GNSS reflectometry from low-cost sensors for continuous in-situ glacier mass balance and flux divergence

Carnegie Mellon University
Civil & Environmental Engineering

Albin Wells[1], David Rounce[1], Louis Sass[2], Caitlyn Florentine[3], Adam Garbo[4], Christopher McNeil[2], Emily Baker[2]

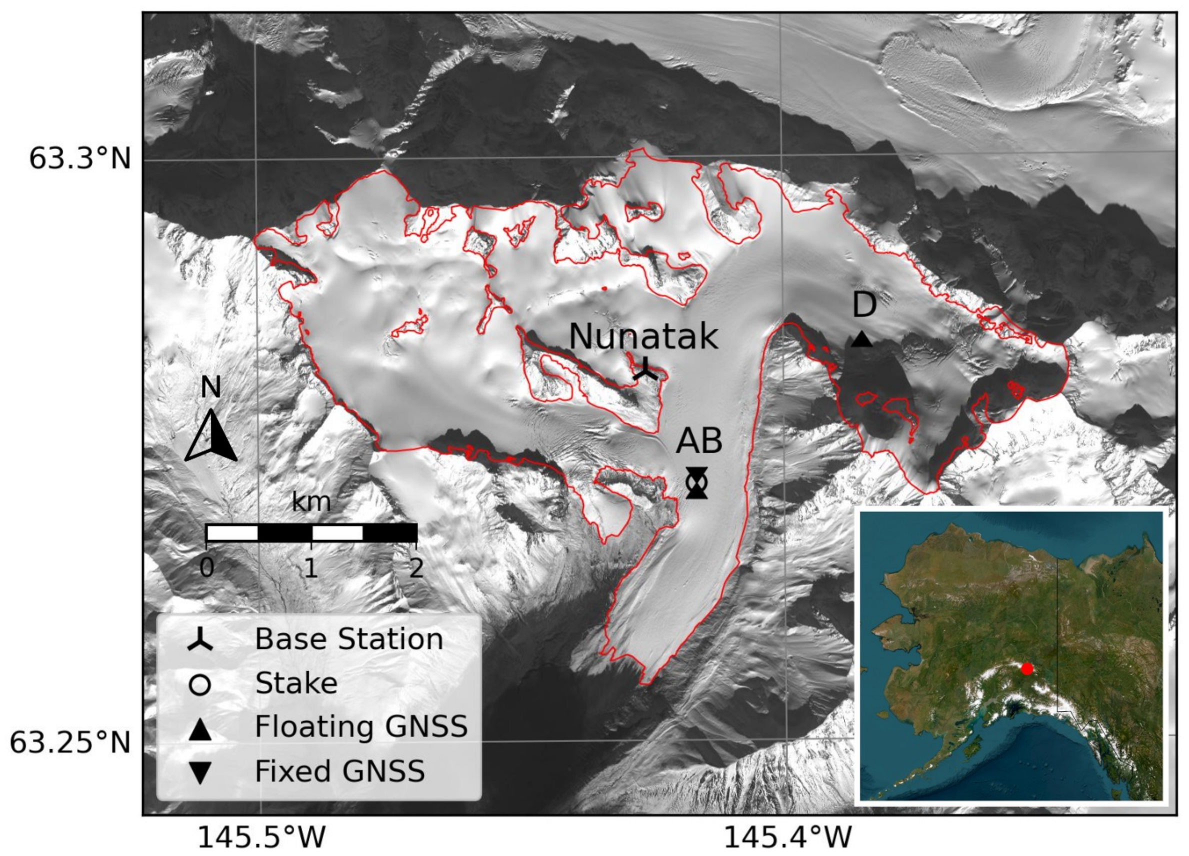
[1]Carnegie Mellon University, Civil and Environmental Engineering; [2]USGS Alaska Science Center; [3]USGS Northern Rocky Mountain Science Center, [4]Carleton University

BACKGROUND AND OVERVIEW

Remote sensing offers unprecedented opportunities to monitor glaciers globally. However, continuous in-situ data are critical validation for parsing total elevation change contributions from climate and glacier dynamics.

This study:

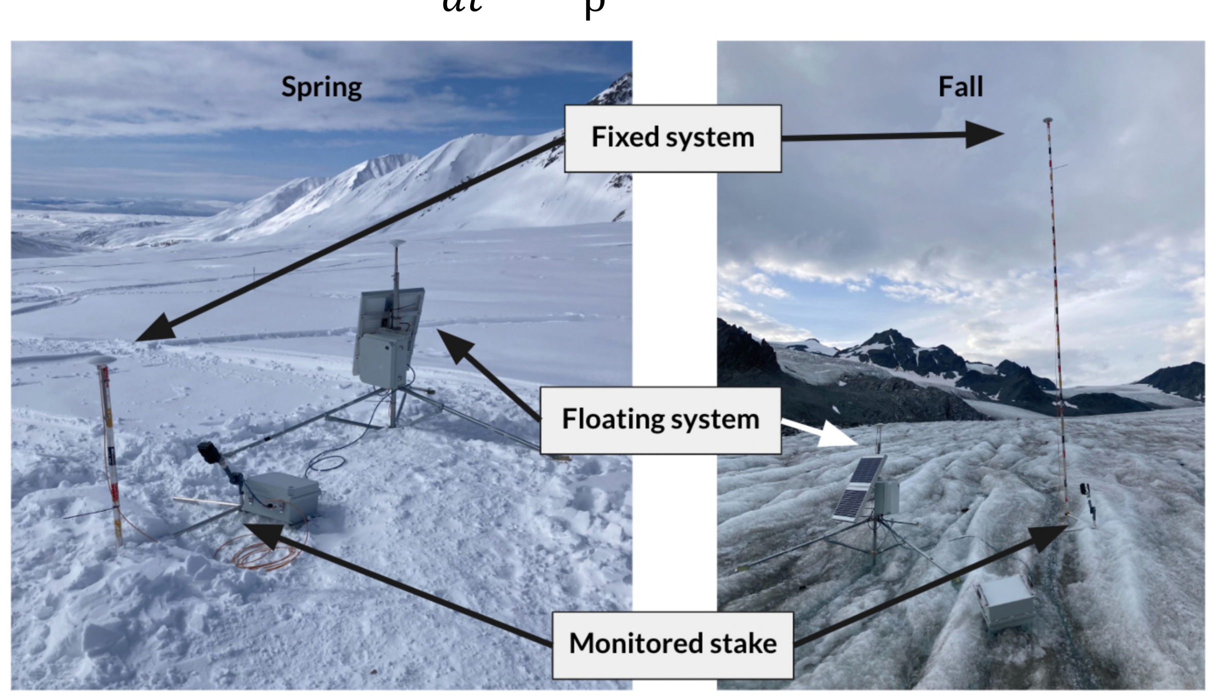
- utilizes low-cost, open-source GNSS systems for contemporaneous **daily climatic mass balance and sub-seasonal flux divergence for Gulkana Glacier**
- demonstrates the first usage of GNSS reflectometry (GNSS-IR) on a mountain glacier

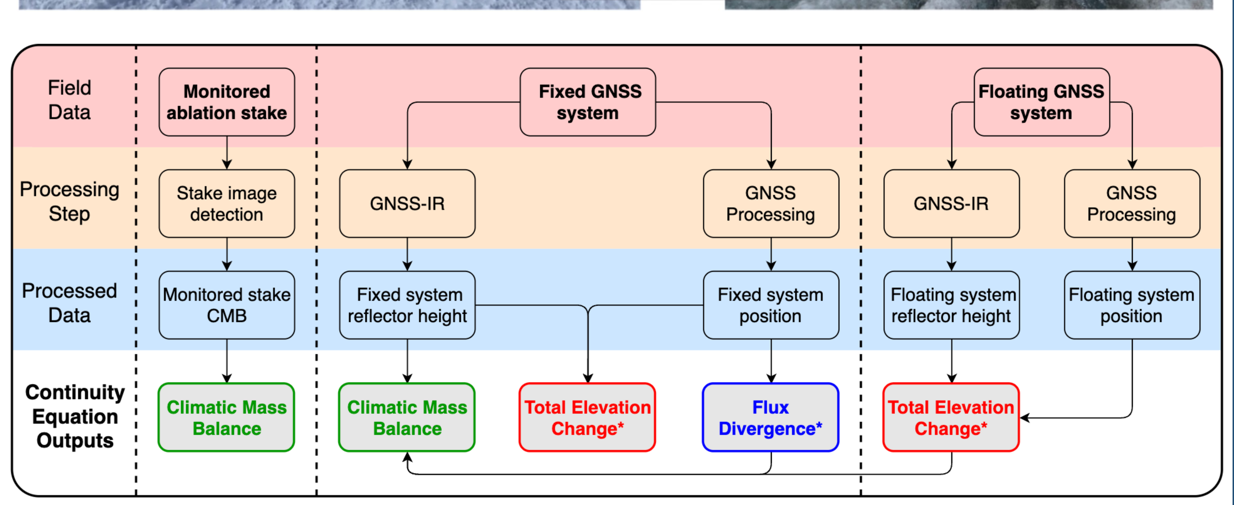


METHODS

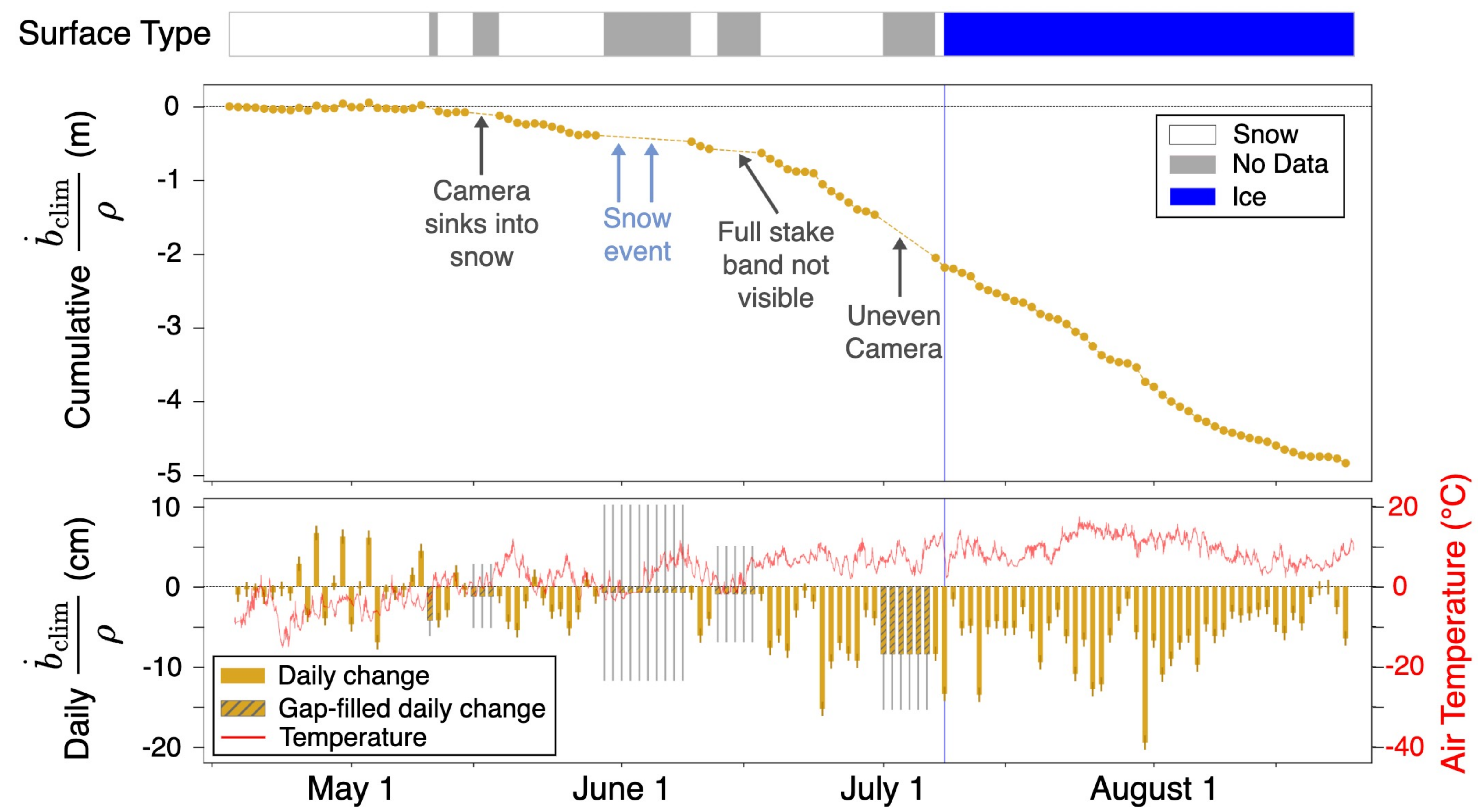
- ***Total elevation change*** is the change in glacier thickness, which is a combination climatic mass balance and glacier dynamics (i.e. ***flux divergence***)
- ***Climatic mass balance*** is the sum of accumulation and ablation on a glacier

$$\frac{dh}{dt} = \frac{\dot{b}_{clim}}{\rho} - \nabla \cdot q$$



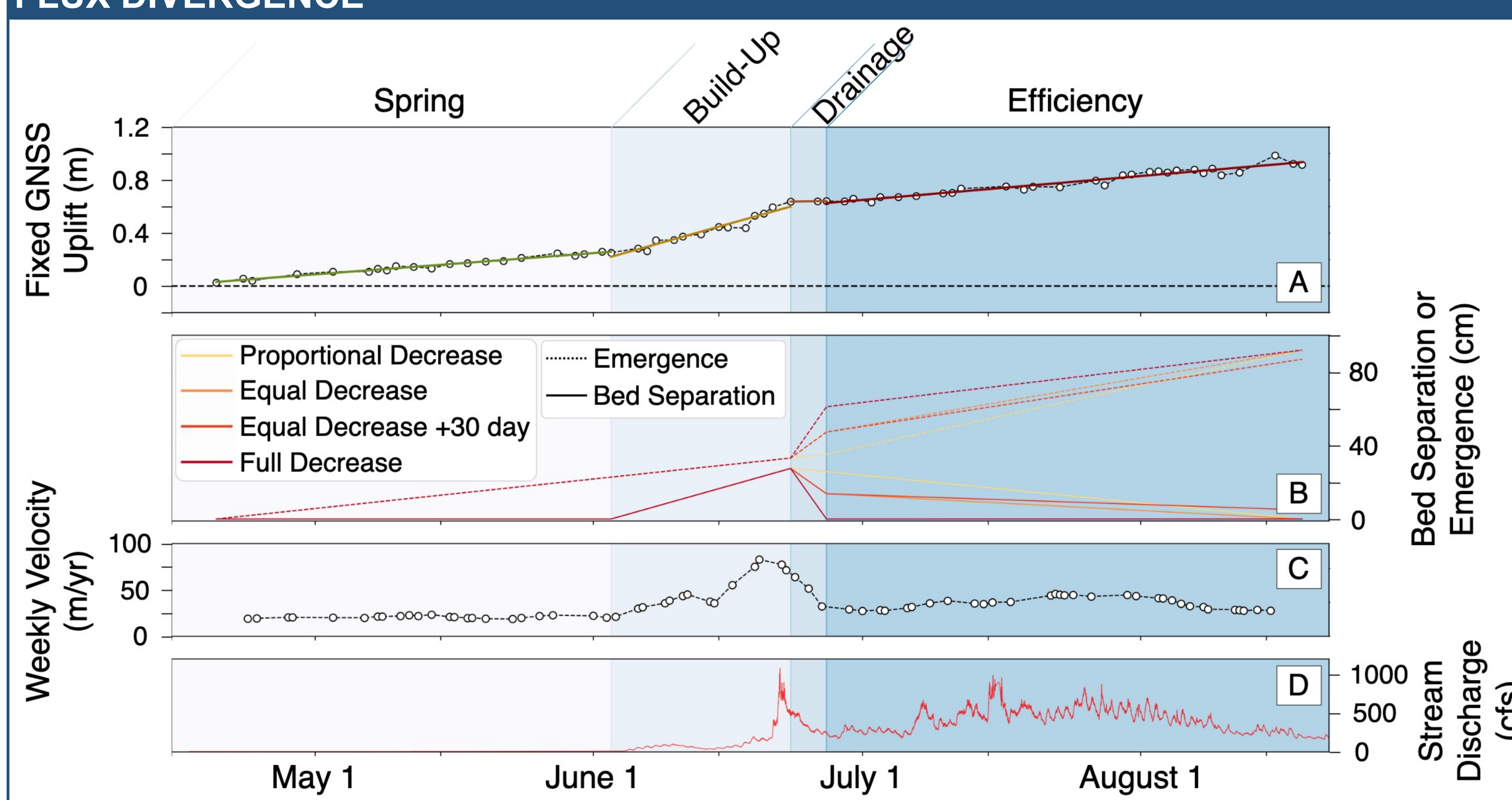


CLIMATIC MASS BALANCE



Monitored stake enables continuous mass balance measurements with cm-level accuracy

FLUX DIVERGENCE



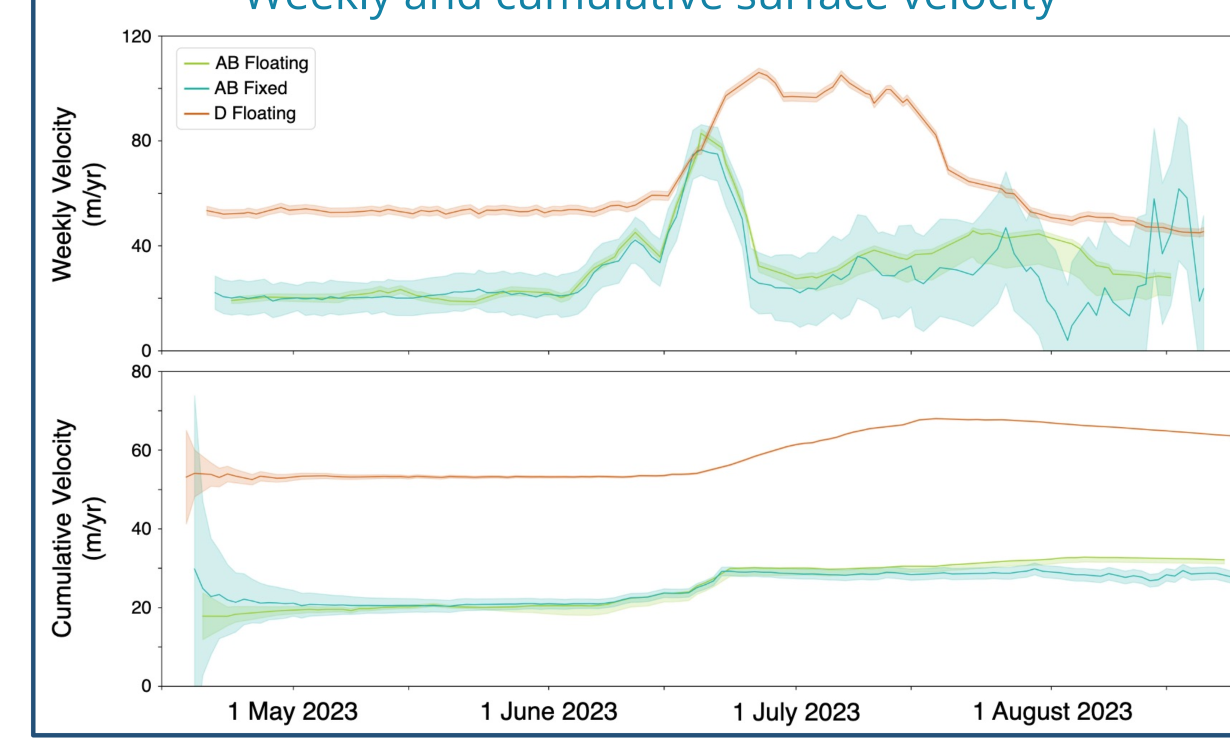
Sub-seasonal change in flux divergence reflects velocity increase

- Ice-bed separation major cause of fixed GNSS elevation change during basal meltwater build-up and drainage

VELOCITY

- **Velocity fluctuations mimic basal hydrology**
  - Fall (rise) in effective pressure from water build-up (release) dictate velocity increase (decrease)
  - Distributed, disconnected accumulation area drainage network show prolonged speed-up
- Sub-seasonal increase in velocity of 70% at site AB
  - 20.8 m/yr before June 3, 35.4 m/yr after June 26

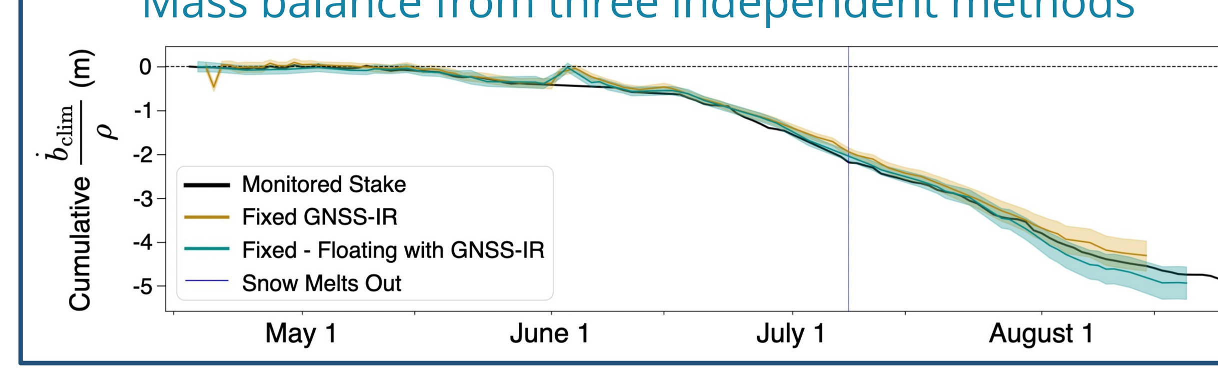
Weekly and cumulative surface velocity



METHOD COMPARISON

- **GNSS-IR captures summer snow**
  - Potential for accumulation season studies
- GNSS signal reflectors provide spatially distributed climatic mass balance
- GNSS-IR limitations on late-summer (heterogeneous) surface

Mass balance from three independent methods



CONCLUSIONS AND NEXT STEPS

- Huge potential for open-source low-cost GNSS systems in high temporal resolution glacier monitoring
- GNSS-IR capability on mountain glacier
- **Fixed GNSS system yields climatic mass balance, flux divergence, and surface elevation change**
- Obtain more field data: deploy five fixed GNSS systems along glacier centerline & study accumulation season
- Estimate strain rates from sequential GNSS systems

REFERENCES

Garbo & Mueller (2024) *Sens* • USGS Benchmark Glacier Program (2023) • Roesler & Larson (2018) *GPS Sols* • Cogley et al. (2010) *Int Hydrol Prog* • USGS Water Resources (2024) • NRCan (2017)

Correspondence to: awwells@cmu.edu