Estimating Icelandic Mass Balance from Multi-Mission Satellite Altimetry

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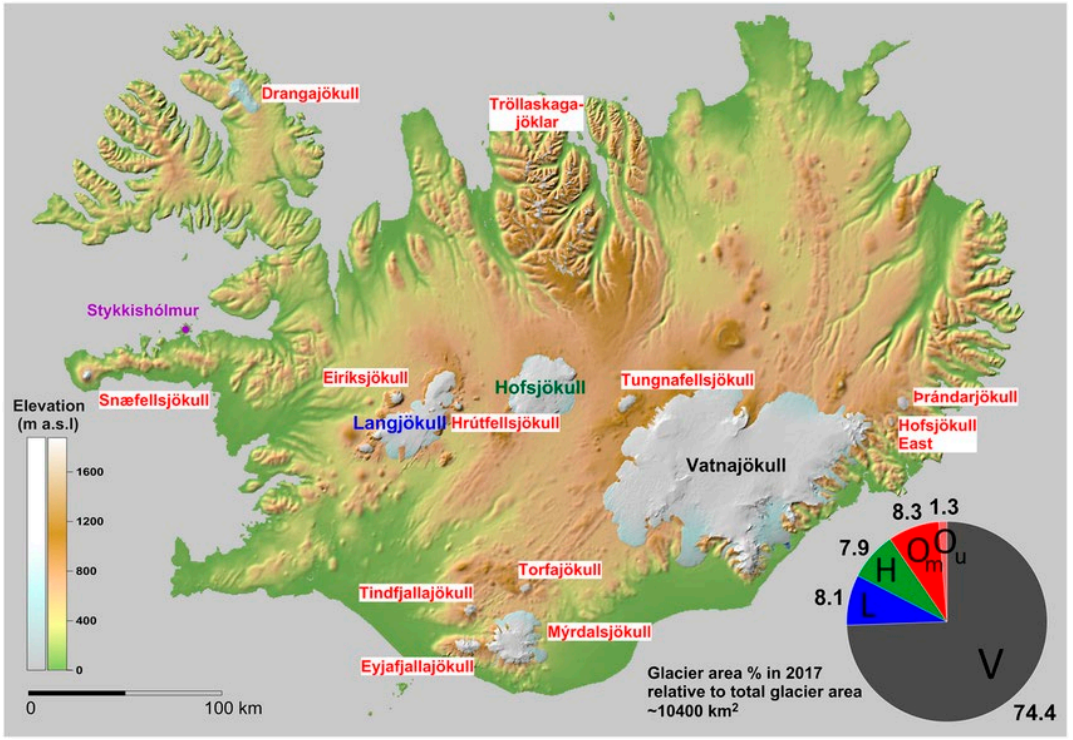
Outline for Presentation

- Icelandic glaciers
- Missions and data
- Methodology
- Elevation change
- CryoSat-2 SWATH and ICESat-2 synergies
- Mass balance
- Mission’s of opportunity

Icelandic Glaciers

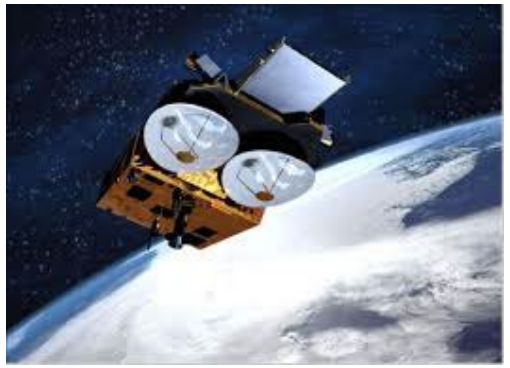
- The volume of glaciers in Iceland (~3,400 km^3 in 2019) corresponds to about 9 mm of potential global sea level rise.
- Iceland is located in a region of maritime climate in the middle of the North Atlantic Ocean with relatively cool summers, mild winters, and high precipitation.
- Hence Icelandic glaciers are highly affected by atmospheric forcing (surface mass balance).
- The annual mass balance of the ice caps in Iceland has been estimated from field measurements since ~1990's.
- Geodetic techniques such as laser and radar altimetry have also been used to estimate mass balance for Icelandic glaciers starting with ICESat in 2003.
- Here we will present a geodetic record spanning two decades (2003-2023) combining several different altimeters and techniques.

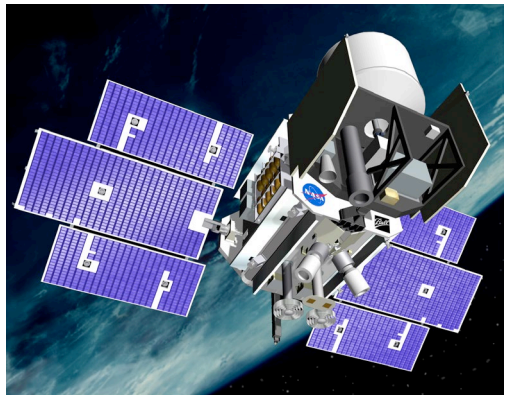


Aðalgeirsdóttir et al (2020): Glacier Changes in Iceland From ~1890 to 2019. doi: 10.3389/feart.2020.523646

Missions & Data

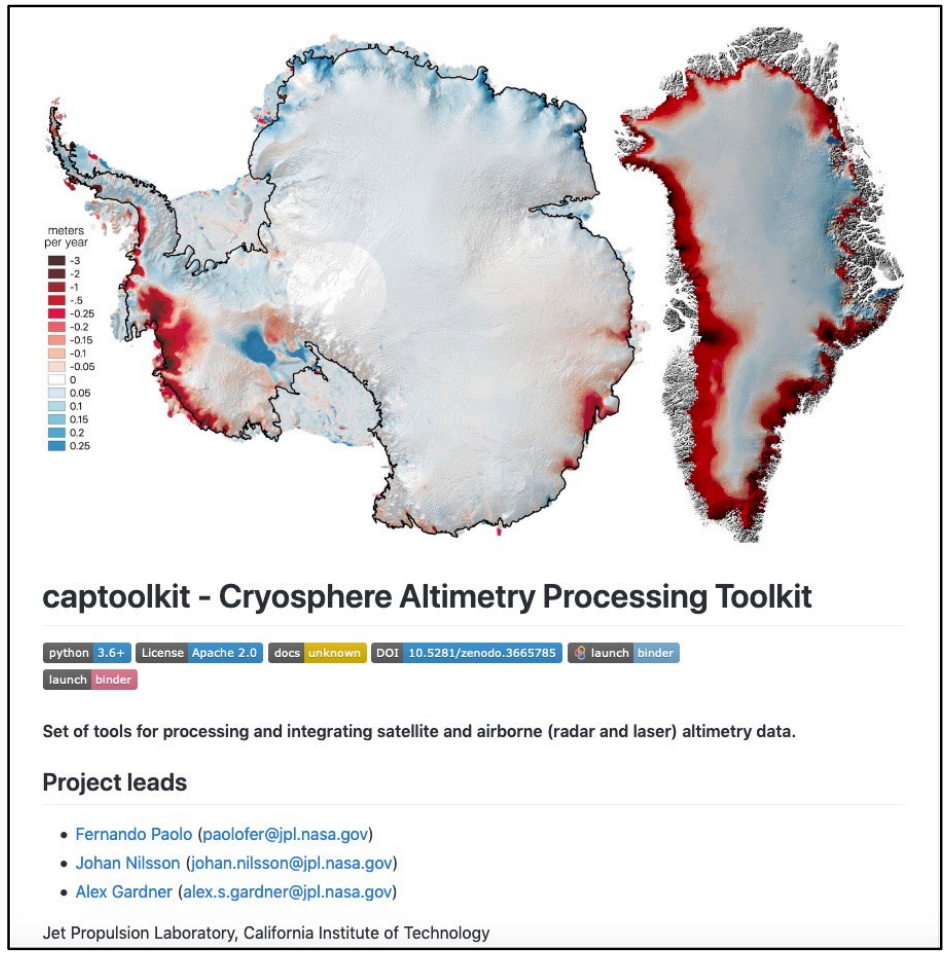
- **ICESat (2003-2009)**
  - Release 34
- **CryoSat-2 (2010-Present)**
  - Baseline-E (20 Hz data)
  - In-house SWATH processing
- **ICESat-2 (2018-Present)**
  - ATL06 Release 006
- **ArcticDEM**
  - Digital elevation model - 100 m resolution
- **Randolph Glacier Inventory (RGI 7.0)**
  - Iceland glacier outlines



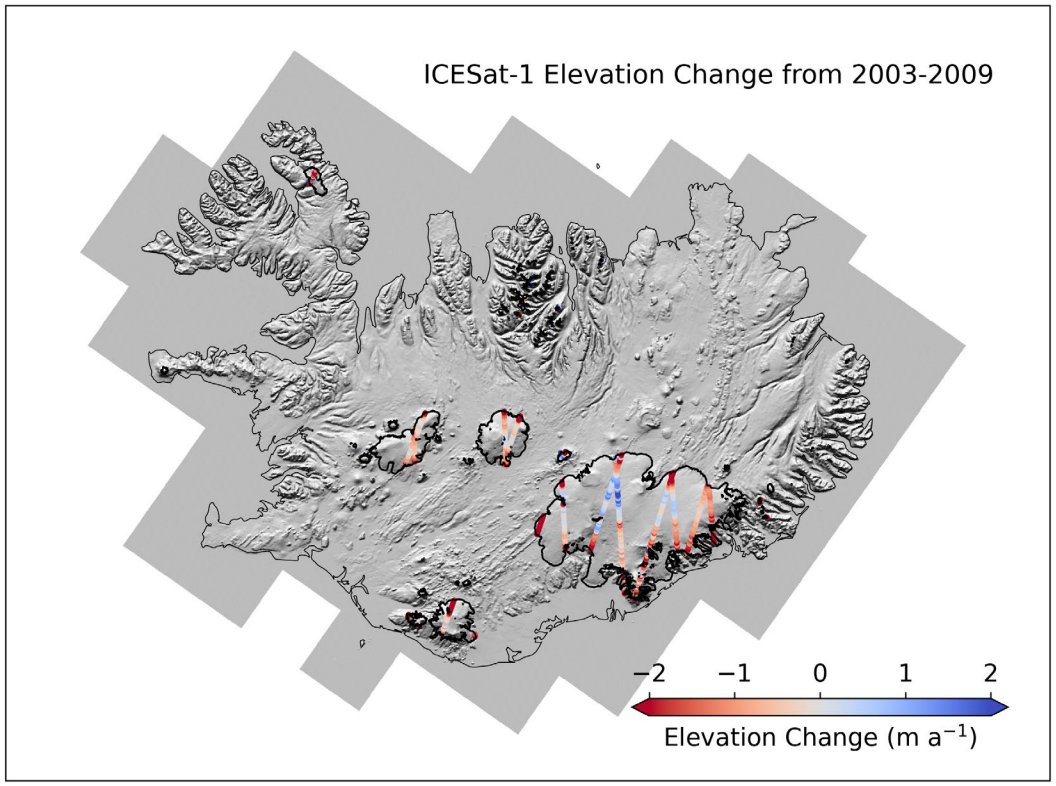


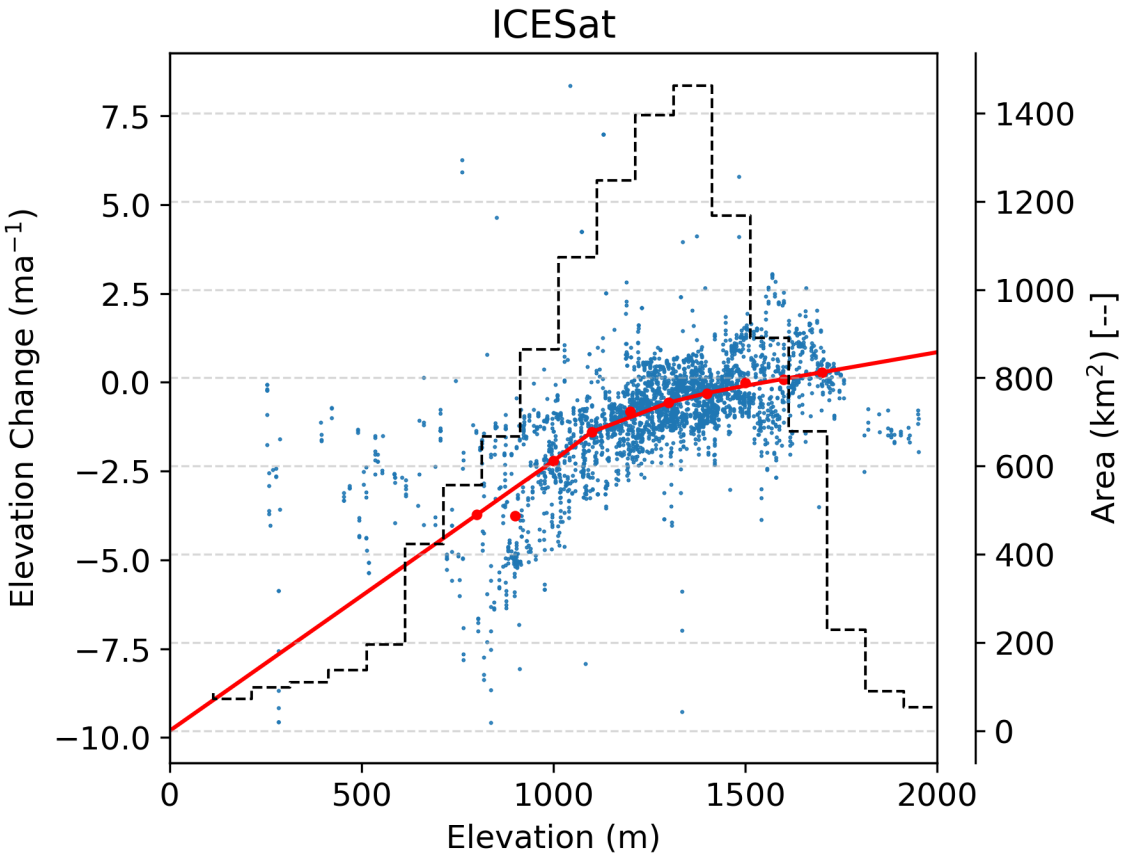
Methodology

- Read data and apply necessary corrections for all missions
- Compute elevation change and time series for each mission
- Define hypsometric relationships (dh versus height) for needed extrapolation using an external DEM.
- Align time series using least-squares adjustment to cross calibrate time series.
- Estimate Mass Balance using density assumption of 850 kg m^{-3}
- Methodology, processing pipelines and code available in JPL's "captoolkit".

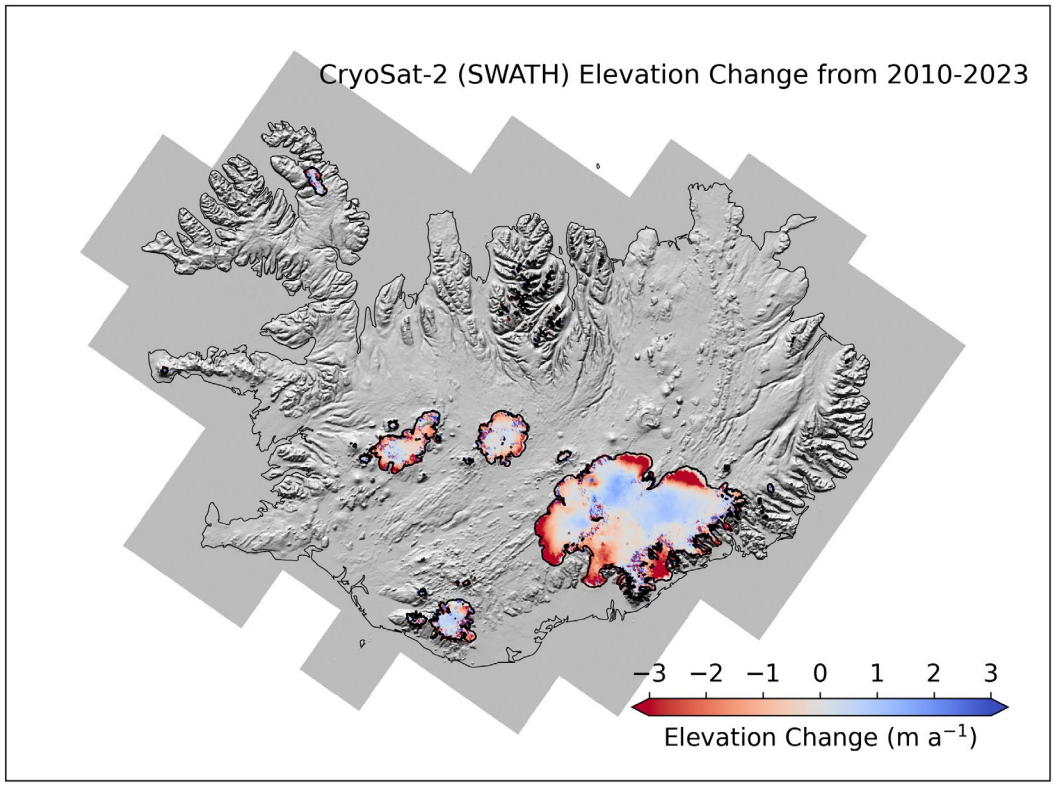


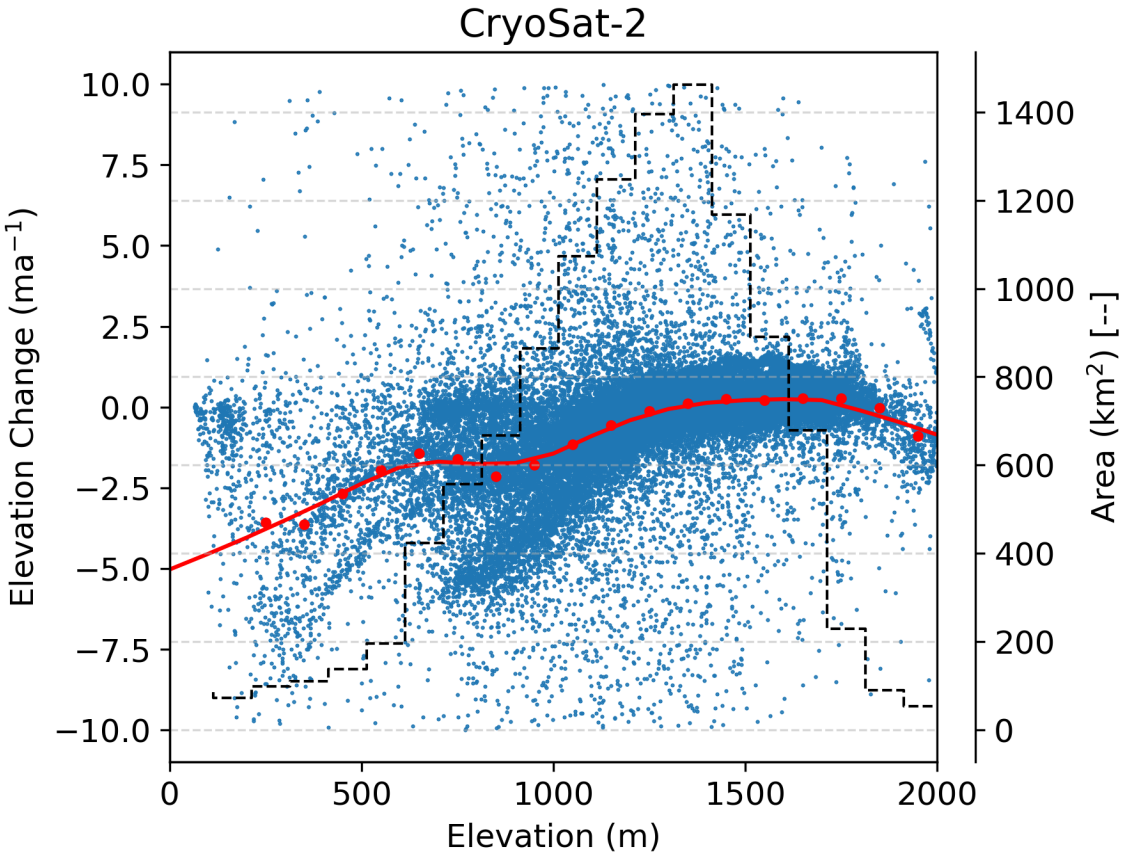
Elevation Change: ICESat



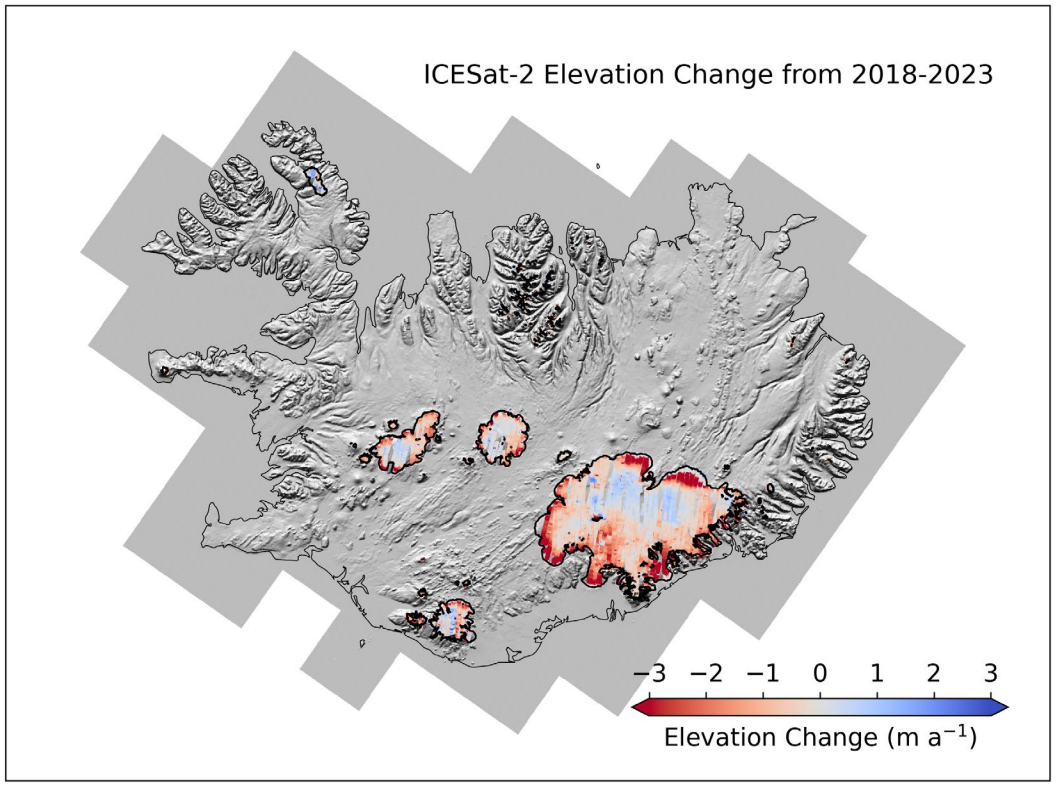


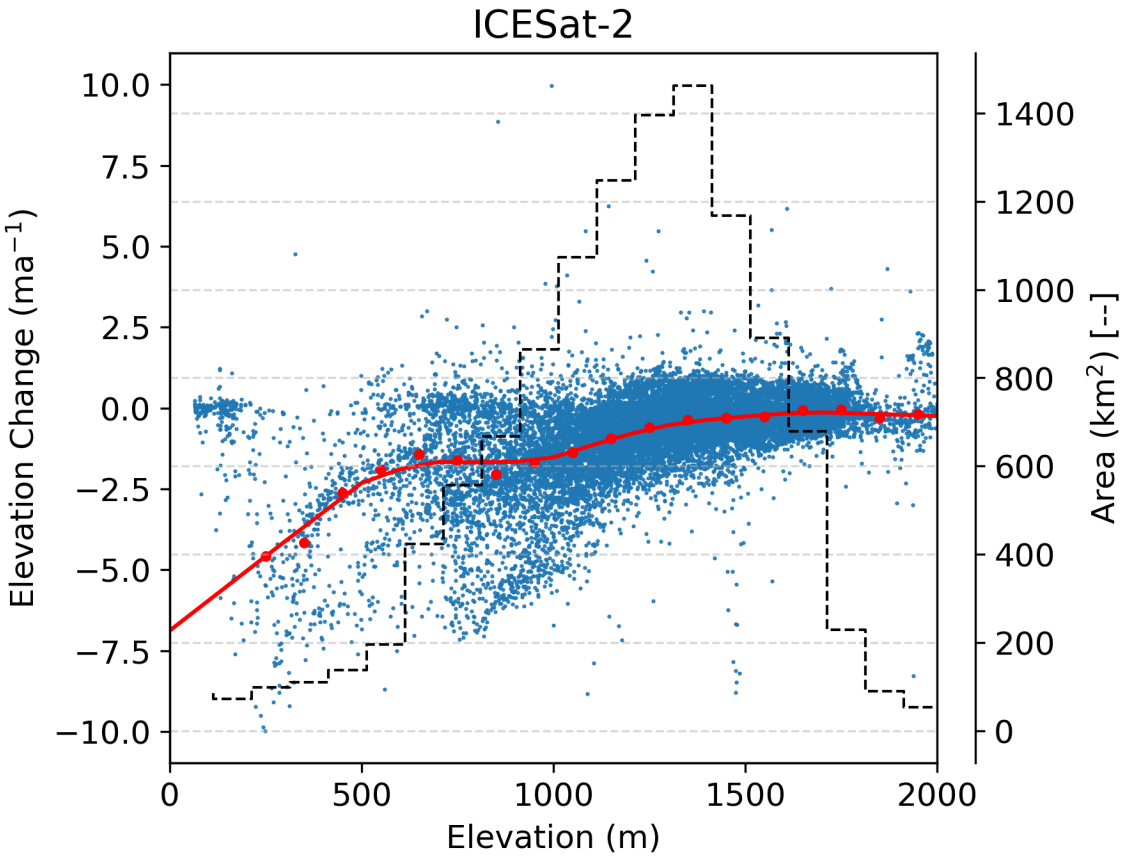
Elevation Change: CryoSat-2 SWATH





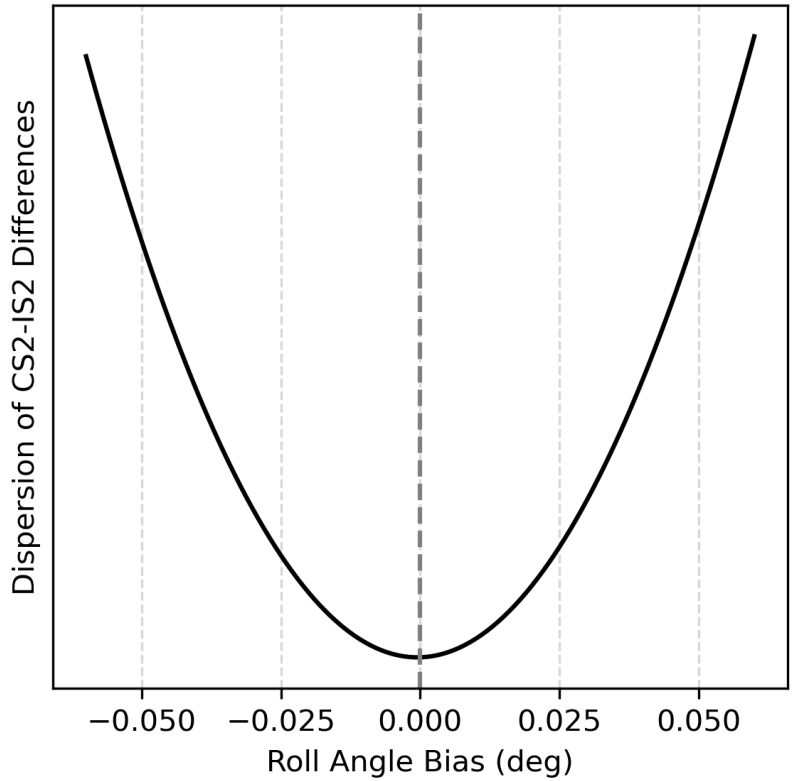
Elevation Change: ICESat-2



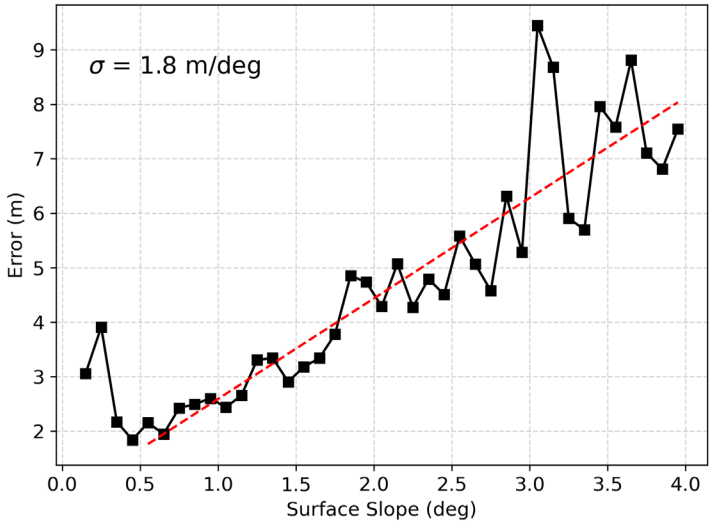


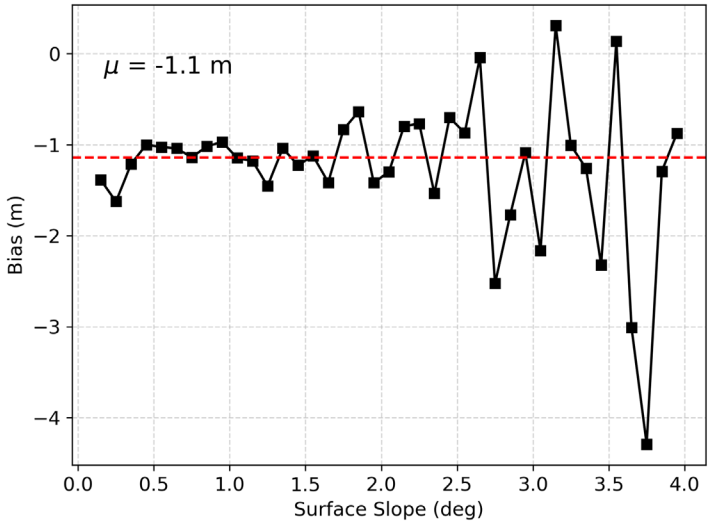
CryoSat-2 / ICESat-2 Synergies

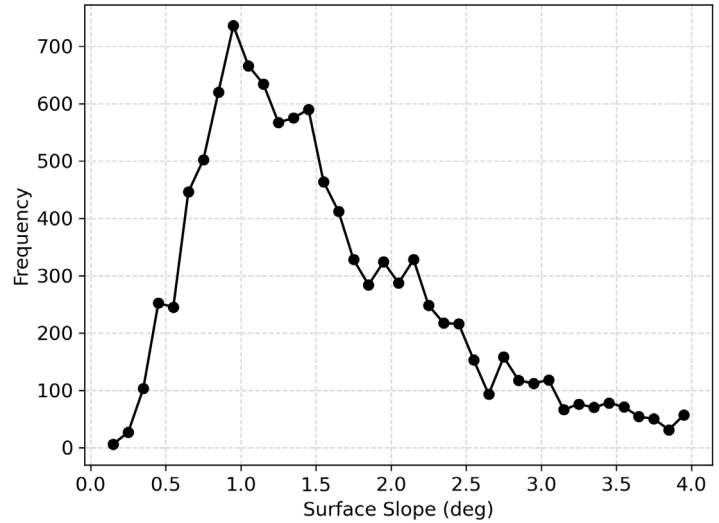
- **Synergies vital for improving estimates of "Mass Balance"**
  - Utilizing strengths and removing weaknesses
  - Especially for SWATH processing
- **Quality assessments**
  - Roll Angle Bias (static and time variable)
  - Accuracy and Precision
  - Uncertainty directly linked to Mass Balance
- **Time variable Radar Penetration**
  - Time variable density
  - Possible estimation of snow-depth



Quality Assessments: SWATH and ICESat-2

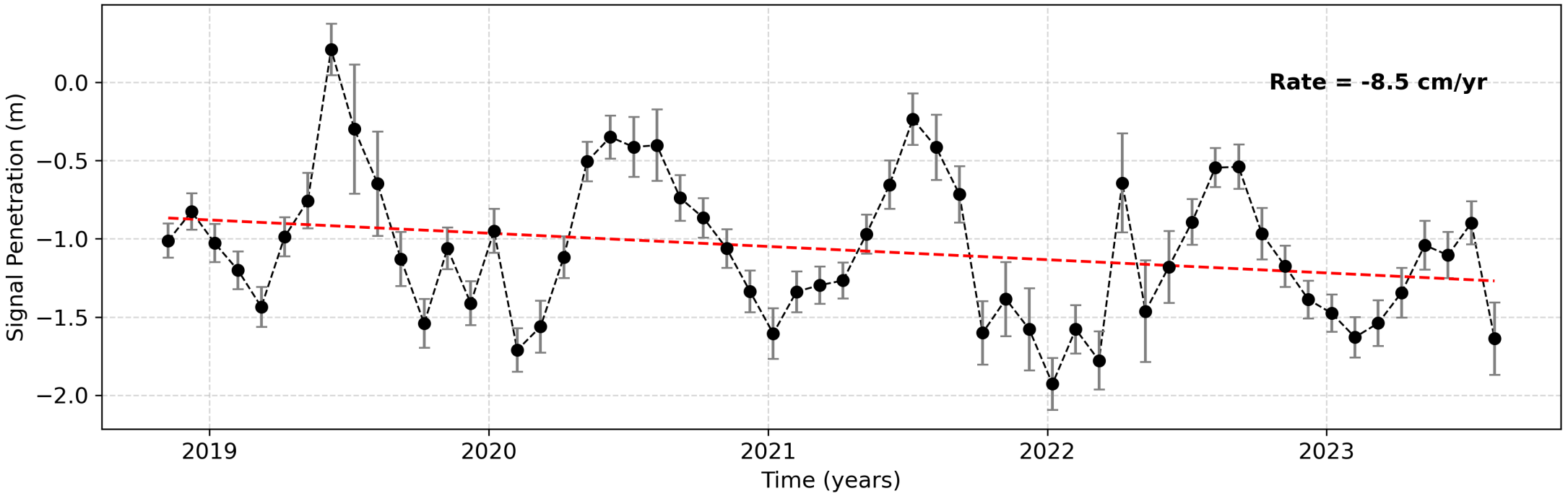




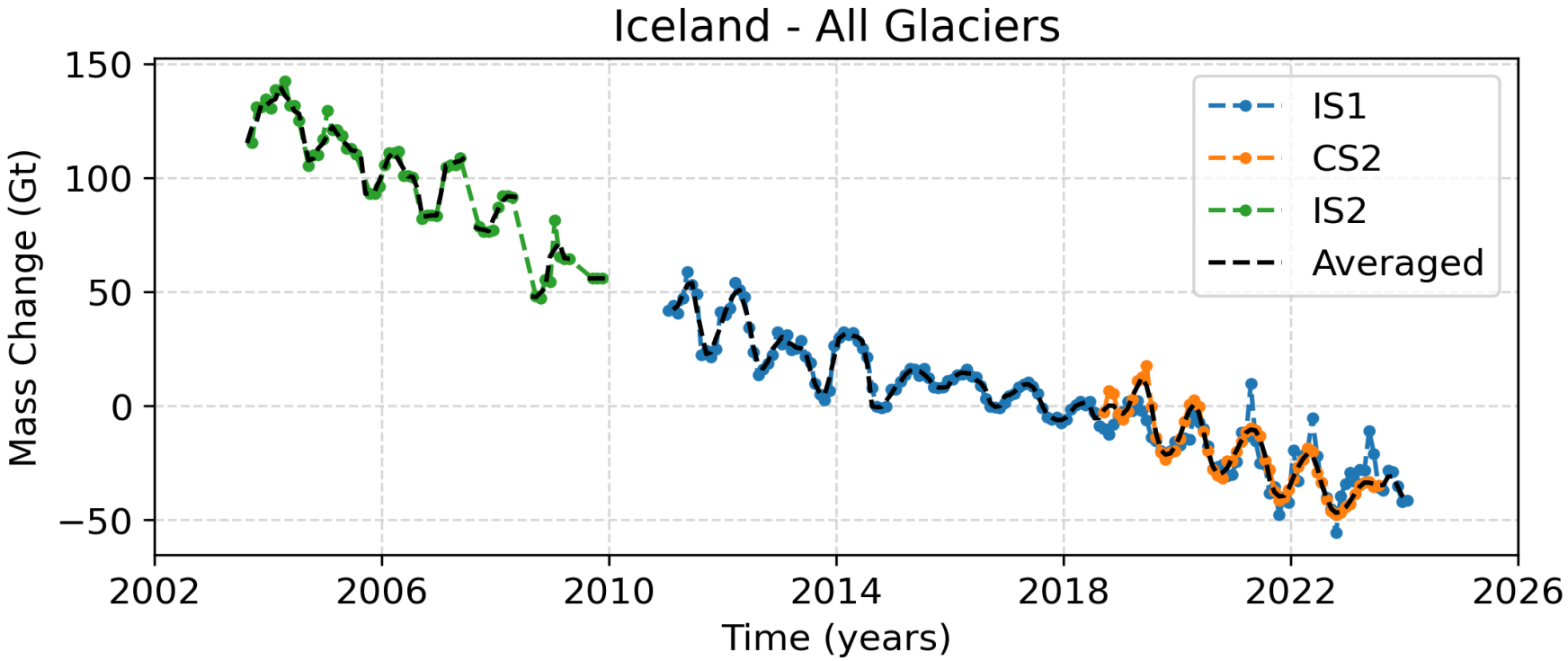


Mean ± Standard Deviation:
-1.1 ± 3.5 m

Radar Penetration Bias



Mass Balance: 2003 - 2023



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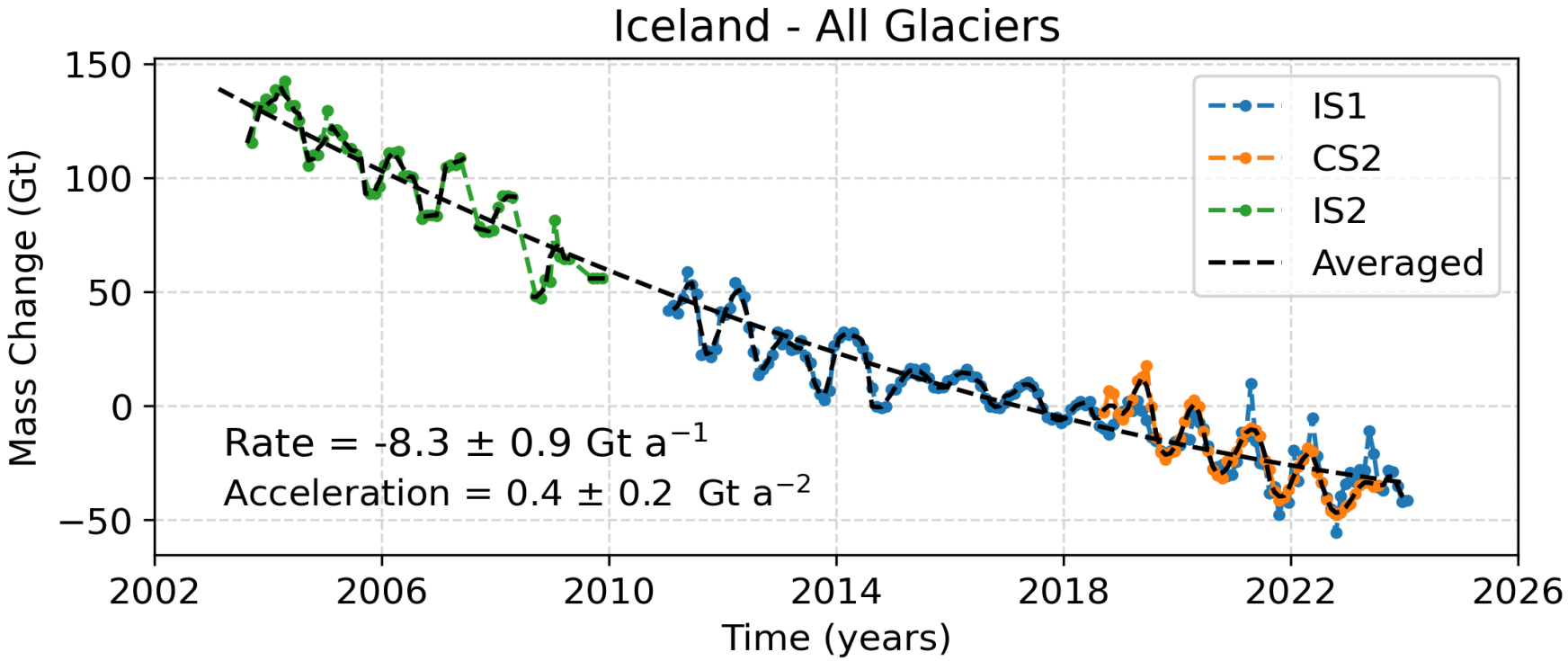
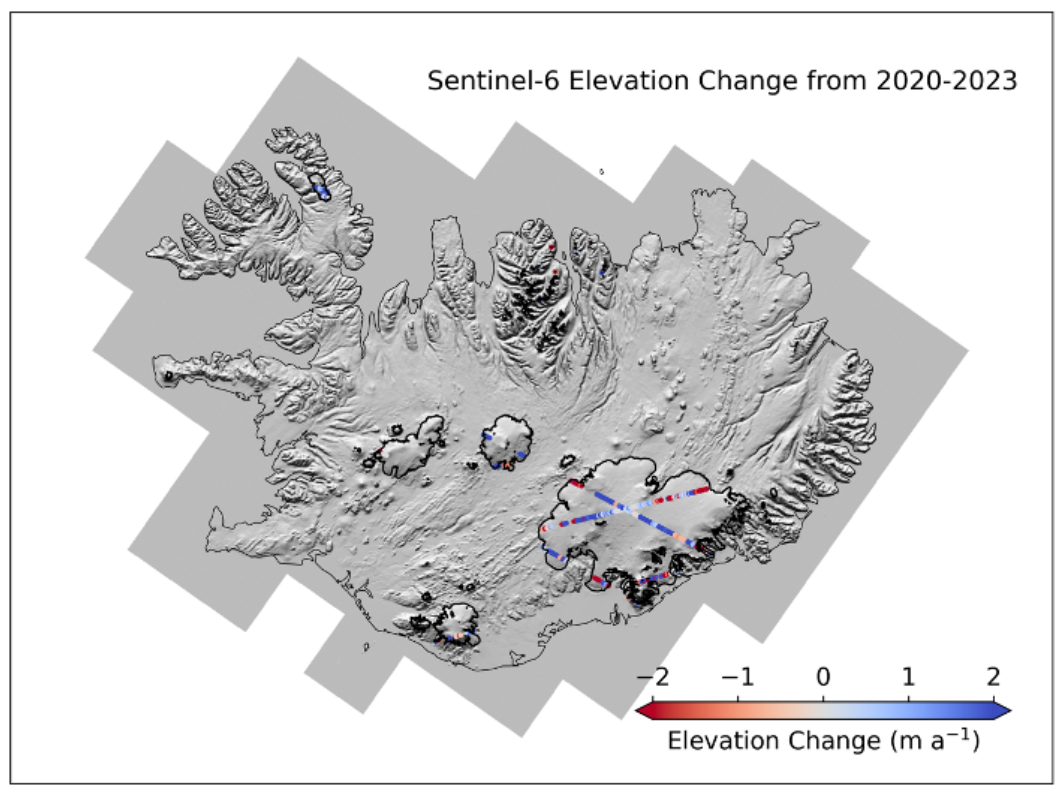
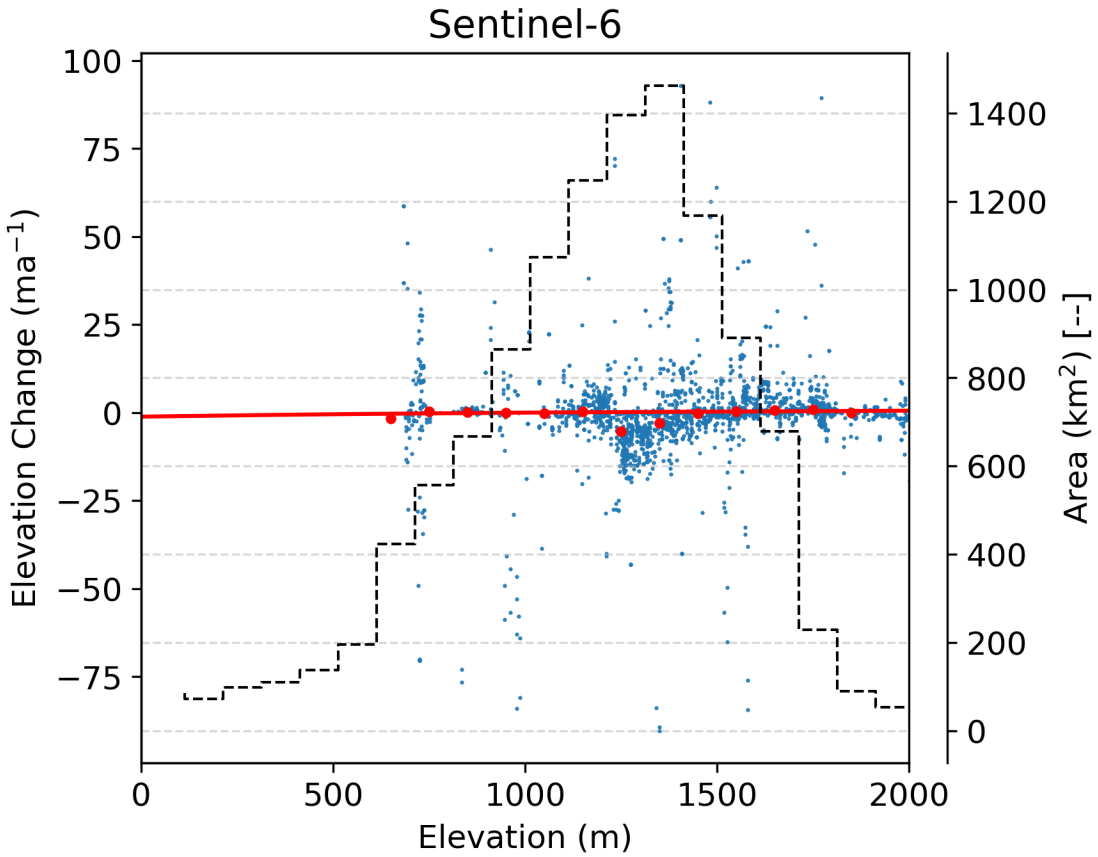


Mission's of Opportunity: Sentinel-6

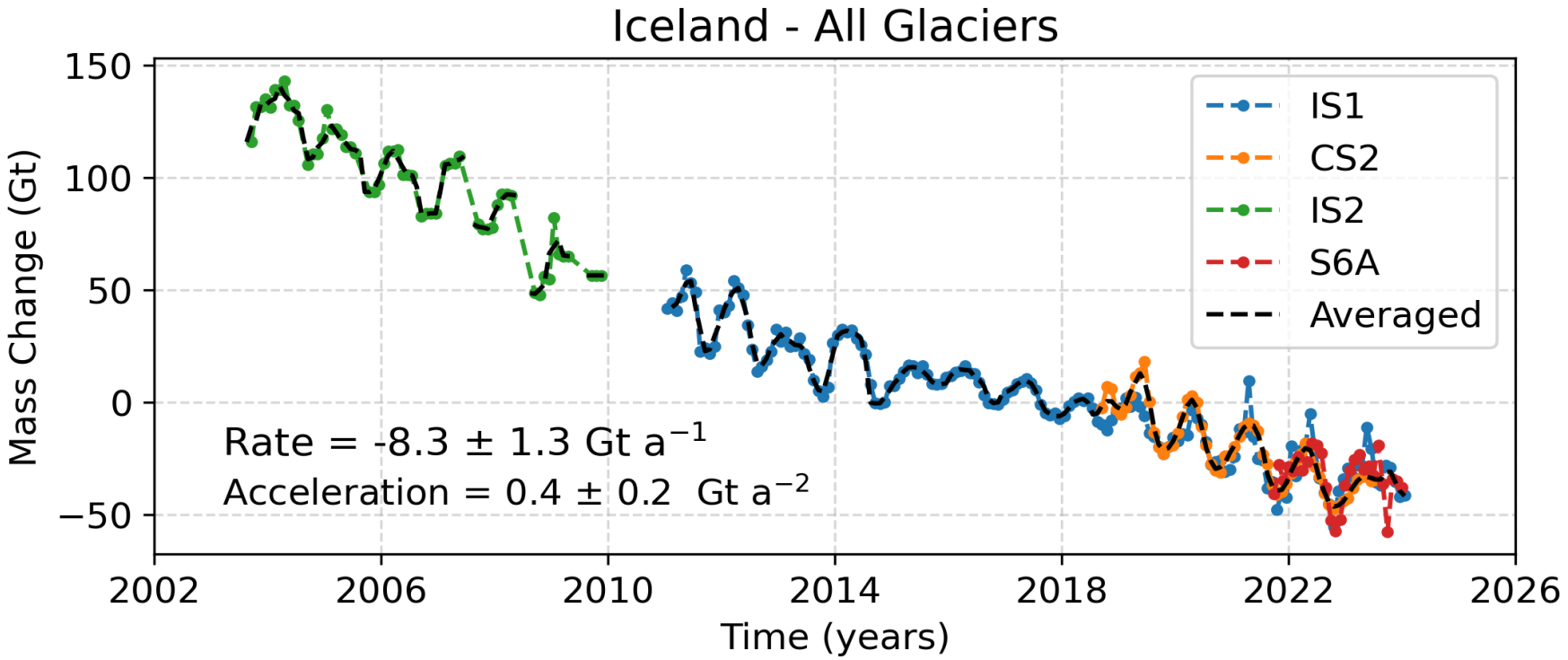
- SAR-missions such as Sentinel-3 and Sentinel-6 can provide improved mapping of both ice sheets and glaciers.
- Have not been fully utilize due to limitations in topographical sampling (not interferometric – slope induced error).
- Sentinel-6 is of interest even though it only covers ± 66 degrees latitude; it does provide coverage for Icelandic and Alaskan glaciers.
- It's main contribution is its higher temporal resolution of ~10 days compared other "Cryosphere" altimeters of ~30 days.
- This would allow for improved sampling of geophysical signals for these regions not possible with other missions.
- Sentinel-6 does not have interferometric capabilities hence there is a need to correct for surface slope as the return is not from nadir.
- This can be achieved using an extrarenal DEM to correct the range to nadir (simplest approach).

Elevation Change: Sentinel-6

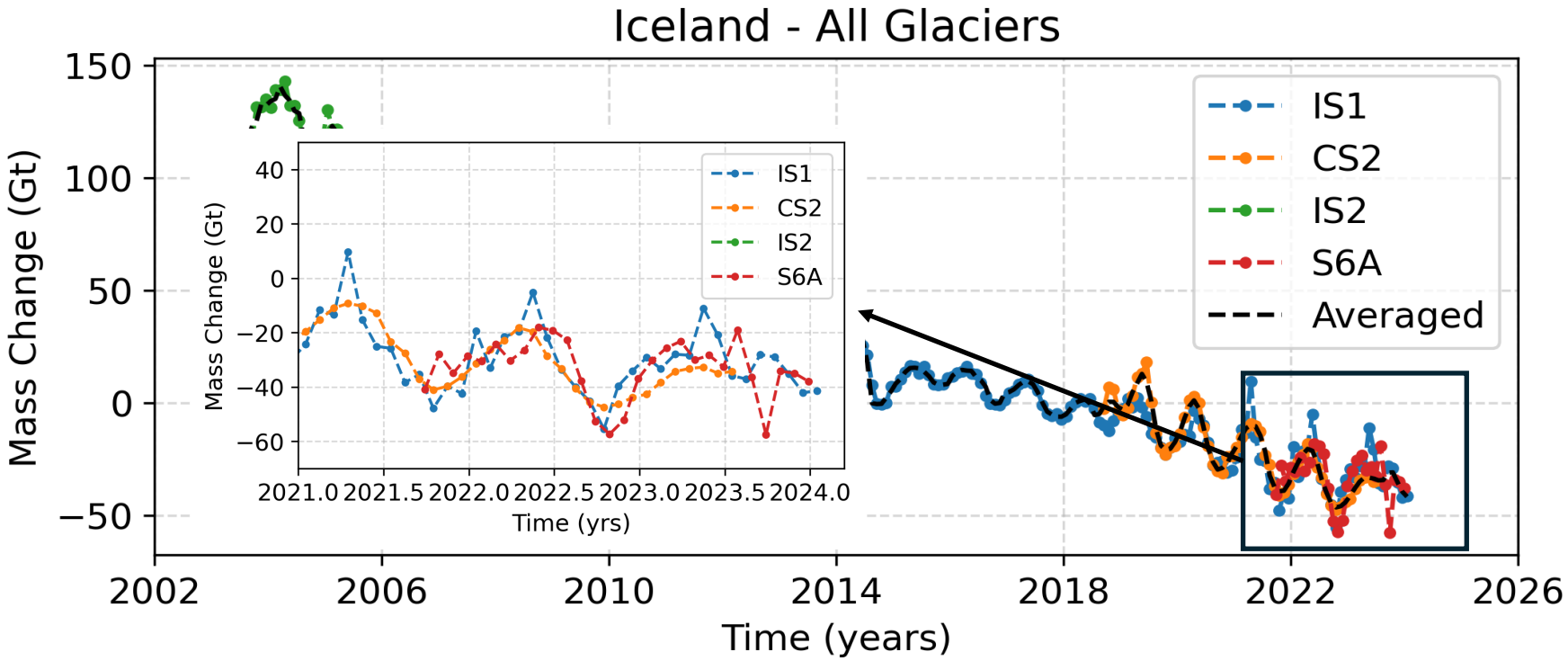




Mass Balance with Sentinel-6



Mass Balance with Sentinel-6



Summary

- Estimated mass balance of -8.3 Gt a^{-1} for 2003-2023, in line with other studies.
- CryoSat-2 and ICESat-2 show excellent capabilities for providing high-resolution mass balance on regional and local scales.
- Leveraging radar and laser data allows for more robust estimation of the error budget.
- Mission of opportunity: Even given relatively crude corrections for topography Sentinel-6 still provide excellent results.
- Future improvements can help alleviate many current limitations of SAR altimetry and their use for mass balance studies.
- CryoSat-2 and ICESat-2 synergies allow for a myriad of new types of studies ranging from snow-depth to quality assessments.

Thank You!

Funding:
Geodetic Data Combination for Increased Spatial Resolution in Earth System Mass Flux
Inter-mission Time Series of Land Ice Velocity and Elevation (ITS LIVE)