glacier mass loss are ubiquitous: **understanding glacier response to the climate has implications for billions of people** across the globe
- Glaciers are losing mass at unprecedented rates as a result of climate change, and new, systematic **remote sensing offers a unique ability to monitor mass loss globally**
- However, our ability to resolve **the *climatic mass balance* is hindered by noise and bias** in data
- **Field measurements and models provide opportunities to validate and improve remote sensing data products**, but integrating these products is still a work in progress!

Carnegie Mellon University

Next Steps

- Increase complexity of synthetic glacier study
- Increase model complexity for deriving velocities
- Assess potential effects of glacier processes (avalanching, wind distribution, firn compaction) on stake observations
- Obtain new/more field data!
- Apply methods to other glaciers in Alaska

Gulkana Glacier, August 2022