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Leveraging Field and Remote Sensing Data for Enhanced Understanding of Glacier Response to the Climate

NORTHWEST GLACIOLOGISTS

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Background and Significance

- Glacier in Alaska constitute >25% of all mountain glacier contributions to sea-level rise; this has widespread implications
- Understanding how glaciers are responding to climate forcing is critical to reducing uncertainties in global models and long-term projections
- Yet, our ability to resolve the *climatic mass balance* is encumbered by a lack of in-situ observations and limitations associated with remote sensing data

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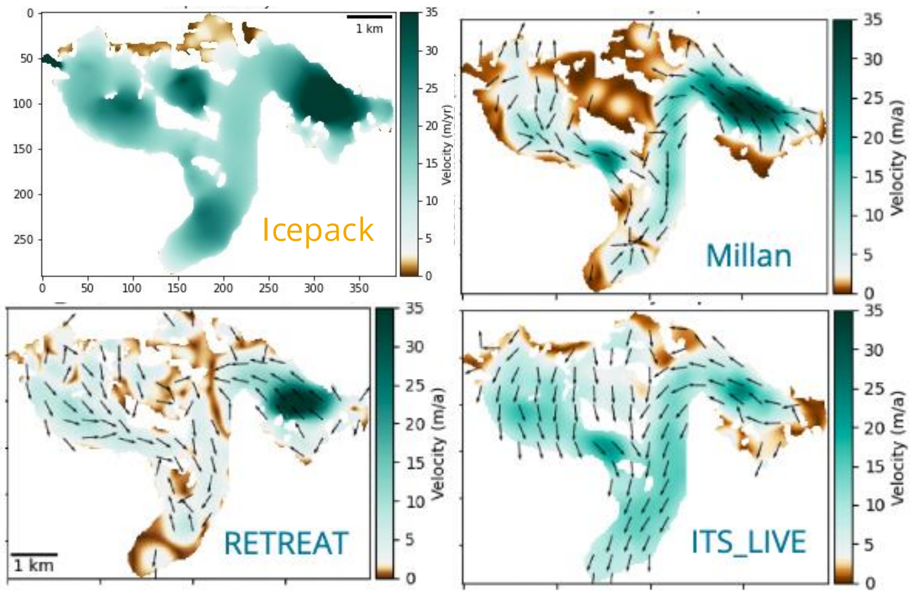
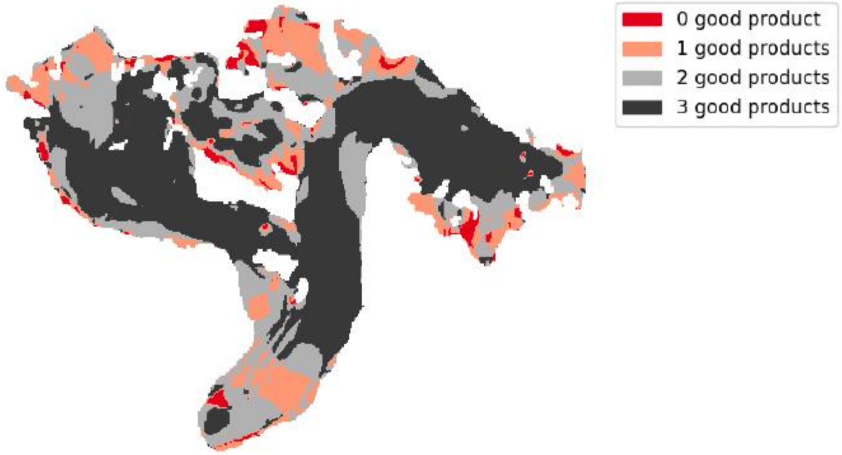
Background and Significance

Gulkana Glacier Ice thickness and Velocity from various large-scale datasets

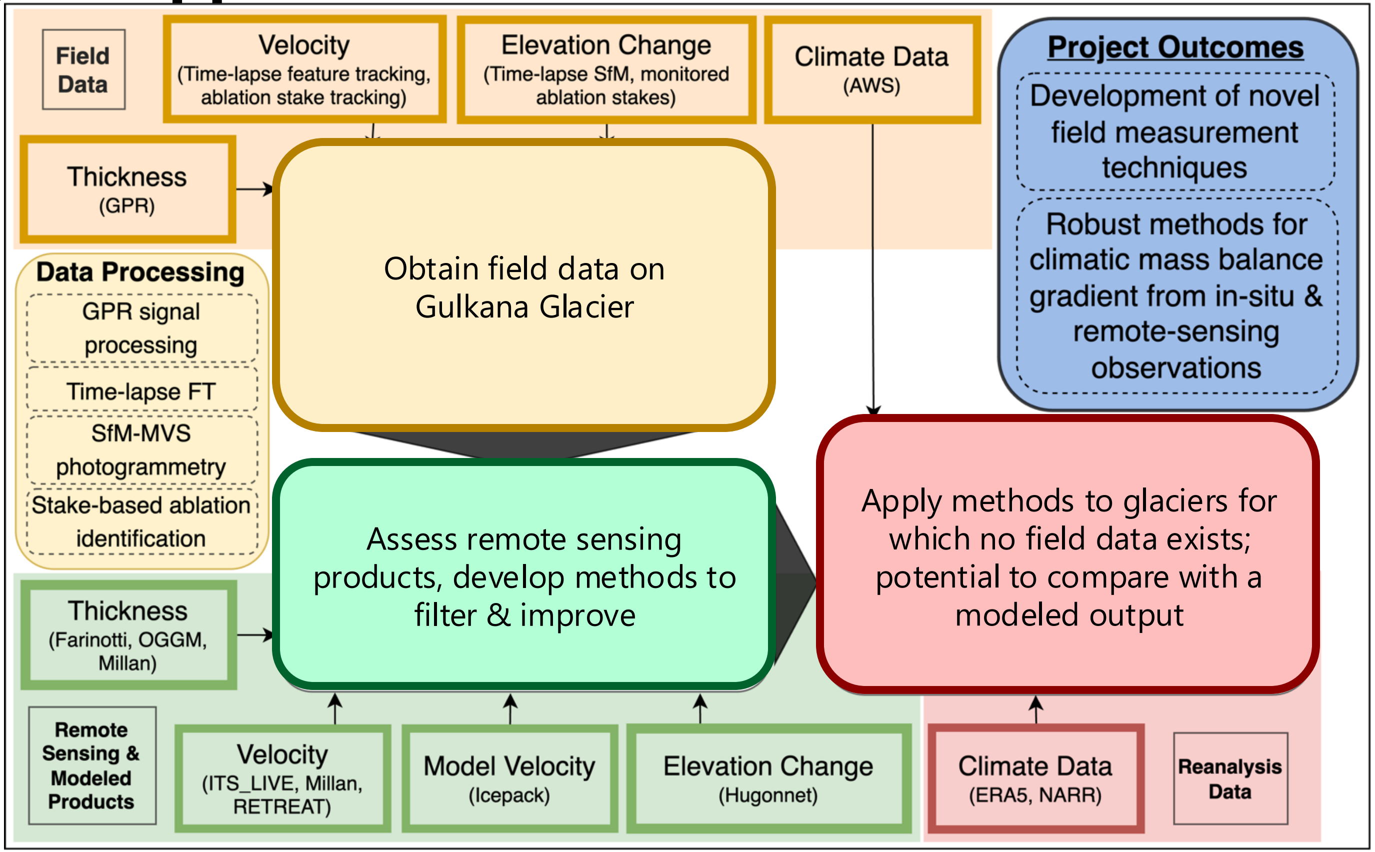


Number of velocity products that are consistent with terrain aspect



Modeled velocity using *Icepack* and solving the Shallow-Ice Approximation yields quite different results too!

Project Approach



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Methods: The Continuity Equation

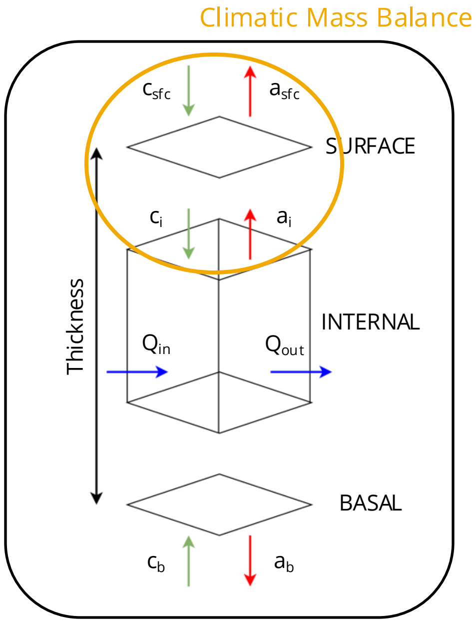
Total Mass Balance: $\dot{b}_{\text{tot}} = \frac{dh}{dt}$

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

where: $\nabla q = h \cdot \left(\frac{du_x}{dx} + \frac{du_y}{dy} \right)$

and u_x, u_y are column-avg velocities,

$$\dot{b}_{\text{clim}} = \frac{\dot{c}_{\text{sfc}} + \dot{a}_{\text{sfc}} + \dot{c}_i + \dot{a}_i}{\rho}$$

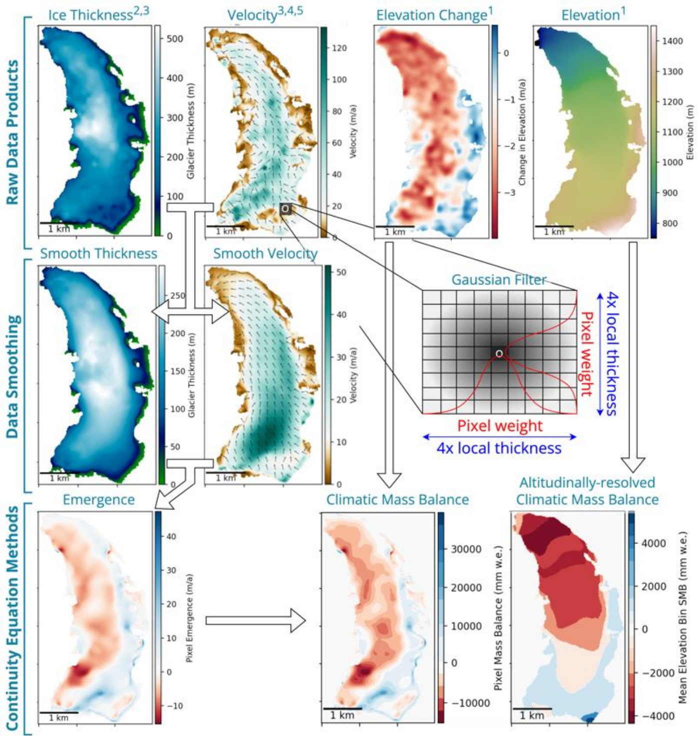


Calculating the climatic mass balance relies on 3 primary data inputs:

- Elevation change
- Ice thickness
- Velocity

DEMs are needed to altitudinally-resolve (bin) the climatic mass balance. Repeat DEMs can also be used to obtain the elevation change signal

Example Remote Sensing Processing Workflow



- Reproject, resample, and clip data based on glacier outline
- Smooth velocity and ice thickness products with a moving-window Gaussian filter with window size based on local pixel ice thickness
- Apply the continuity equations
- Altitudinally-resolve into elevation bins

Remote sensing datasets are from:

1. Hugonnet et al. (2021)
2. Farinotti et al. (2019)
3. Millan et al. (2022)
4. Gardner et al. (2019)
5. Friedl et al. (2021)

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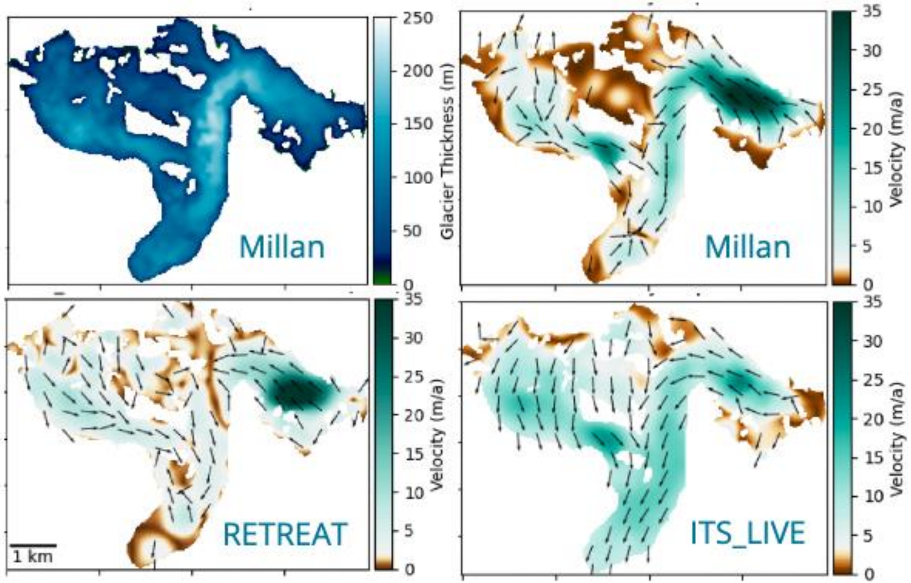
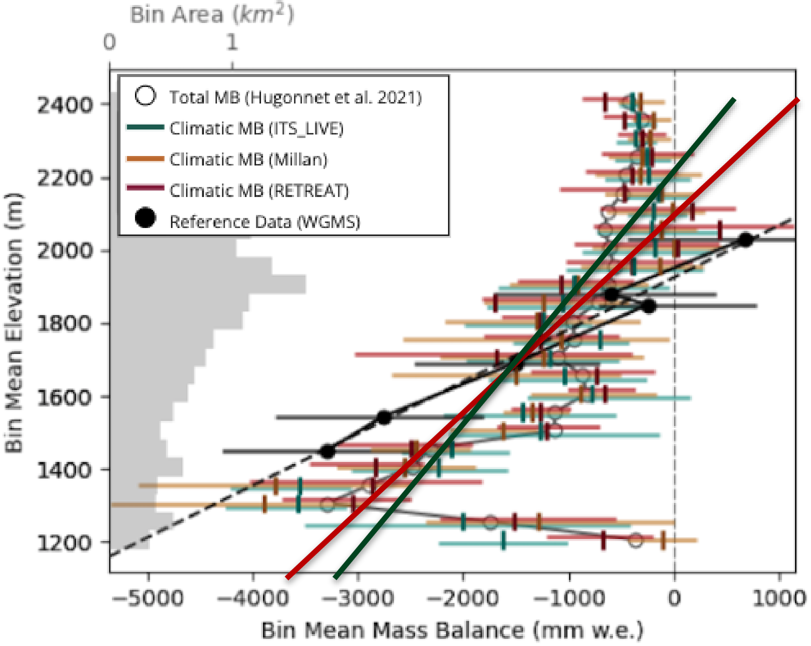
Remote Sensing Datasets on Gulkana

Gulkana Glacier Ice thickness and Velocity from various large-scale datasets



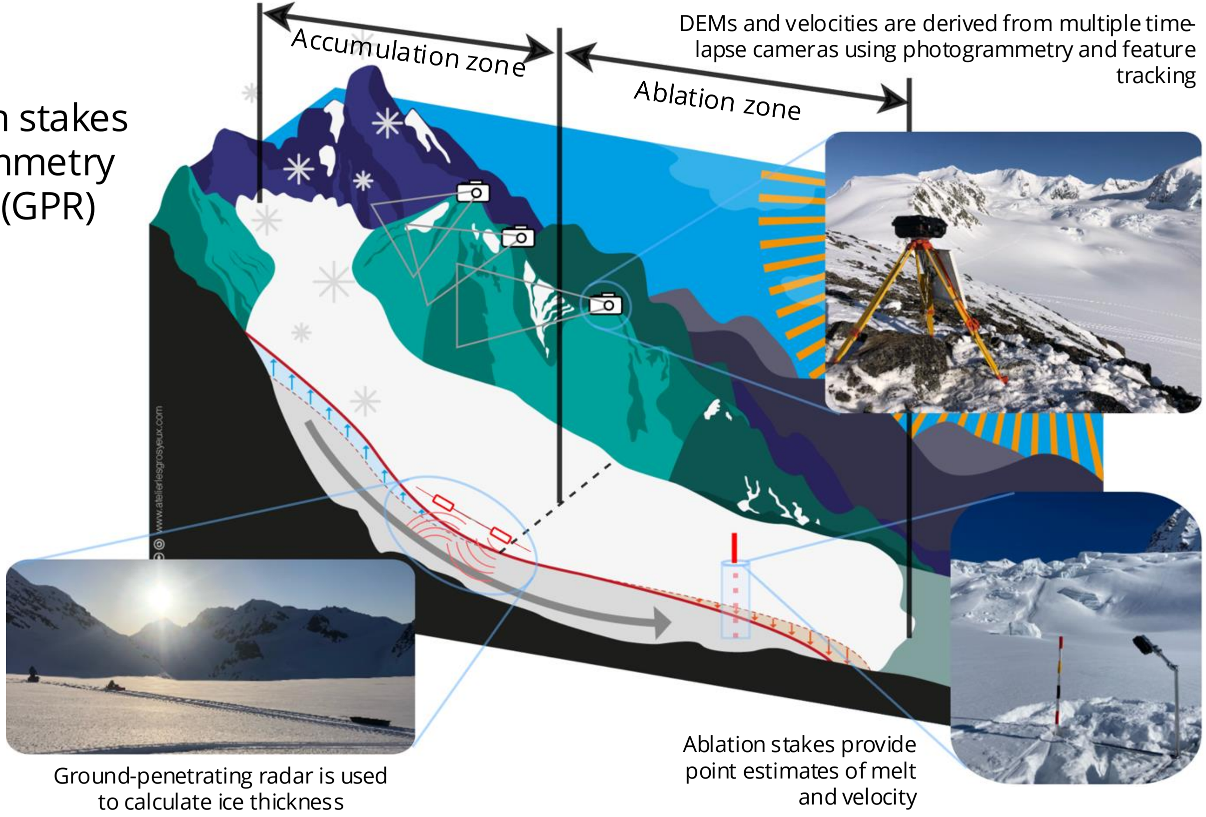
Total and Climatic Mass Balance of Gulkana using different velocity products



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

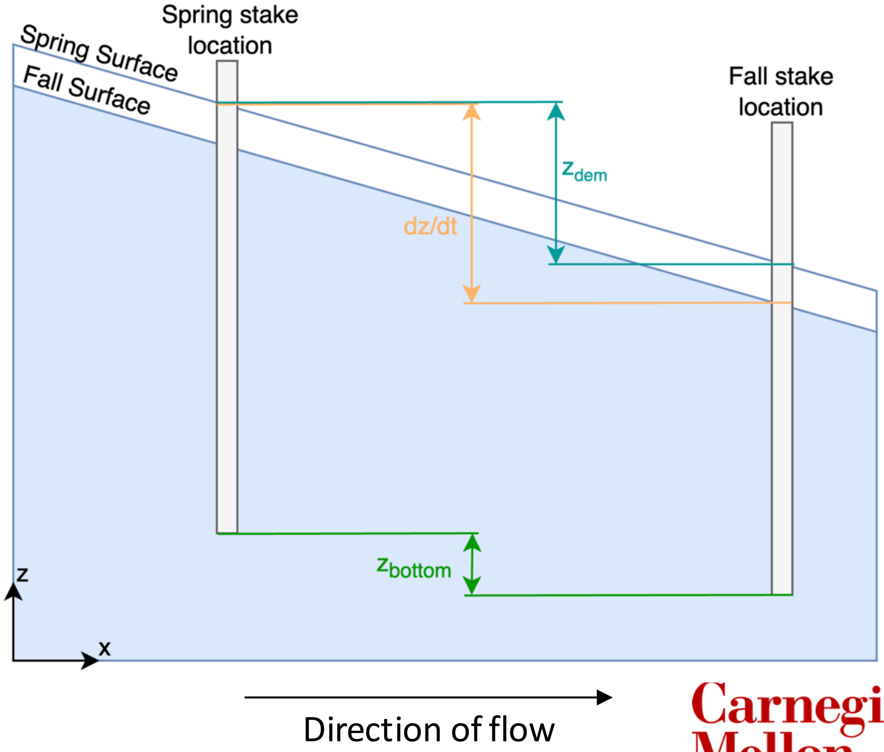
Field Data Measurements

- Monitored banded ablation stakes
- Time-lapse MVS photogrammetry
- Ground-Penetrating Radar (GPR)



Monitored Ablation Stakes

- $Emergence = z_{bottom} - z_{dem}$
- $\dot{b}_{clim} = \frac{dz}{dt} + \frac{emergence}{dt}$
- Climatic mass balance is also observed directly from stake measurements



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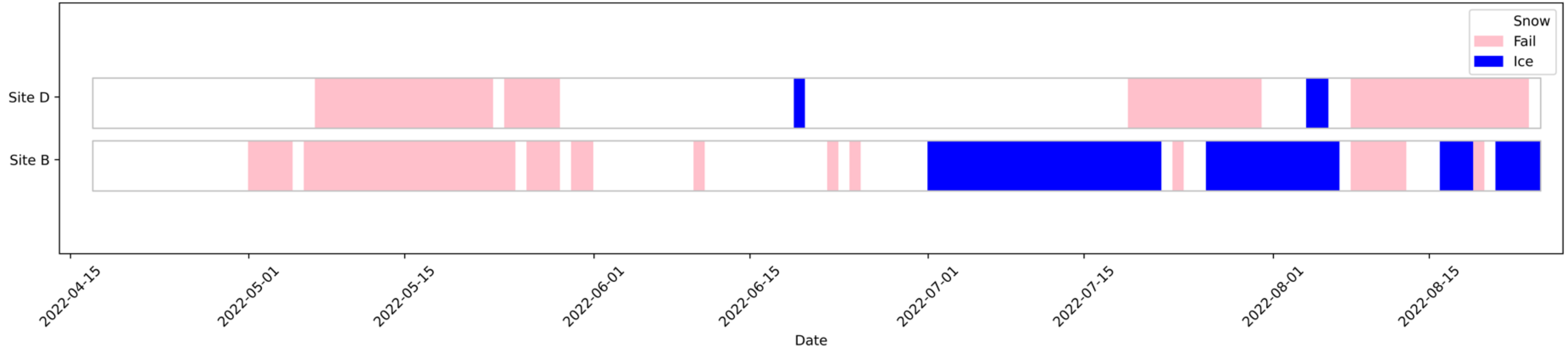
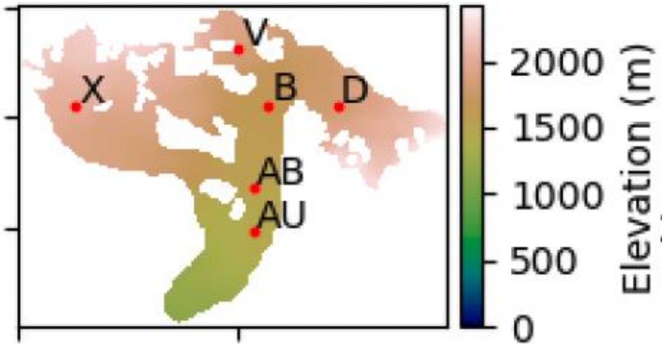
Monitored Ablation Stake Results

Gulkana Stake Data Time Series: Glacier Surface Type



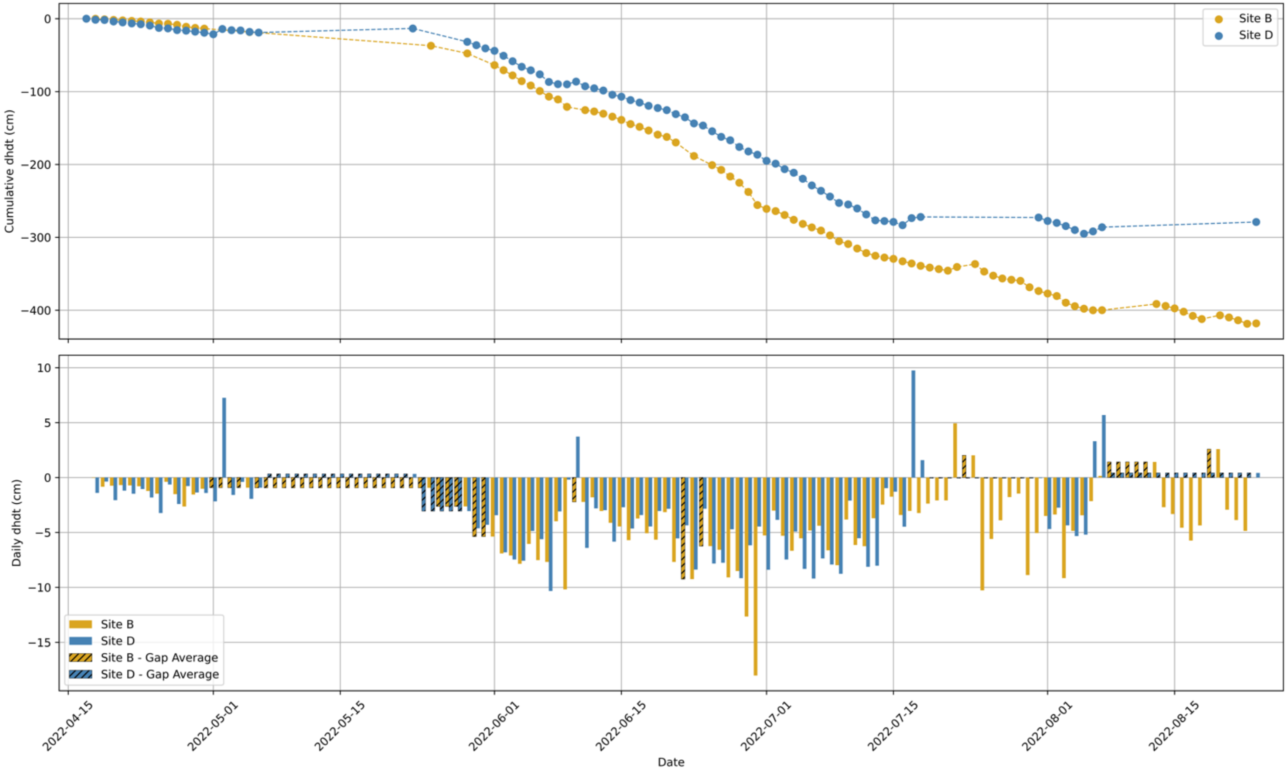
USGS Ablation Stake Sites



Daily time-lapse at Site B

Monitored Ablation Stake Results

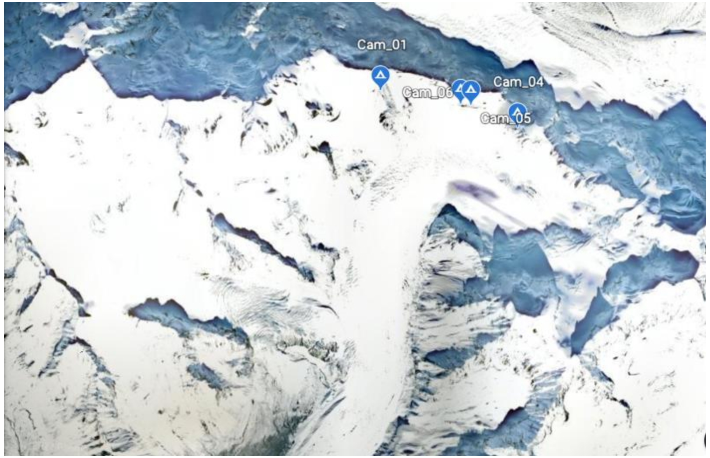
Gulkana Stake Cumulative and Daily Elevation Change



- Climatic mass balance:
  - -4.18 m at site B
  - -2.79 m at site D
- Change in sfc elevation:
  - -5.70 m at site B
  - -5.78 m at site D
- Change in elevation at the bottom of the stake:
  - -1.86 m at site B
  - -2.82 m at site D
- Change in elevation due to glacier slope:
  - -1.77 m at site B
  - -2.31 m at site D
- Emergence velocity:
  - -0.25 m/yr at site B
  - -1.45 m/yr at site D

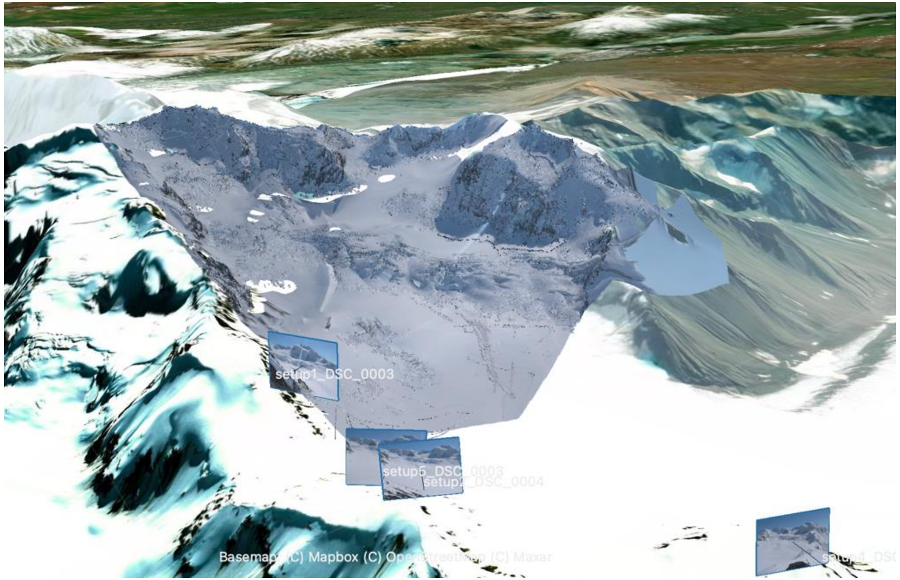
Time-lapse Cameras

- Four cameras placed on moraines, pointed towards the accumulation area in the main branch of the glacier
- Each camera takes 3 pictures per day at the exact same time, such that features have identical lighting for a set of images

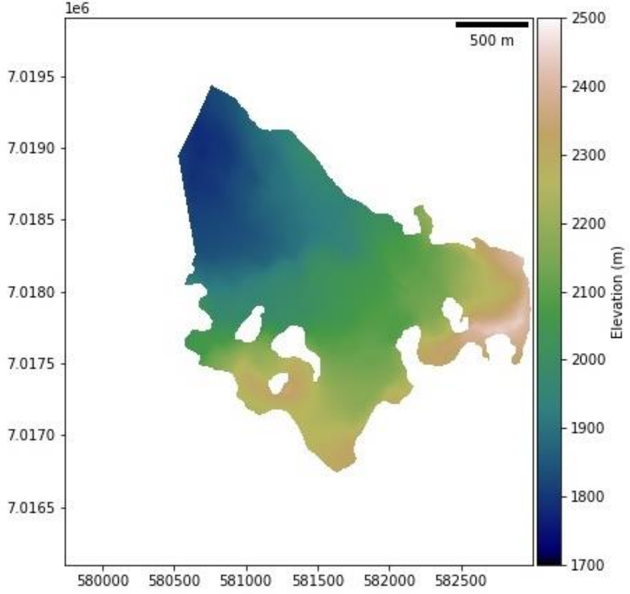


Time-lapse Camera Results

Photogrammetric output for April 2022 DEM

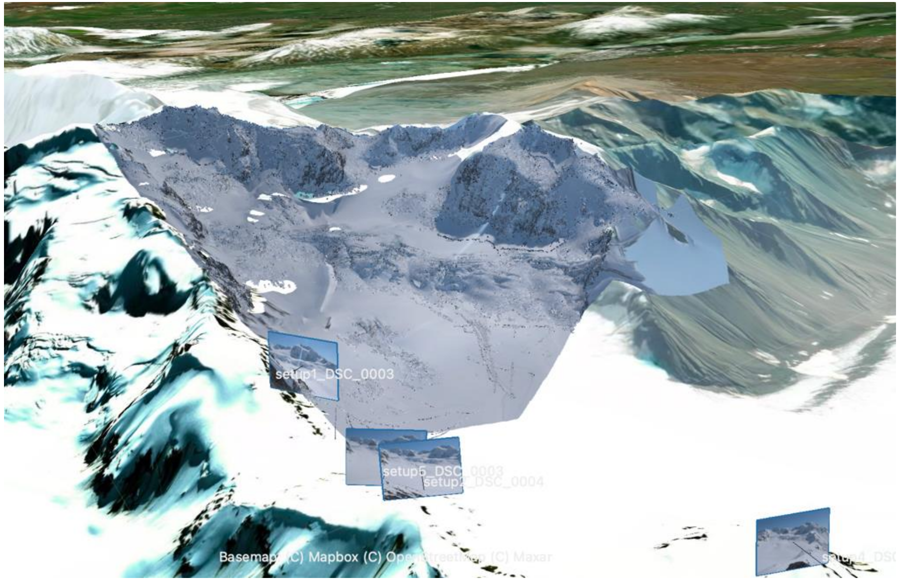


April DEM from time-lapse cameras

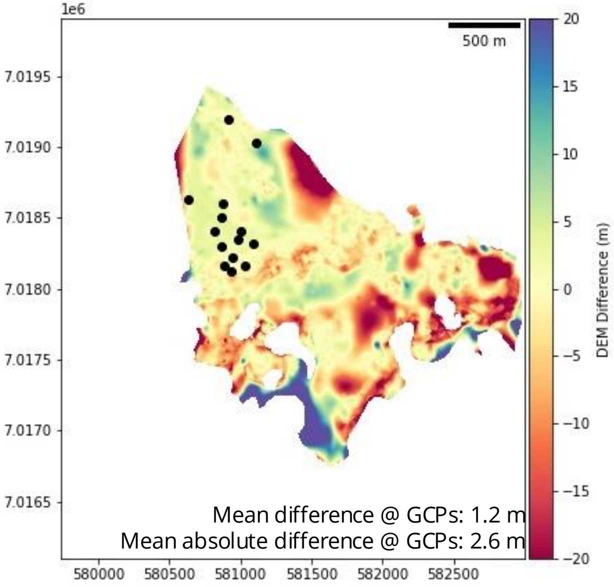


Time-lapse Camera Results

Photogrammetric output for April 2022 DEM



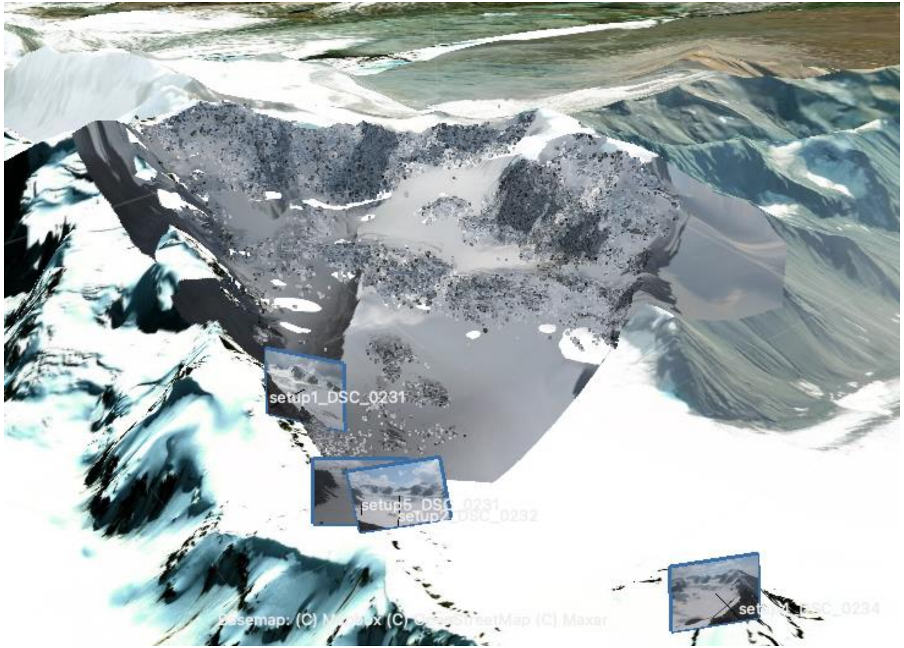
Difference between USGS 2m DEM (2021) and our April DEM (2022)



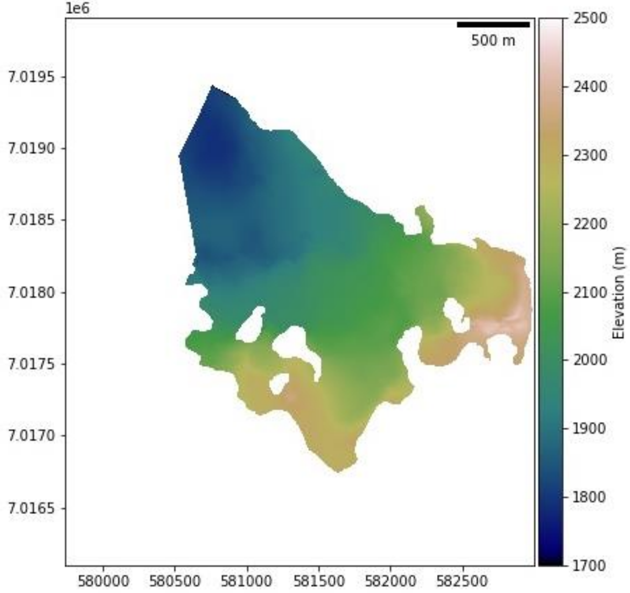
- Mean difference of -2.2 m
- Mean absolute difference of 9.2 m

Time-lapse Camera Results

Photogrammetric output for July 2022 DEM

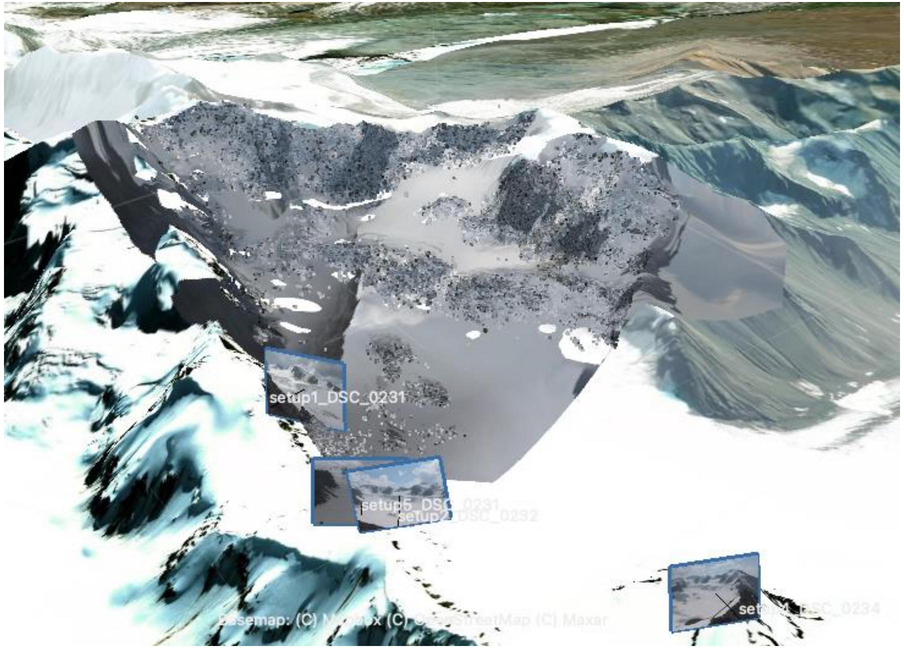


July DEM from time-lapse cameras

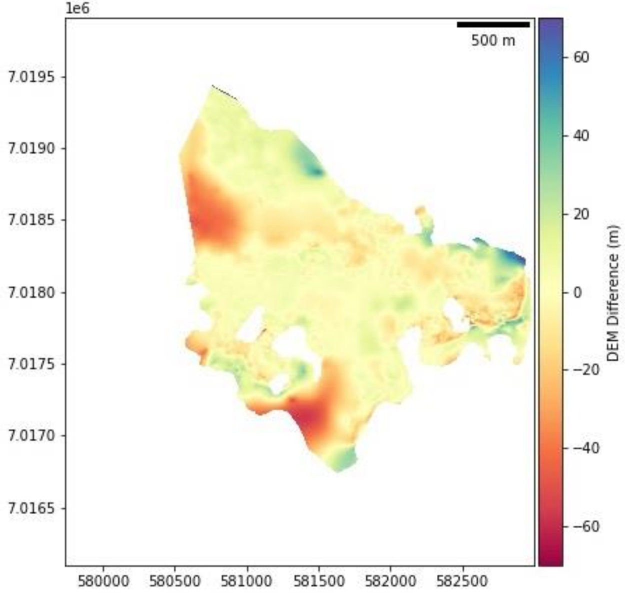


Time-lapse Camera Results

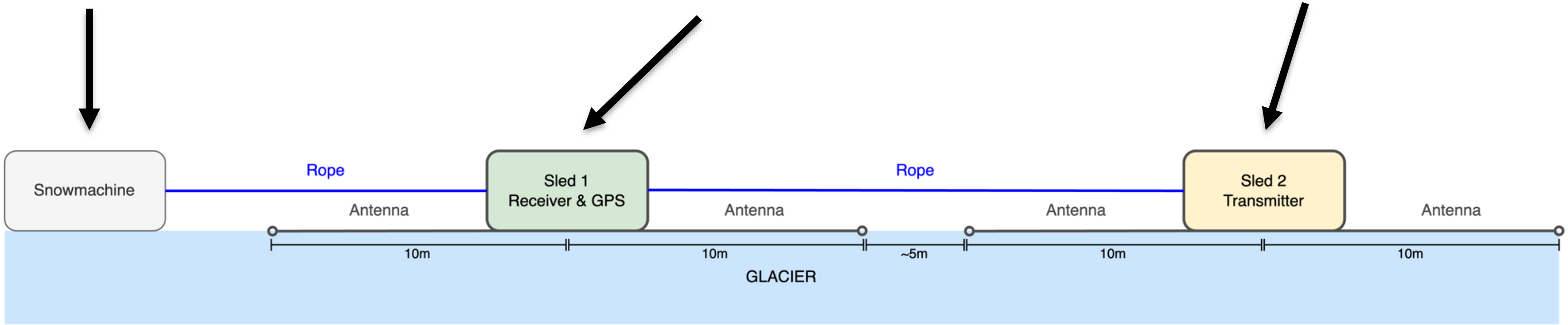
Photogrammetric output for July 2022 DEM



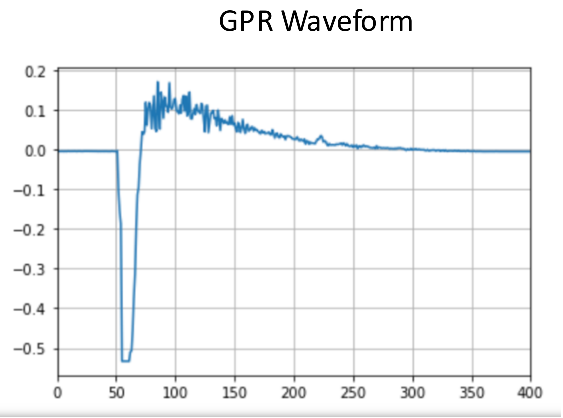
Difference between April and July DEMs



Ground-Penetrating Radar

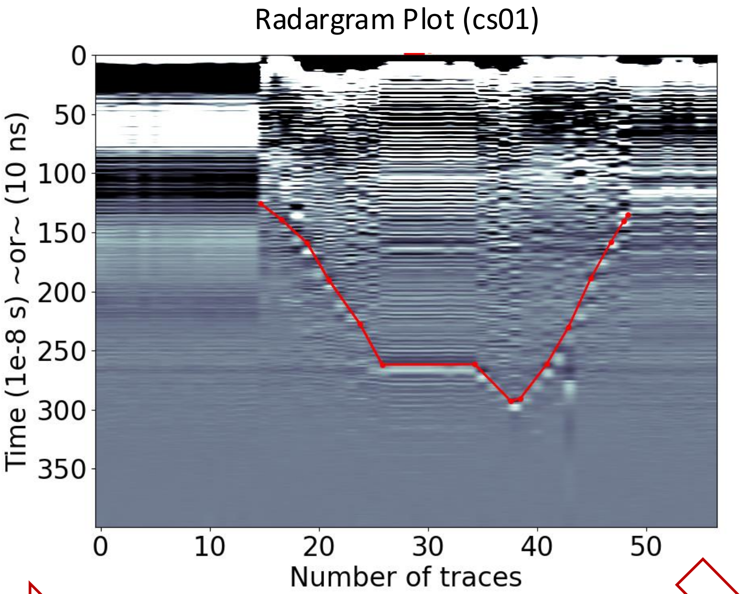


Ground-Penetrating Radar Data: Sample Cross-Section (cs01)

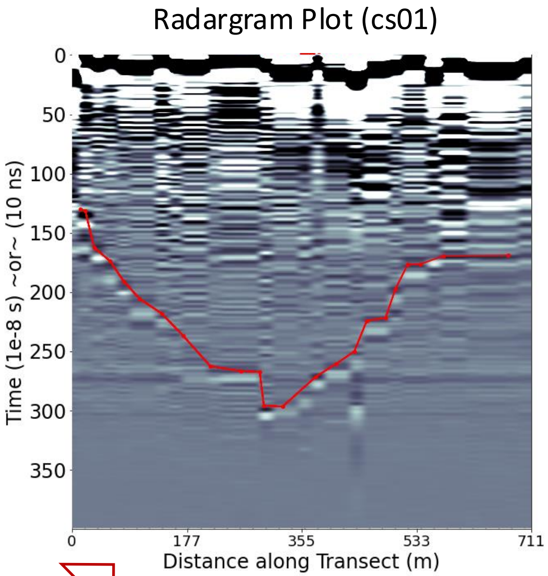


Raw data files (x58)

Time adjustment, signal filtering, radargram size reduction



Rubber-banding



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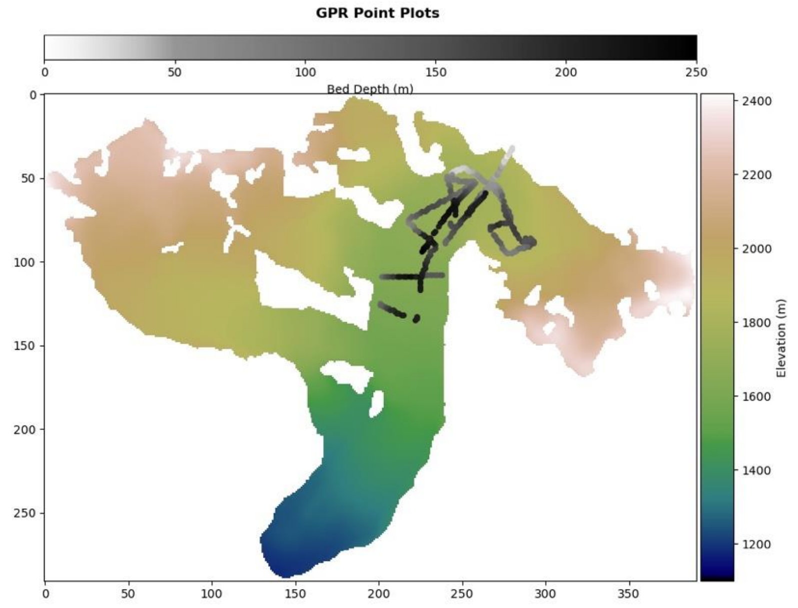
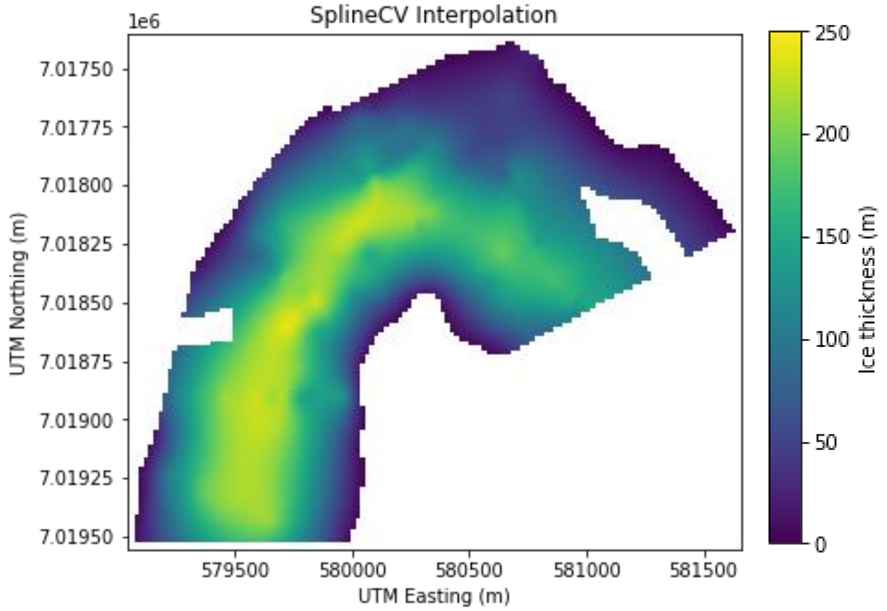
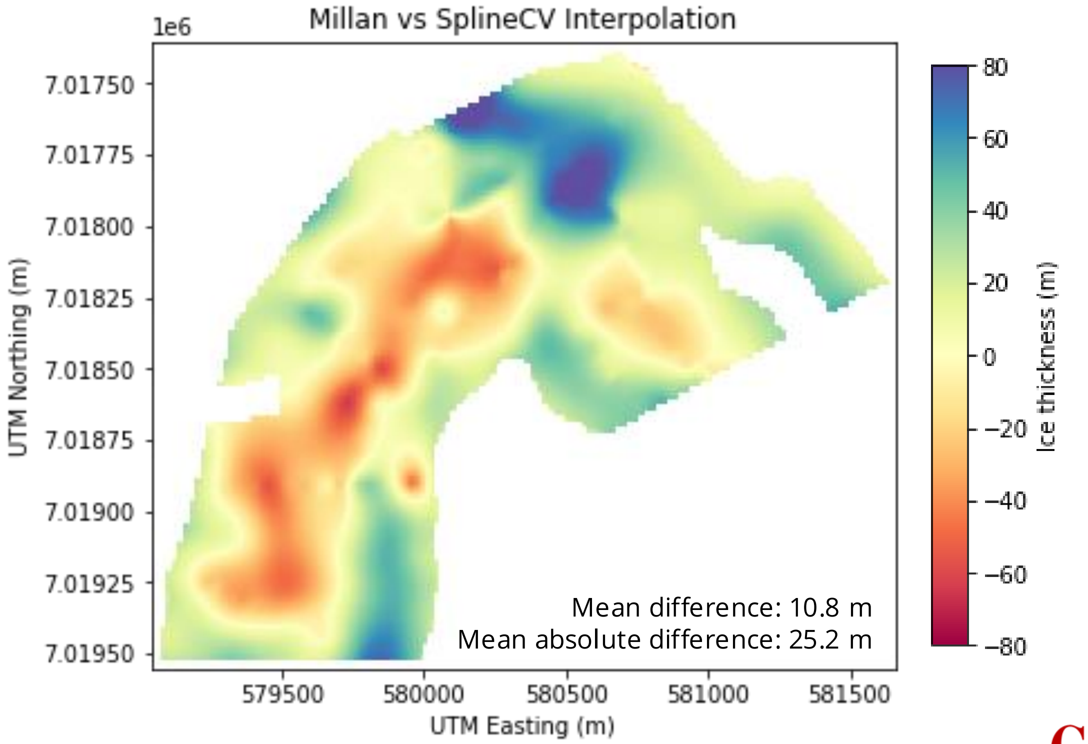
Ground-Penetrating Radar: Gulkana Results





Spline fit, cross-validated

Ground-Penetrating Radar: Comparing to Remote Sensing Data



Note: Positive values indicate the Millan thickness is greater than our interpolated field results

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Takeaways and Next Steps

- We have a whole host of in-situ and modeled data to calibrate and validate remote sensing products
- Using this field data to constrain the climatic mass balance from remote sensing can reconcile discrepancies in remote sensing products and quantify/reduce uncertainties in the data
- Quantifying and reducing uncertainties in remote sensing products is critical for improved models and projections
- Next steps are to processing field data and continue developing modeled products, such that datasets the climatic mass balance gradient derived from the data align with field observations

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Thank you! Questions?