Deriving Climatic Mass Balance Gradients through the Integration of Field Measurements, Modeling, and Remote Sensing

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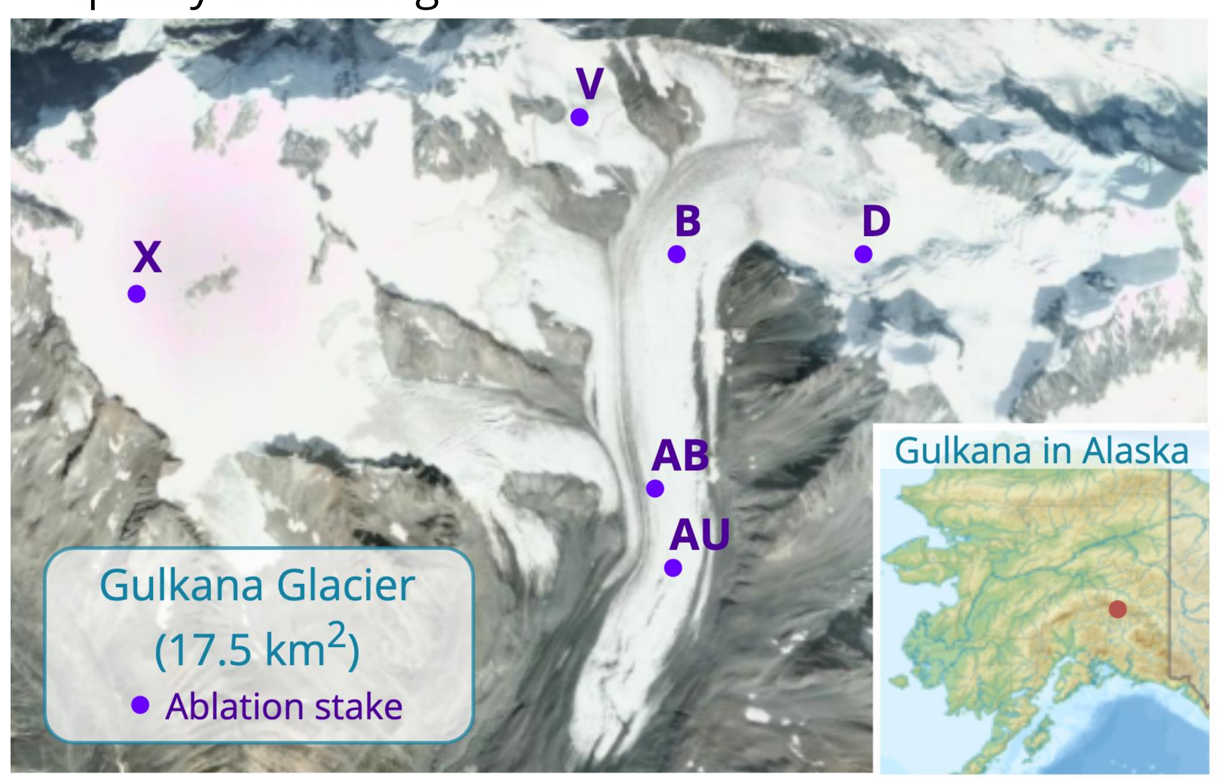
BACKGROUND AND OVERVIEW

Roughly 25% of global mountain glacier mass loss is from Alaska. Large-scale remote sensing offers unprecedented opportunity to monitor glaciers, but in-situ observations are critical to validate remote sensing data products.

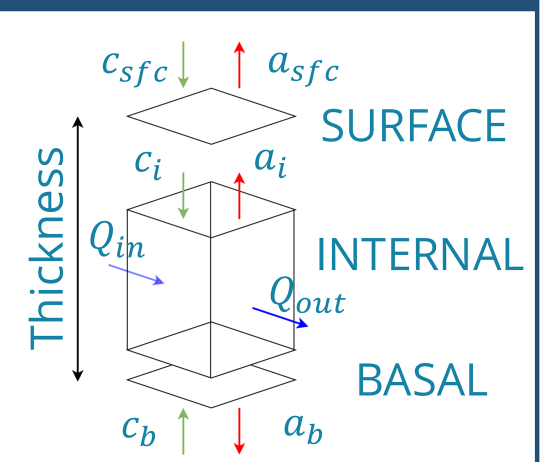
This study:

- utilizes remotely sensed and modeled surface velocity, ice thickness, and elevation change to **estimate the climatic mass balance gradient for Gulkana Glacier**
- evaluates the performance of different products compared to in-situ measurements
- begins to integrate modeled products to replace poor quality or missing data



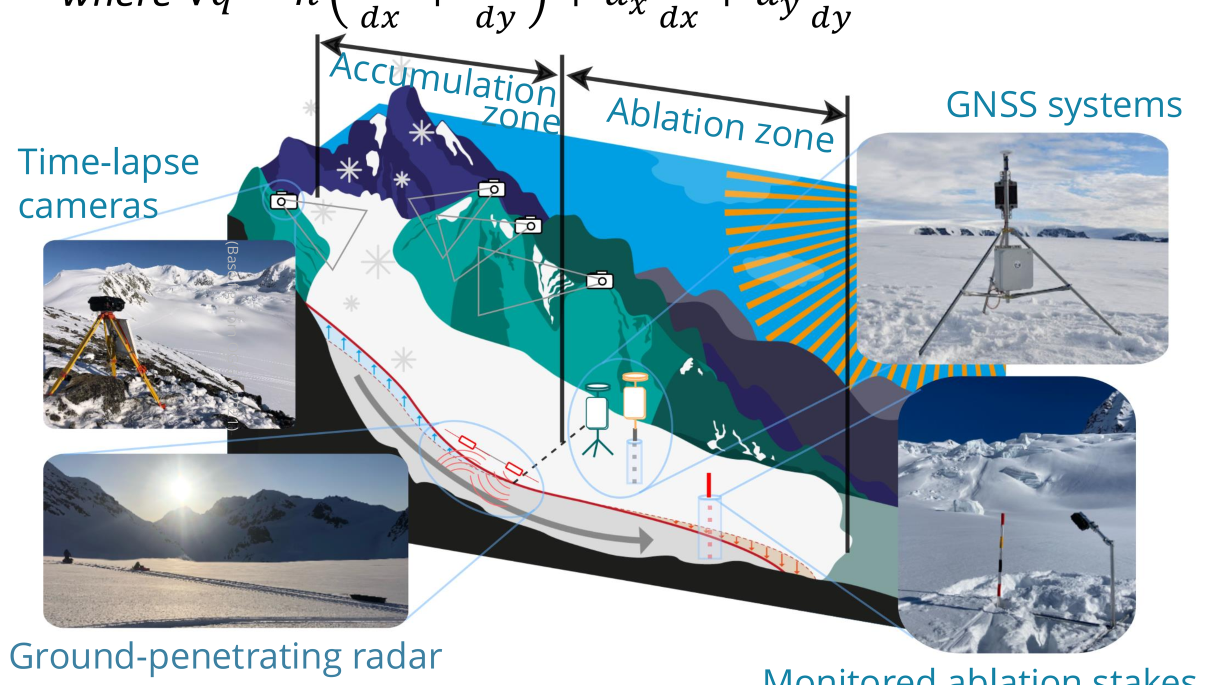
METHODS

- ***Total mass balance*** is surface elevation change, which is a combination of mass change from accumulation/ablation and ice flux.
- ***Climatic mass balance*** accounts for ice flux to reveal melt from surface processes



$$\dot{b}_{clim} = \dot{b}_{tot} + \nabla q$$

$$\text{where } \nabla q = h\left(\frac{du_x}{dx} + \frac{du_y}{dy}\right) + u_x\frac{dh}{dx} + u_y\frac{dh}{dy}$$

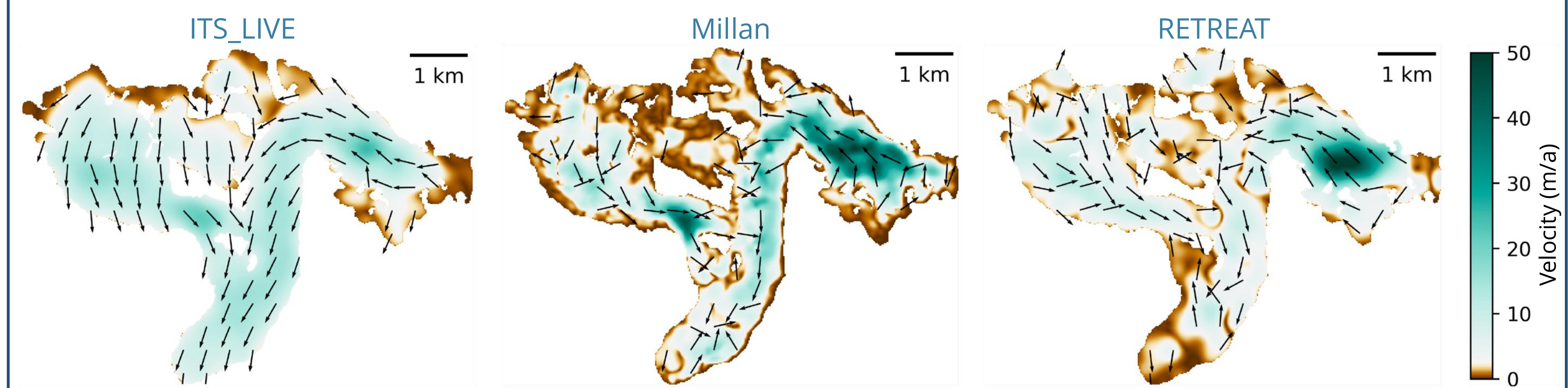


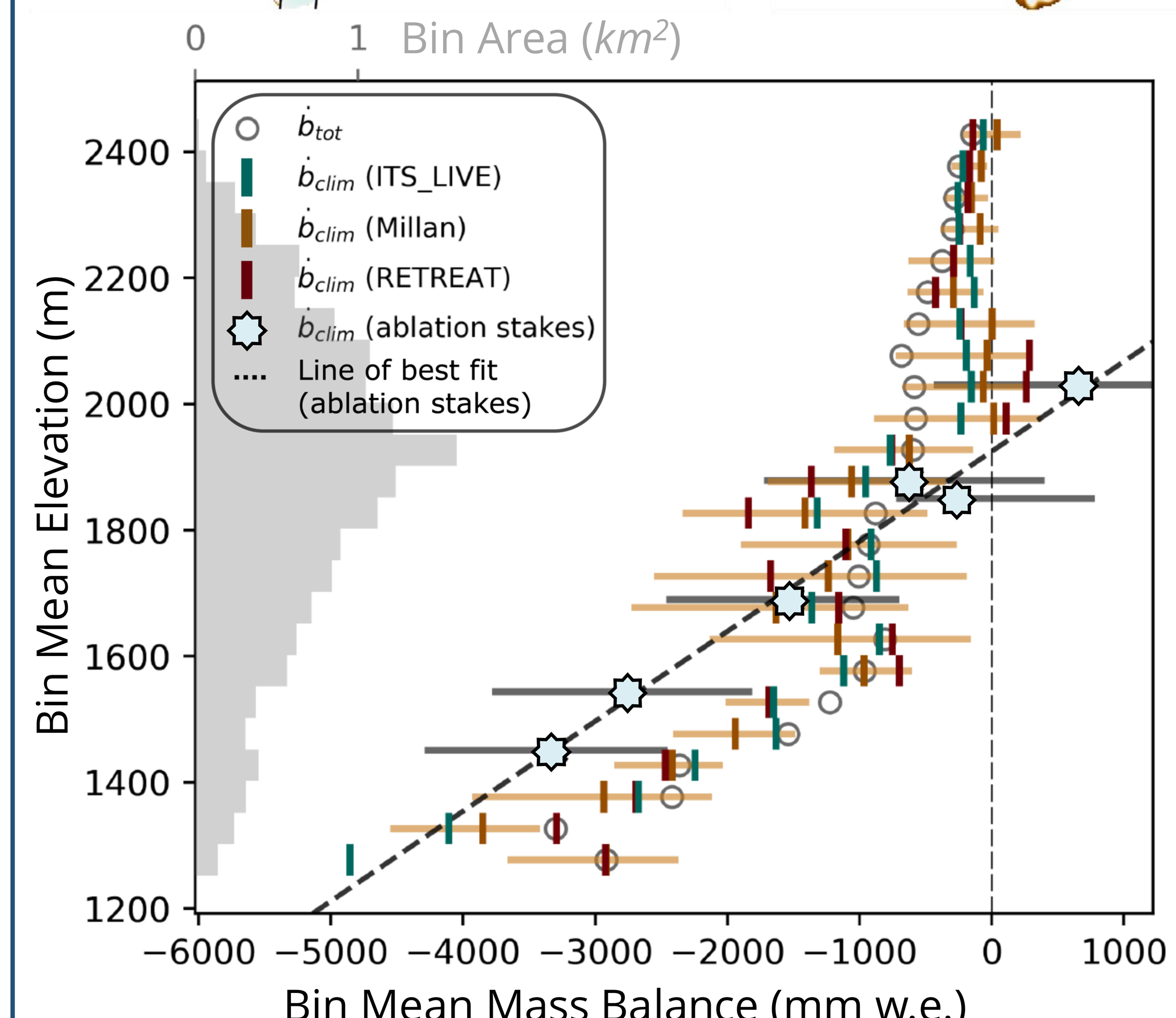
Datasets:

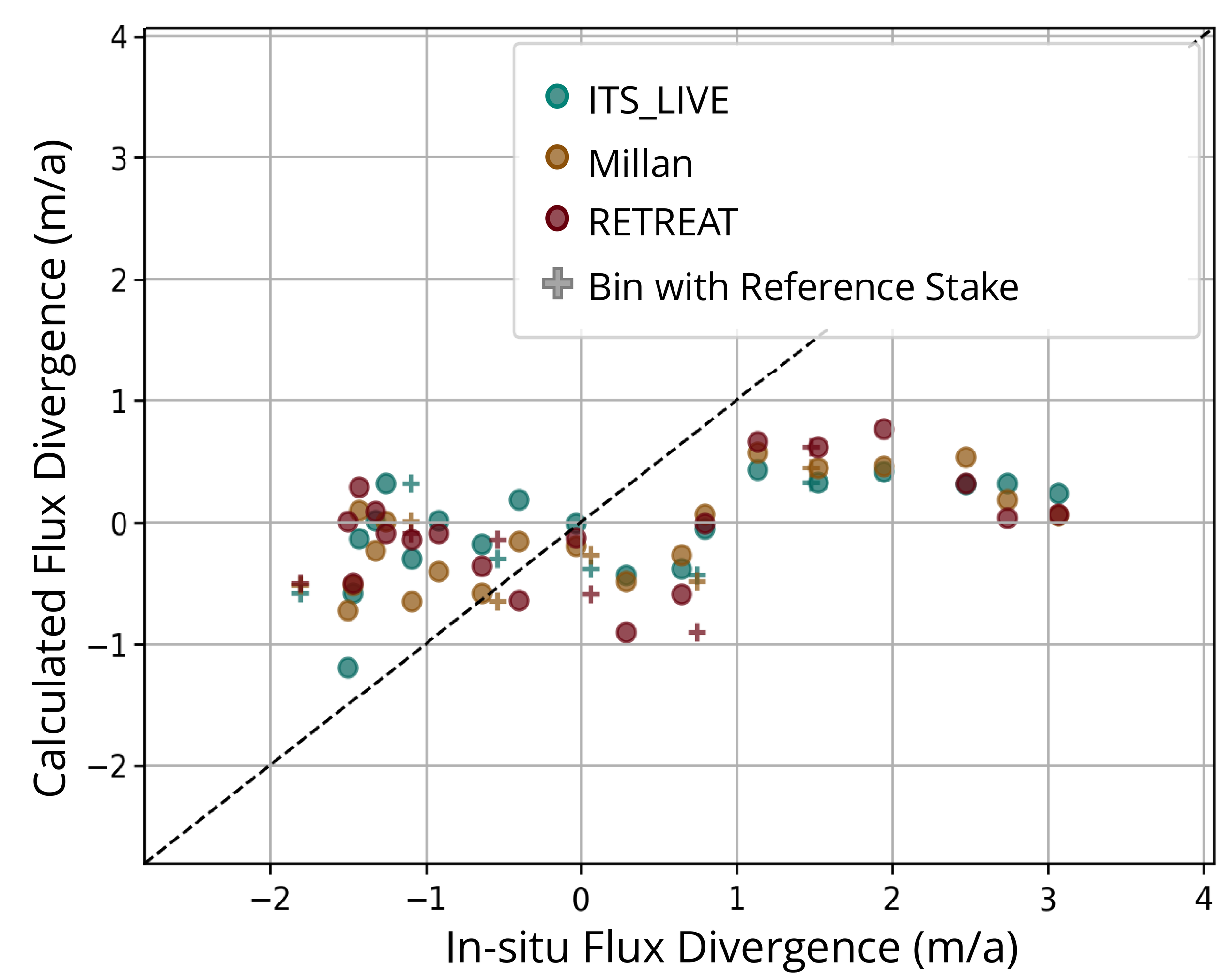
- Glacier inventory (RGI Consortium 2017)
- Elevation (Copernicus 2021, USGS 2019)
- Elevation change: 2015-2019 (Hugonnet et al. 2021)
- Surface velocity: 2017-2018 (Millan et al. 2022, MEaSUREs ITS_LIVE; NASA 2019, RETREAT 2021)
- Ice thickness (Millan et al. 2022, Farinotti et al. 2019)

REMOTE SENSING DATA

Three velocity products are used with the Millan ice thickness to estimate climatic mass balance

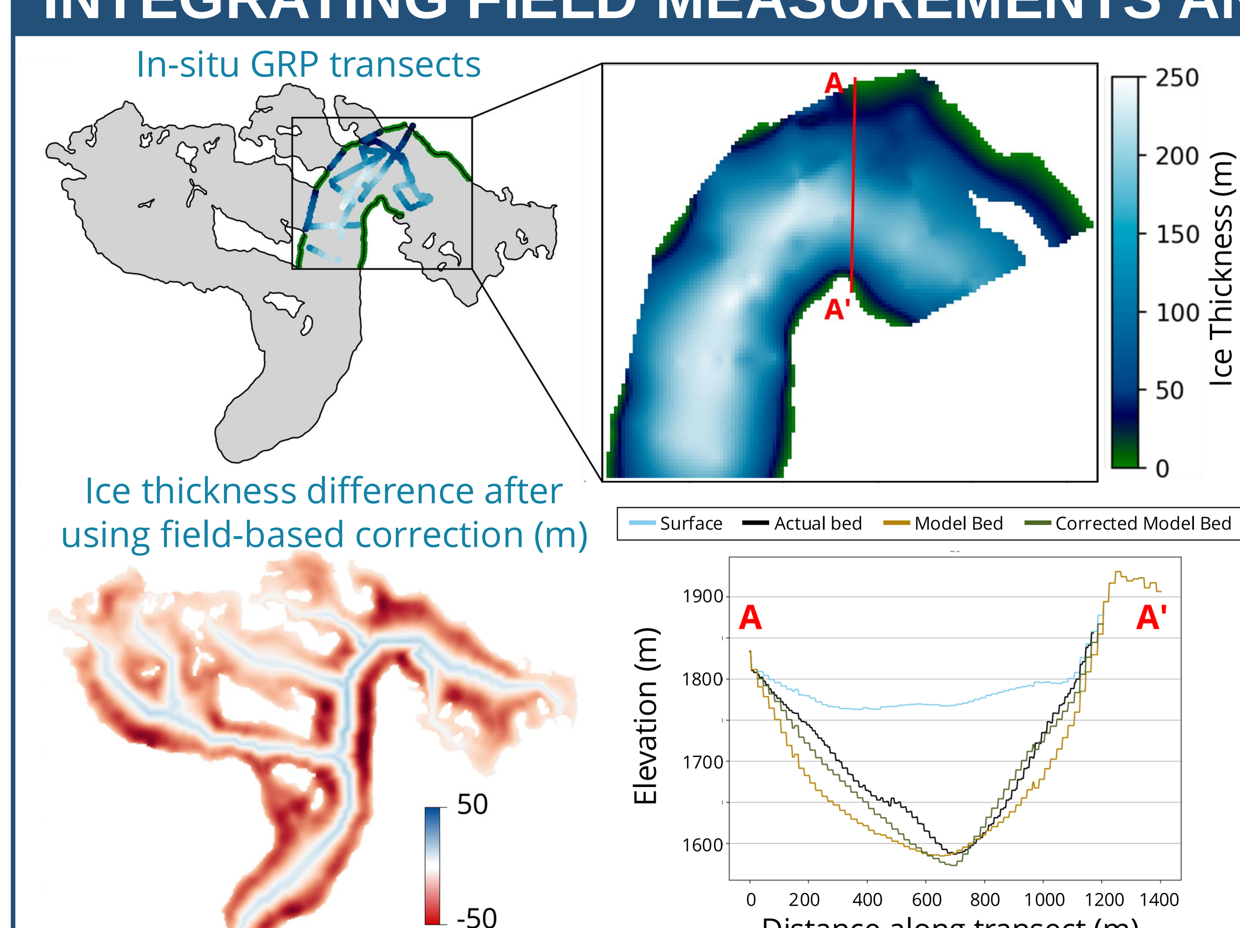






- **Surface velocity greatly impacts the flux divergence and thus the climatic mass balance**
- **However, no individual surface velocity products generate flux divergences and climatic mass balances consistent with field observations**

INTEGRATING FIELD MEASUREMENTS AND MODELS

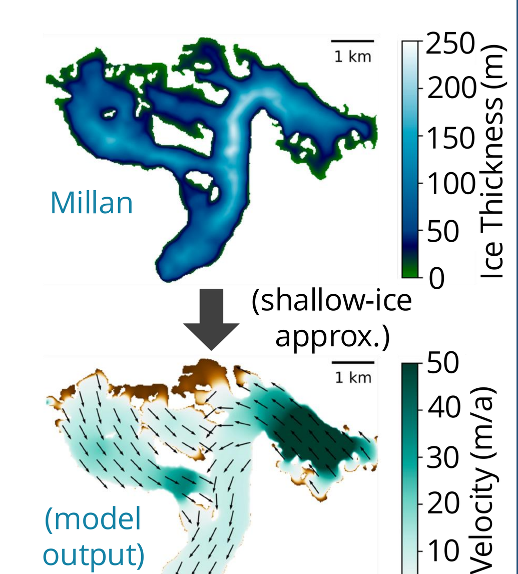


For Gulkana, ice thickness products…

- underestimate thickness along centerlines
- overestimate thickness at margins

Velocity at Ablation Stake Locations (m/a)

Data Source	AU	AB	B	D
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



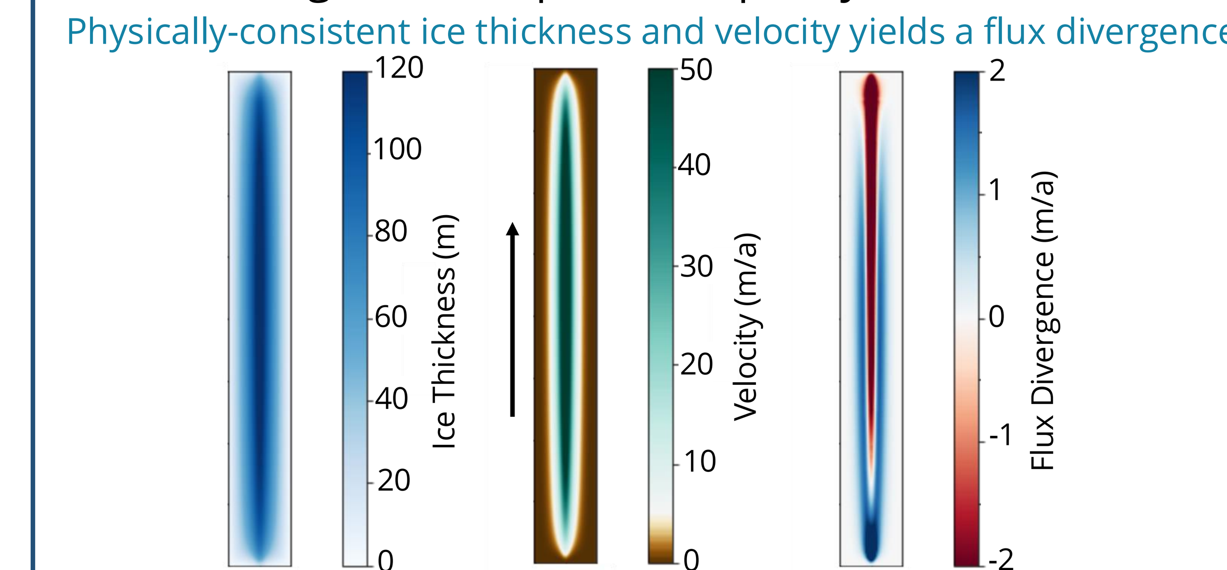
- Physical intuition and point velocities constrain realistic model outputs from Icepack (Shapero et al. 2021)
- Apply Bayesian inference for a **composite velocity**
  - use modeled velocity as prior estimate
  - use remote sensing velocities and their uncertainties as observations

Methods are still being developed; no composite exists yet

THEORETICAL FLUX DIVERGENCE

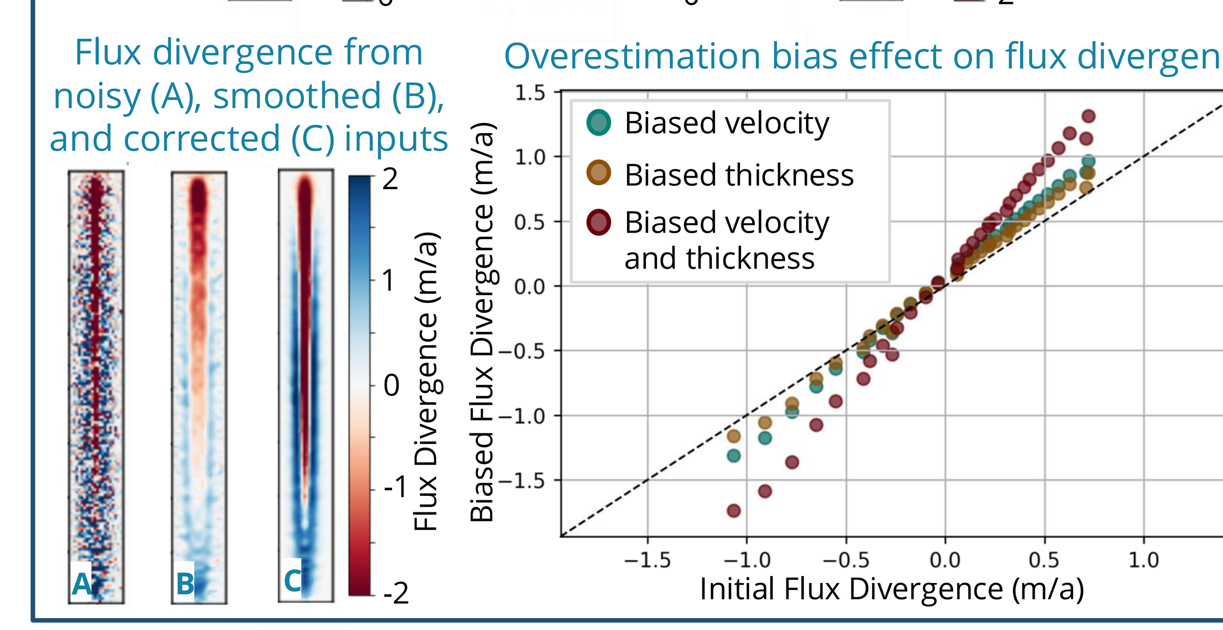
- A theoretical approach models the sensitivity of the flux divergence to input data quality and noise

Physically-consistent ice thickness and velocity yields a flux divergence



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

Overestimation bias effect on flux divergence



NEXT STEPS

- Increase complexity of theoretical approach to simulate more realistic glaciers
- Introduce higher-order model for velocity
- Investigate propagation of errors through ice thickness and velocity inversions
- Assess potential effects of glacier processes (avalanching, wind distribution, firn compaction) on stake observations
- Obtain more field data for ground-truth
- Climatic mass balance gradient for other Alaska glaciers

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