New insight into Greenland's subglacial hydrology – leveraging high resolution satellite data for a future Digital Twin

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CEEDS
CENTRE OF EXCELLENCE IN ENVIRONMENTAL DATA SCIENCE

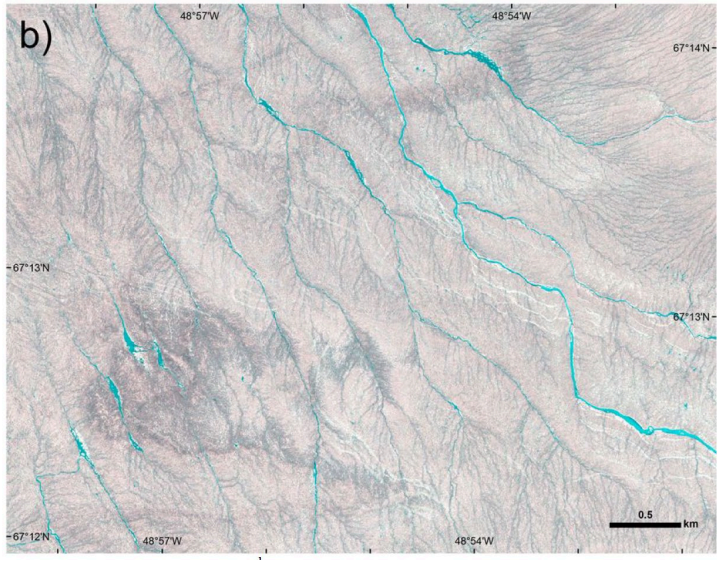
4DGreenland

EO4SMB
Surface Mass Balance
Snowfall accumulation
Accumulation rate
Ablation rate
Meltwater runoff

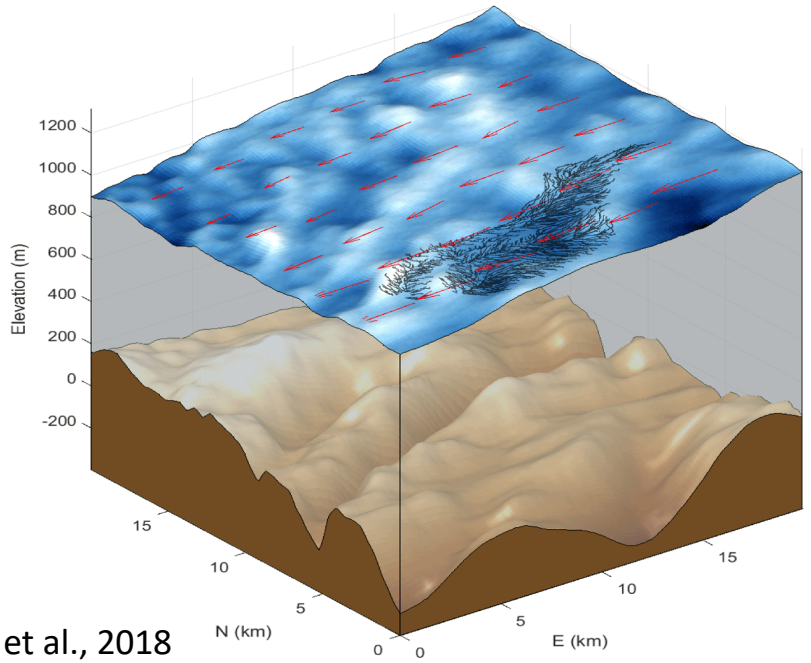
esa

Motivation

- Constraining subglacial hydrology is challenging:
  - Buried between kilometers of ice.
  - Highly dynamic.
  - Highly heterogeneous over small spatial scales.



Smith et al., 2015



Crozier et al., 2018

Motivation

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- We have rich data, increasing sophisticated statistical methods and process models.

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  - Buried between kilometers of ice.
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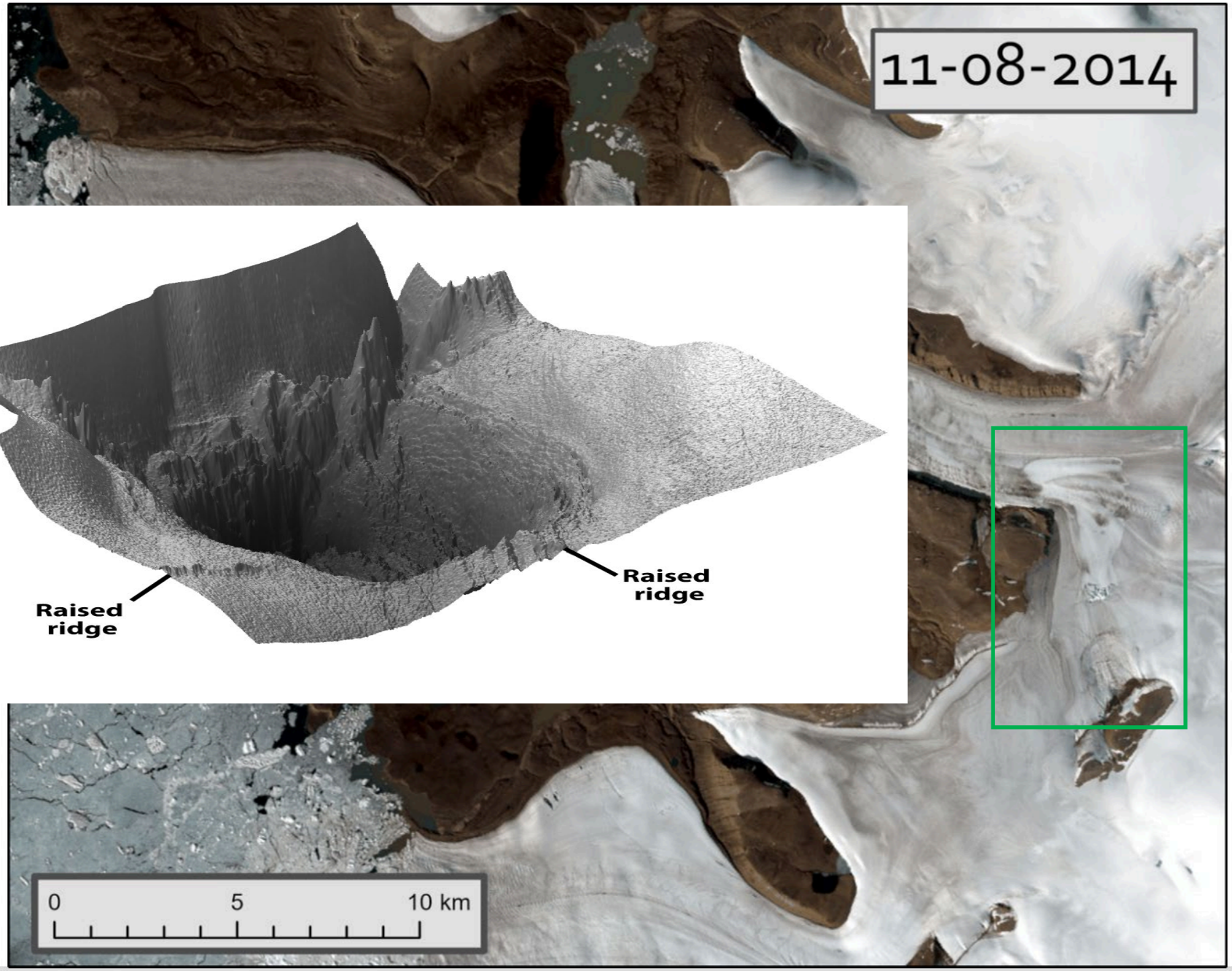
- We have the building blocks.


11-08-2014
Raised ridge
Raised ridge
0
5
10 km

Where should we be in 10 years time?

Comprehensive mapping, using EO, of Greenland's subglacial hydrology, and its dynamics.

2-way information flow between data and models.

Operationally-implemented data mining algorithms.

Automated systems that detect anomalies in Real Time

Operational forecasting of future subglacial lake drainages.

Dynamic, adaptive software for EO and models.

- Observations can amend not only the state but also the structure of models or indeed the mix of models in ensembles.
- Models can inform adaptive data sampling strategies, QA.

Where should we be in 10 years time?

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Operational forecasting of future subglacial lake drainages.

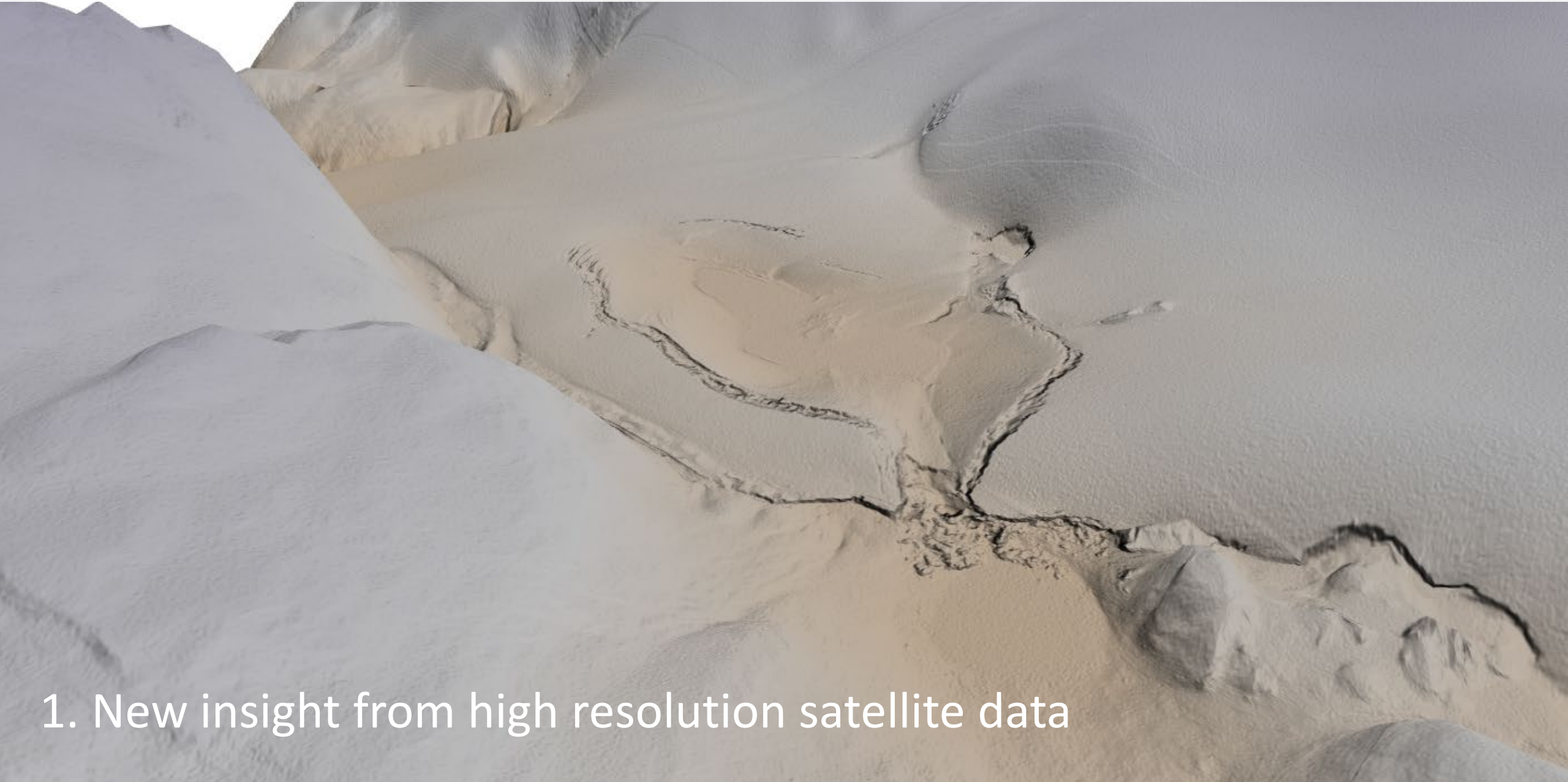
Dynamic, adaptive software for EO and models.

- Mining the past: Exploiting high-resolution, high volume data streams.
- Monitoring the present: Near Real Time monitoring and anomaly detection.
- Forecasting the future: Early warning systems and adaptive sampling.

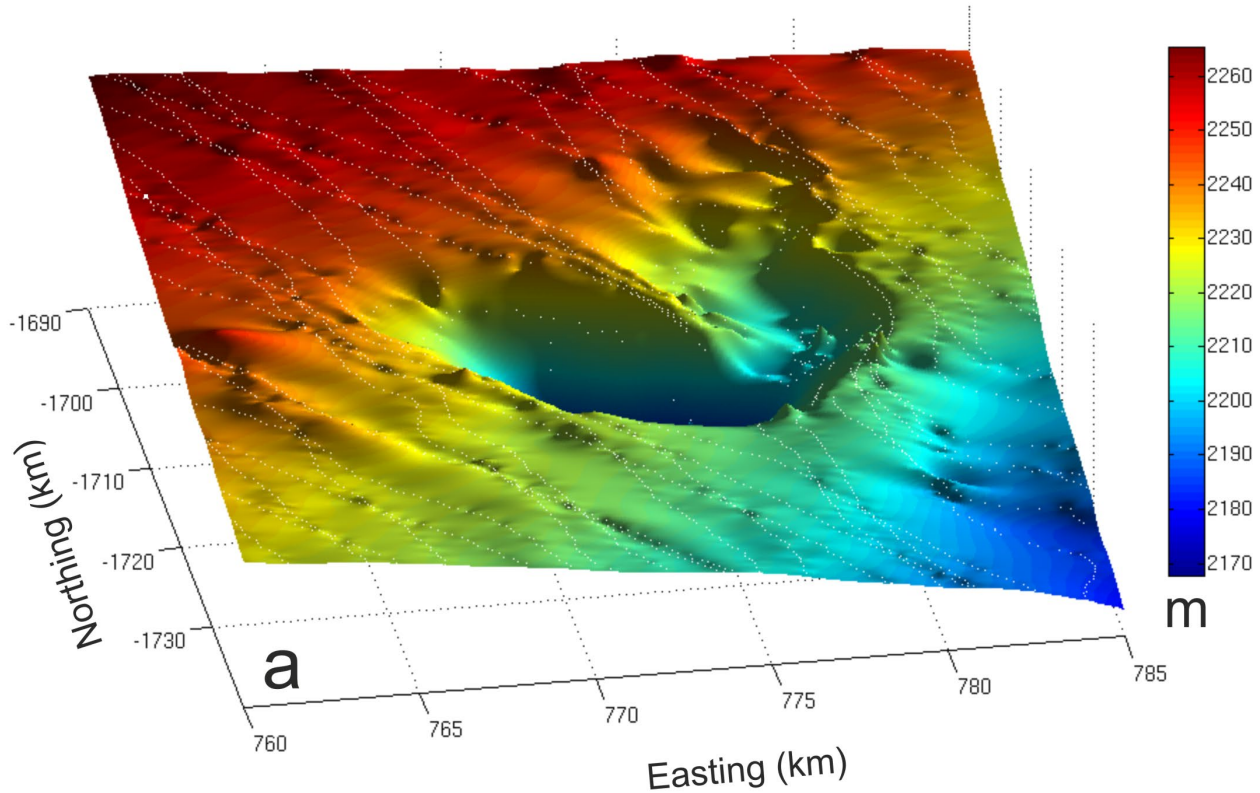
Mining the past

Monitoring the present

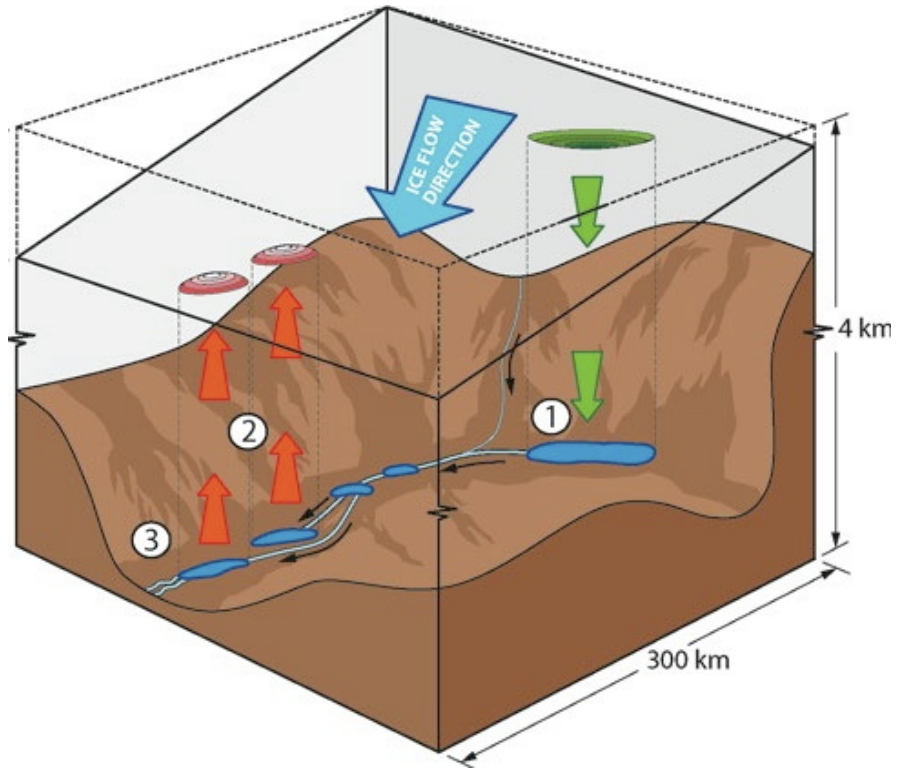
Forecasting the future



1. New insight from high resolution satellite data

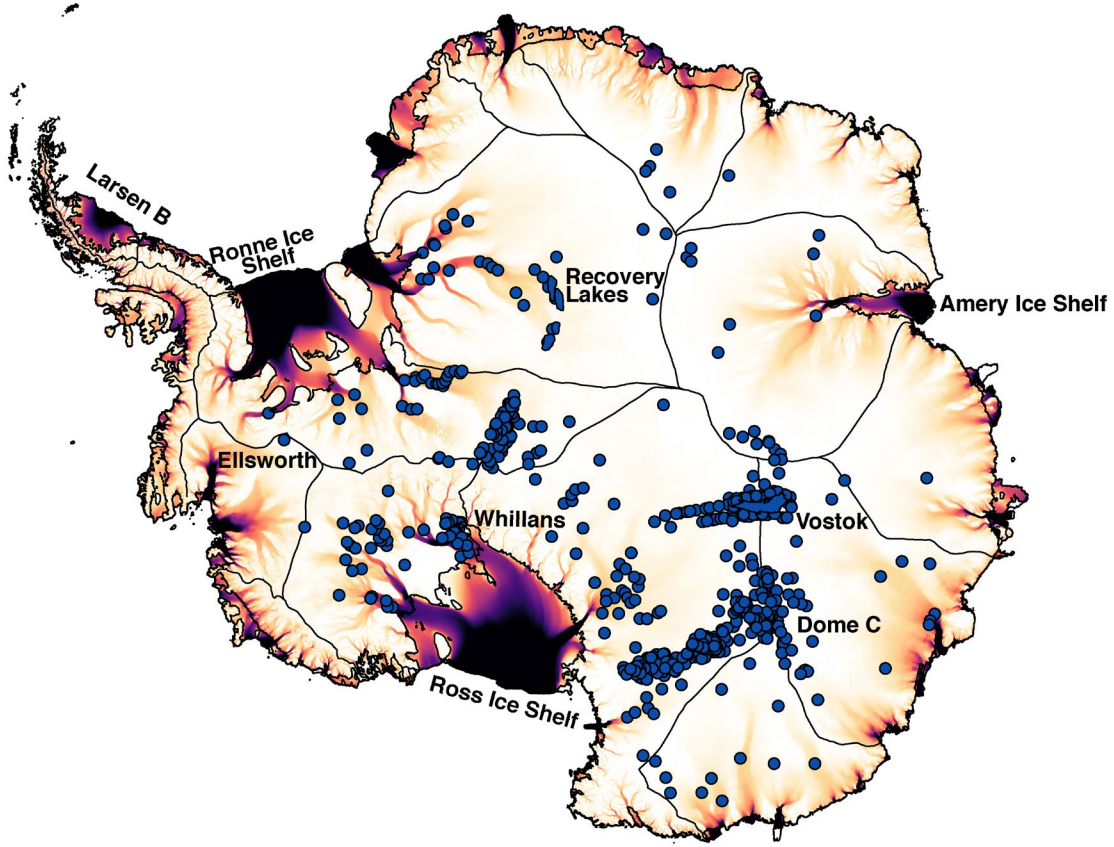


McMillan et al., 2013



Wingham et al., 2006

675 lakes; 140 active

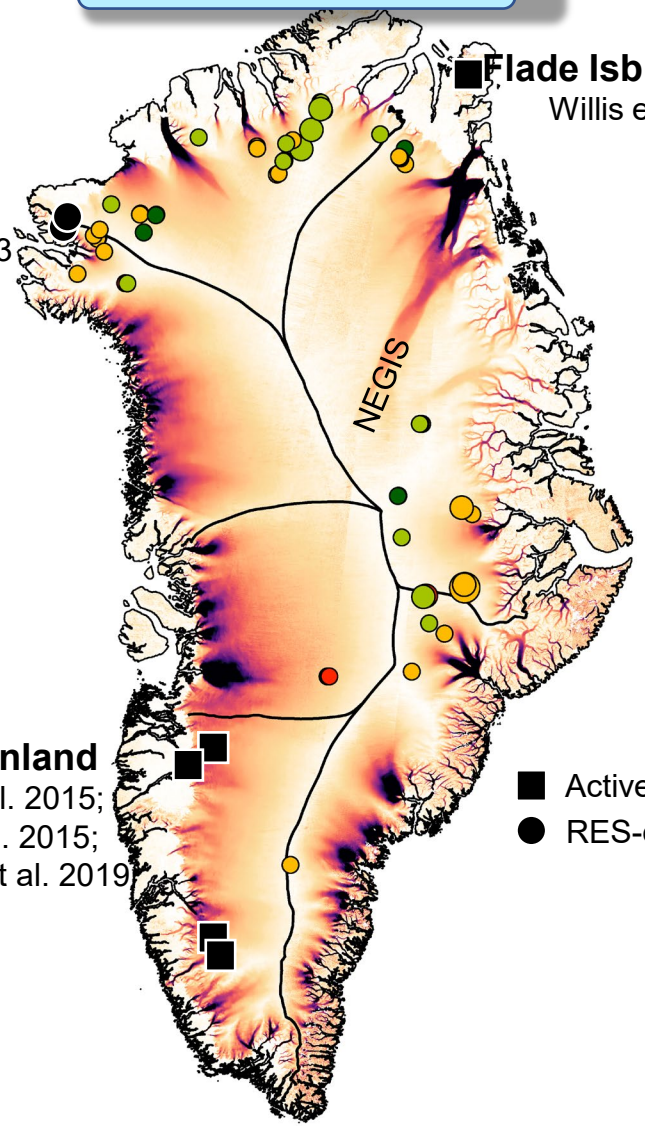


Distribution of Antarctic subglacial lakes

64 lakes; 6 active

Flade Isblink Ice Cap
Willis et al. 2015

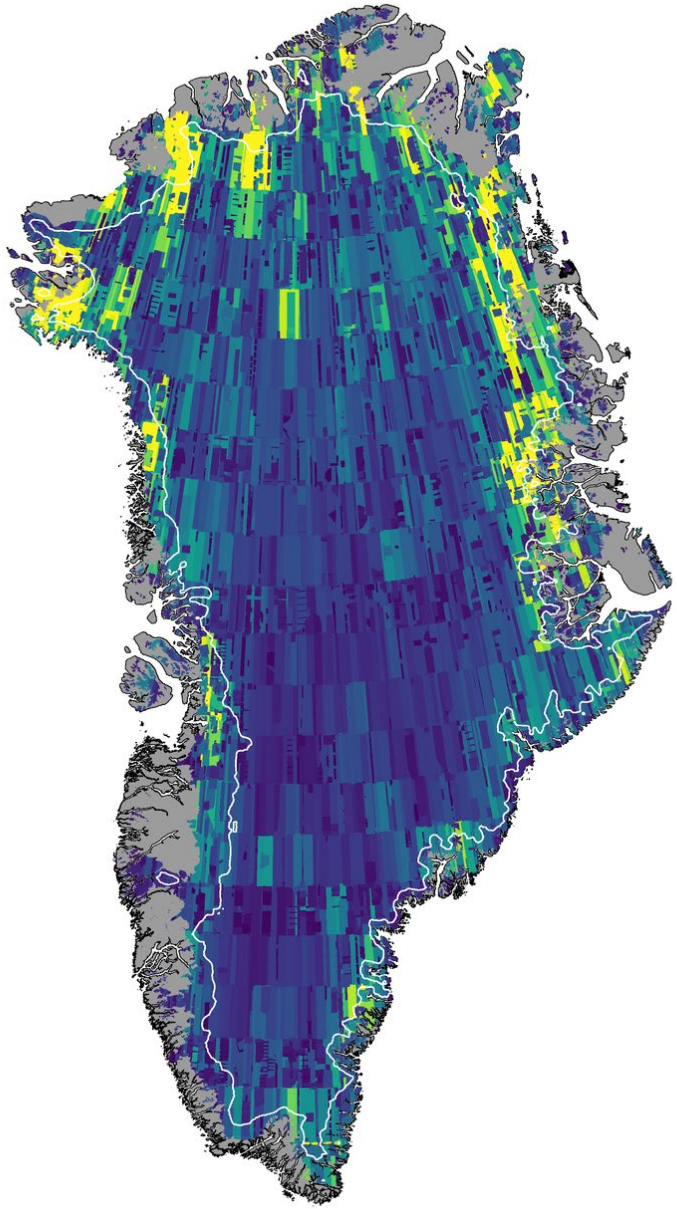
Bowdoin Gl.
Palmer et al. 2013



SW Greenland
Palmer et al. 2015;
Howat et al. 2015;
Livingstone et al. 2019

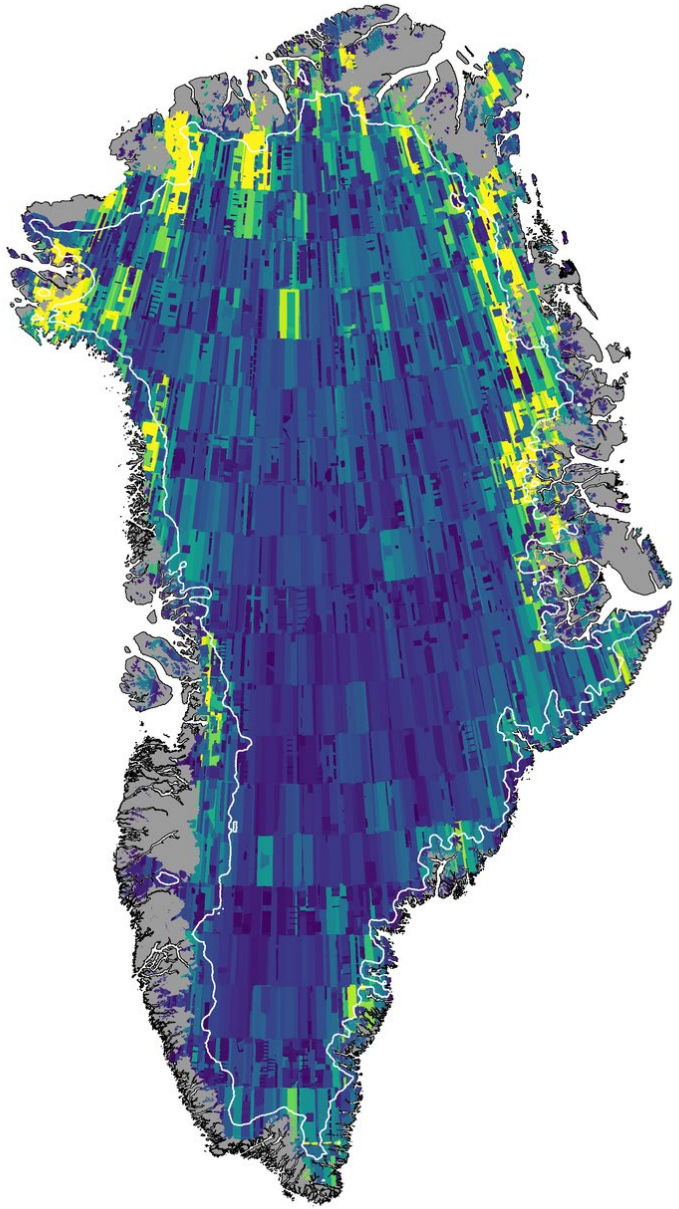
■ Active subglacial lake
● RES-detected lake

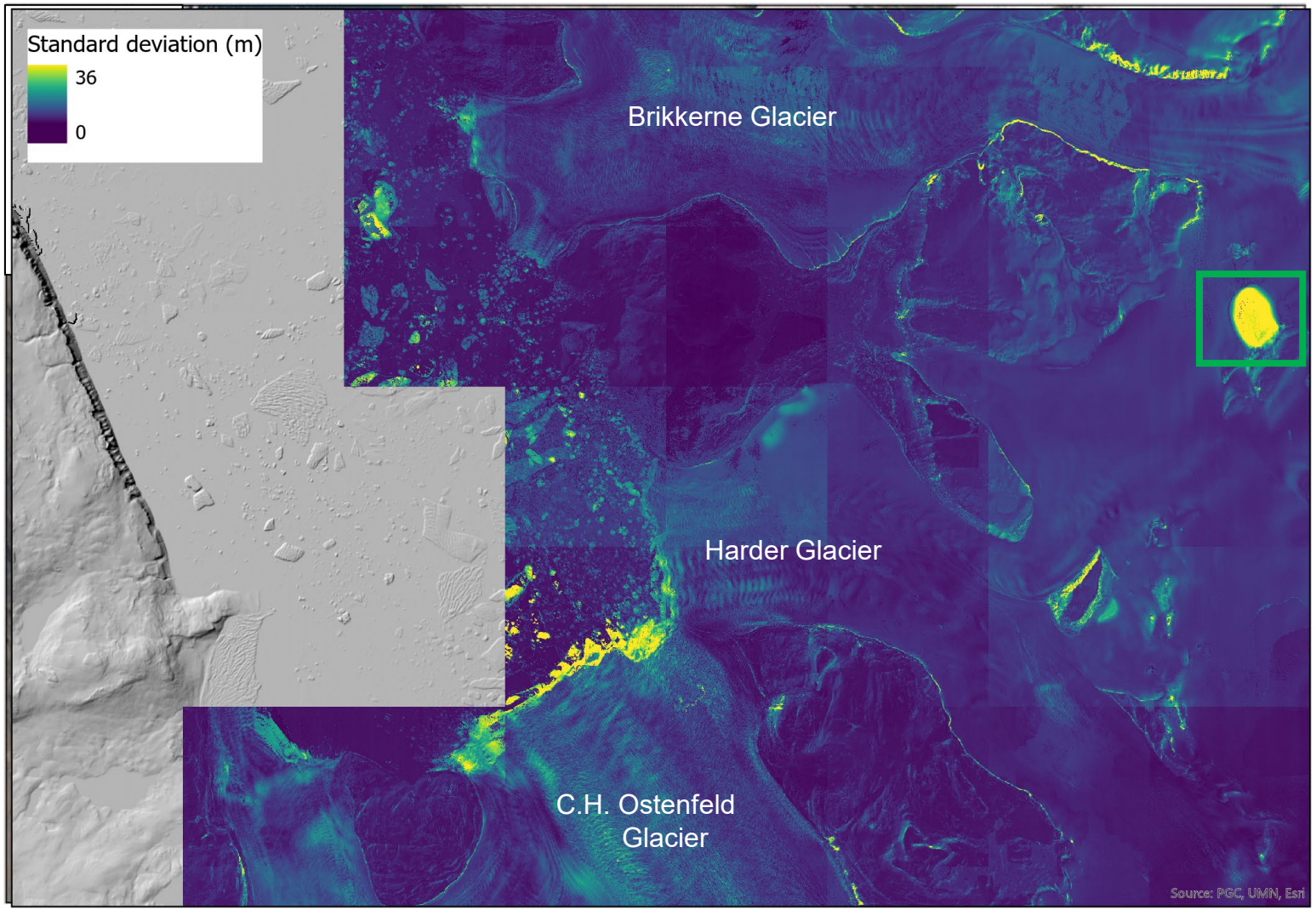
Distribution of Greenland subglacial lakes (Bowling et al., 2019)

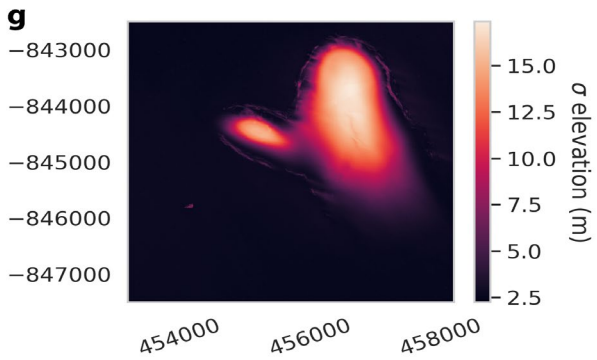


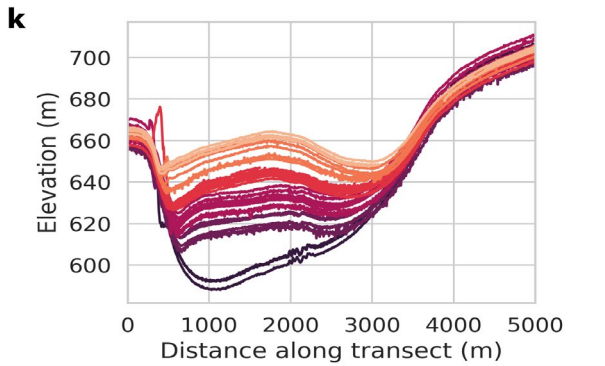
Number of repeat ArcticDEM stripfiles

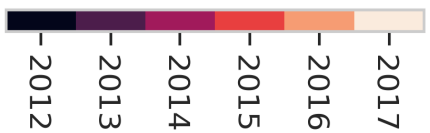
0 >100

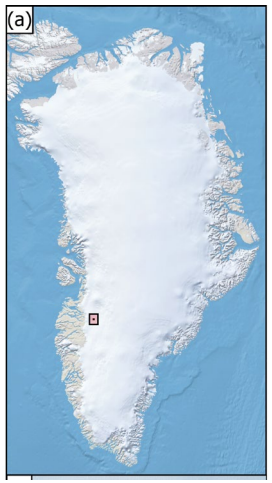

Number of repeat ArcticDEM stripfiles
0
>100

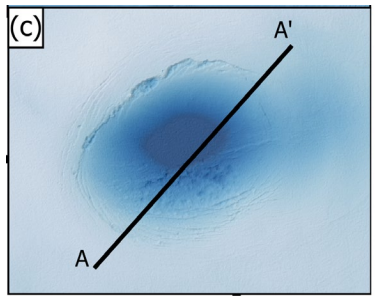

Standard deviation (m)
36
0
Brikkerne Glacier
Harder Glacier
C.H. Ostenfeld Glacier
Source: PGC, UMN, Esri

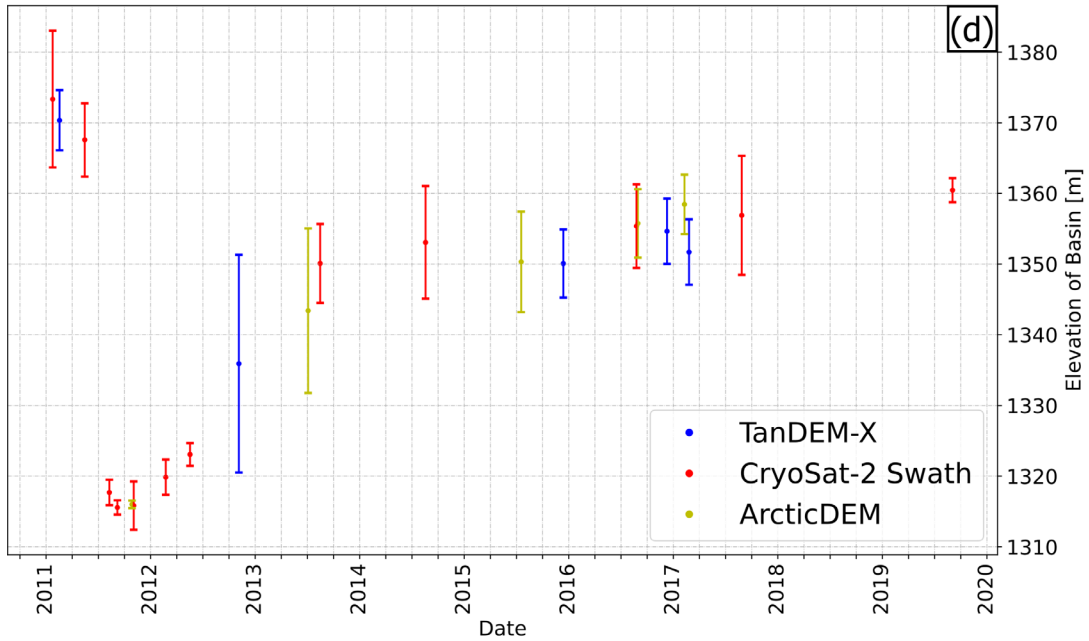












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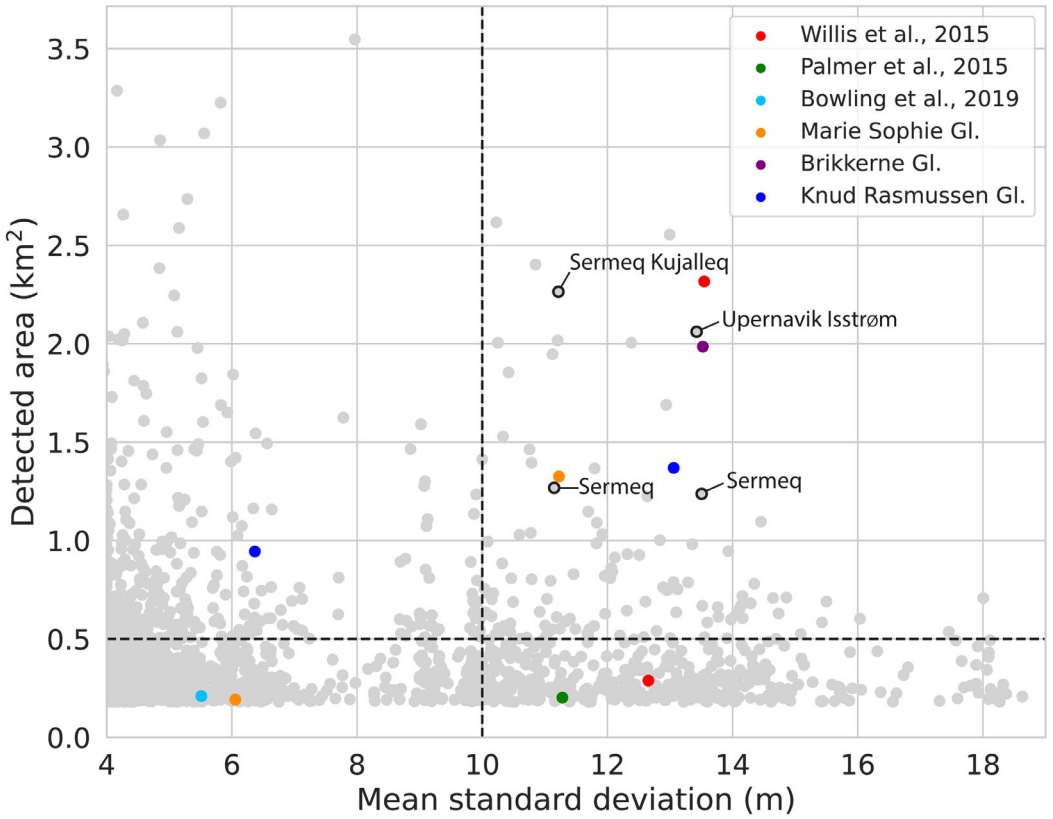
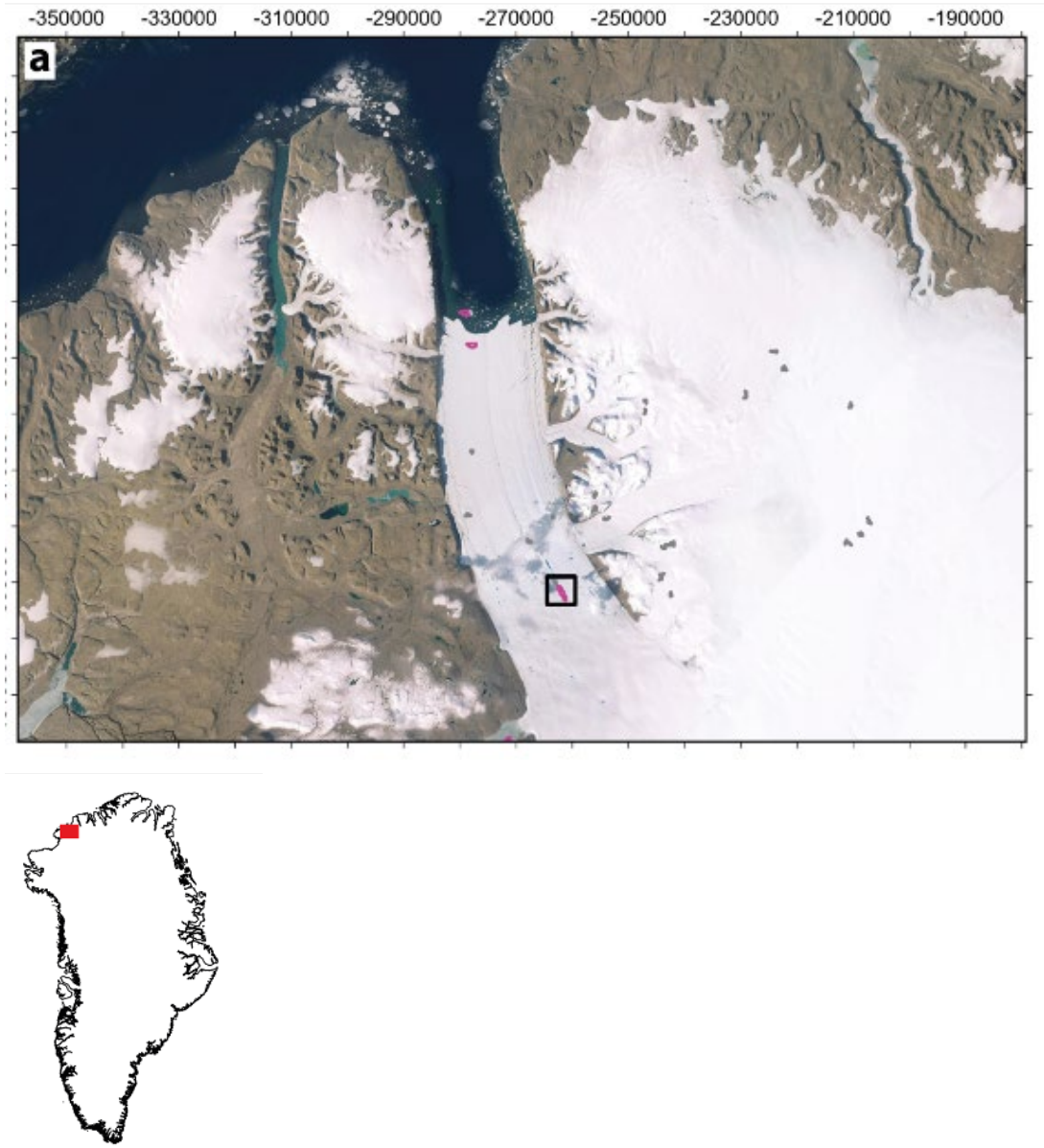
4DGreenland

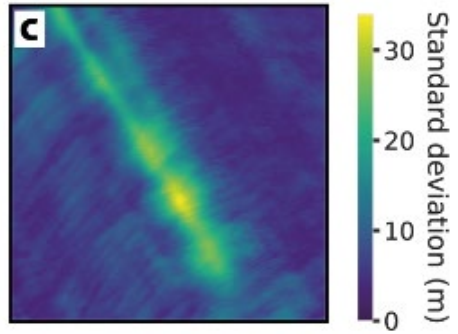


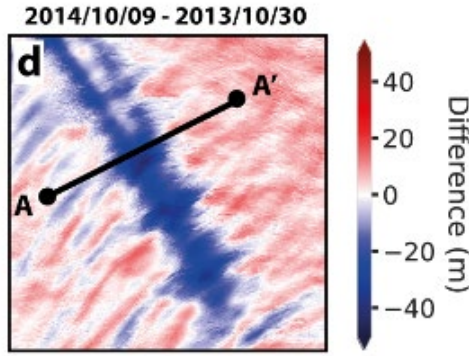
- 10^4 - 10^6 candidate features.
- Lakes have distinctive characteristics.
- Opportunities for data mining to identify new lakes.
- Opportunities to leverage other data sources, e.g. optical, SAR.
- Opportunities to extract other subglacial hydrological signatures.

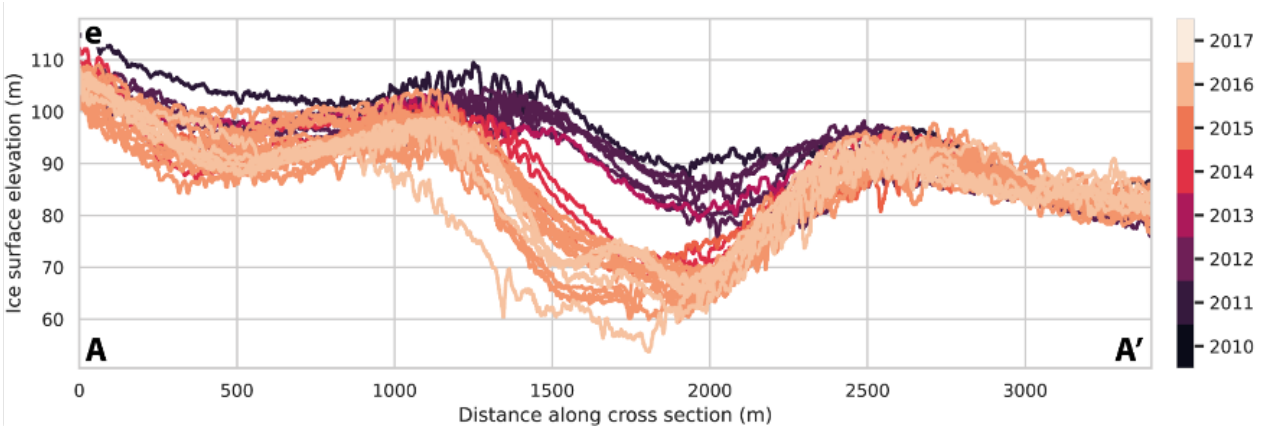
Beyond subglacial lakes

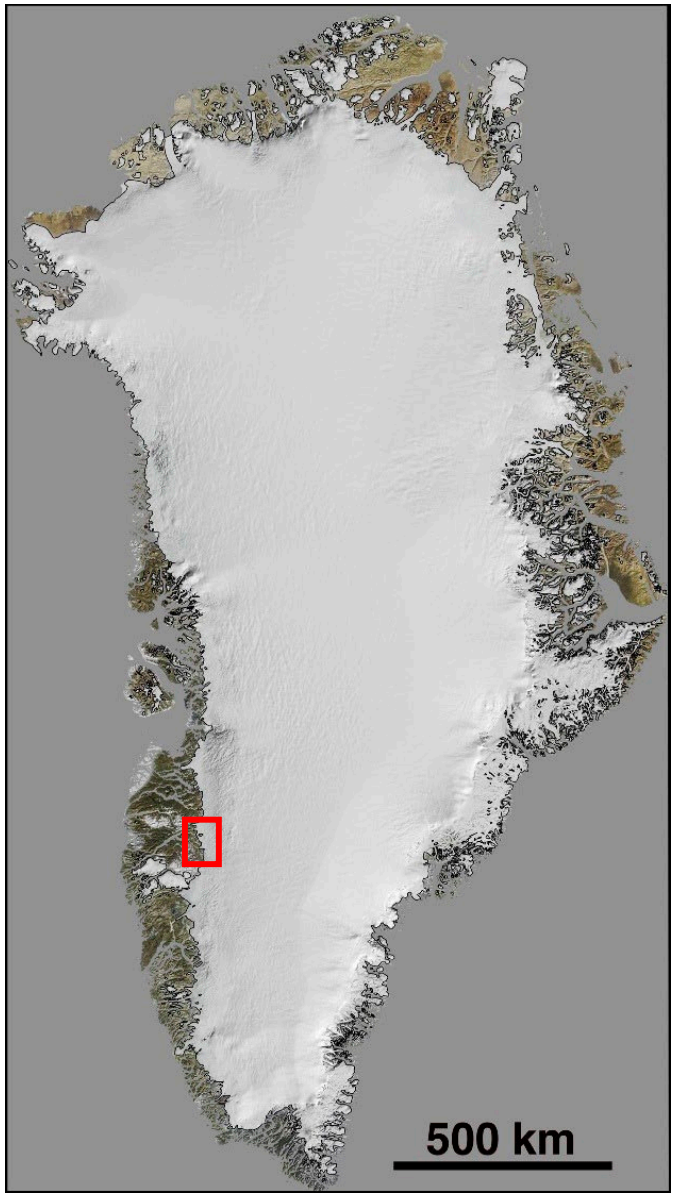
Beyond subglacial lakes

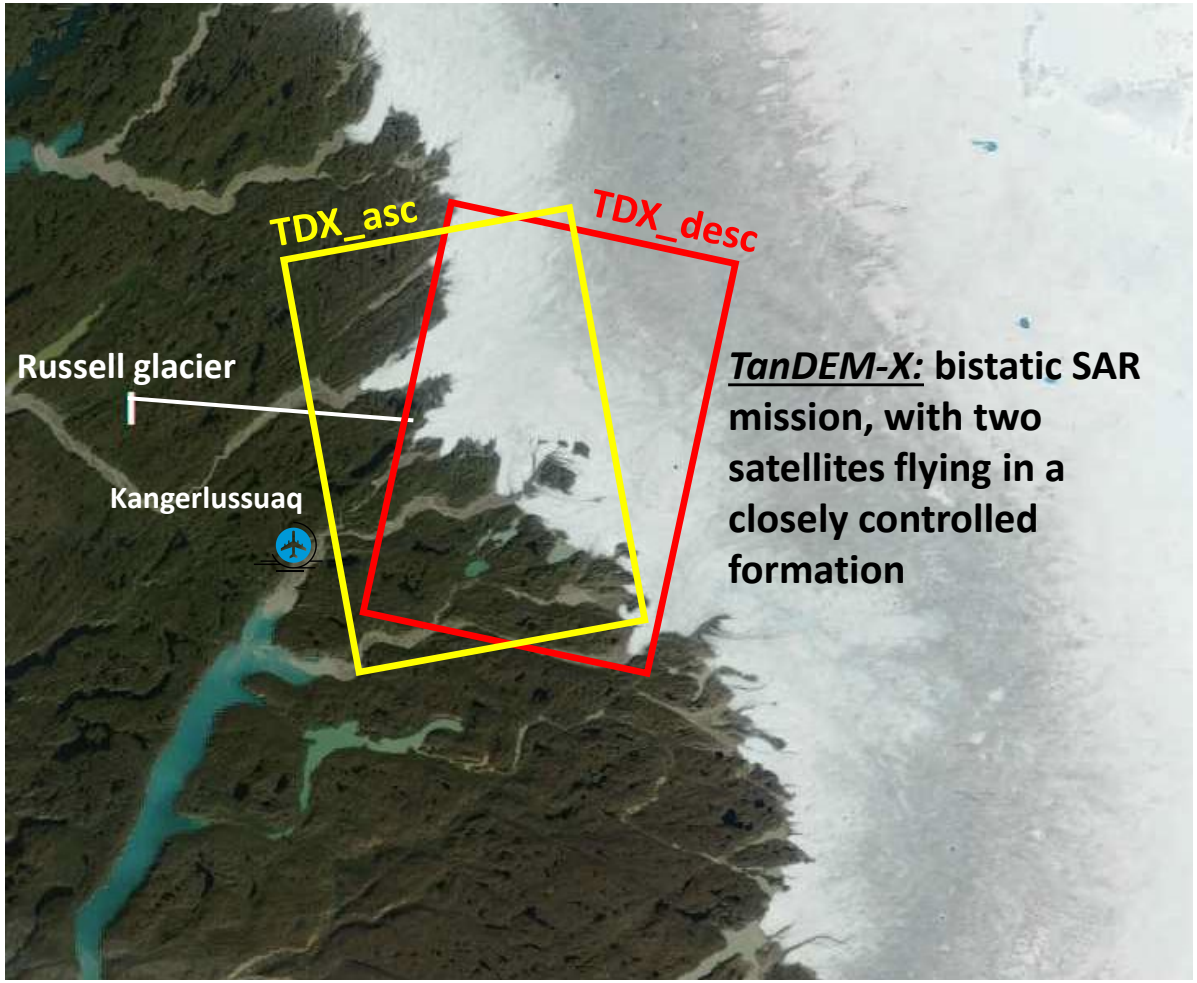




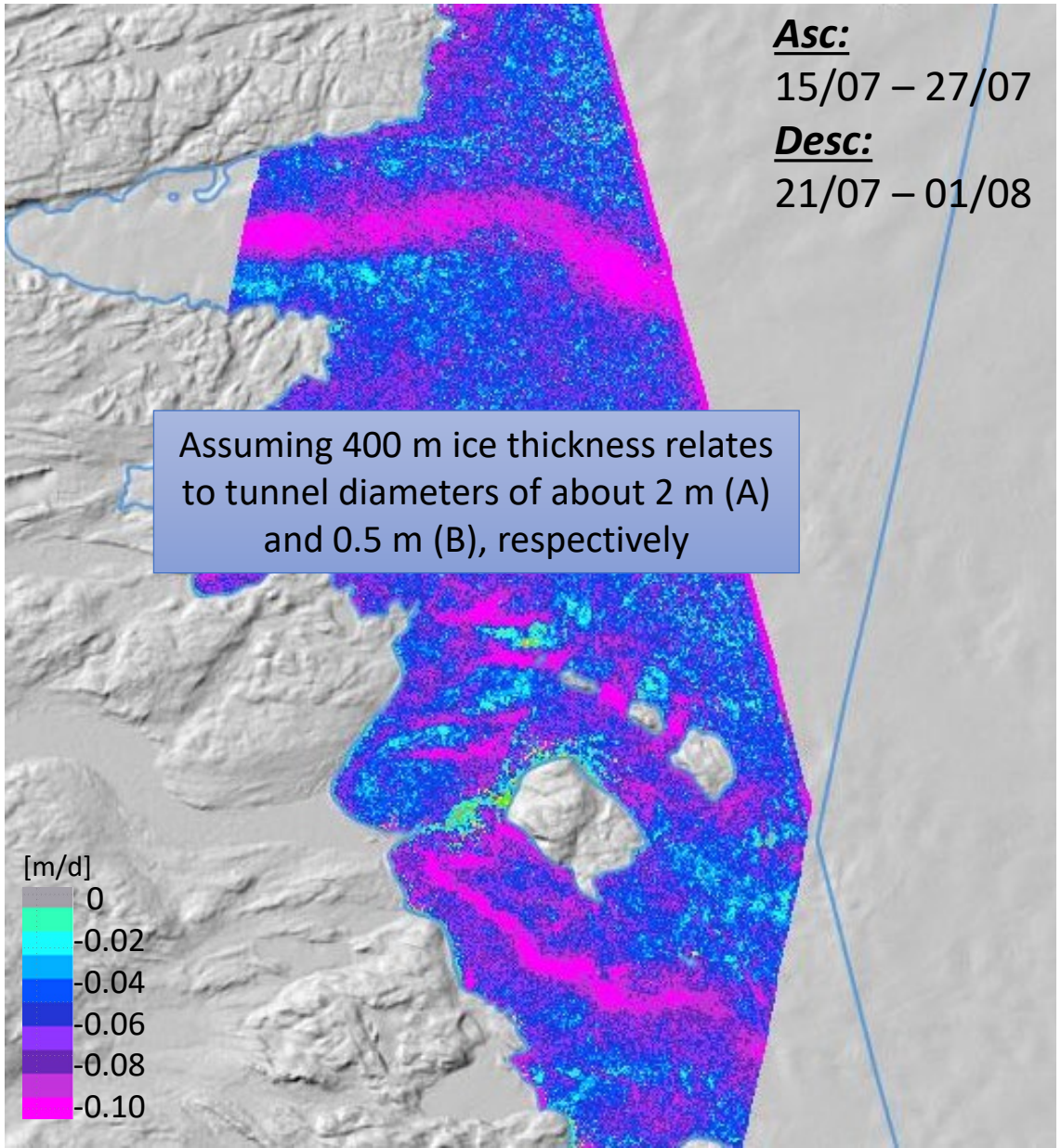


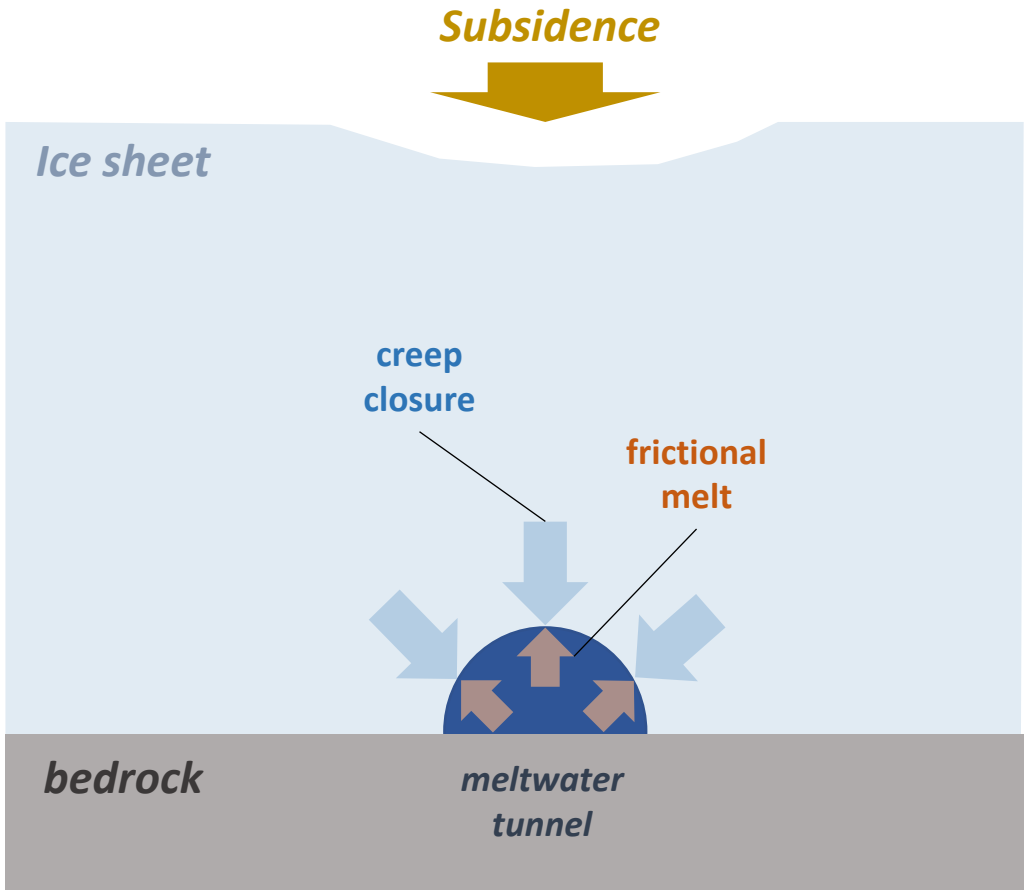


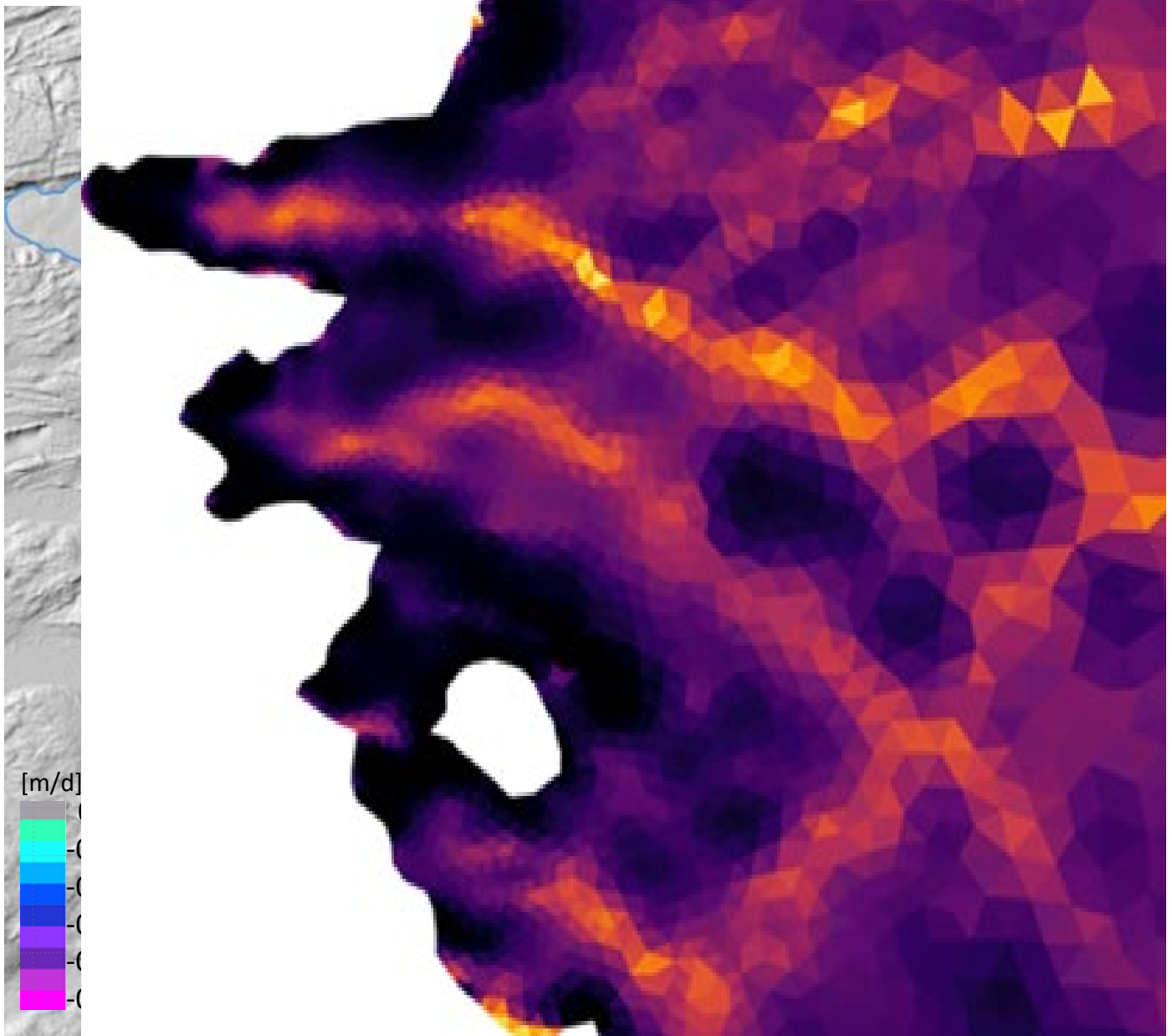




TanDEM-X: **bistatic SAR mission, with two satellites flying in a closely controlled formation**


Asc:
15/07 – 27/07
Desc:
21/07 – 01/08
Assuming 400 m ice thickness relates to tunnel diameters of about 2 m (A) and 0.5 m (B), respectively
[m/d]
0
-0.02
-0.04
-0.06
-0.08
-0.10


Subsidence
Ice sheet
creep closure
frictional melt
bedrock
meltwater tunnel

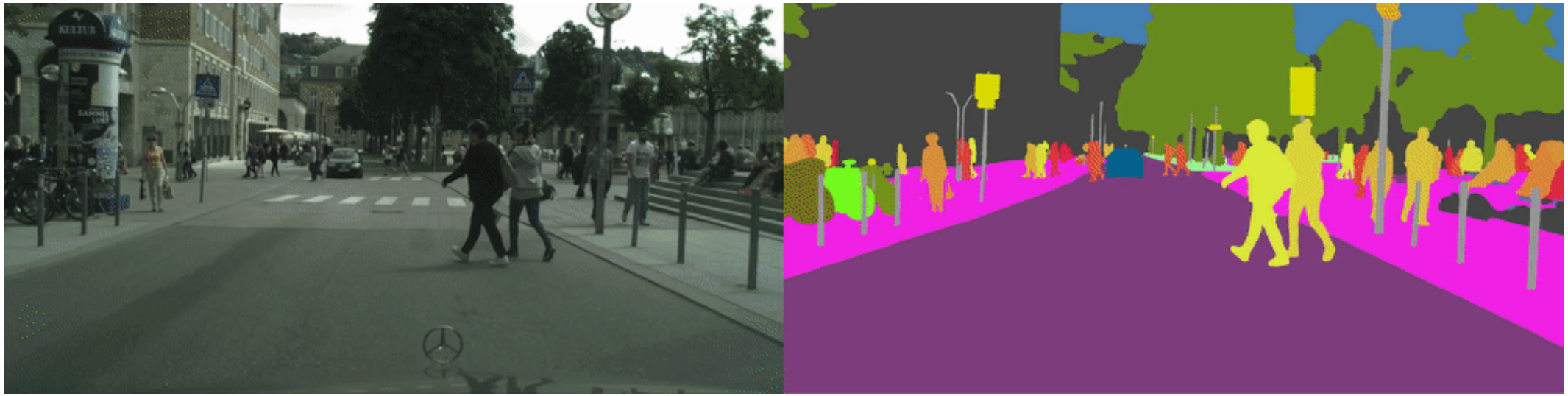


Brickerhoff et al., 2021

Near Real Time Monitoring and Anomaly Detection

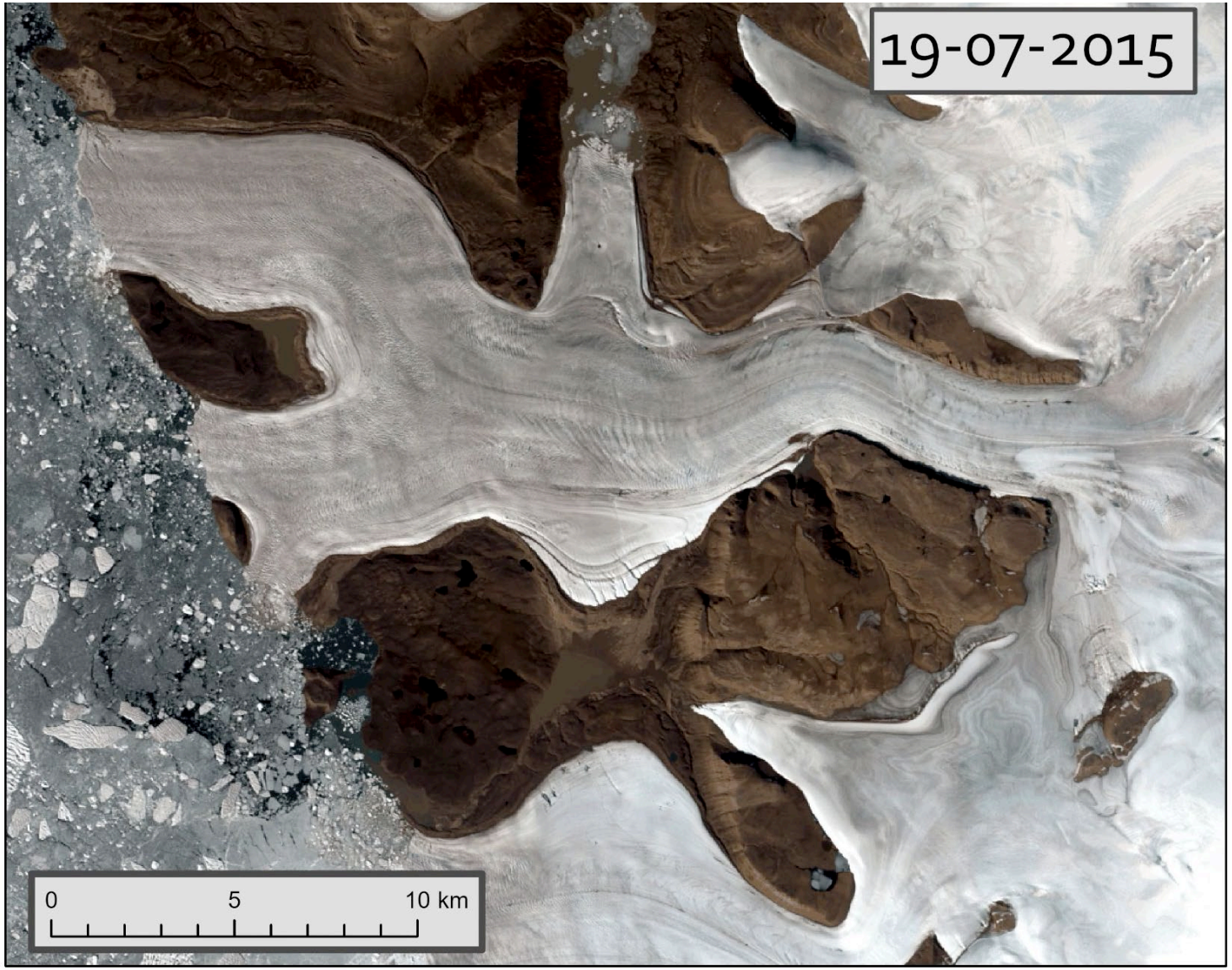
Near Real Time Monitoring and Anomaly Detection

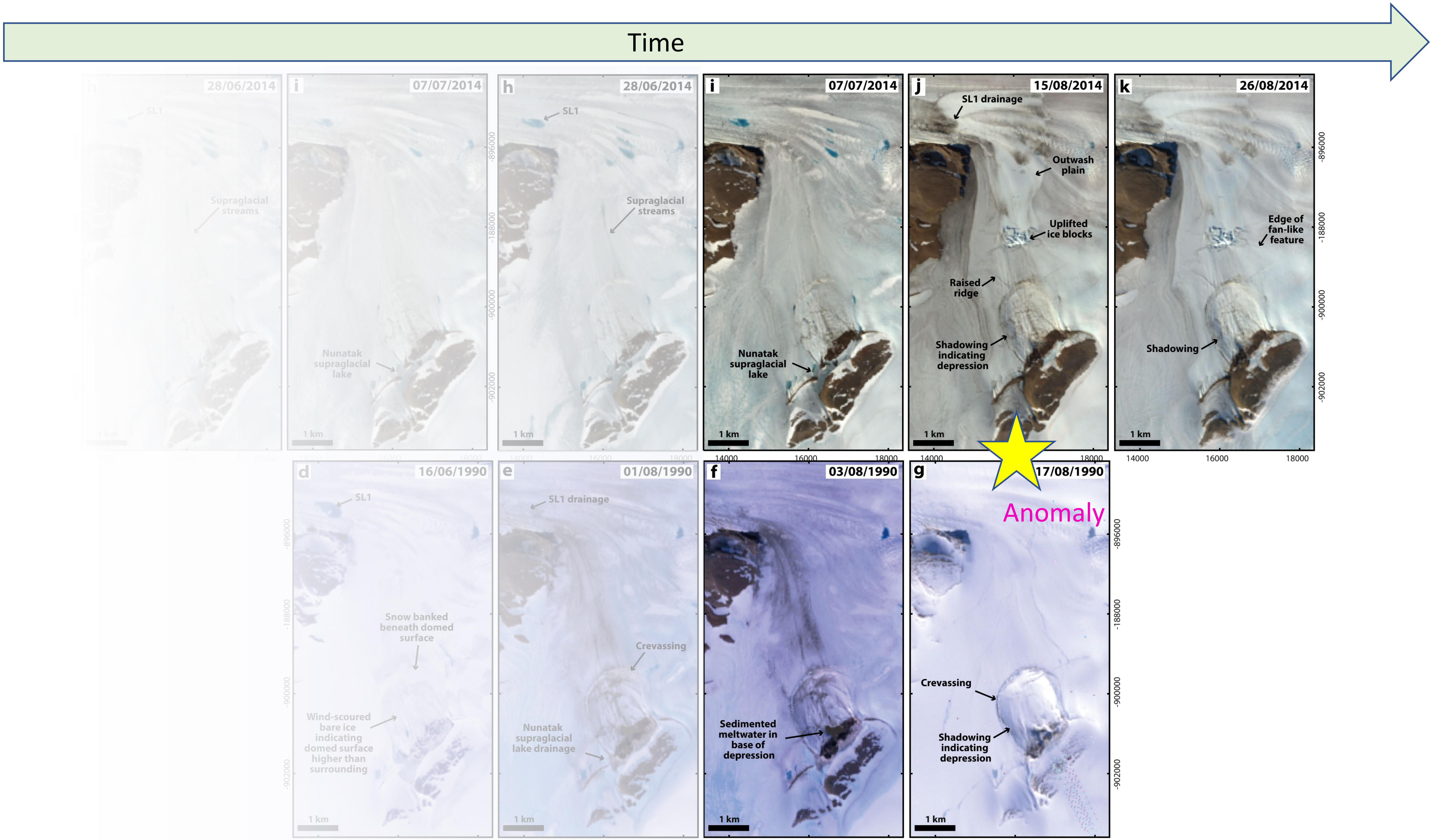
- Deep Learning for Video Prediction.
- Established in fields such as video surveillance, traffic management etc.
- Aim is to predict the next video frame, by training a network on the preceding history of frames.
- Once the network is trained, it can be used to detect anomalies in in-streaming data.



https://ai.googleblog.com/2021/04/holistic-video-scene-understanding-with.html

We now have satellite movies of the ice sheet



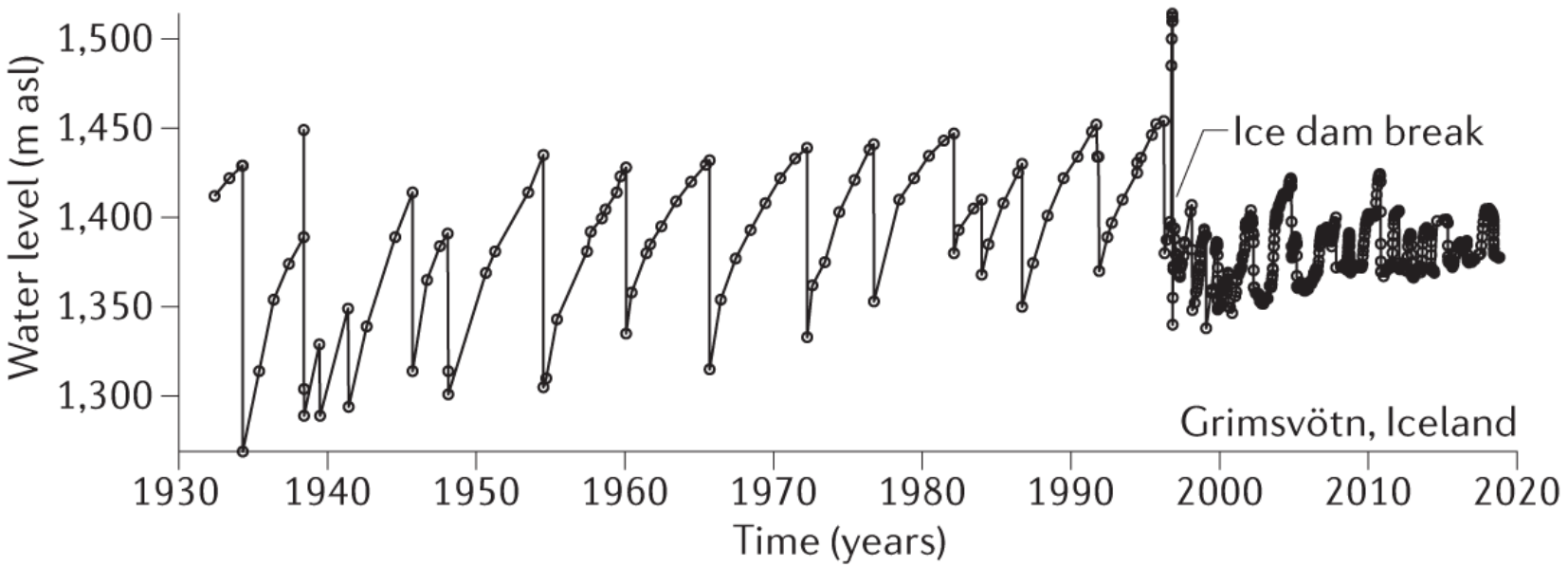


Time
h 28/06/2014
SL1
Supraglacial streams
1 km
i 07/07/2014
Nunatak supraglacial lake
1 km
h 28/06/2014
SL1
Supraglacial streams
1 km
i 07/07/2014
Nunatak supraglacial lake
1 km
j 15/08/2014
SL1 drainage
Outwash plain
Uplifted ice blocks
Raised ridge
Shadowing indicating depression
1 km
k 26/08/2014
Edge of fan-like feature
Shadowing
1 km
14000
16000
18000
-896000
-188000
-900000
-902000
d 16/06/1990
SL1
Snow banked beneath domed surface
Wind-scoured bare ice indicating domed surface higher than surrounding
1 km
e 01/08/1990
SL1 drainage
Crevassing
Nunatak supraglacial lake drainage
1 km
f 03/08/1990
Sedimented meltwater in base of depression
1 km
g 17/08/1990
Anomaly
Crevassing
Shadowing indicating depression
1 km

Mining the past | Monitoring the present | Forecasting the future

Forecasting

- Where there is repetitive structure there is the potential to forecast.
- Range of conventional and AI-based forecasting approaches.



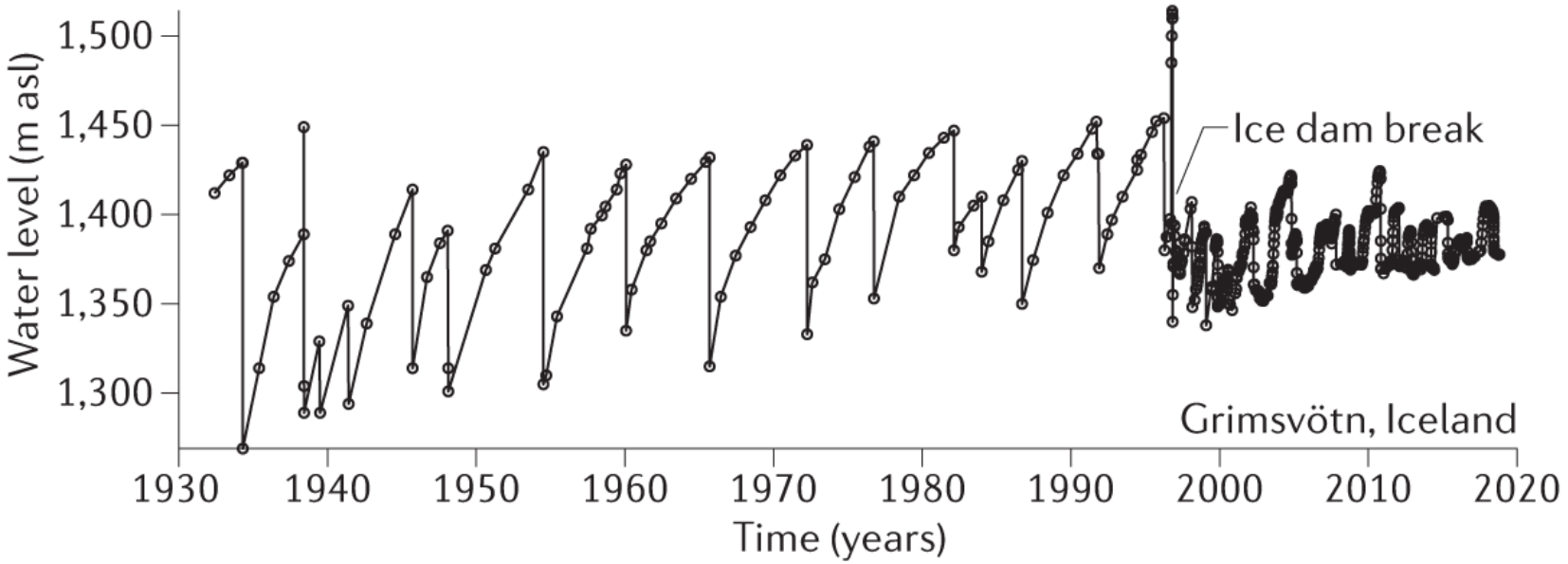
Subglacial lake evolution, Iceland

Livingstone et al., 2022

- Where there is repetitive structure there is the potential to forecast.
- Range of conventional and AI-based forecasting approaches.
- Revolutionise our capacity to undertake targeted fieldwork and airborne campaigns.

Improve process-based understanding

Underpin Early Warning Systems



Subglacial lake evolution, Iceland

Livingstone et al., 2022

Perspectives

Information Flow from Models to Data

Adaptive sampling

Observation QA

Information Flow from Models to Data

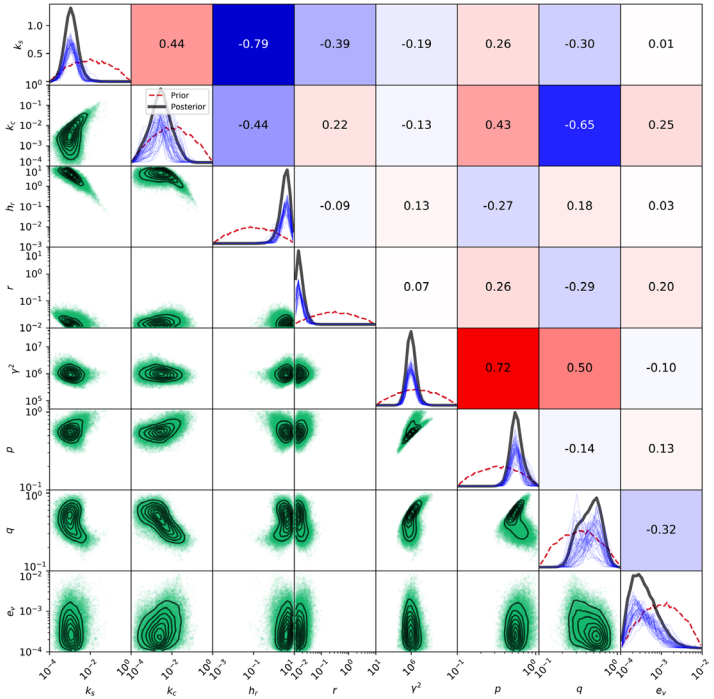
Adaptive sampling

Observation QA

Coupling of Observations, Physical and Statistical Models

Emulation

Model Coupling



Brickerhoff et al., 2021

Information Flow from Models to Data

Adaptive sampling

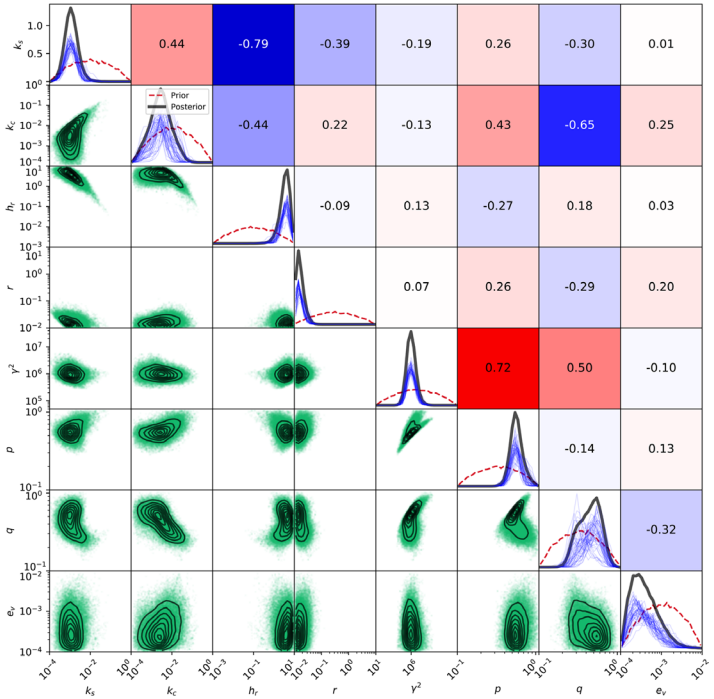
Observation QA

Coupling of Observations, Physical and Statistical Models

Emulation

Model Coupling

Adaptive software, natural selection and intelligent models



Brickerhoff et al., 2021

Summary

- Digital Twins can be transformative.
- They will drive fundamental innovation in ways of working.
- They require sustained, long-term investment; they will deliver sustained, long-term rewards.
- Demands closer collaboration with data scientists, computer scientists and statisticians.

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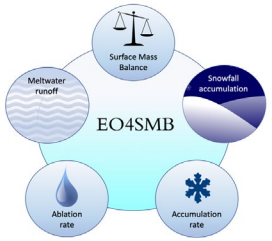
4DGreenland



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