Perspectives from monitoring Greenland Ice Sheet mass balance through the PROMICE and GC-Net programmes

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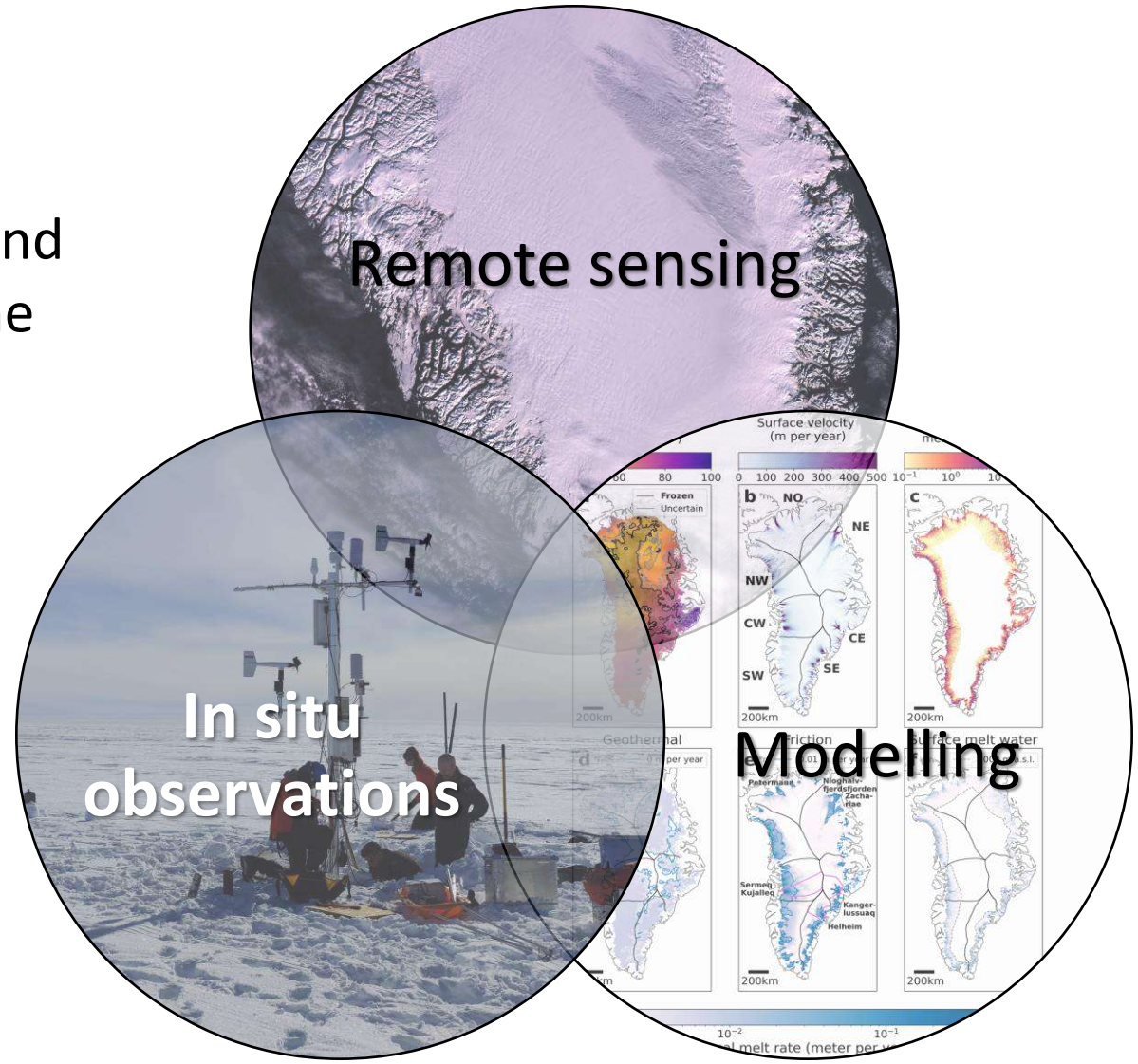
EU Polar Science Week Session:
Gaps and Opportunities of Future Sensors in Monitoring Ice Sheet Dynamics, Discharge and Surface Processes

The PROMICE|GC-Net Programmes

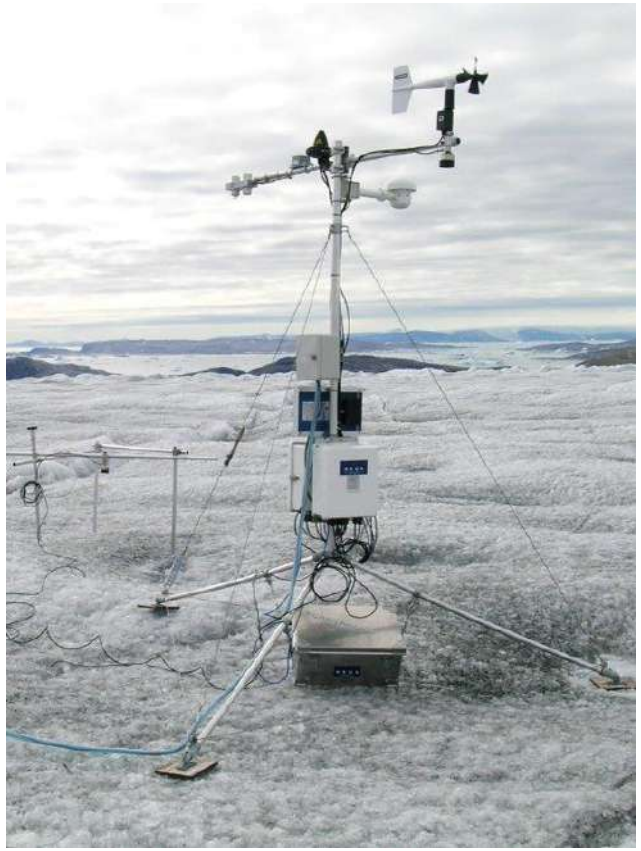
Task

Quantify and understand the mass balance of the Greenland Ice Sheet

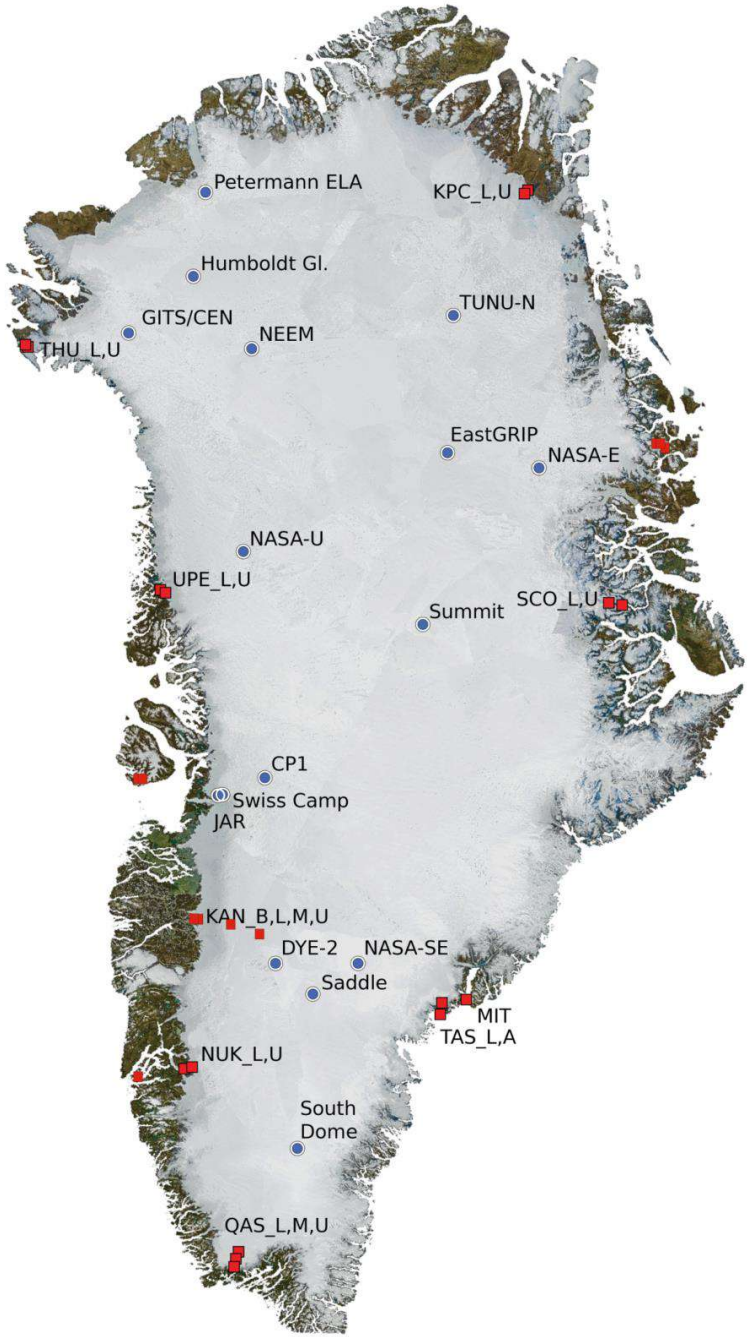


PROMICE

- Programme for Monitoring of the Greenland Ice Sheet
- Ice sheet margin monitoring since 2007
- One-boom tripod design



Fausto et al. (2021)



GC-NET

- Greenland Climate Network
- Interior ice sheet monitoring since 1995
- Two-boom mast design
- GEUS assumed responsibility in 2020
- 15 new stations installed since 2021

Weather station measurements

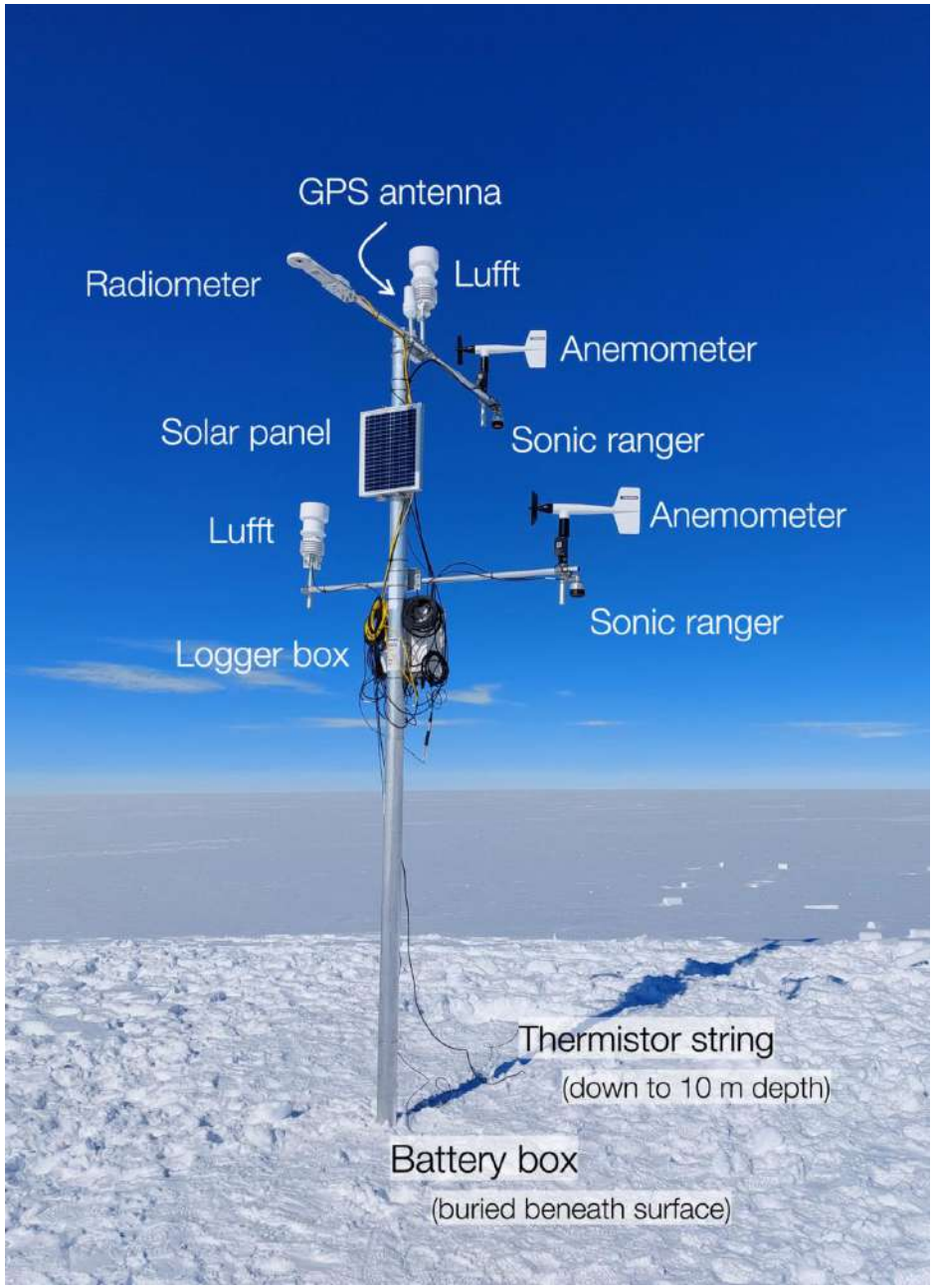


Figure: Anja Rutishauser, https://tinyurl.com/438ruhne

- Air temperature
- Relative humidity
- Wind speed and direction
- Precipitation
- Radiation (shortwave and longwave)
- Snow height
- Position/elevation (to 10 cm accuracy)
- Snow/ice temperature in the upper 10 m

i. 10-minute measurements collected from the field
ii. Hourly measurements transmitted via Iridium

Weather station measurements

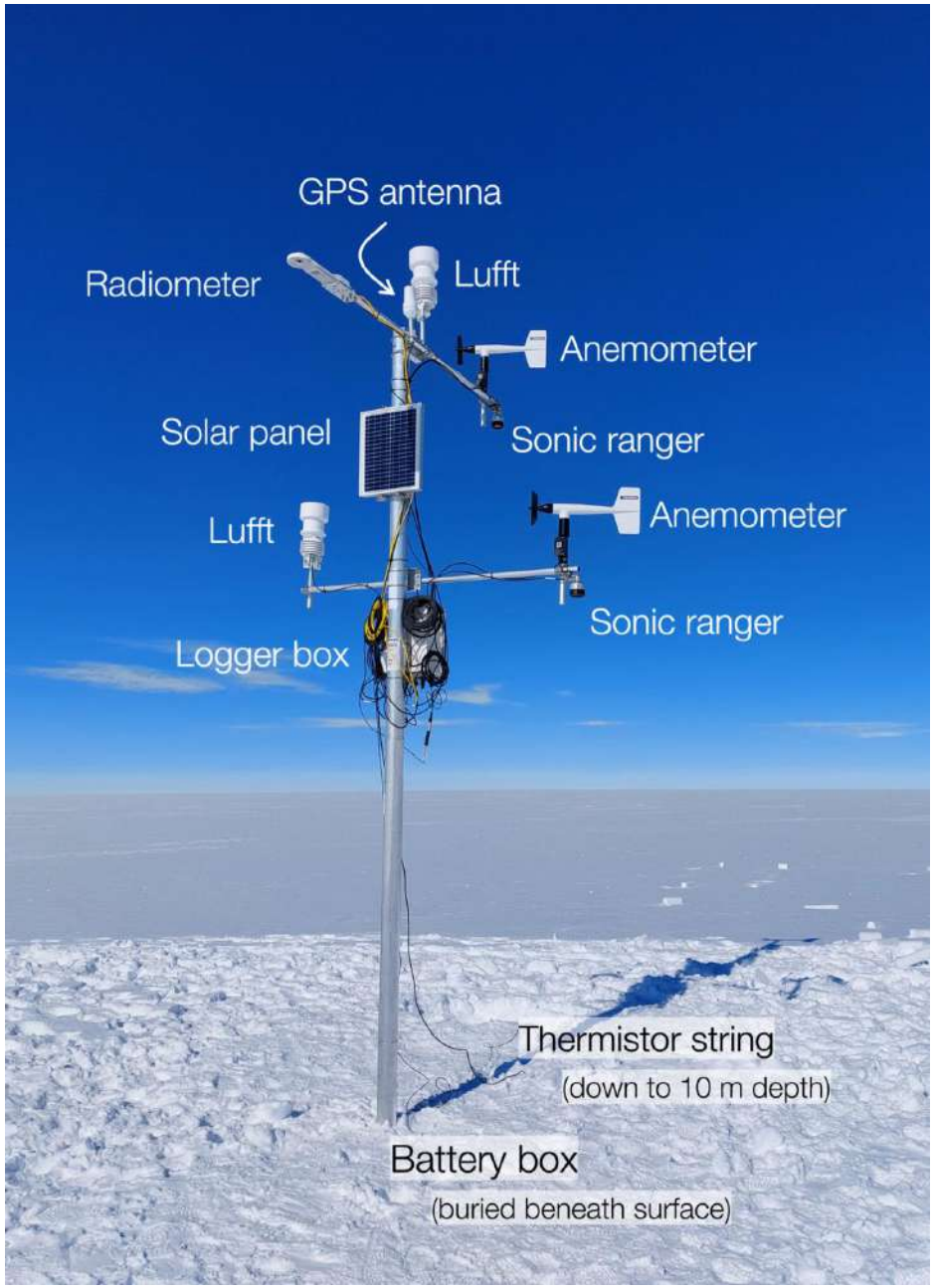


Figure: Anja Rutishauser, https://tinyurl.com/438ruhne

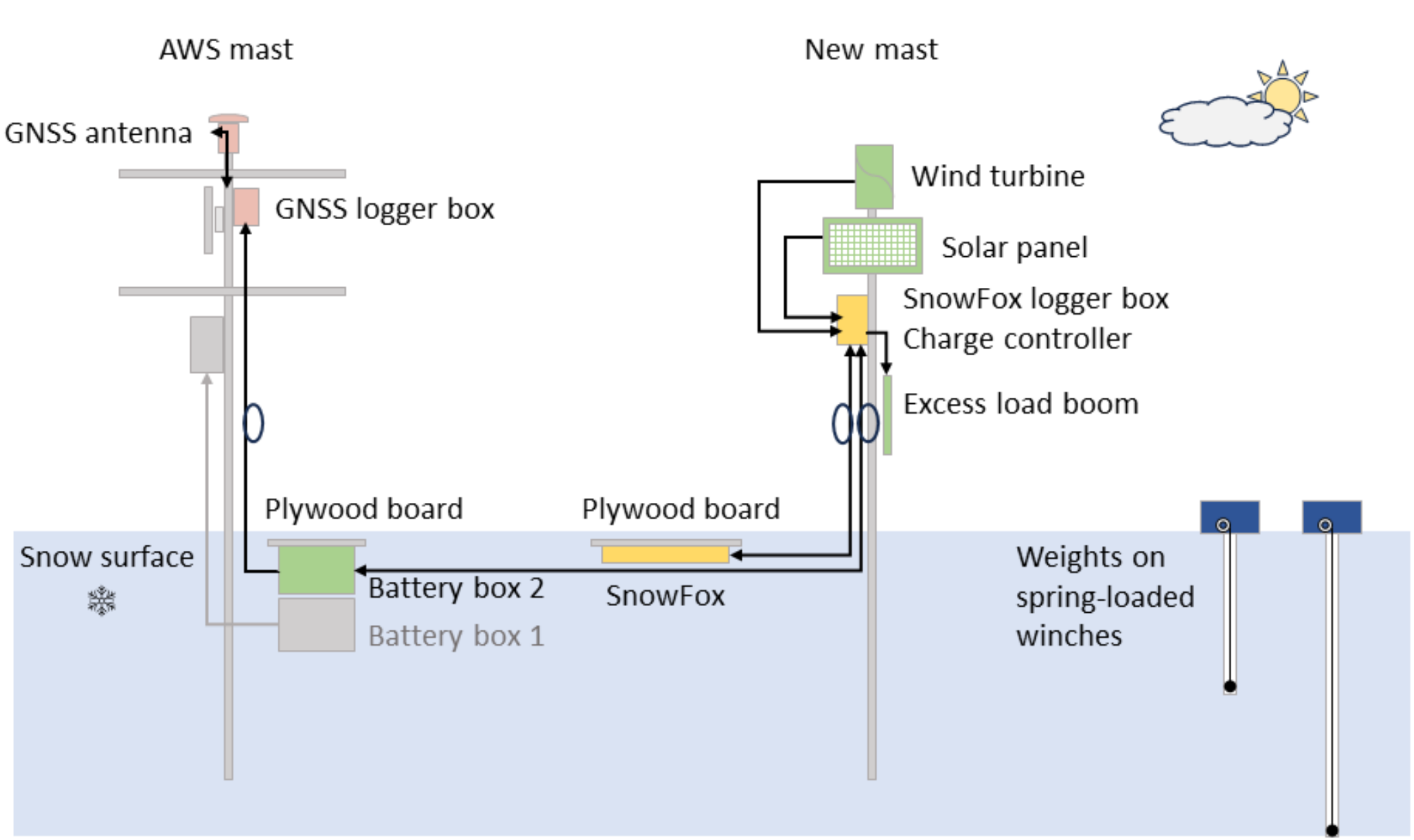
Snow density & temperature profile measured at GC-Net stations during annual field visits

Stations try to be visited each year to:

- Perform station maintenance
- Collect data
- Switch out old/faulty sensors
- Re-adjust station installation

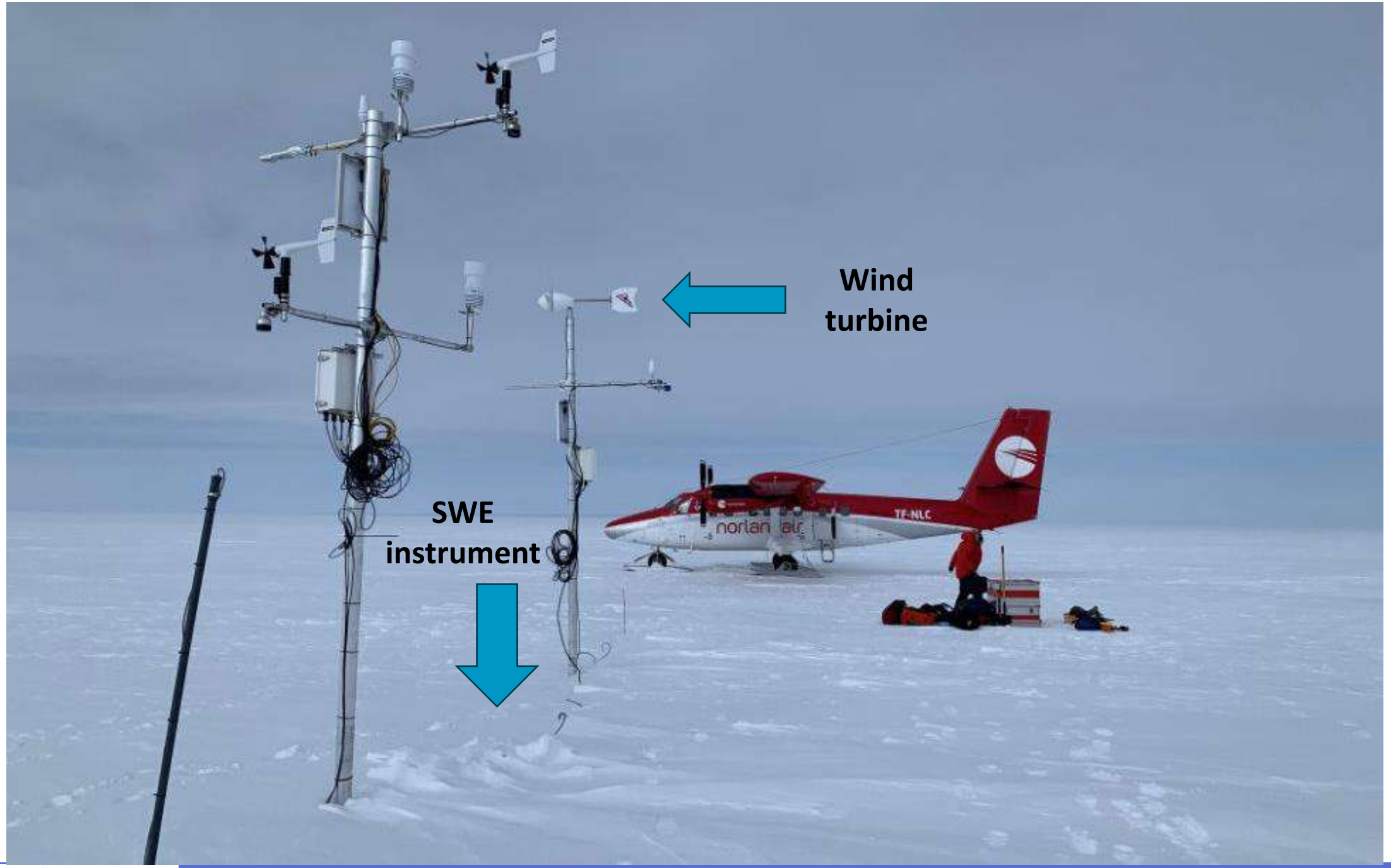
Snow-water equivalent & firn compaction

PROMICE | GC-NET

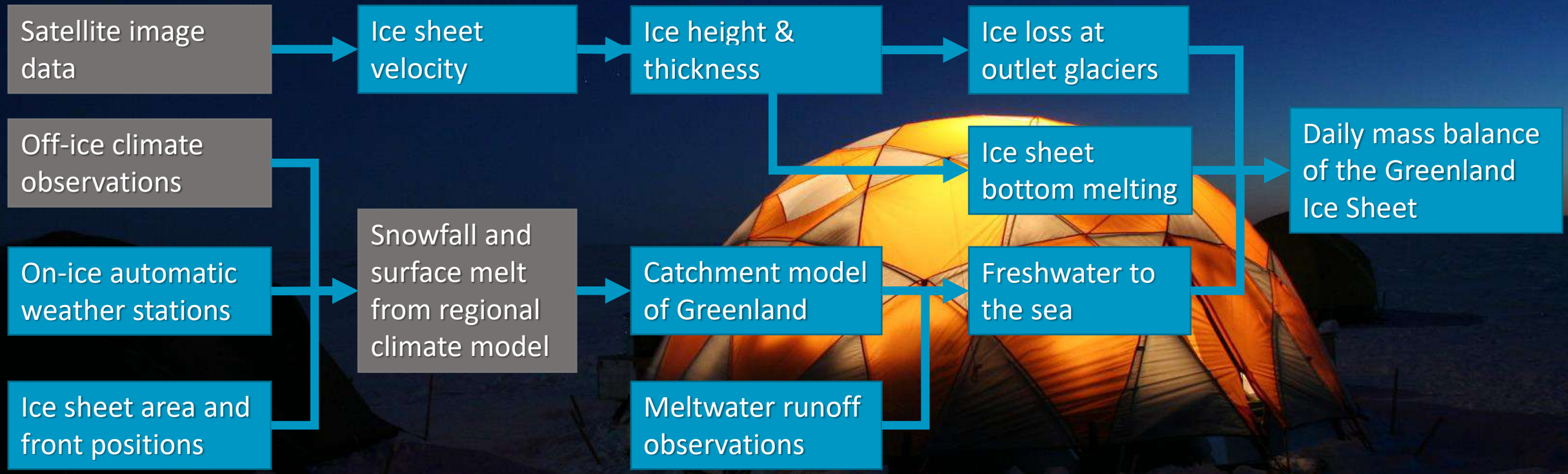


Colour legend

- Additional power system
- GNSS system
- SnowFox system
- Snow compaction

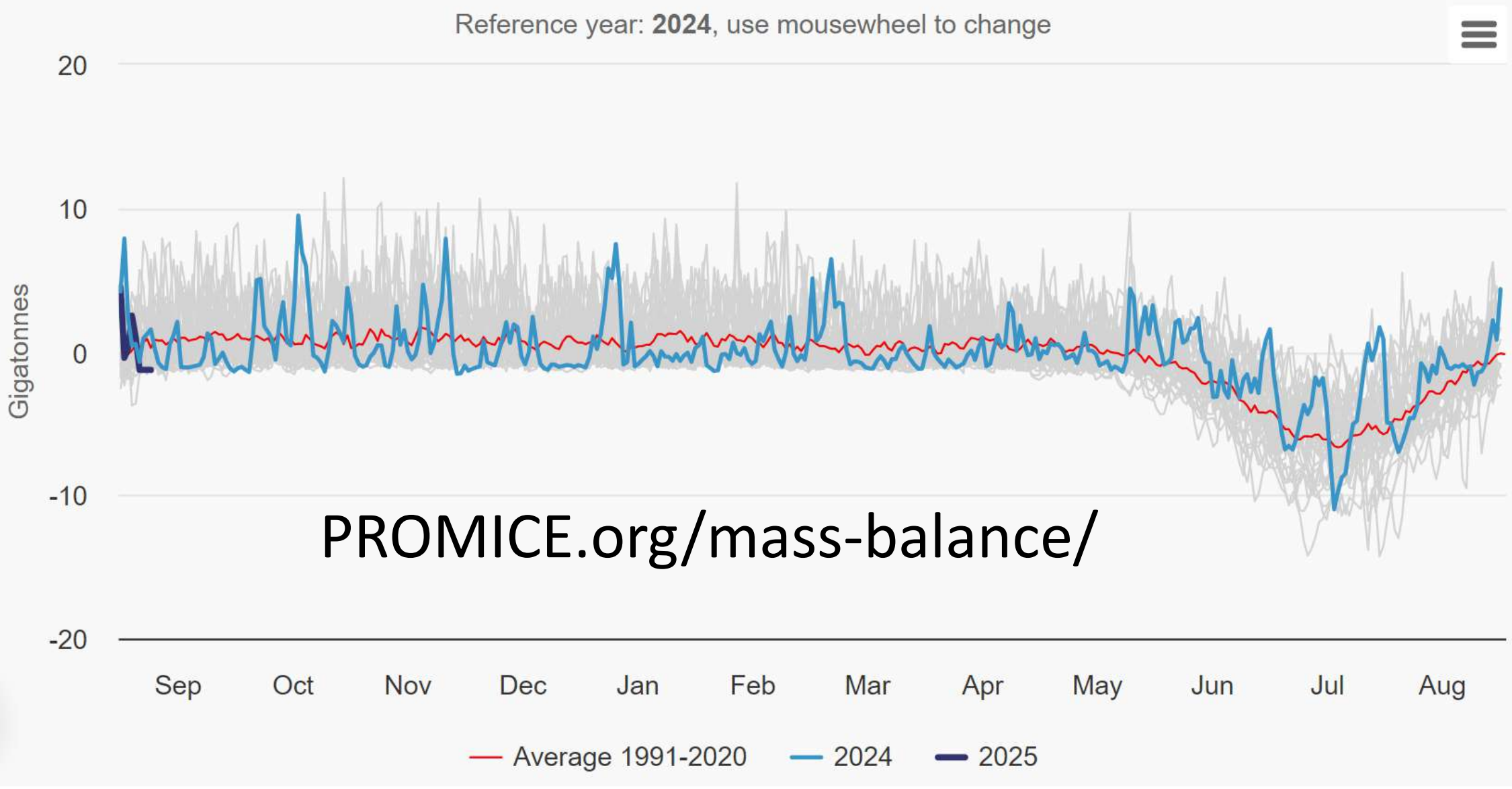

Wind
turbine
SWE
instrument
TF-NLC
norlandair

How we derive ice sheet mass balance



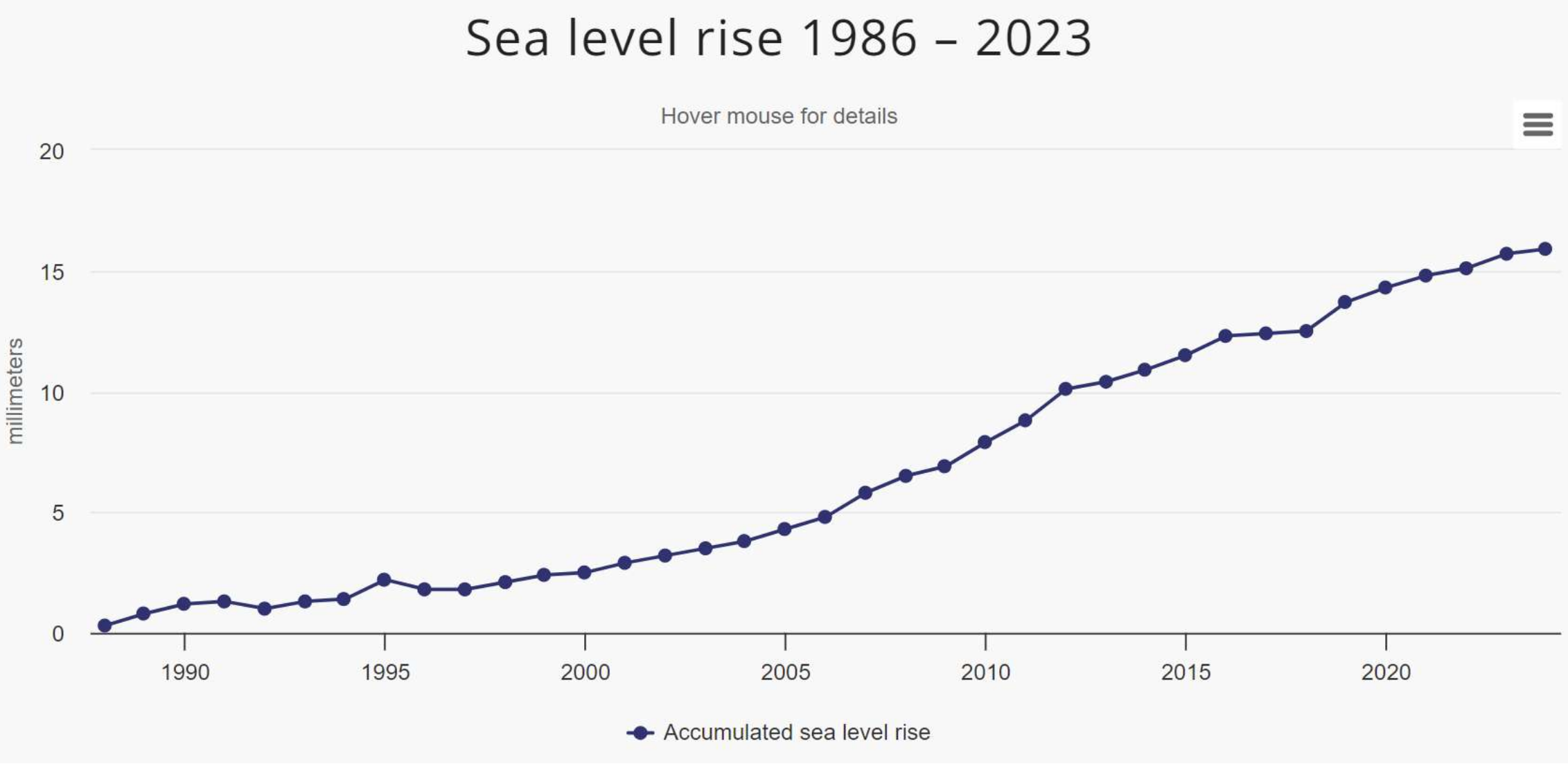
PROMICE | GC-NET

Ice sheet mass balance per Arctic hydrological year

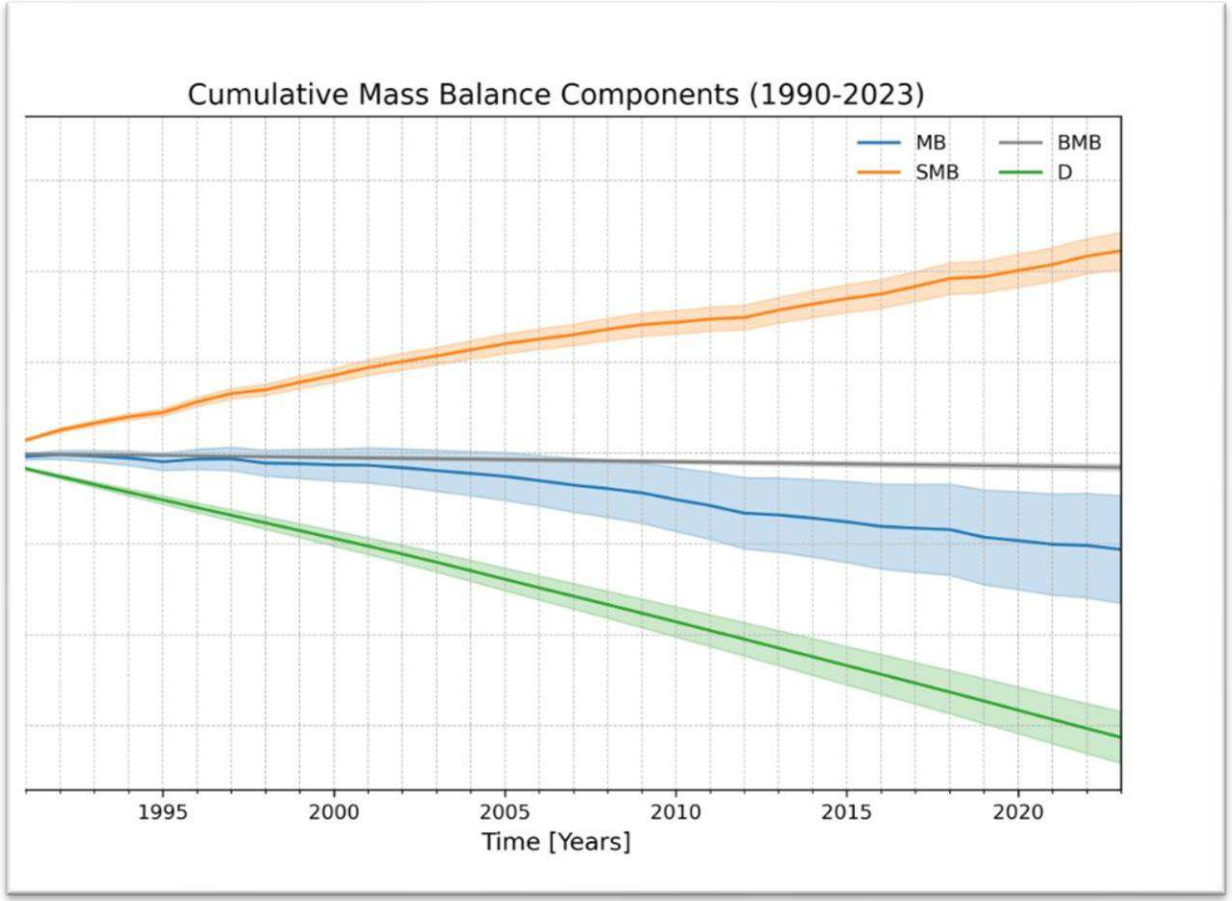


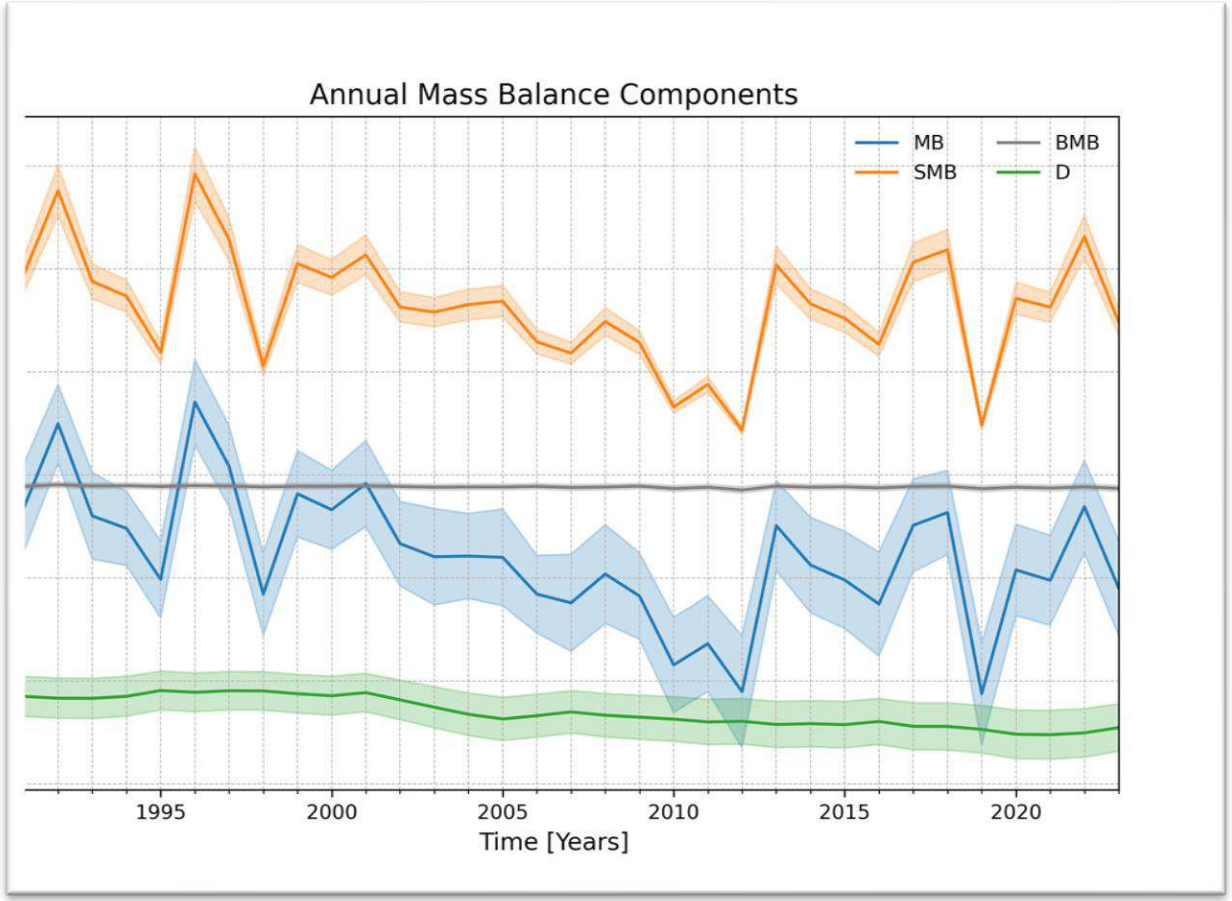
PROMICE.org/mass-balance/

Greenland Ice Sheet melt contribution to sea level: 15 mm since 1986

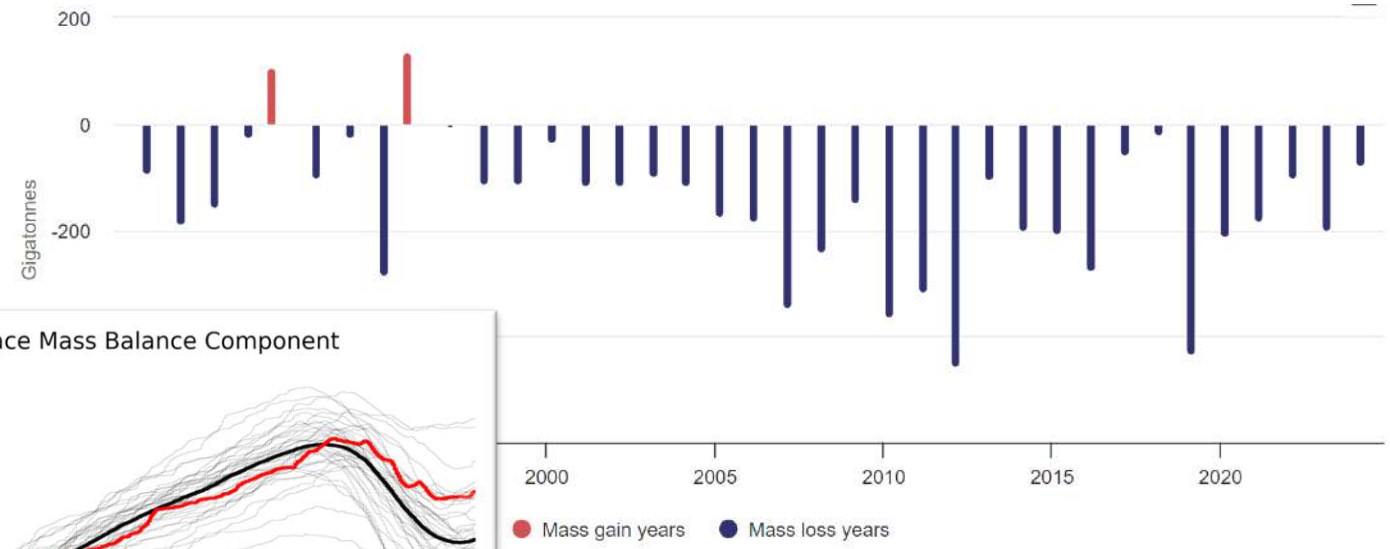


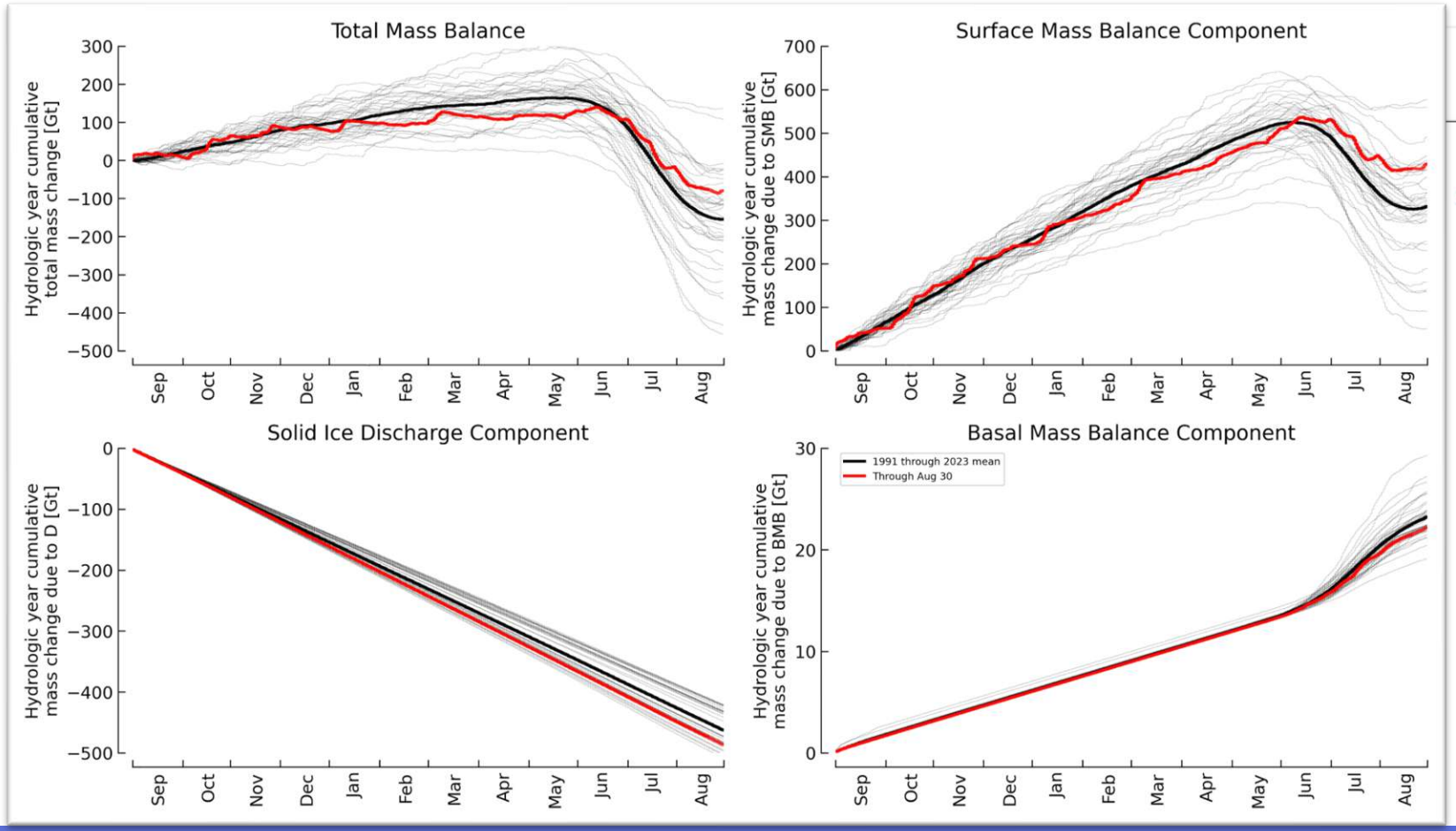
Total Mass Balance of the Greenland Ice Sheet:
MB = SMB + BMB + D





The mass balance of the Greenland Ice Sheet for the hydrological year 2024

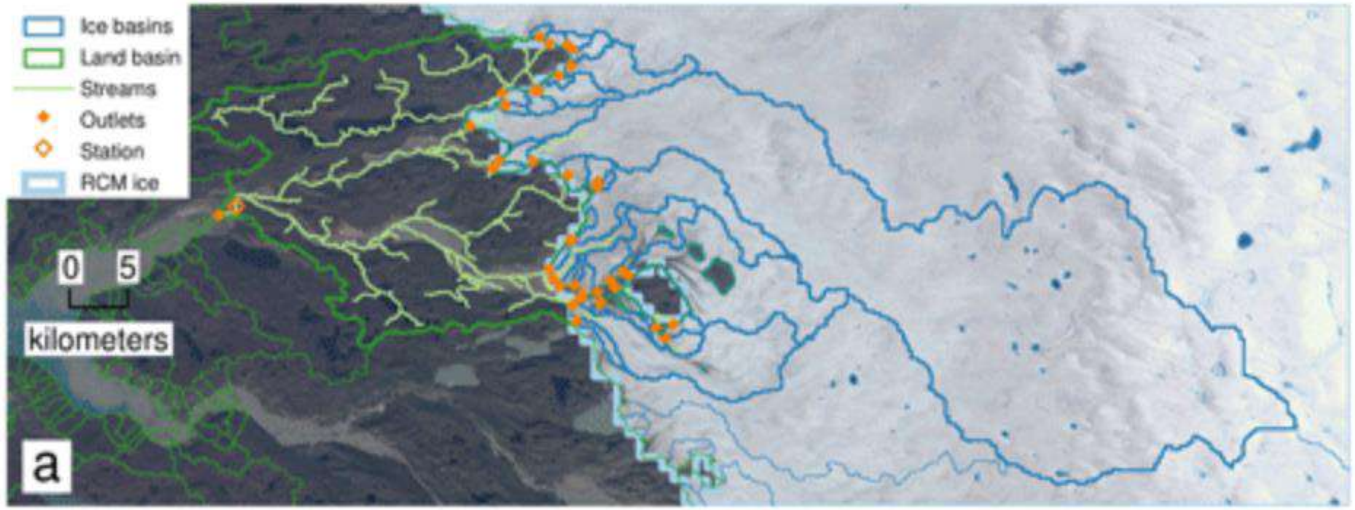


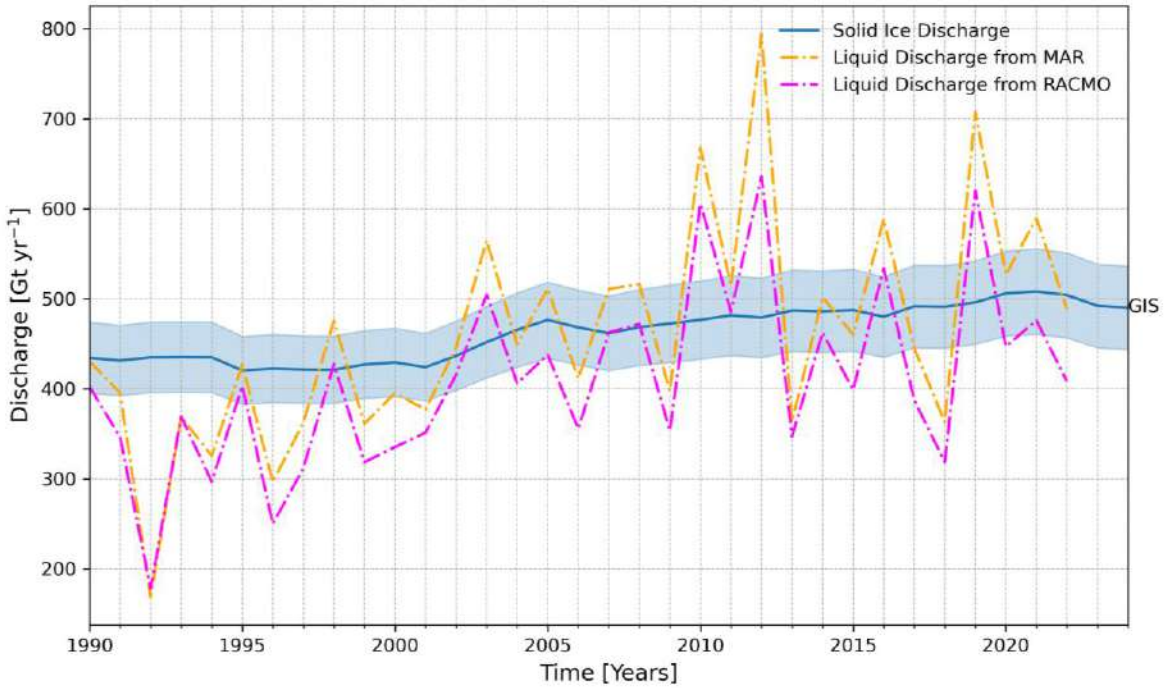


2024 was less negative than the past five years due to a more positive surface mass balance, balancing out the higher-than-average dynamic mass loss

Freshwater flux from the surface of Greenland

- Solid ice (D) and liquid runoff have a comparable contribution





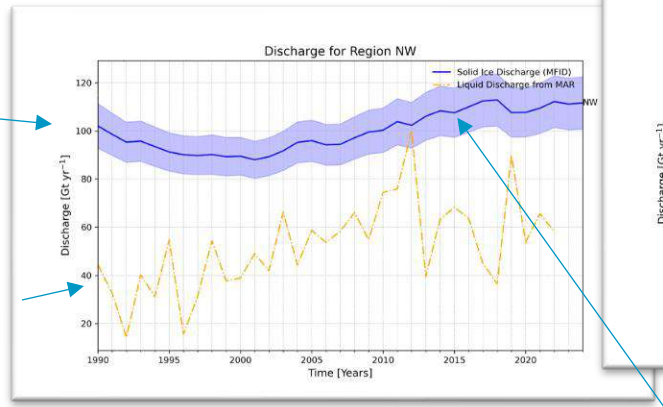
Mankoff et al., 2020: Greenland liquid water discharge from 1958 through 2019

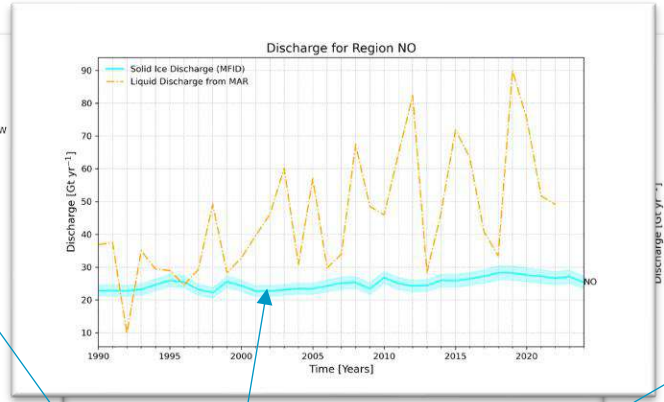
Karlsson et al., 2023: A data set of monthly freshwater fluxes from the Greenland ice sheet's marine-terminating glaciers on a glacier–basin scale 2010–2020

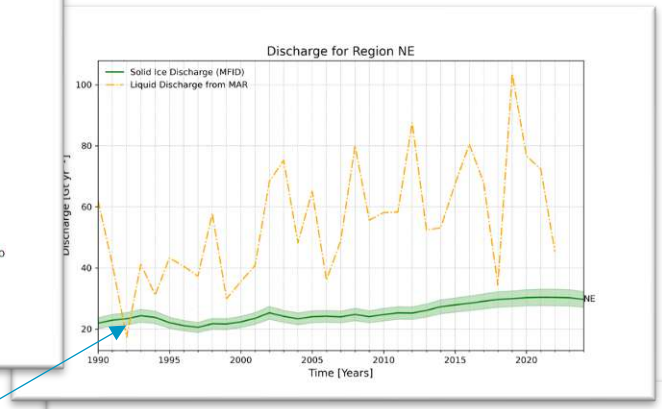
Freshwater flux from liquid and solid components on a regional scale

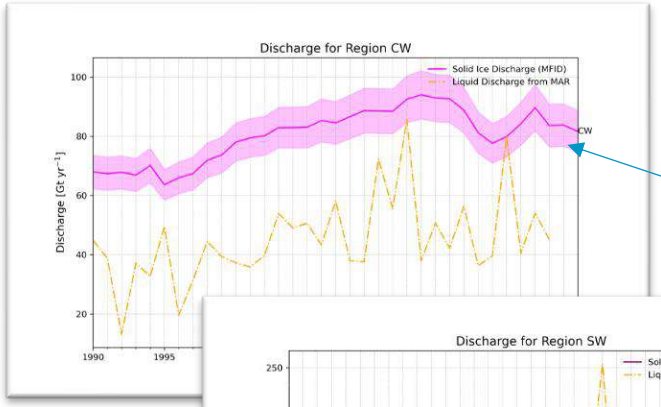
Solid

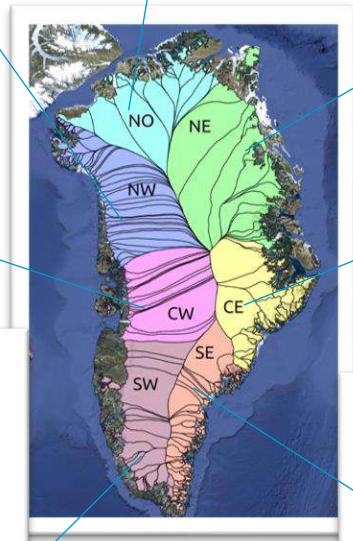
Liquid (MAR)

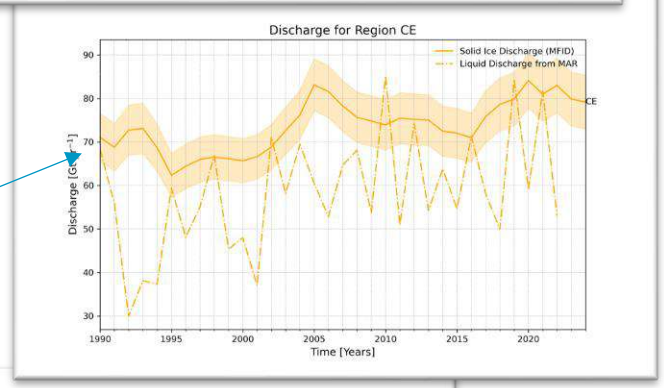


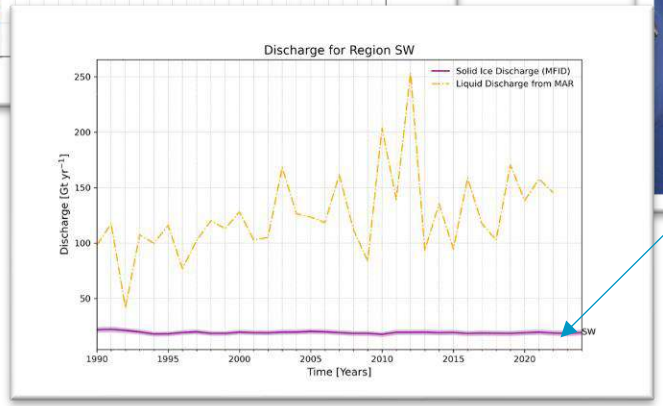


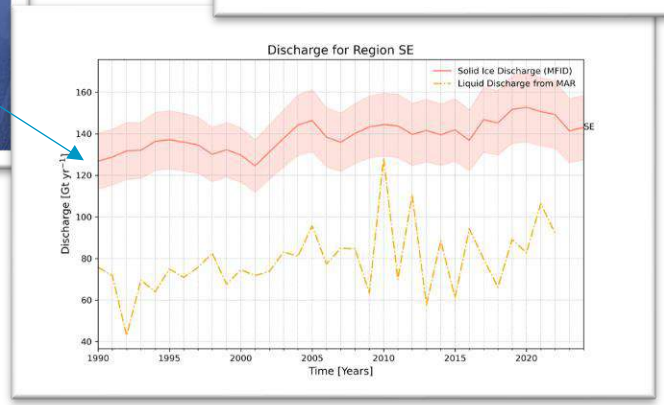




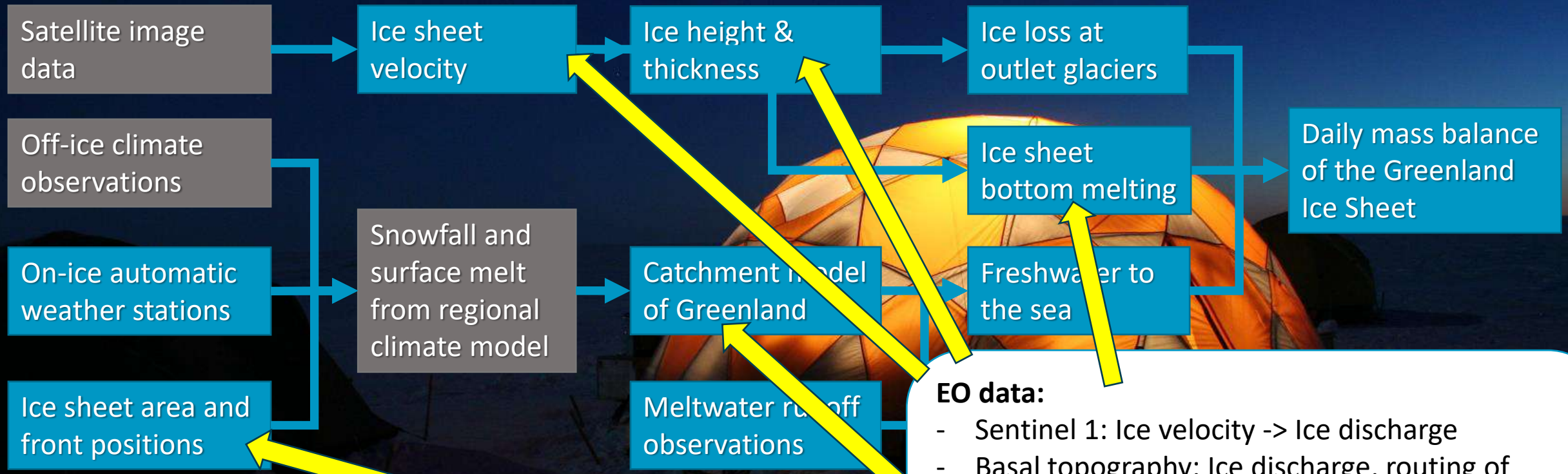








How we derive ice sheet mass balance



EO data:

- Sentinel 1: Ice velocity -> Ice discharge
- Basal topography: Ice discharge, routing of meltwater
- Surface topography: Ice discharge, routing of meltwater, catchment models to sum up our results
- Extent of glaciers: Flux gates

PROMICE | GC

On-going development

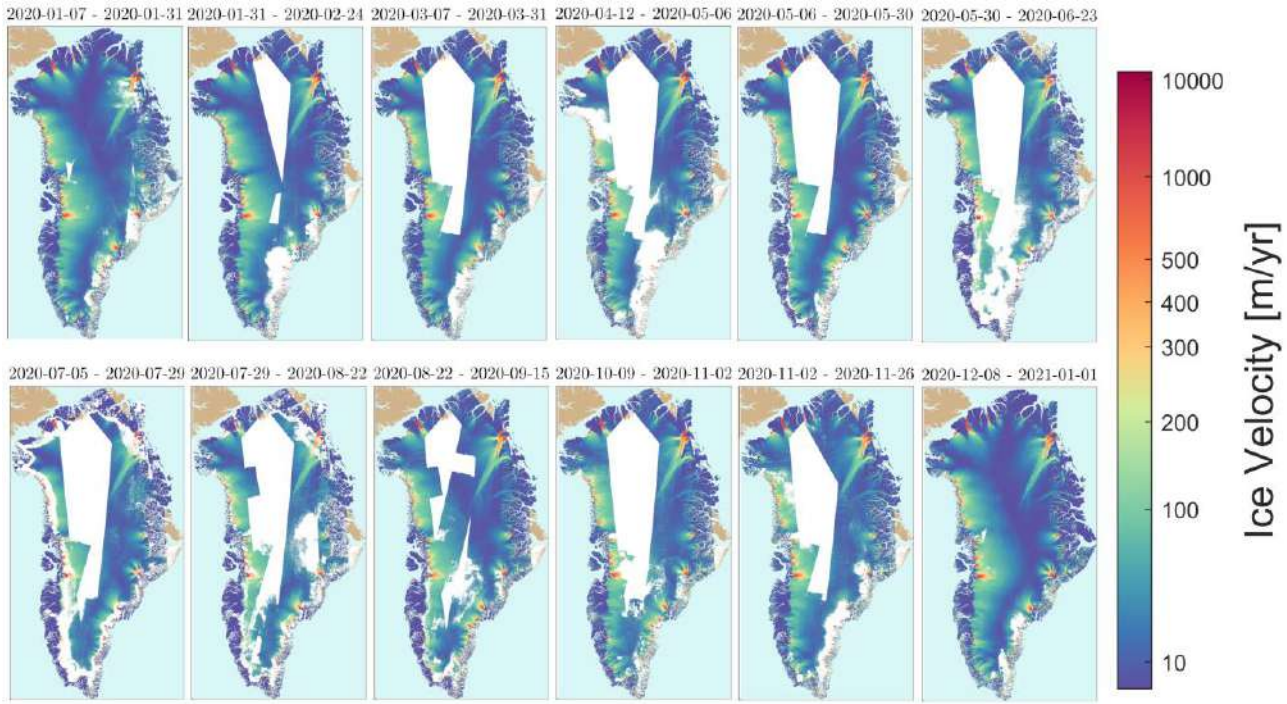
Higher temporal resolution and lower uncertainty in the solid ice discharge product

- Thickness changes on monthly timescales
- From static ice geometry mask to changing ice geometry

Monitoring ice flow

The PROMICE ice velocity Product

Examples of the PROMICE IV product over the year:



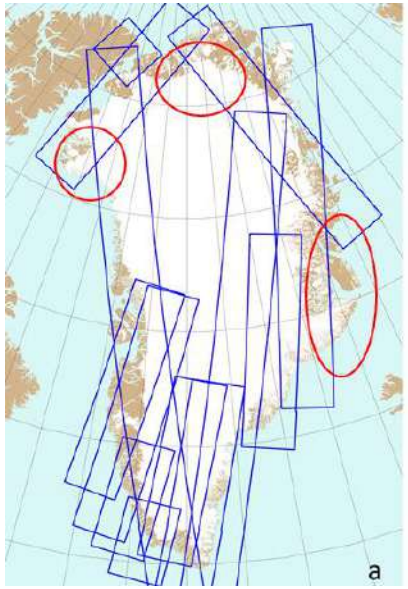
- The PROMICE ice velocity product is a time series of ice velocity mosaics that is freely available at: https://dataverse.geus.dk/dataverse/Ice_velocity
- A new mosaic is available every 12 days.
- Spatial resolution: 200 m
- Method: offset tracking
- The product spans the period: Jan 2016 – present
- Other products available: Winter maps and a 5-year-average map

- Based on Sentinel-1 SAR data.
- Each product spans two cycles of Sentinel-1A (i.e. 24 days) including all available 6 and 12 day pairs
- Details: https://essd.copernicus.org/articles/13/3491/2021/

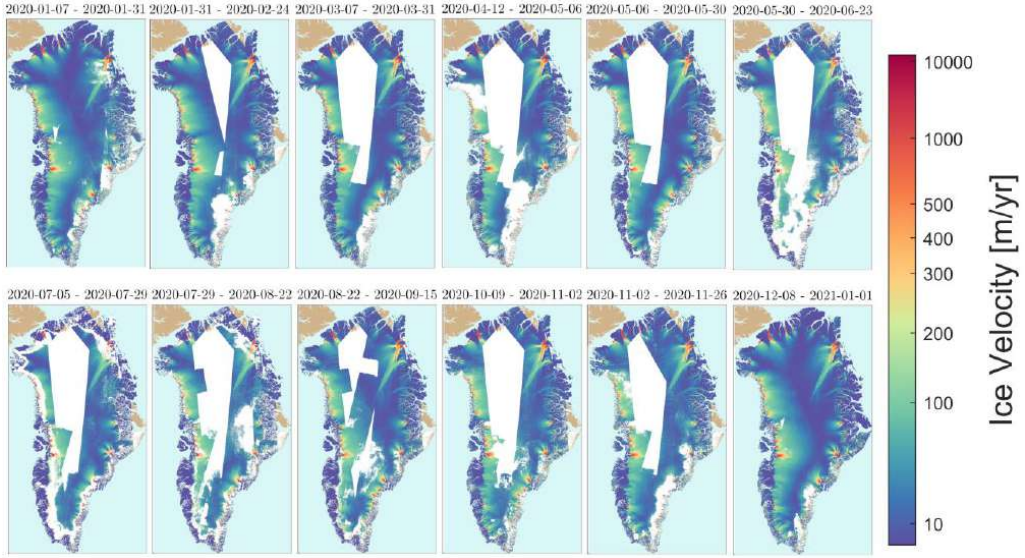
Gaps

Since the failure of Sentinel-1B the ice velocity product is based on 12 day pairs only from 1A resulting in lower spatial coverage:

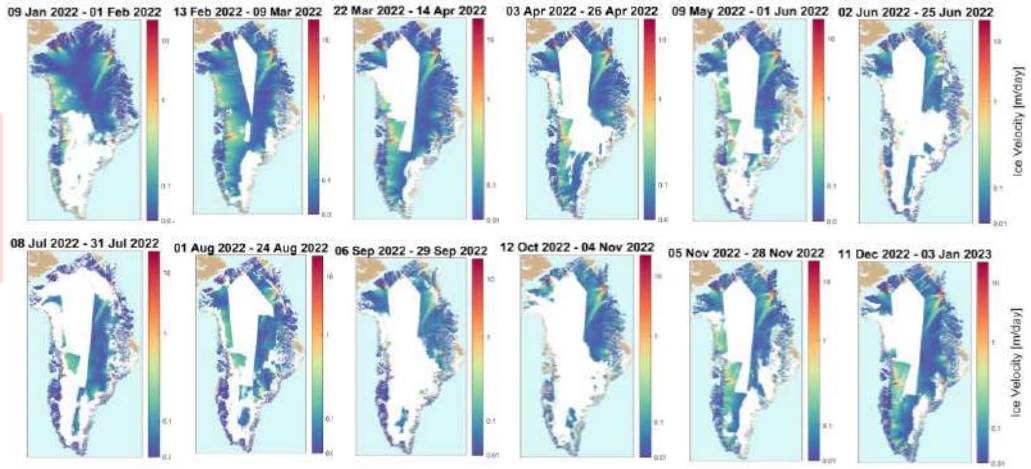
Typical IW mode coverage



2020:
Sentinel-1 A&B
6 and 12 day pairs



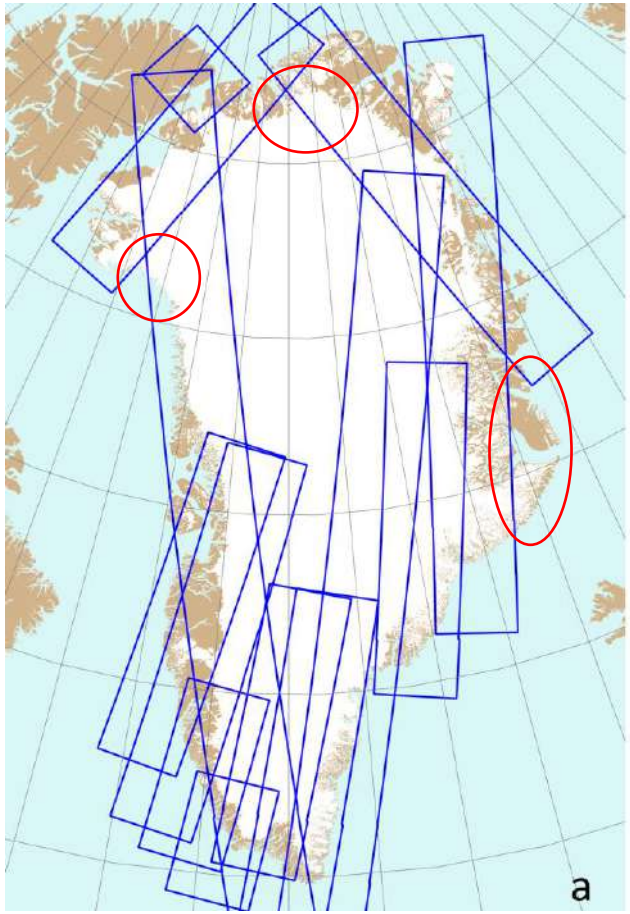
2022:
Sentinel-1 A
12 day pairs only



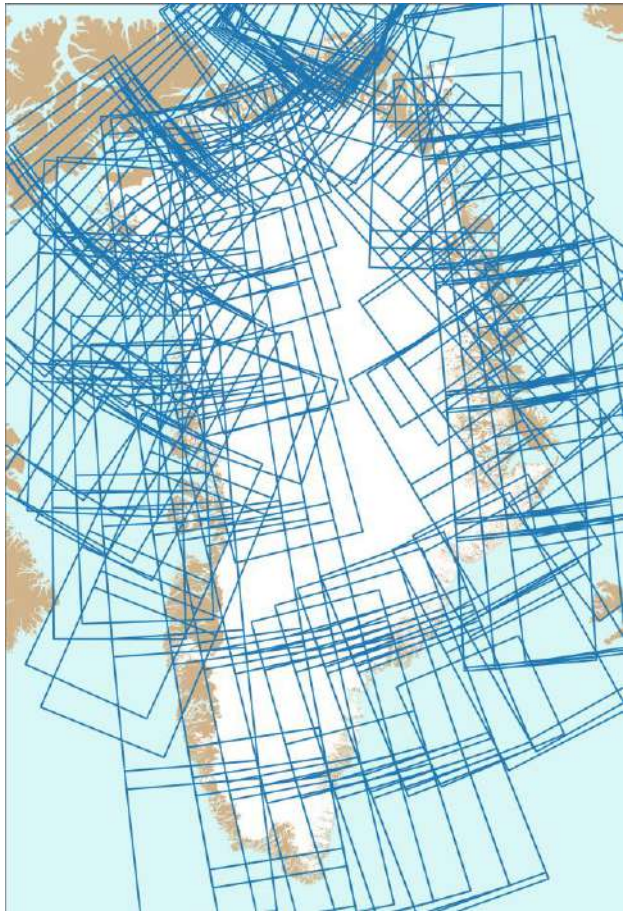
Opportunities: Can EW mode fill gaps?

EW coverage

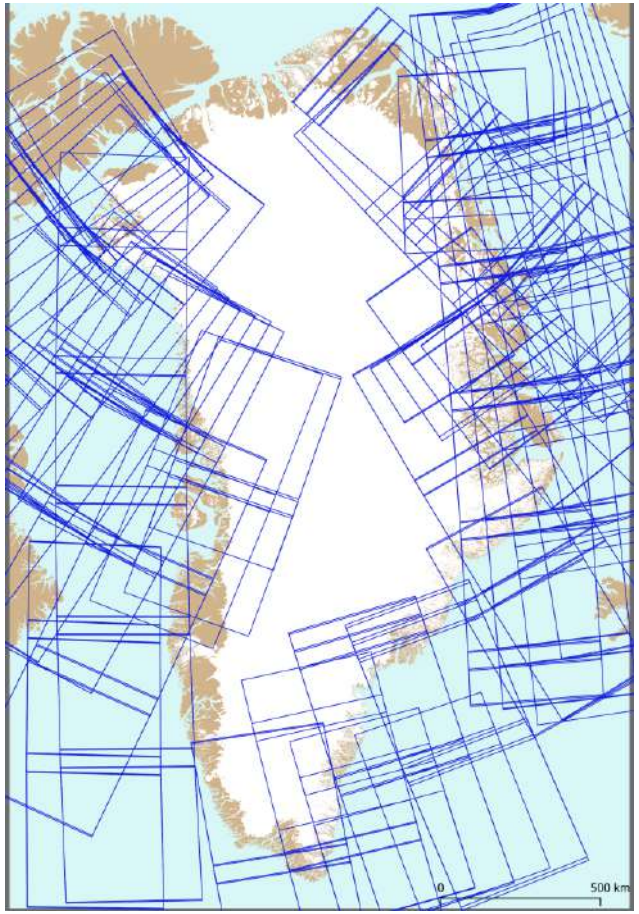
Typical IW mode coverage



Summer 2021



May 2024



Opportunities: Can EW mode fill gaps?

EW coverage

Coverage for November 2021

IW coverage

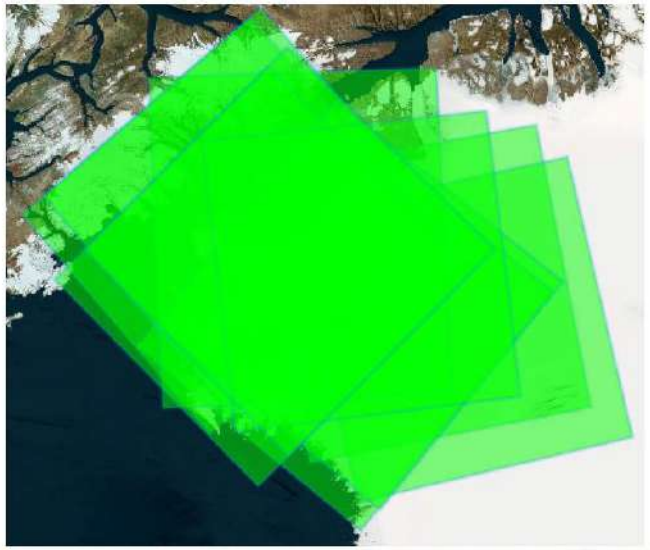


Figure 3.2: *Bing Aerial background map in QGIS [25] with EW data files (see table 3.1) shown in green in projection EPSG 3413*

Pilot study in a Master's thesis[1] project by Elisabeth Barfod Damgaard (Supervised by John Merryman Boncori)

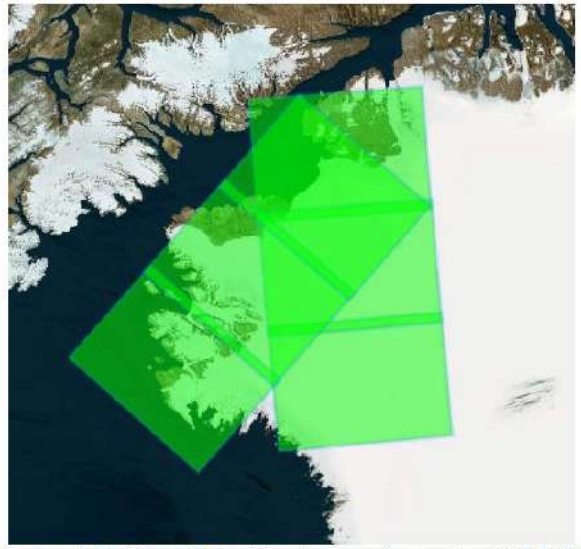
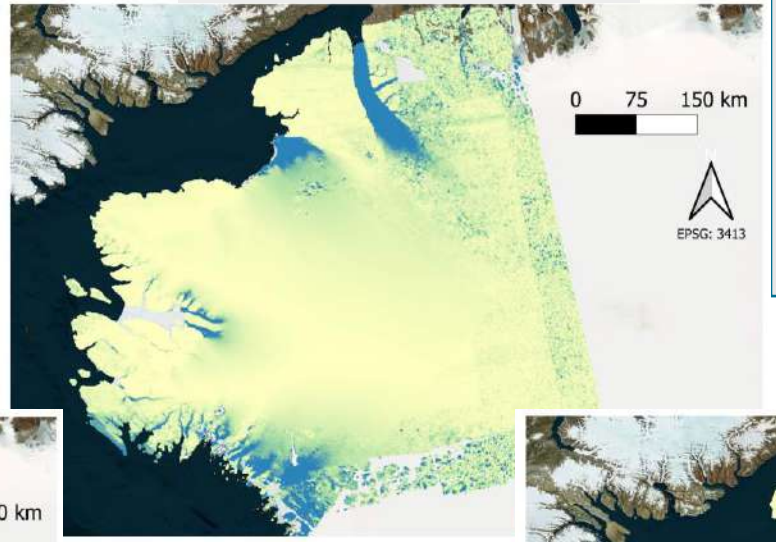


Figure 3.3: *Bing Aerial background map in QGIS [25] with IW data files (see table 3.2) shown in green in projection EPSG 3413*

[1]Damgaard, Elisabeth Barfod, *'Potential of Sentinel-1 EW SLC imagery for In-SAR applications in Greenland'*, 2024

Opportunities: Can EW mode fill gaps?

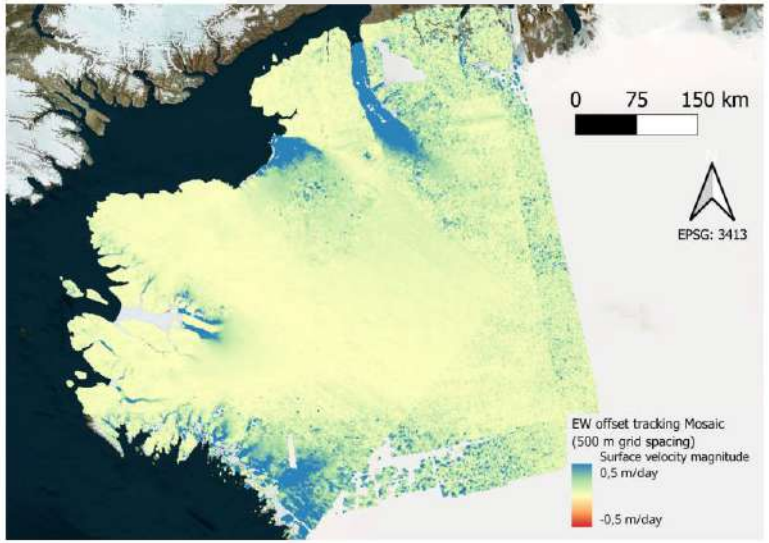
EW + IW mosaic



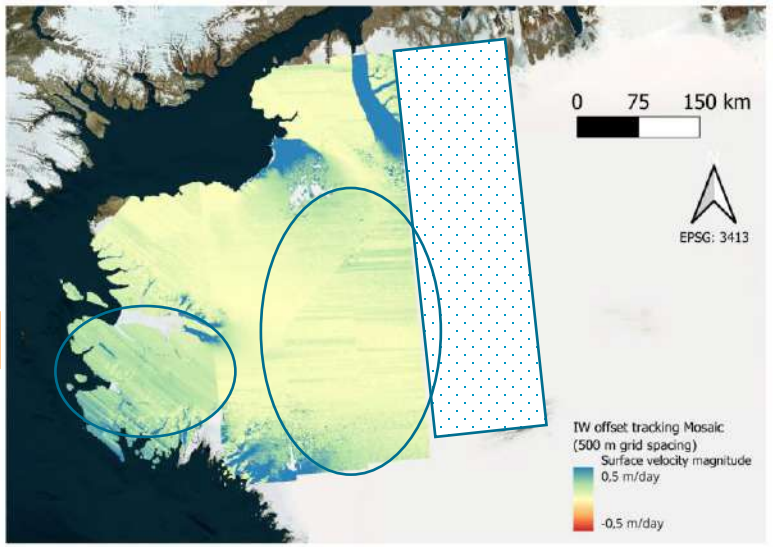
Increased spatial coverage

Reduction of ionospheric effects
-> Compared to IW mode only

EW mosaic



IW mosaic



GEUS Dataverse > Nature and climate >

Greenland Freshwater Flux on Glacier-basin Scales

Version 5.0

https://dataverse.geus.dk/

SCAN ME

Karls
Scale

Cite

Freshwater Runoff

(GEUS)

GEUS Dataverse > Nature and climate > Programme for Monitoring of the Greenland Ice Sheet (PROMICE) and the Greenland Climate Network (GC-Net) > Freshwater Runoff >

Streams, Outlets, Basins, and Discharge [k=1.0]

Version 5.0

Description

GEUS Dataverse > Nature and climate > Programme for Monitoring of the Greenland Ice Sheet (PROMICE) and the Greenland Climate Network (GC-Net) >

Greenland ice sheet mass balance from 1840 through next week

Version 890.1

Description

Subject

Keyword

Related Pub

Notes

GEUS Dataverse > Nature and climate > Programme for Monitoring of the Greenland Ice Sheet (PROMICE) and the Greenland Climate Network (GC-Net) > Ice Discharge >

Greenland Ice Sheet solid ice discharge from 1986 through last month: Discharge

Version 98.0

Description

Mankoff, Ken; Solg
last month: Dischar

Cite Dataset

Subject

Keyword

Related Publicat

Description

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Related Publication

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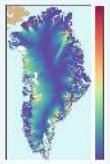
Ice velocity

(PROMICE)

GEUS Dataverse > Nature and climate > Programme for Monitoring of the Greenland Ice Sheet (PROMICE) and the Greenland Climate N

Greenland Ice Velocity from Sentinel-1 Edition 4

Version 18.0



Solgaard, Anne Munck; Kusk, Anders, 2024, "Greenland Ice Velocity from Sentinel-1 Edition 4", https://doi.org/10.22008/FK2/LFZLZN, GEUS Dataverse, V18

Cite Dataset

Learn about Data Citation Standards.

Description

Recommendations: Gaps and Opportunities

GAP	OPPORTUNITY
• Reduced quality of Sentinel-1 based IV maps since S1B failure	• Use already obtained EW mode data by making the data available as SLCs over land ice
• Bedrock elevation at outlet glaciers	• New ice-penetrating radar systems
• In-situ validation of satellite observations on the Greenland ice sheet	• In situ opportunities via PROMICE|GC-Net field infrastructure