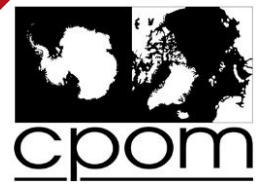
Recent advances and future opportunities in measuring Surface Mass Balance processes from space

Jenny Maddalena, Malcolm McMillan, Amber Leeson, Robert Wassink, Diarmuid Corr, Emily Glen, Tom Slater, Laura Melling, Jacqueline Otto, Dominic Hardy, Romilly Close, Diego Moral Pombo

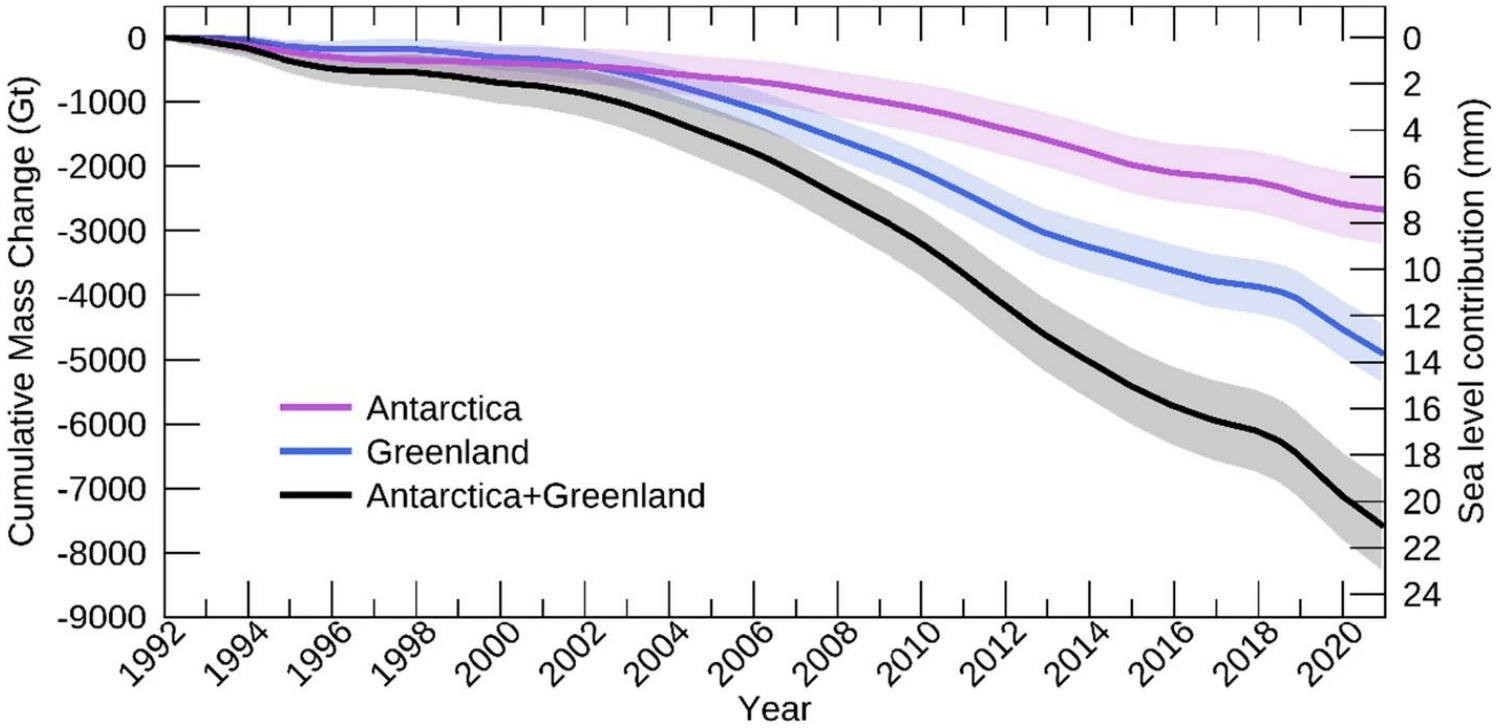


Lancaster University

Background

The Greenland and Antarctic ice sheets lost a total of 7.6 trillion tonnes of ice, contributing 21 mm to global mean sea level rise between 1992 and 2020 (IMBIE).

EO data can be exploited to gain understanding into ice sheet surface processes.

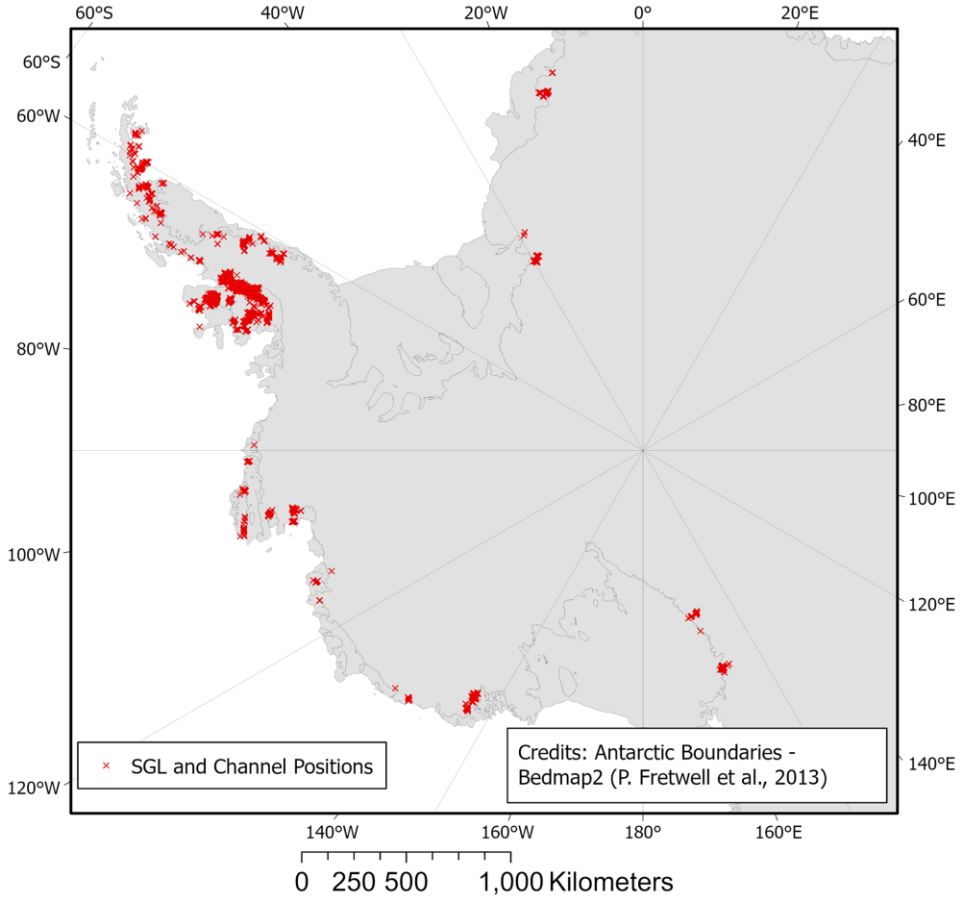


Otosaka, I.N., Horwath, M., Mottram, R. *et al.* Mass Balances of the Antarctic and Greenland Ice Sheets Monitored from Space. *Surv Geophys* **44**, 1615–1652 (2023). https://doi.org/10.1007/s10712-023-09795-8

Mapping Supraglacial Hydrology

Increasing surface hydrology on the Greenland and Antarctic ice sheets.

Traditionally studies have used the NDWI thresholding method to map supraglacial lakes over ice sheets.



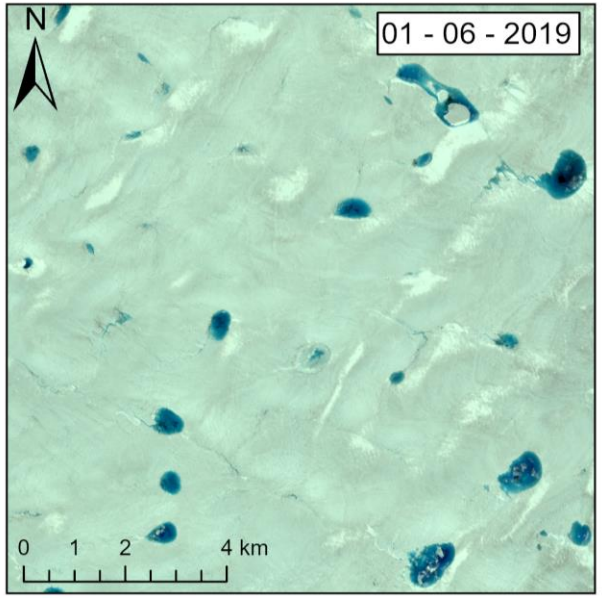
(Corr et al., 2022)

Mapping Supraglacial Hydrology

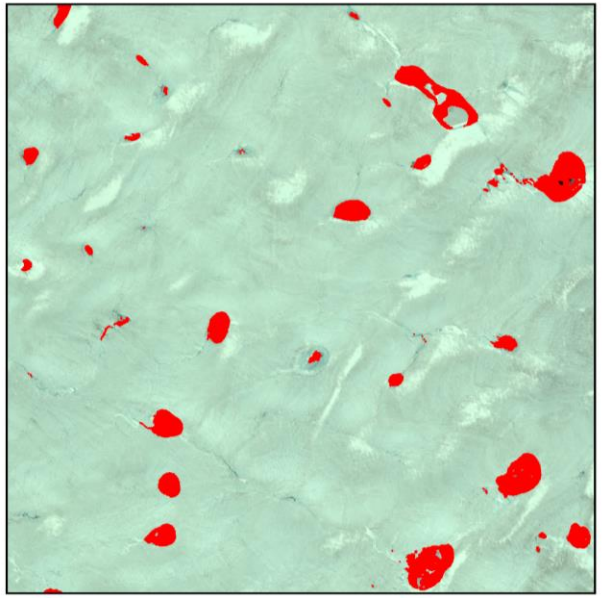
Traditional methods use an NDWI static thresholding approach.

NDWI static thresholding requires intensive manual post-processing.

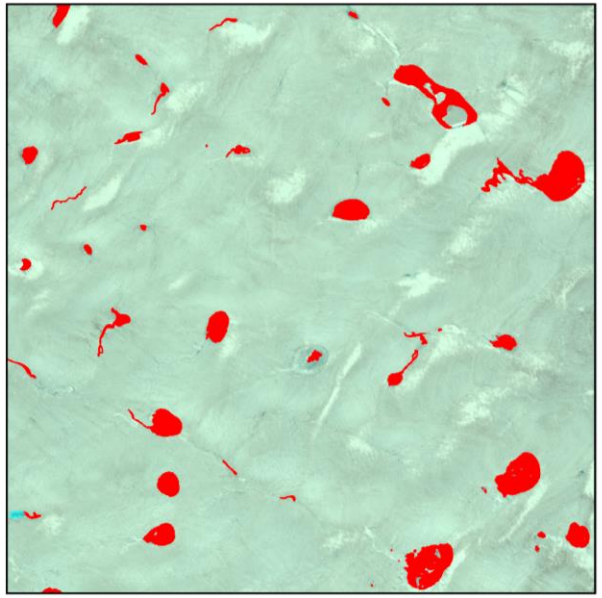
Not suitable for large scale studies or near real-time mapping.



RGB Sentinel-2 image



First-pass: surface water automatically detected by NDWI method



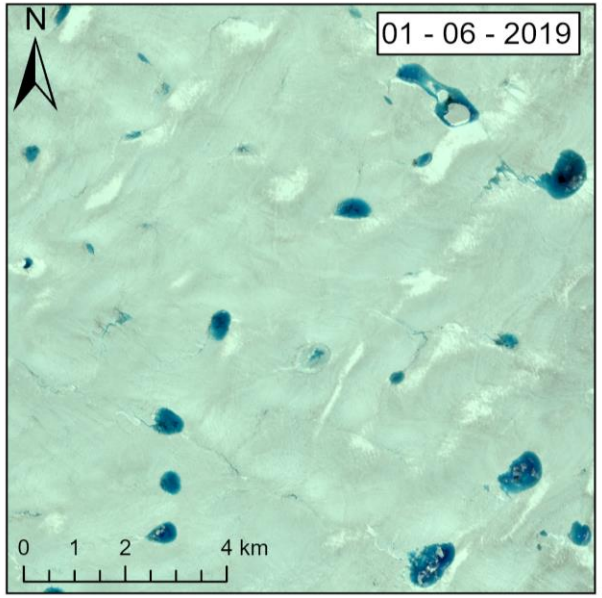
Second-pass: manual enhancement of surface water detected by NDWI method

Mapping Supraglacial Hydrology

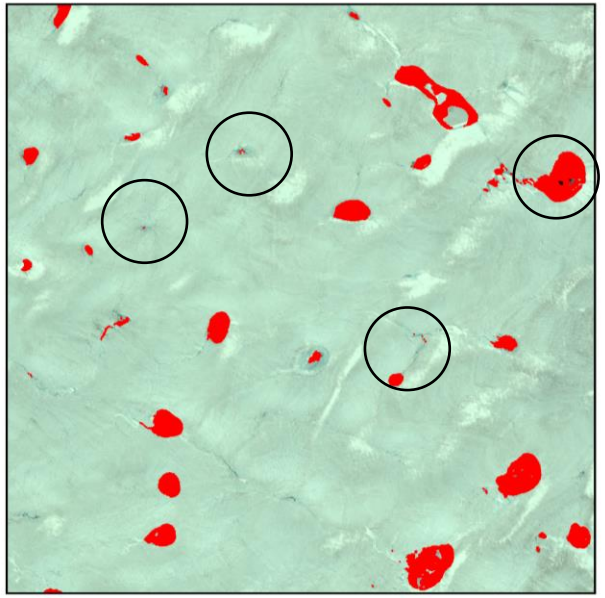
Traditional methods use an NDWI static thresholding approach.

NDWI static thresholding requires intensive manual post-processing.

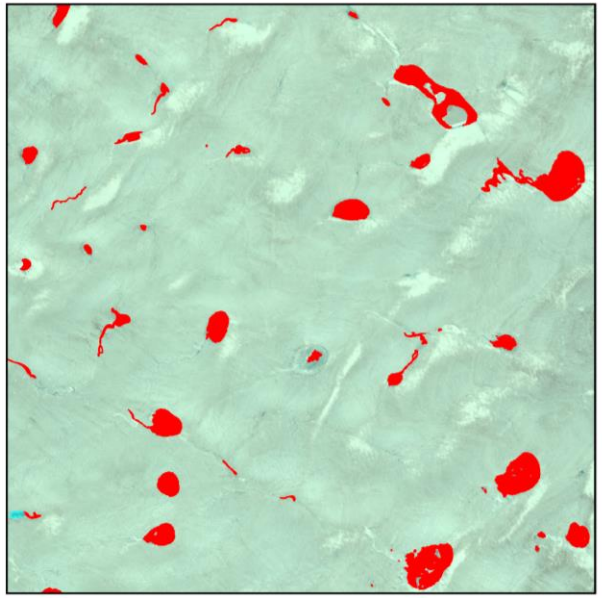
Not suitable for large scale studies or near real-time mapping.



RGB Sentinel-2 image



First-pass: surface water automatically detected by NDWI method



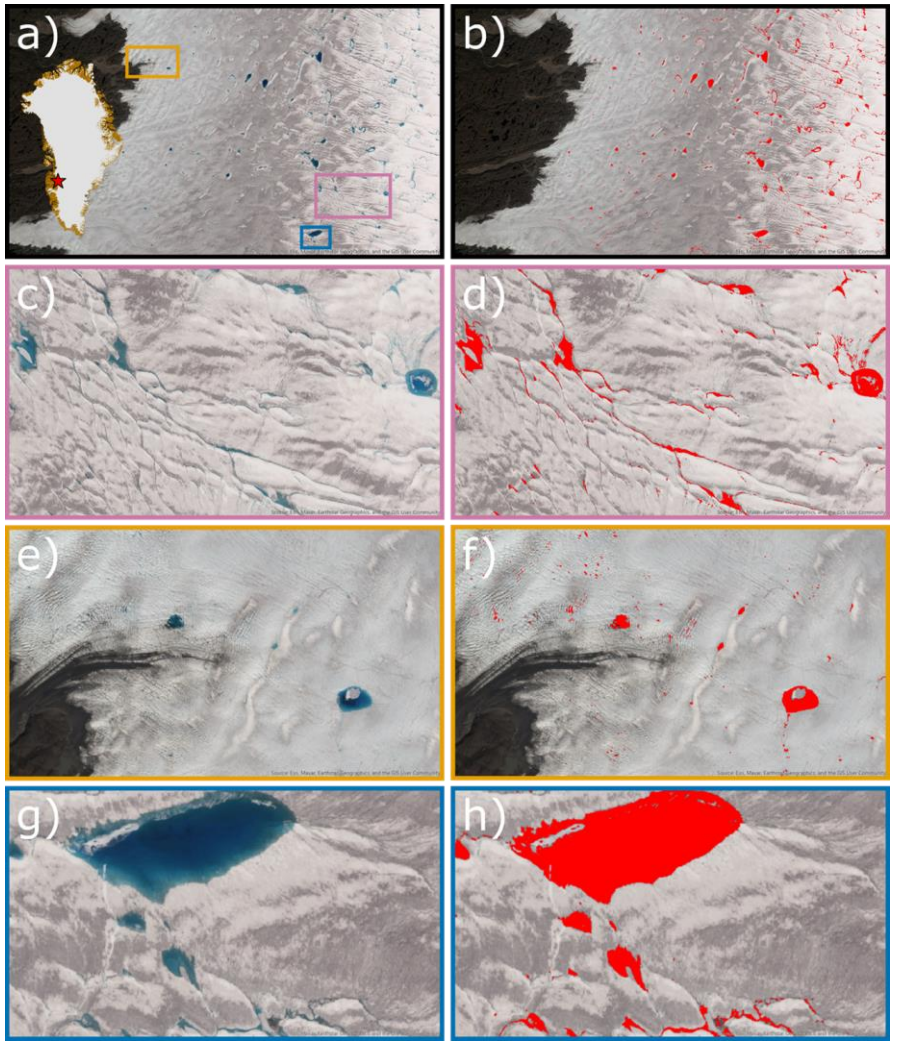
Second-pass: manual enhancement of surface water detected by NDWI method

(Glen et al 2024 under review)

Mapping Supraglacial Hydrology

Developed machine learning methods to map supraglacial hydrology from optical data, capable of operating over large spatial and temporal scales.

The Random Forest algorithm resulted in a more robust, transferable method.



Random Forest Classification

Mapping Supraglacial Hydrology

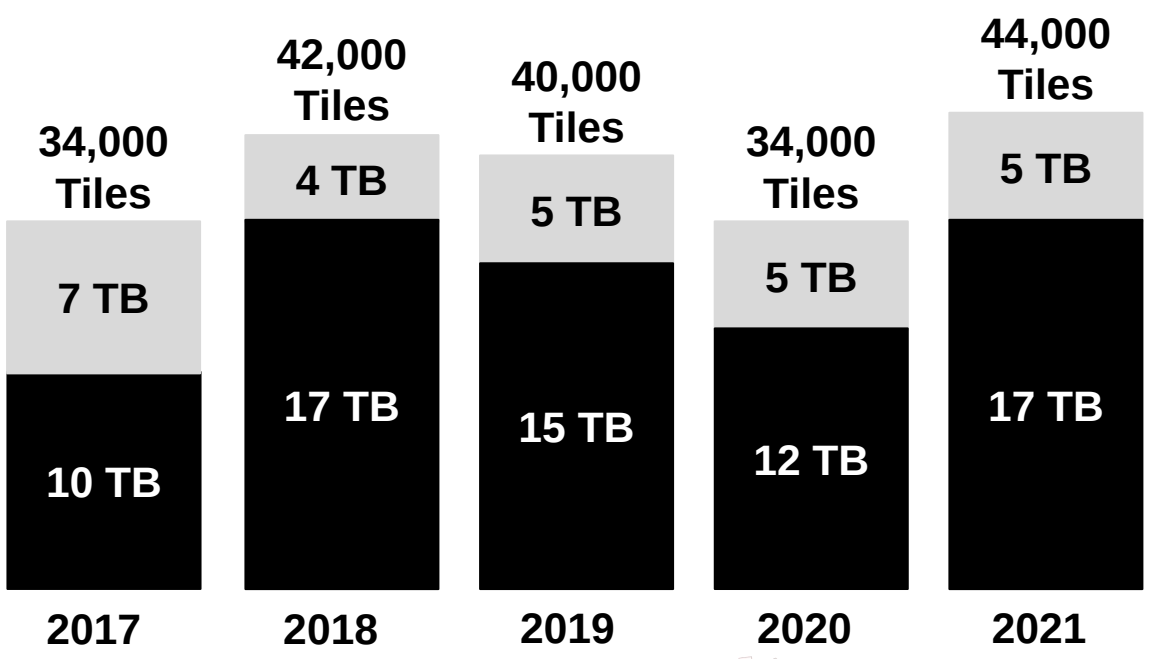
Antarctica

Greenland

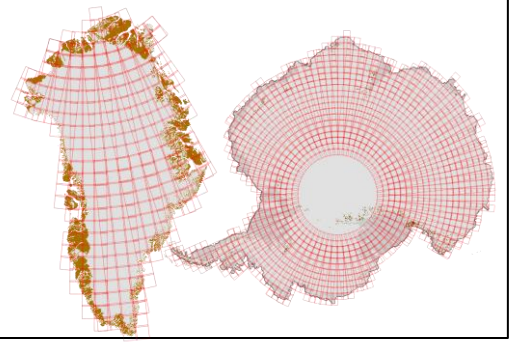
Mean: 1 Tile ≃ 0.5 GigaBytes

Ice Sheet Wide Roll Out of Algorithm:

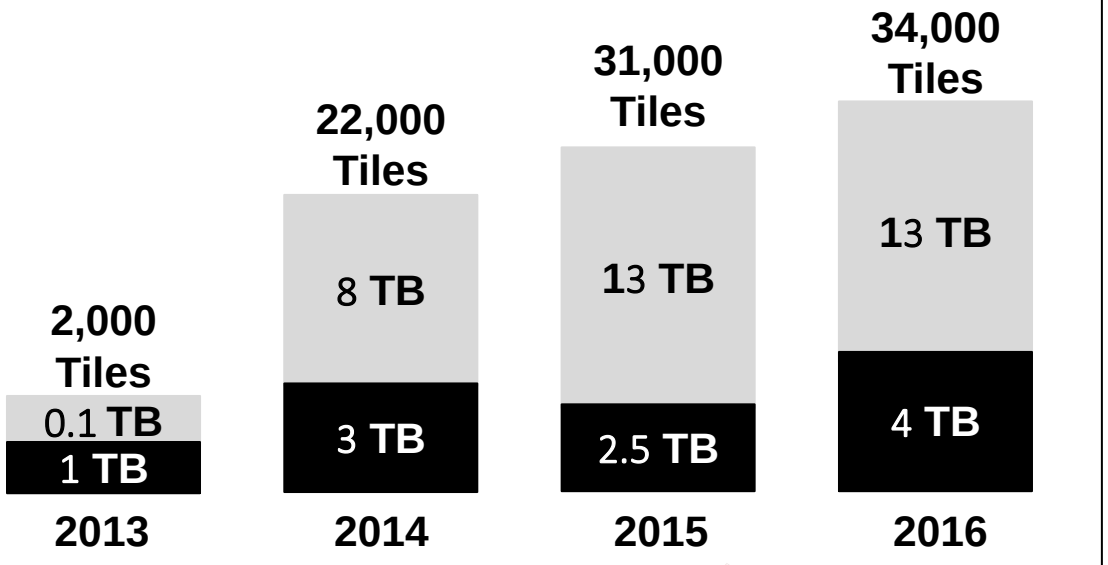
Sentinel-2: Revisit times of 5-10 days.



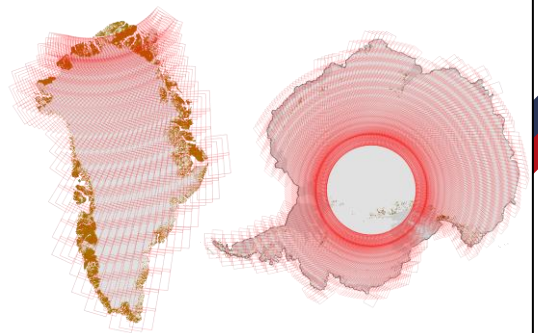
Permits fortnightly monitoring since 2017.



Landsat-8: Revisit times of ~16 days.



Permits monthly monitoring since 2013.

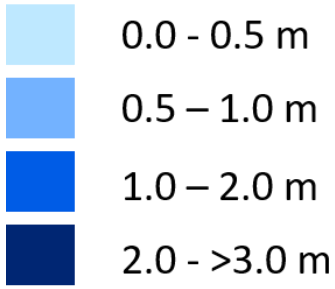


Mapping Supraglacial Hydrology

Exploring spatial distribution of supraglacial meltwater.

Icesheet wide product (Greenland only) of supraglacial lake extent and depths at monthly sampling between 2013-2021.

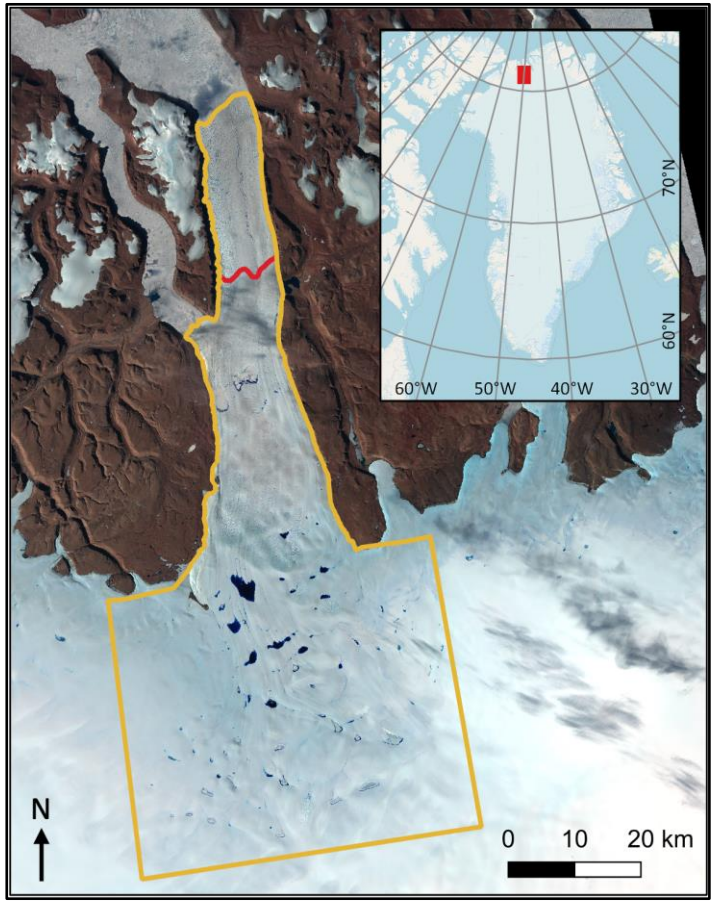
More information on 4DGreenland website:
https://4dgreenland.eo4cryo.dk/



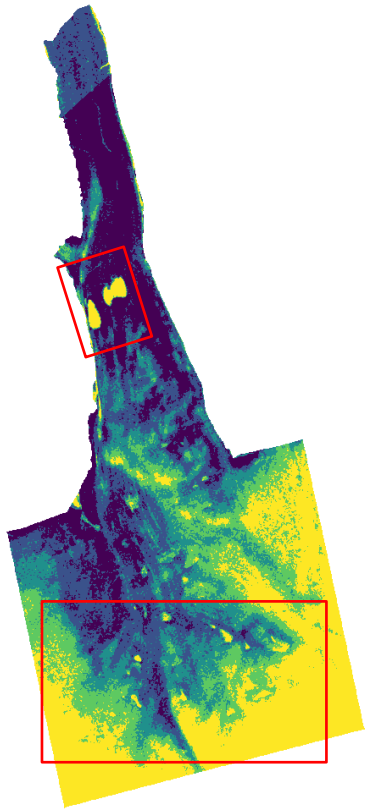
July 2016 Maximum Supraglacial Hydrology Extent and Volume.

Supraglacial Hydrology: Opportunities

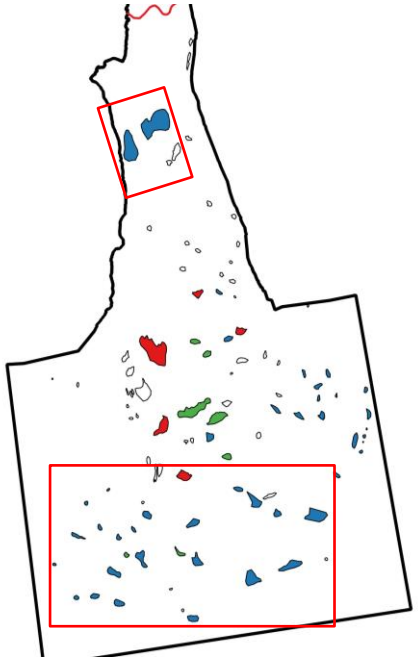
Wintertime lake evolution: towards automated mapping of winter lakes from Sentinel-1 SAR

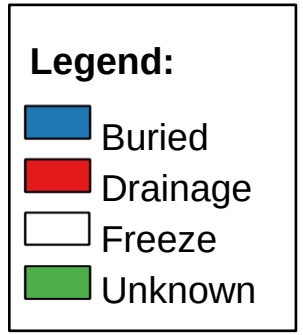


Credit: Jacqueline Otto



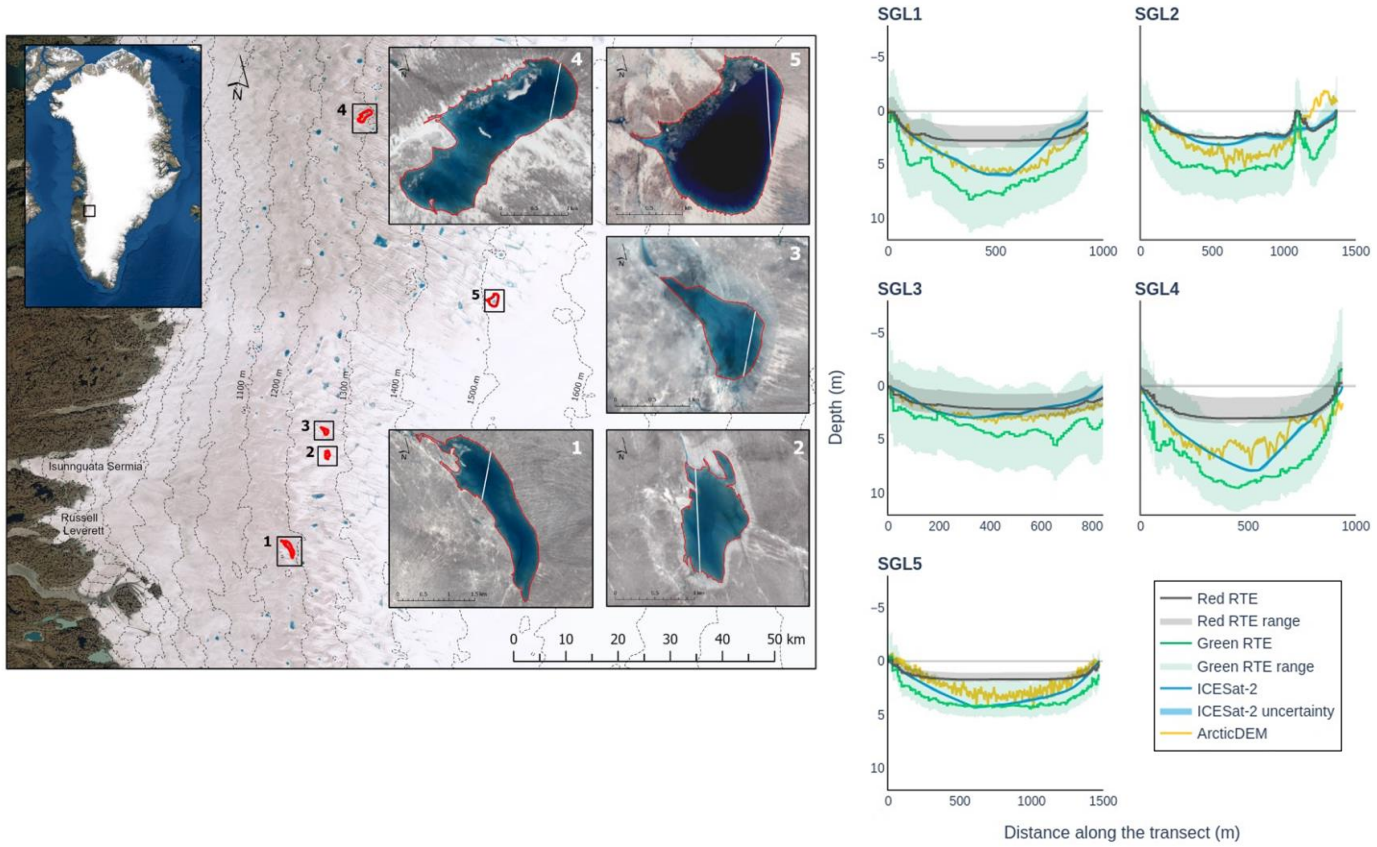
S1 15-12-2020





Supraglacial Hydrology: Opportunities

Constraining volume estimates.

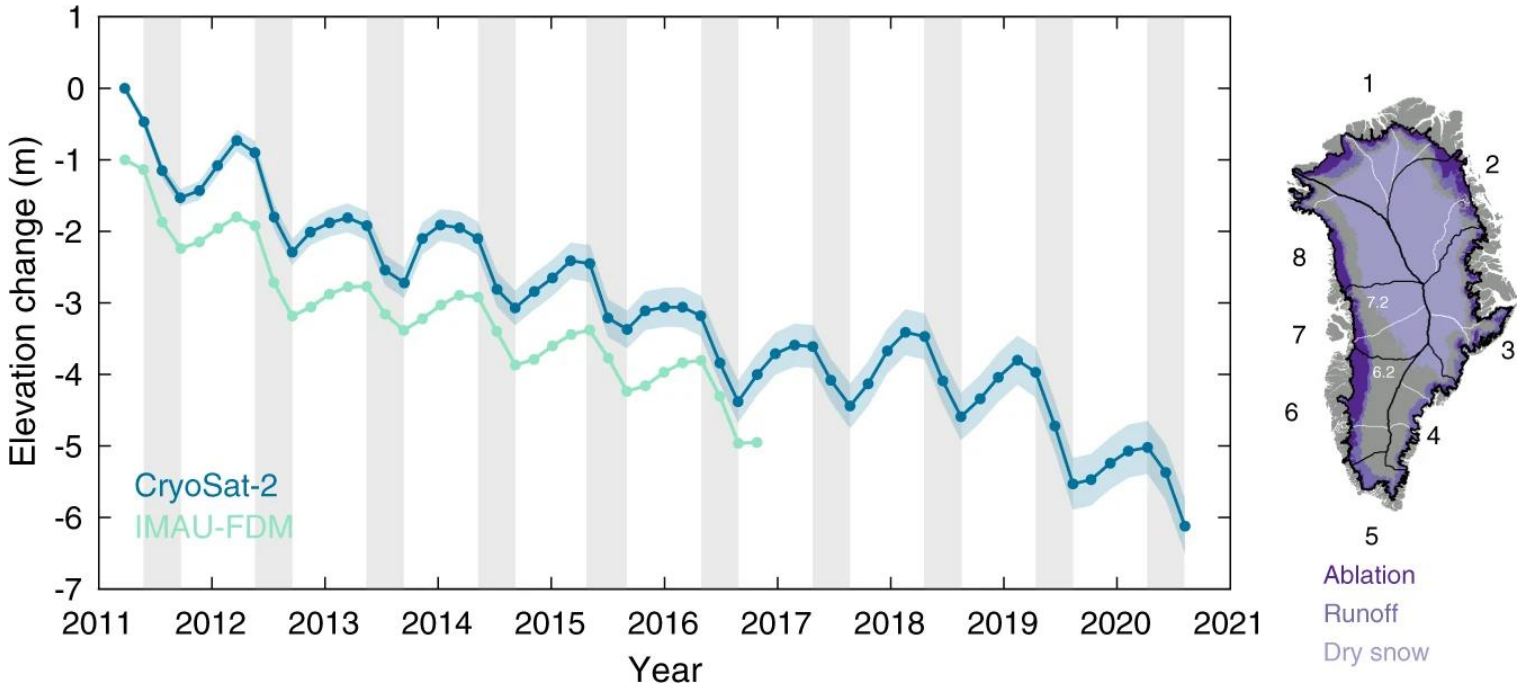


(Melling et al., 2023)

- Red Radiative Transfer Equation (RTE) depths plateau at approximately 3 m.
- Green RTE systematically overestimates depth across the majority of the lakes.
- Opportunity to explore potential of machine learning or deep learning to estimate depths.

Measuring Surface Mass Balance Processes using Altimetry

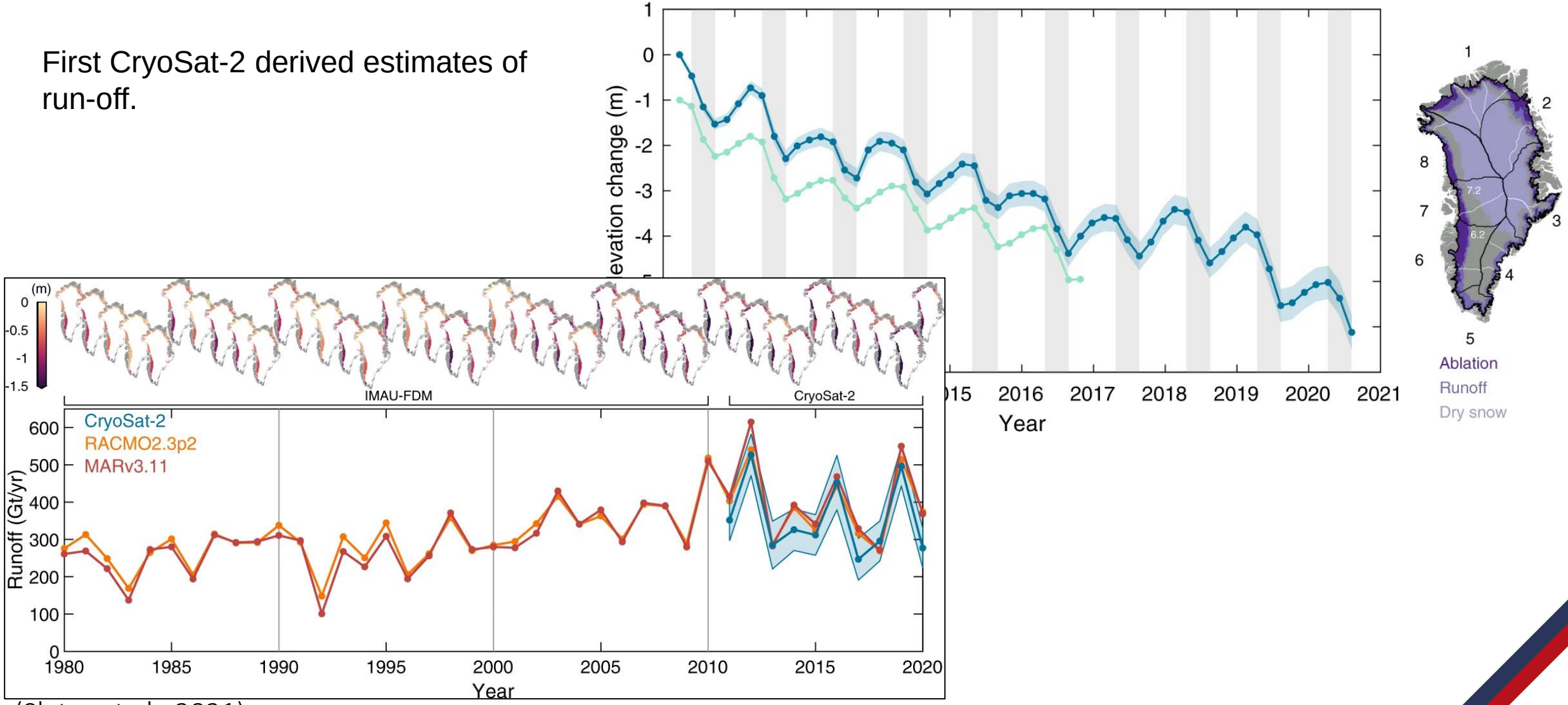
First CryoSat-2 derived estimates of run-off.



(Slater et al., 2021)

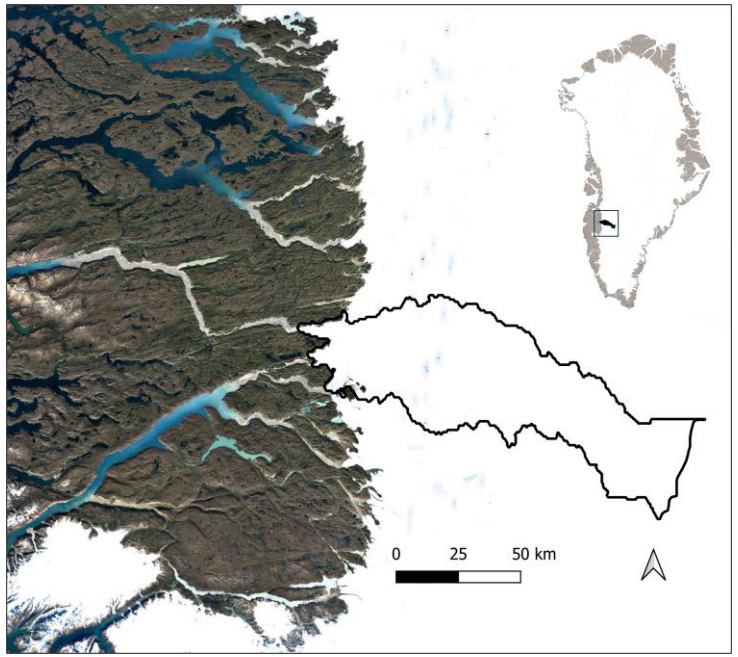
Measuring Surface Mass Balance Processes using Altimetry

First CryoSat-2 derived estimates of run-off.

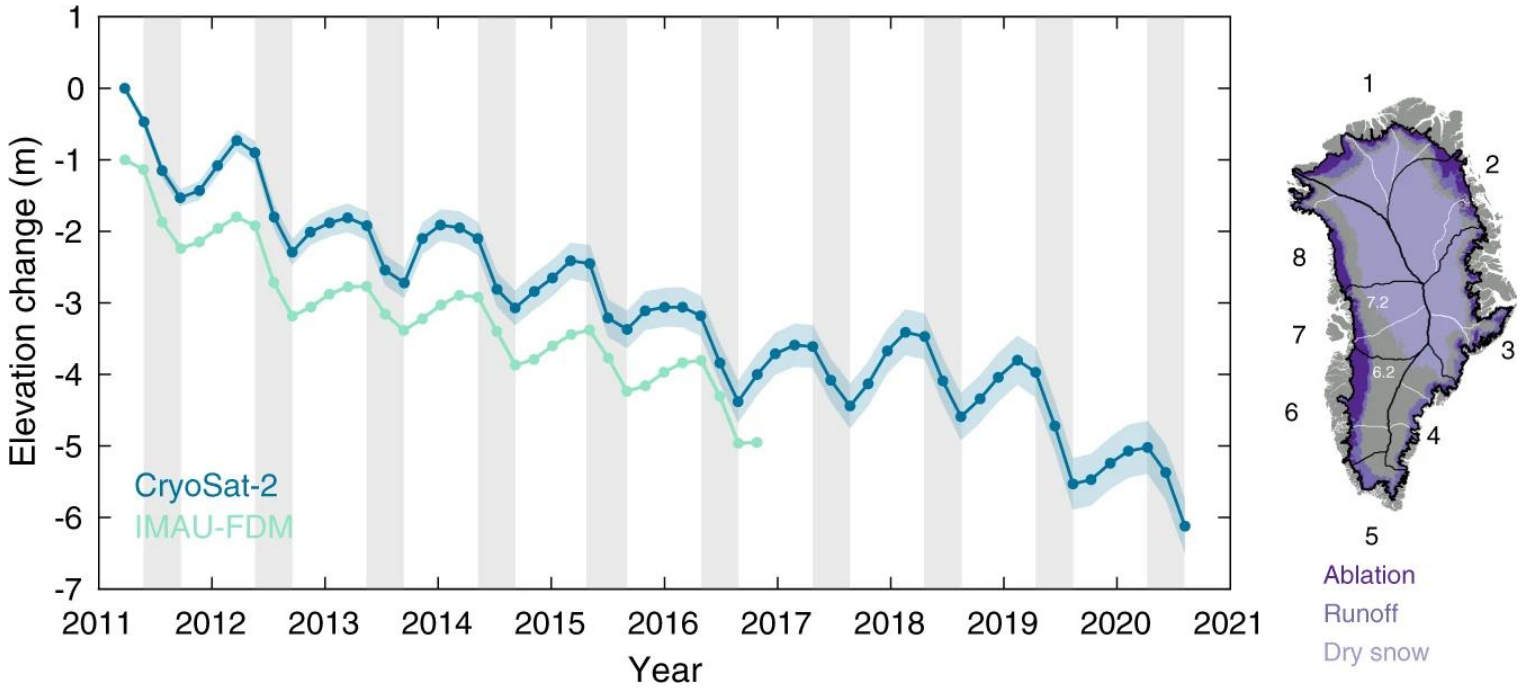


(Slater et al., 2021)

Measuring Surface Mass Balance Processes using Altimetry

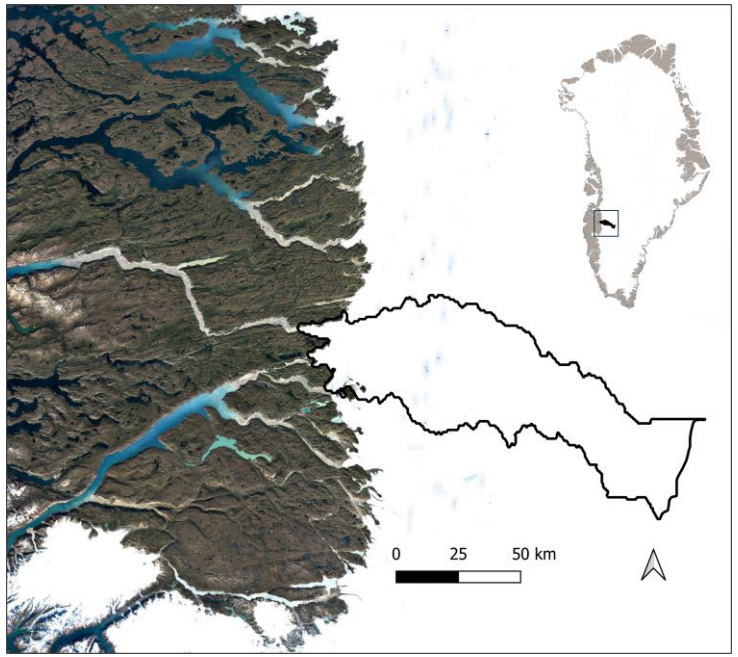


Watson catchment: 2.0% of total ablation zone of the GrIS

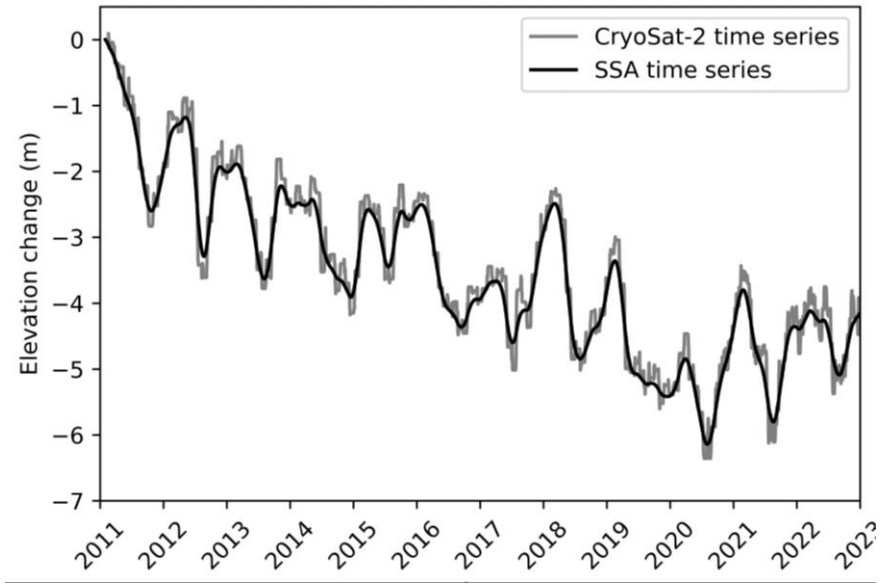


(Slater et al., 2021)

Measuring Surface Mass Balance Processes using Altimetry



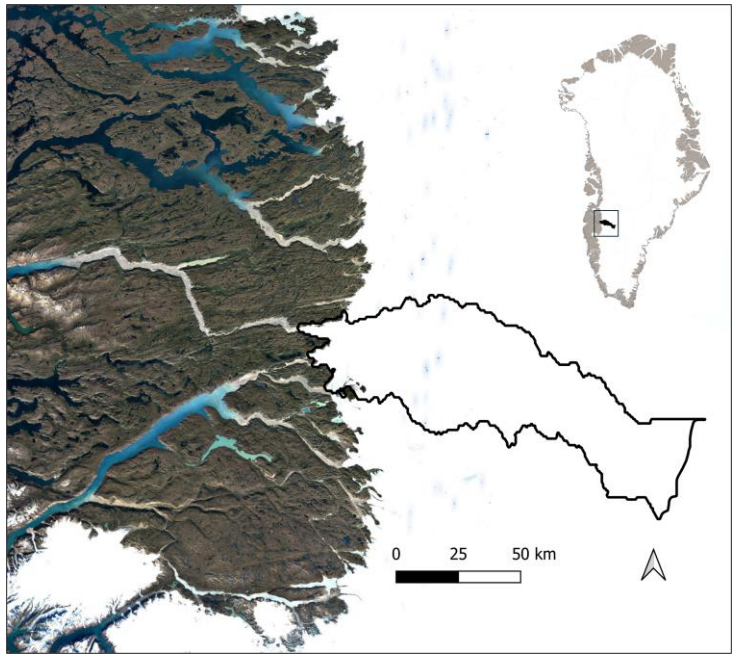
Watson catchment: 2.0% of total ablation zone of the GrIS



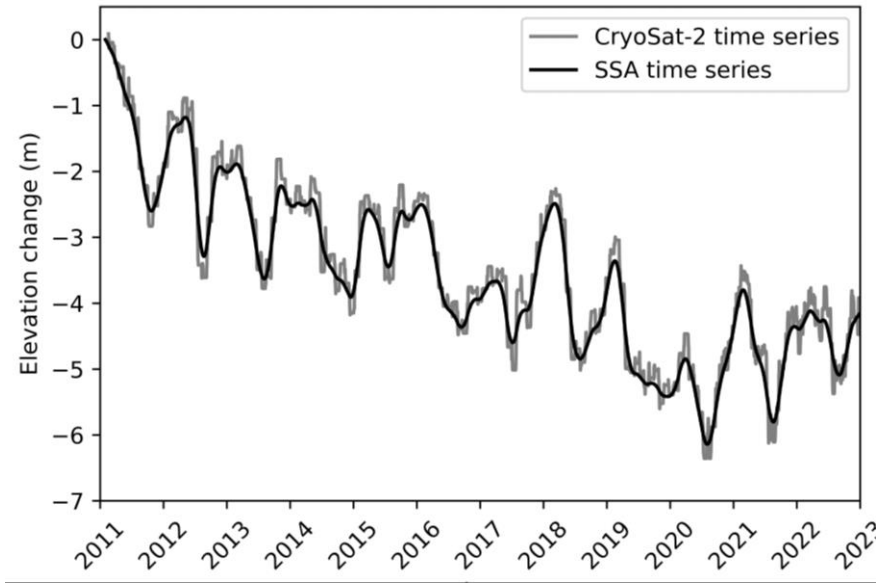
Method differences at catchment scale:

- Ingestion of Cryo-TEMPO data.
- Avoids needing to use Gaussian smoothing used in previous solution.
- Implementation of sliding window instead of a static epoch average.
- Implementation of single spectrum analysis.

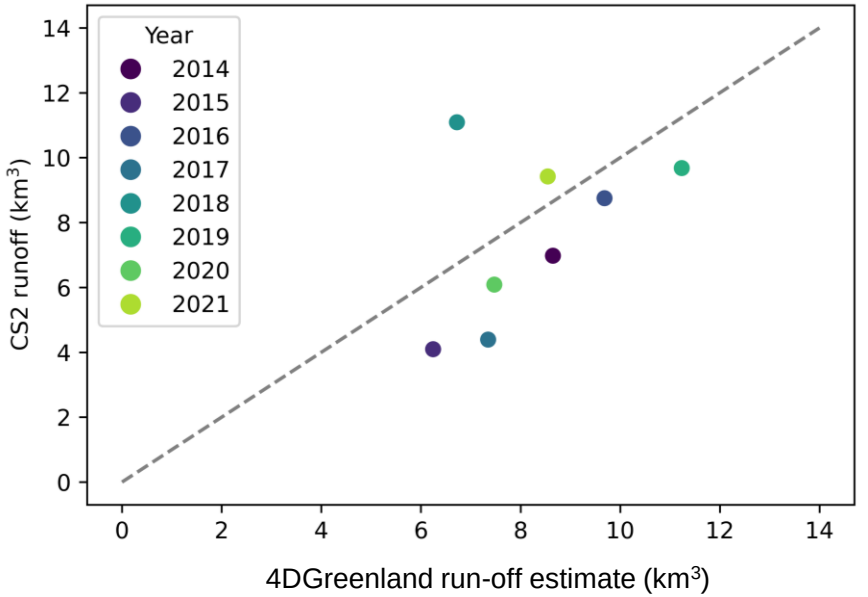
Measuring Surface Mass Balance Processes using Altimetry



Watson catchment: 2.0% of total ablation zone of the GrIS



4DGreenland integrated assessment surface run-off



Promising comparison to run-off derived in 4DGreenland integrated assessment (surface run-off only).

Potential to apply to other study sites.

Potential to extend to other altimeters.

Future Opportunities

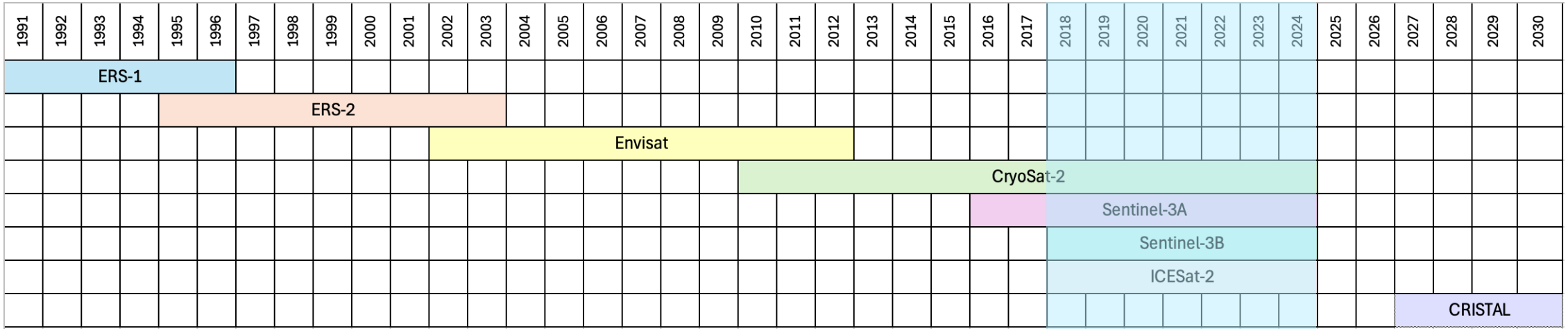
In future, work towards:

- Multi-sensor approach to monitor surface mass balance processes and inform process-based understanding of mass loss.
- Work towards model-observation integration towards future predictions.

Future Opportunities: Data Assimilation

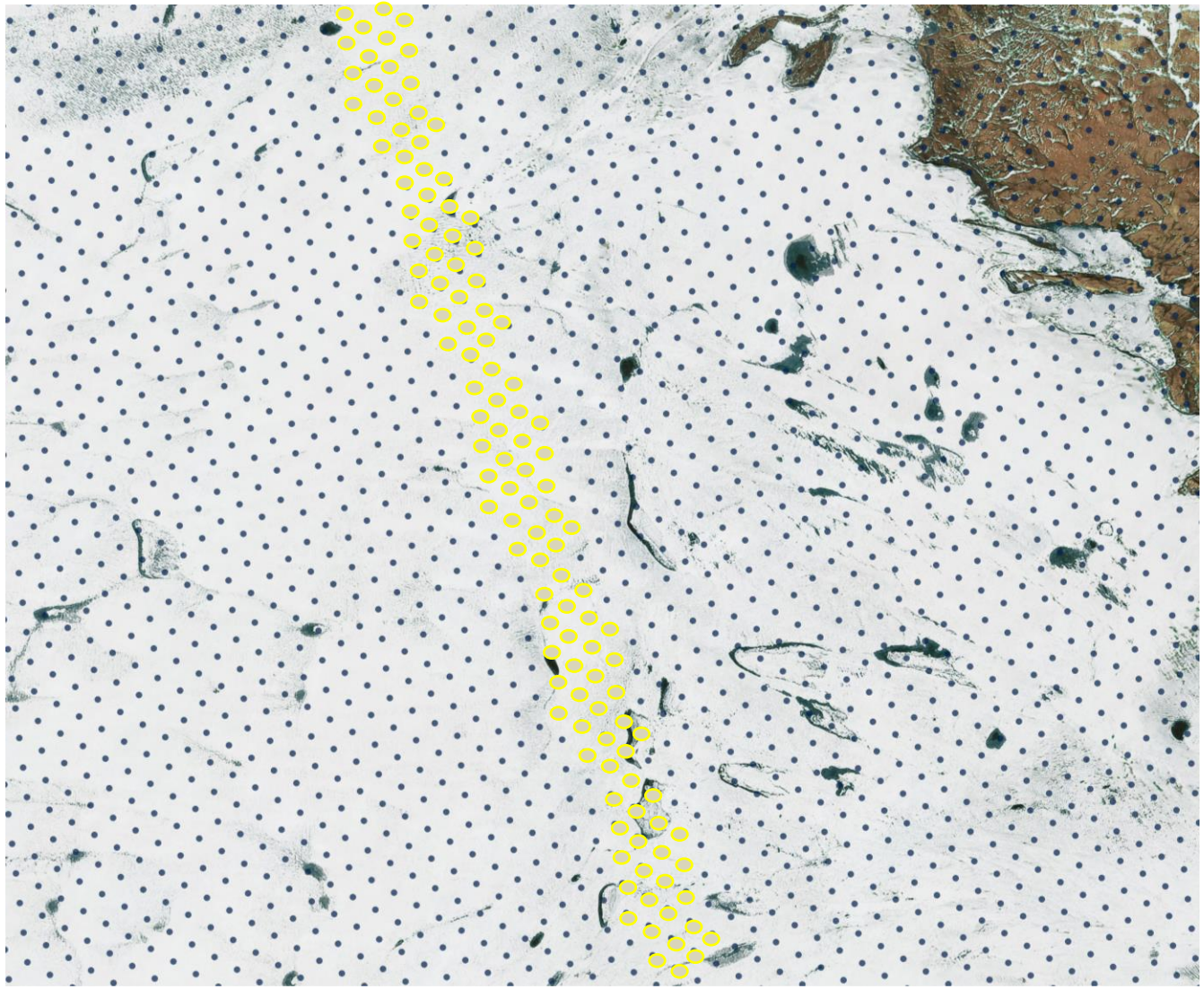
Current approaches are:

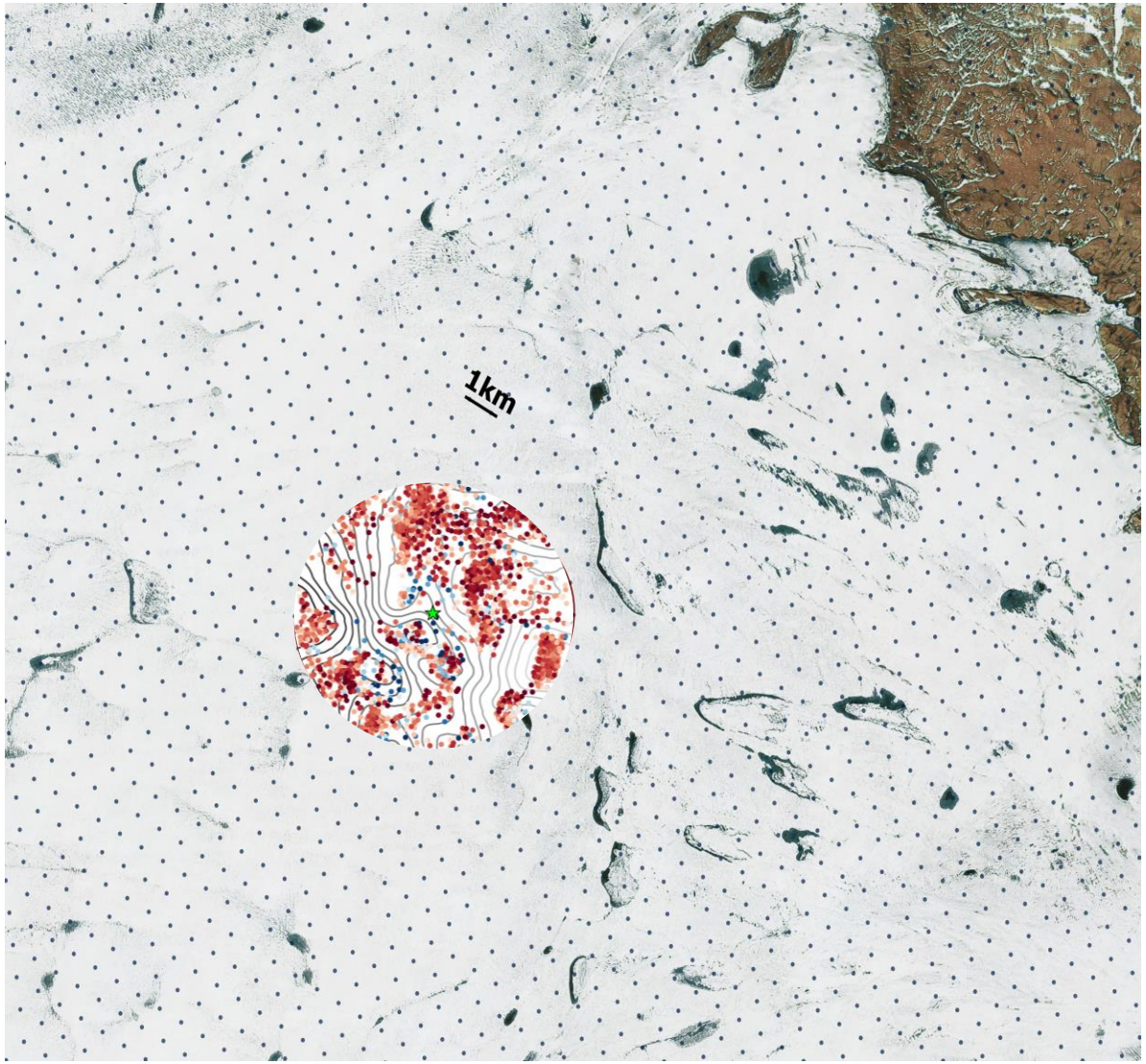
- Built for a single in-orbit mission at any one time.
- Difficult to handle parallel missions with different uncertainties.
- Not naturally suited to operational frameworks.

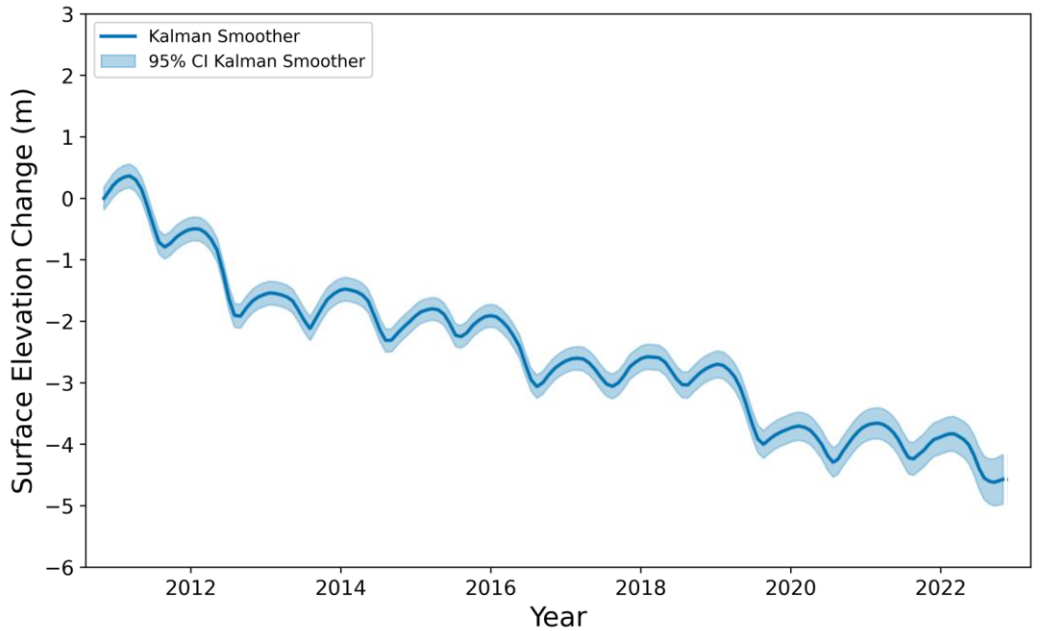


Ultimately we want to assimilate altimetry into physical ice sheet models to support future forecasts and projections.

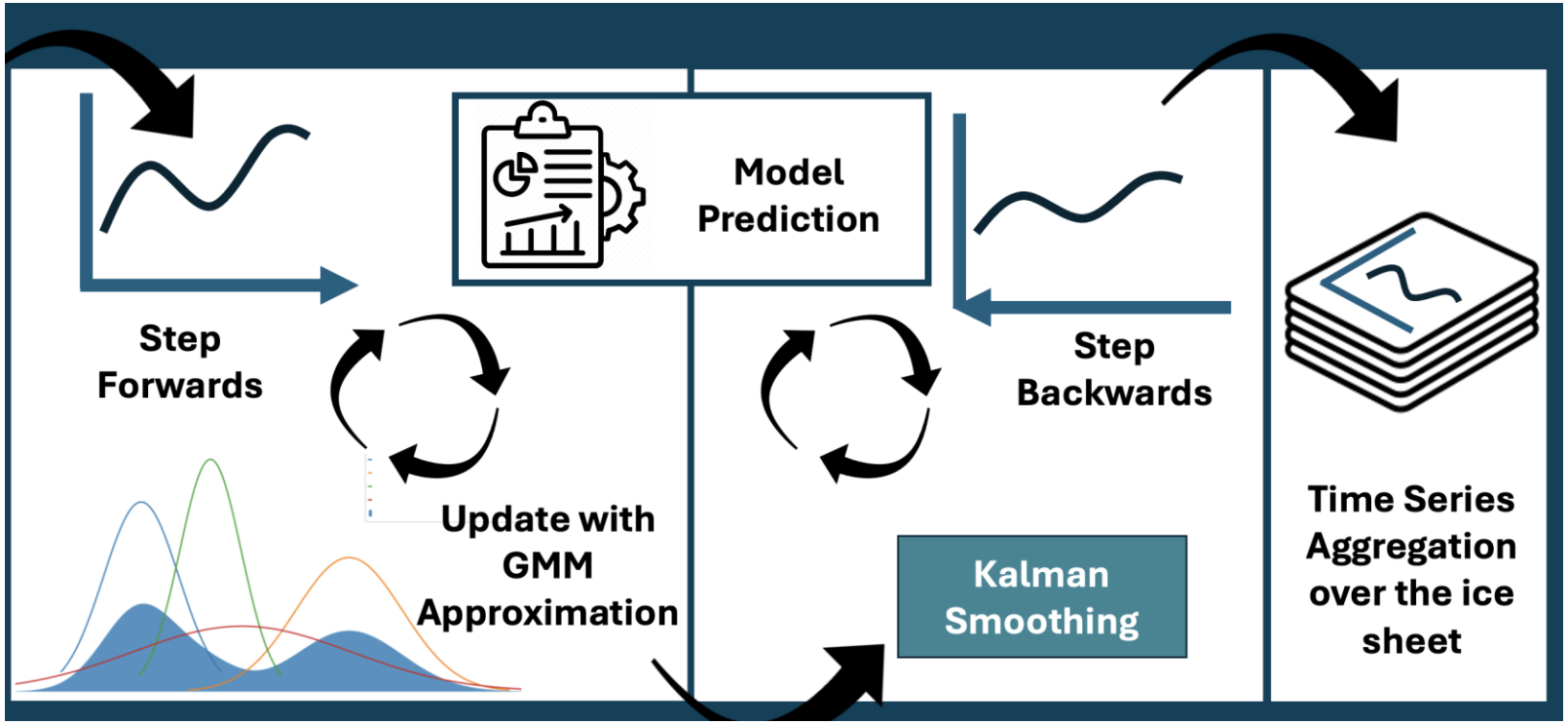
Kalman Filtering + Gaussian Mixture Modelling




1km


Kalman Smoother
95% CI Kalman Smoother
Surface Elevation Change (m)
3
2
1
0
−1
−2
−3
−4
−5
−6
2012
2014
2016
2018
2020
2022
Year

Future Opportunities: Data Assimilation



- Robust uncertainty quantification.
- Extension to multiple missions.
- Framework for future integration of ice sheet model.

Active Areas of Research

1. Wintertime lake evolution

2. Constraining volume estimates - method development – potentially using deep learning.

3. Sub-glacial lakes: GLOBE.

4. Kalman Filters.

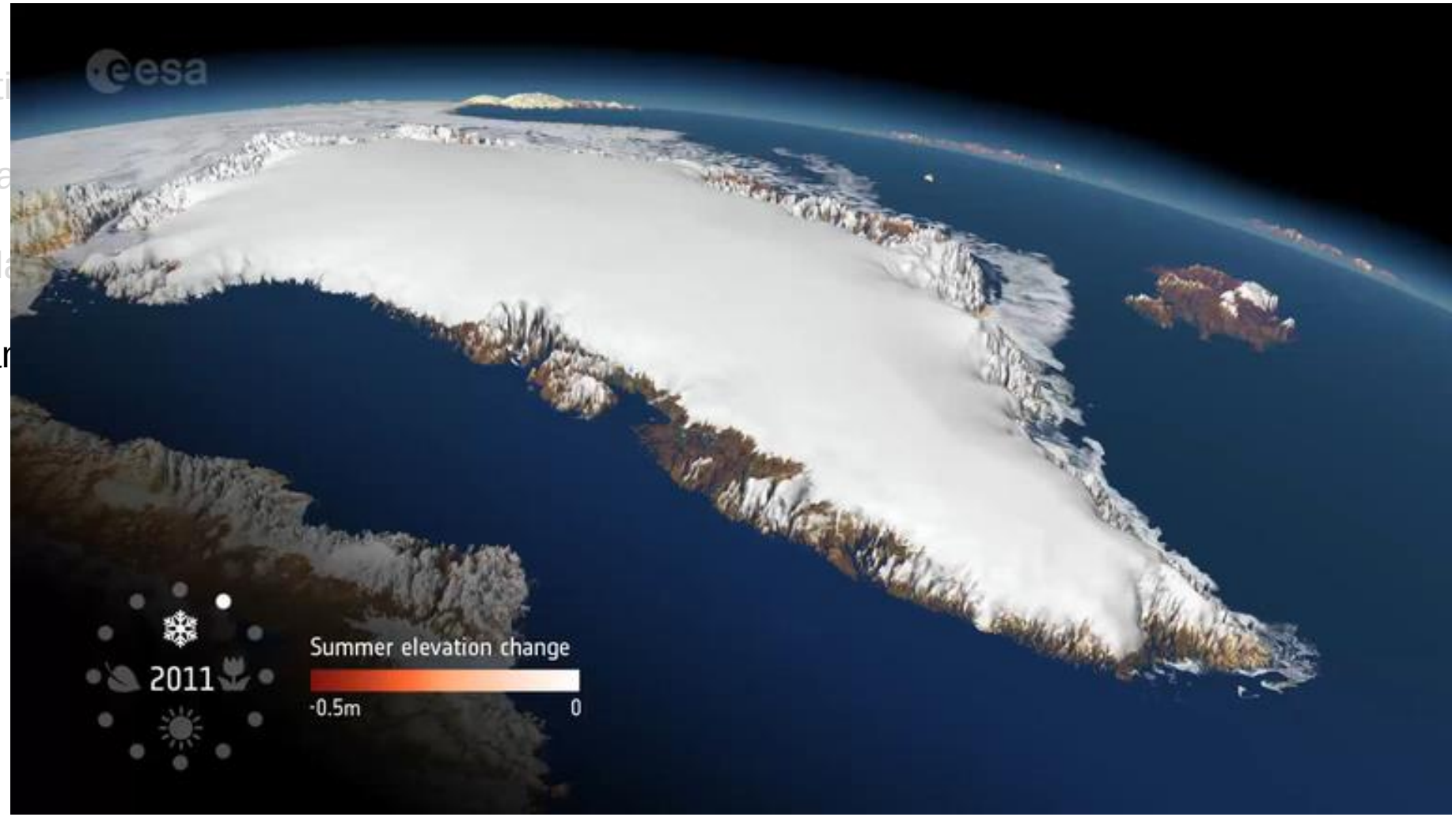
Active Areas of Research

1.Winterti

2.Constra

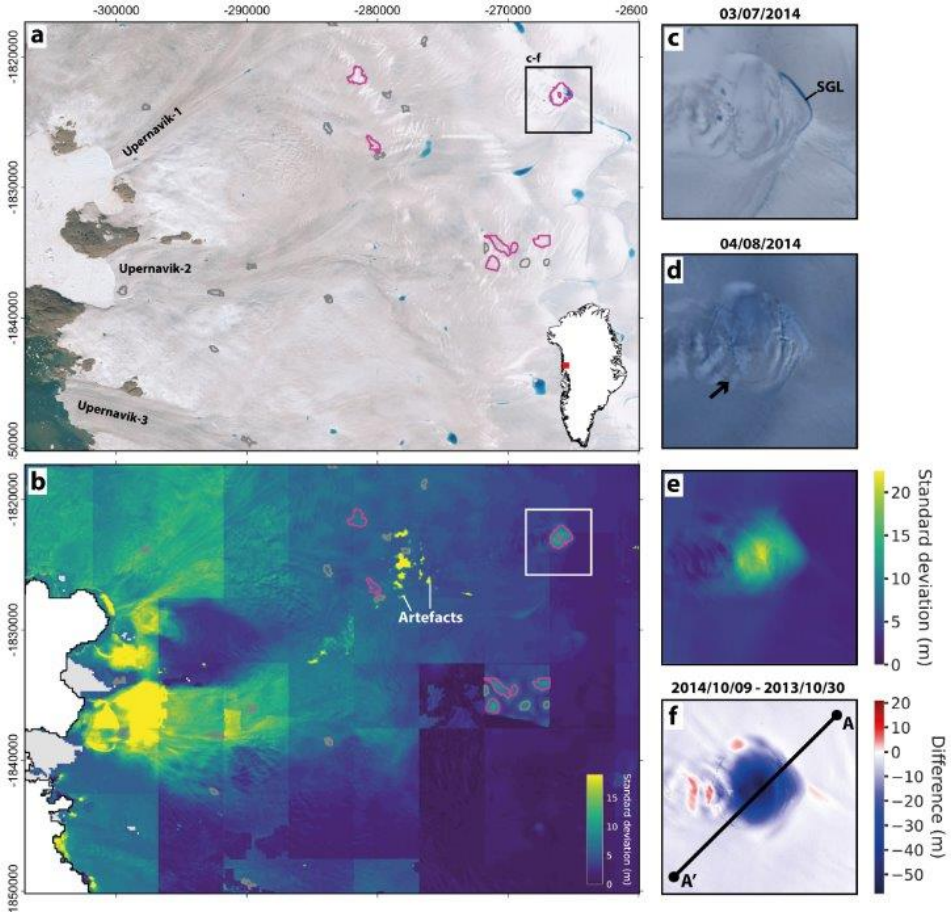
3. Sub-gl

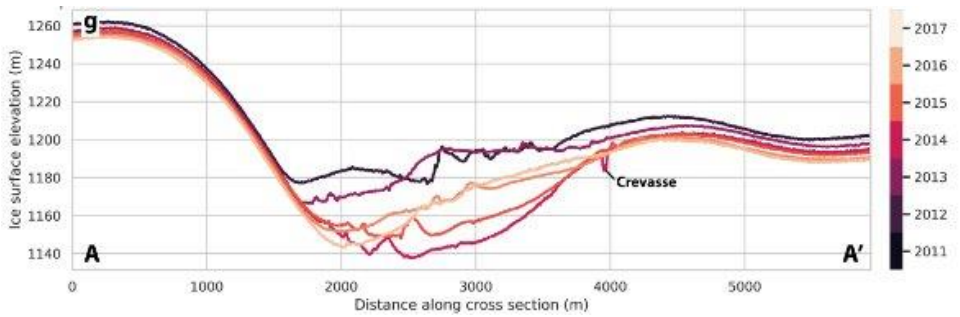
4. Kalmar



Supraglacial Hydrology: Opportunities

Sub-glacial lakes: The Greenland Subglacial Lake Observatory (GLOBE ERC project)





Bowling et al., 2019.