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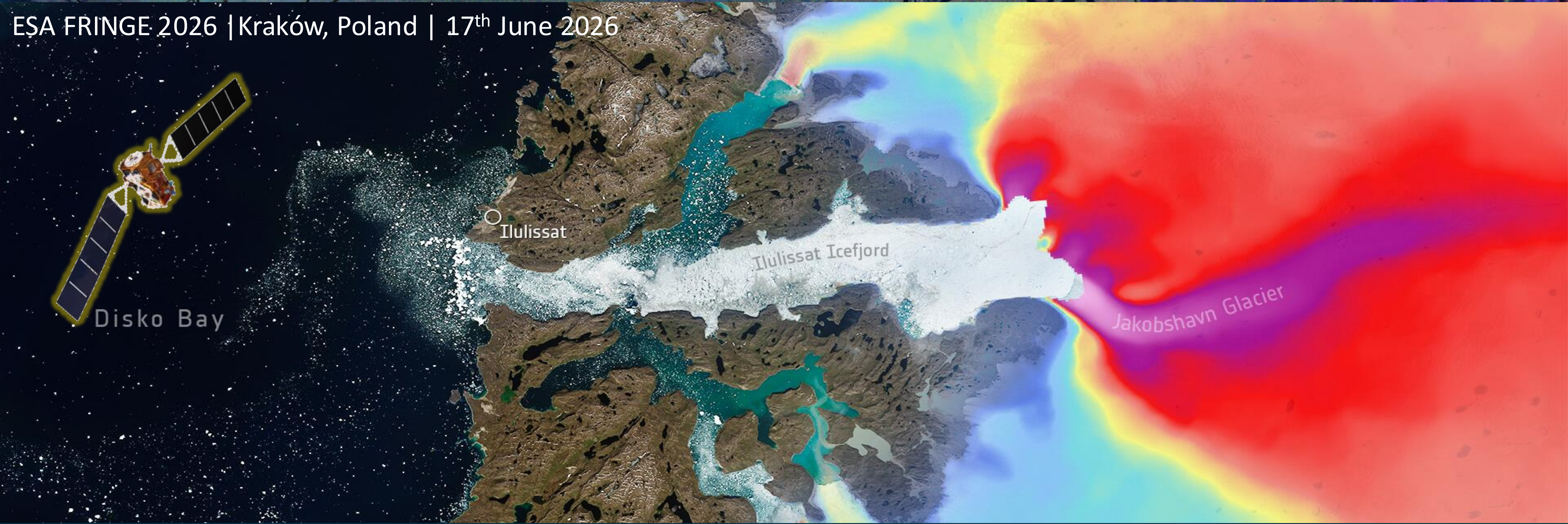
ESA FRINGE 2026 | Kraków, Poland | 17th June 2026



Monitoring Ice Velocity and Discharge with SAR Satellite Missions: Present Capabilities and Future Prospects

<u>Jan Wuite</u>, Thomas Nagler, Markus Hetzenecker, Bryan Cantal and Helmut Rott

ENVEO - Environmental Earth Observation IT GmbH, Innsbruck, Austria

enveo

Sentinel-1 Polar Acquisitions

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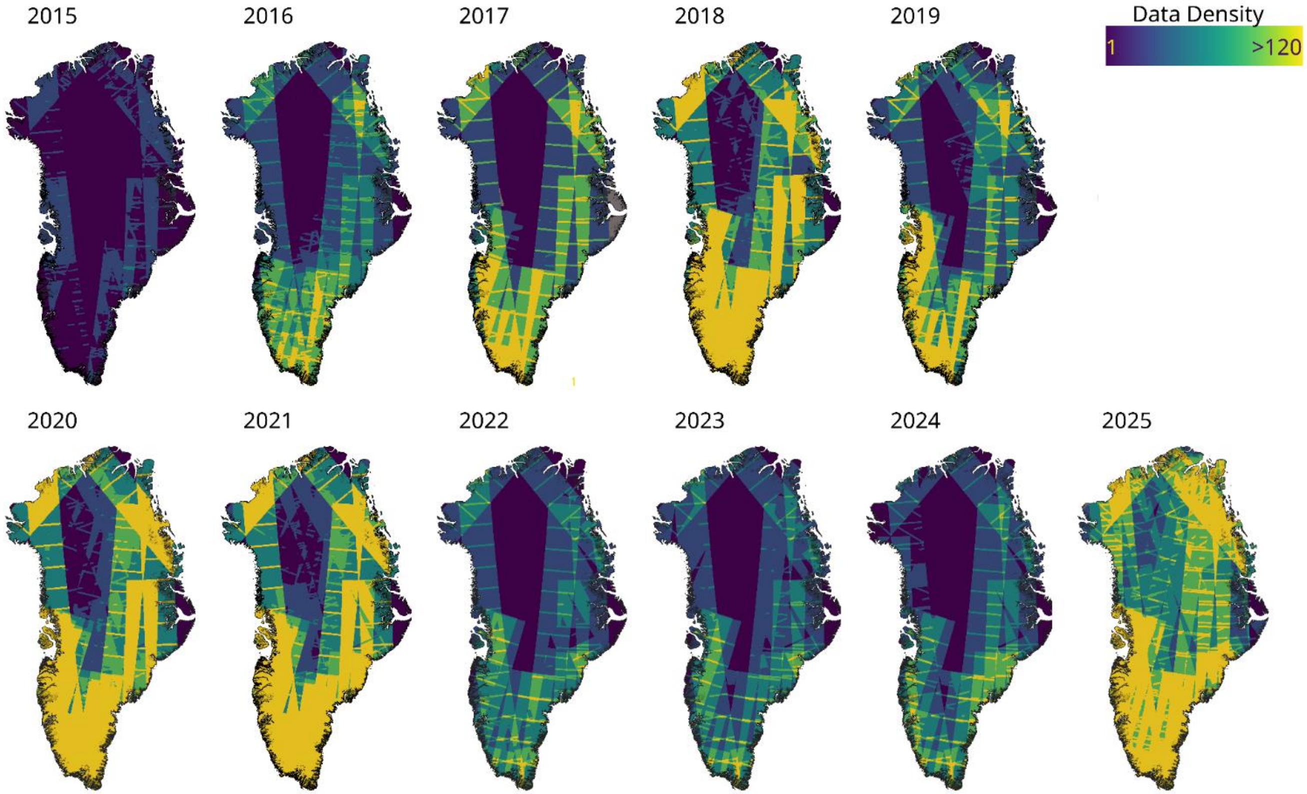
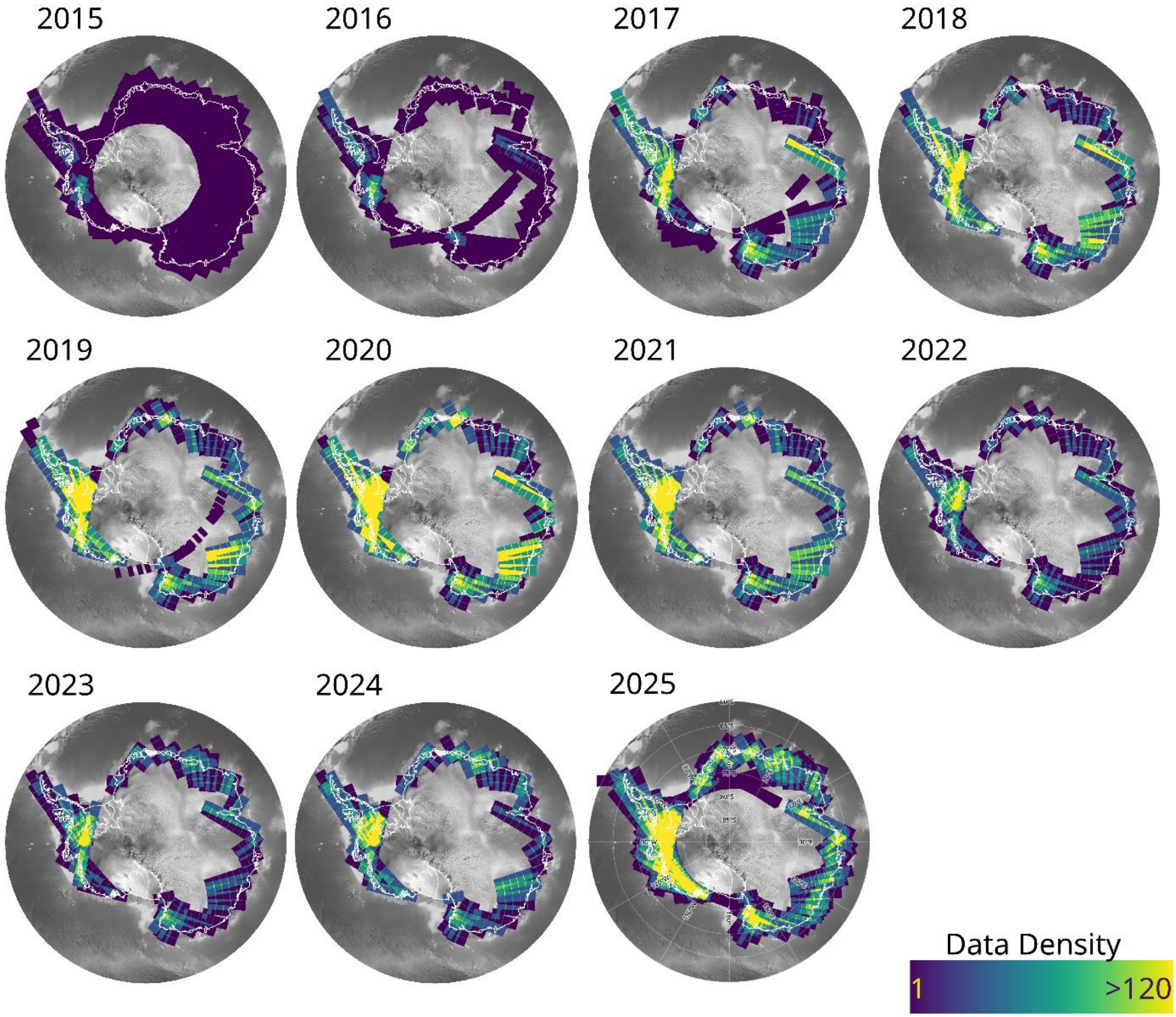
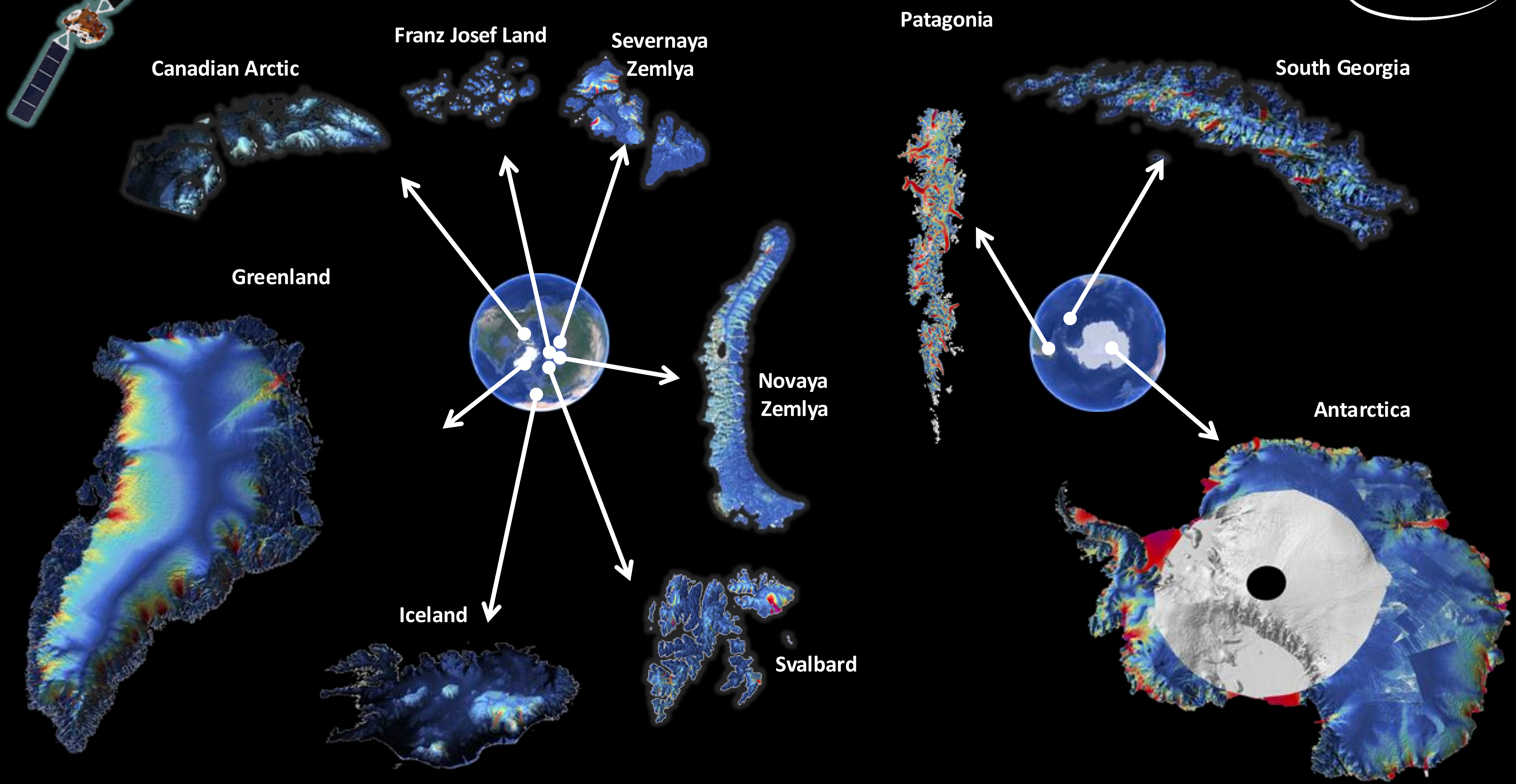


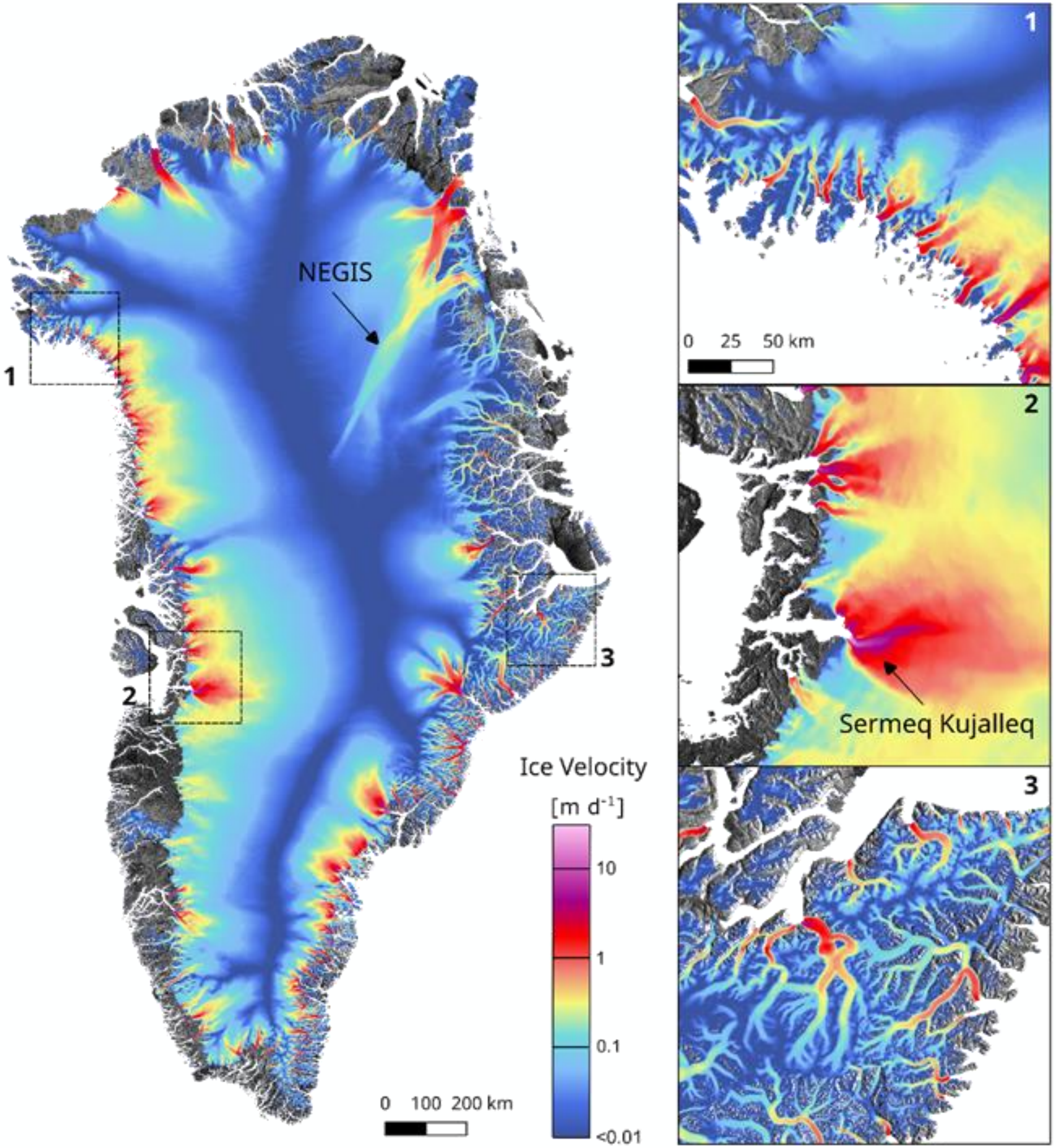


Annual SENTINEL-1 Interferometric Wide (IW) Swath SLC Data Density

Polar Ice Velocity Mapping using Sentinel-1

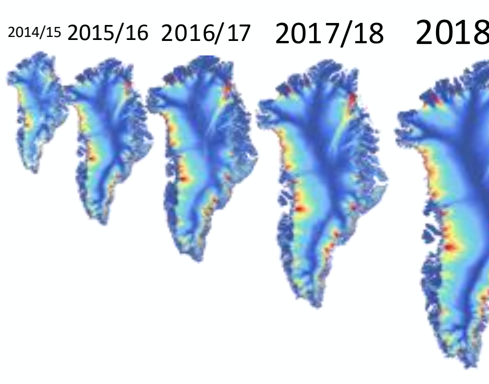


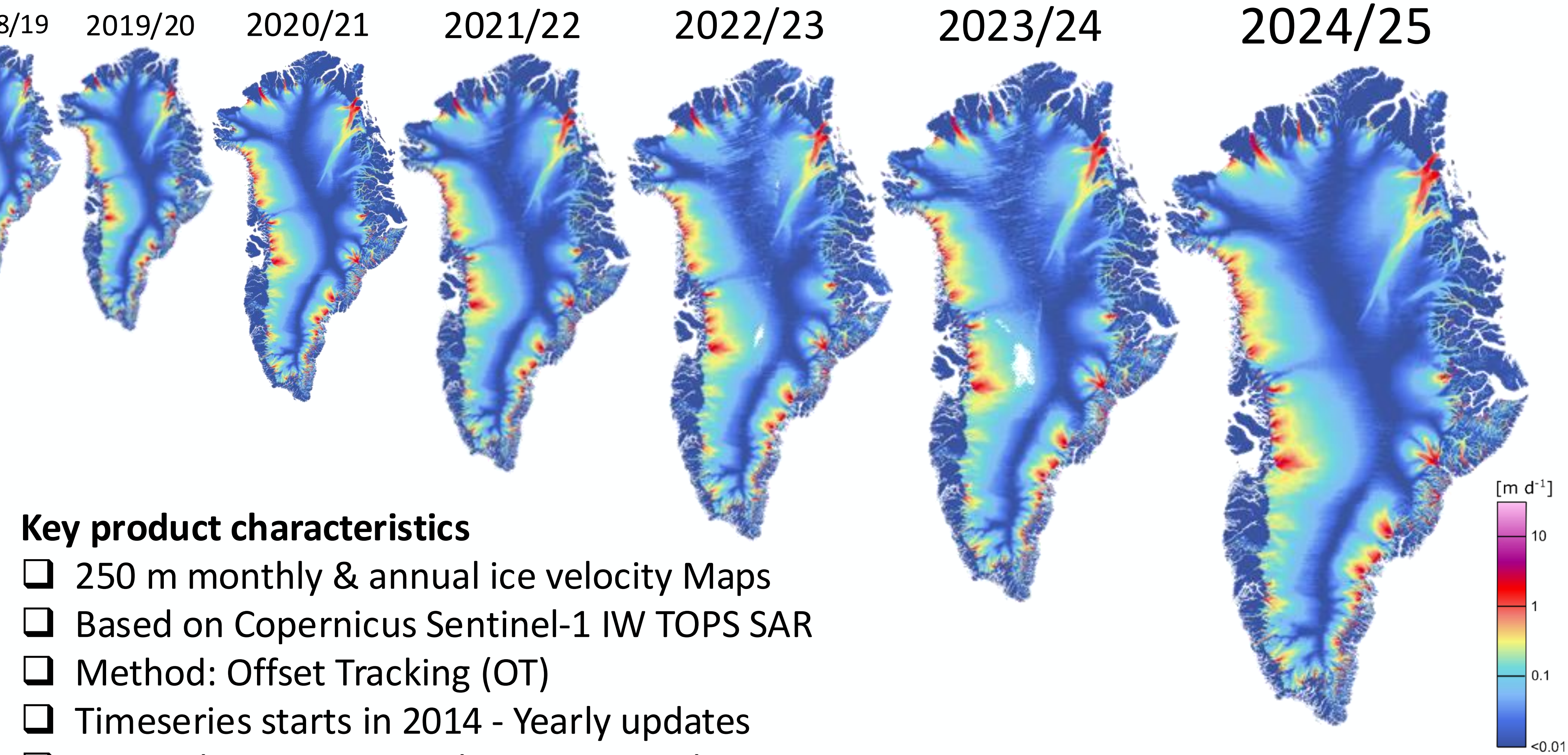
Greenland Ice Velocity



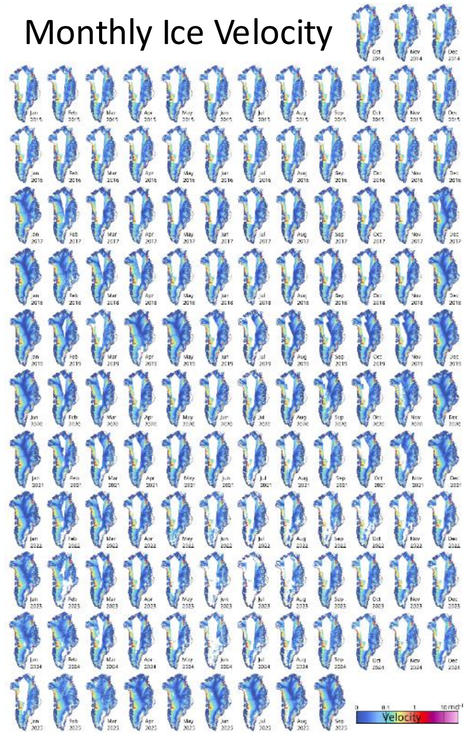
Sensor: Sentinel-1 SAR
Method: Offset Tracking
Period: 2014 to 2024
Pixel spacing: 250 m
Data: ~55,000 S1 SLC products

Greenland Ice Velocity





Monthly Ice Velocity



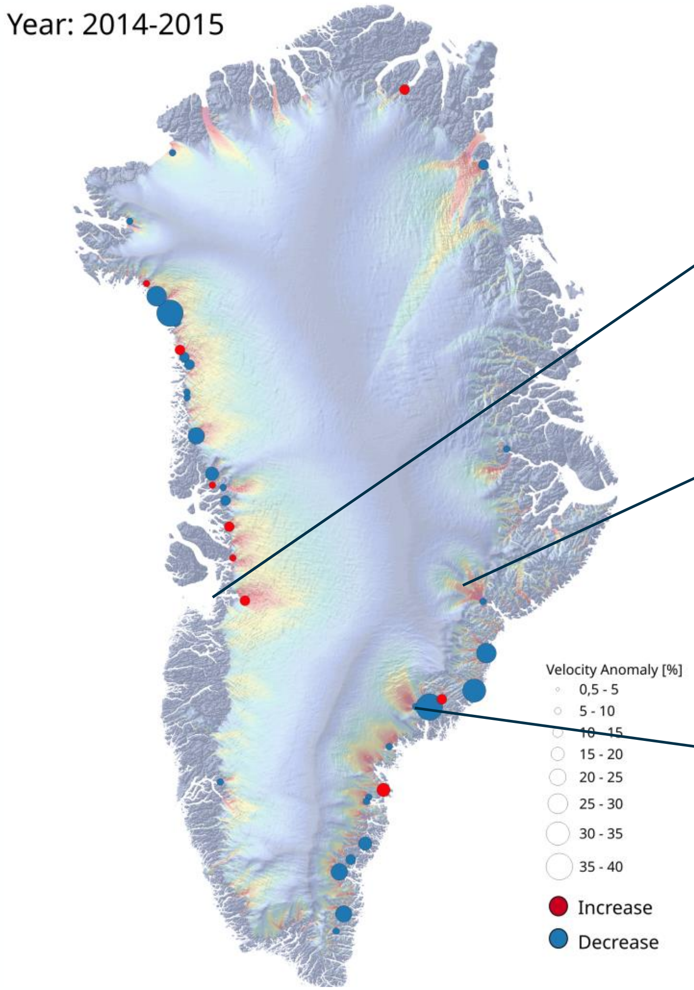
Key product characteristics

- ❑ 250 m monthly & annual ice velocity Maps
- ❑ Based on Copernicus Sentinel-1 IW TOPS SAR
- ❑ Method: Offset Tracking (OT)
- ❑ Timeseries starts in 2014 - Yearly updates
- ❑ Data volume per annual map: 24 tracks, ~2000 scenes, 6.6 TB
- ❑ Products available: Copernicus Climate Data Store, ENVEO Cryoportal

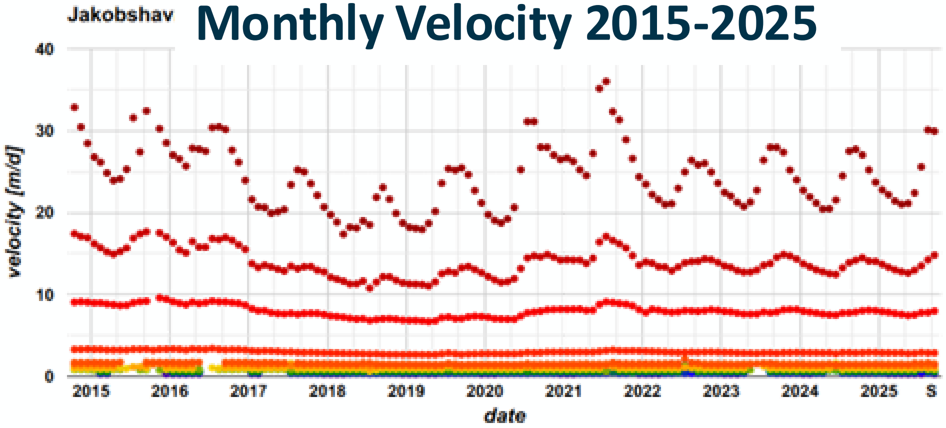
Climate Change Service

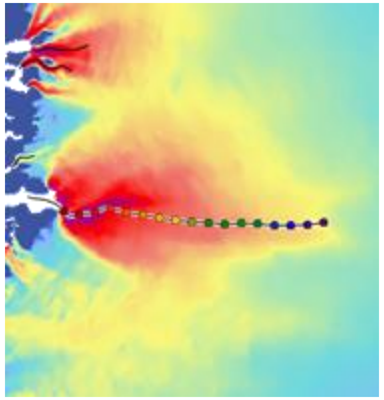
Greenland Ice Velocity

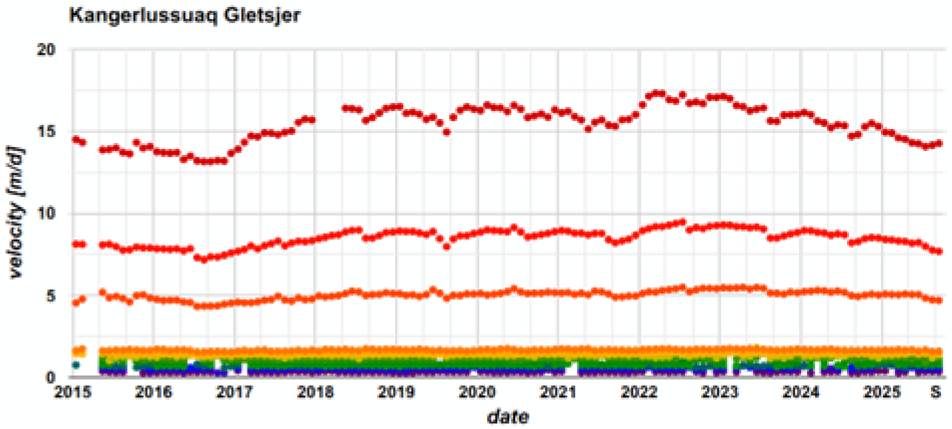
Annual velocity anomalies for Greenland outlet glaciers relative to 2014-2024

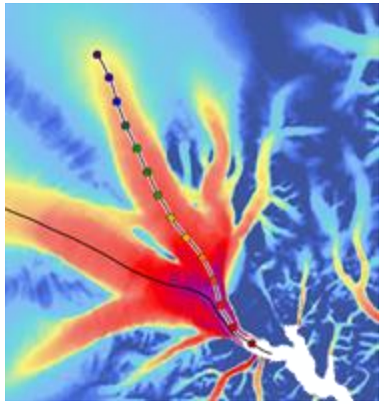


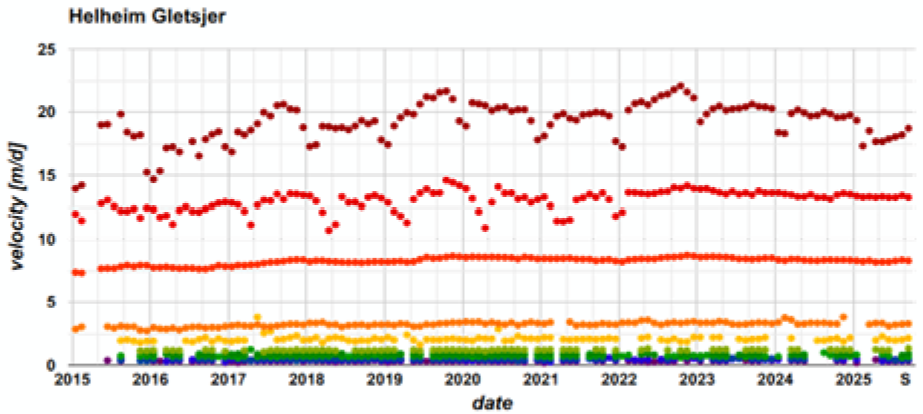
Monthly Velocity 2015-2025

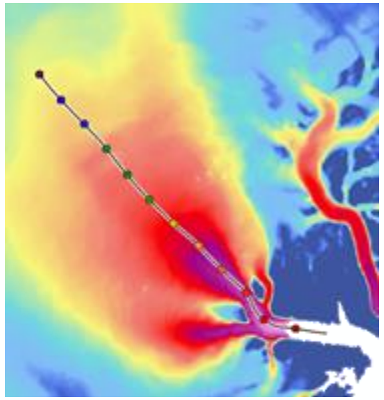












Greenland Solid Ice Discharge

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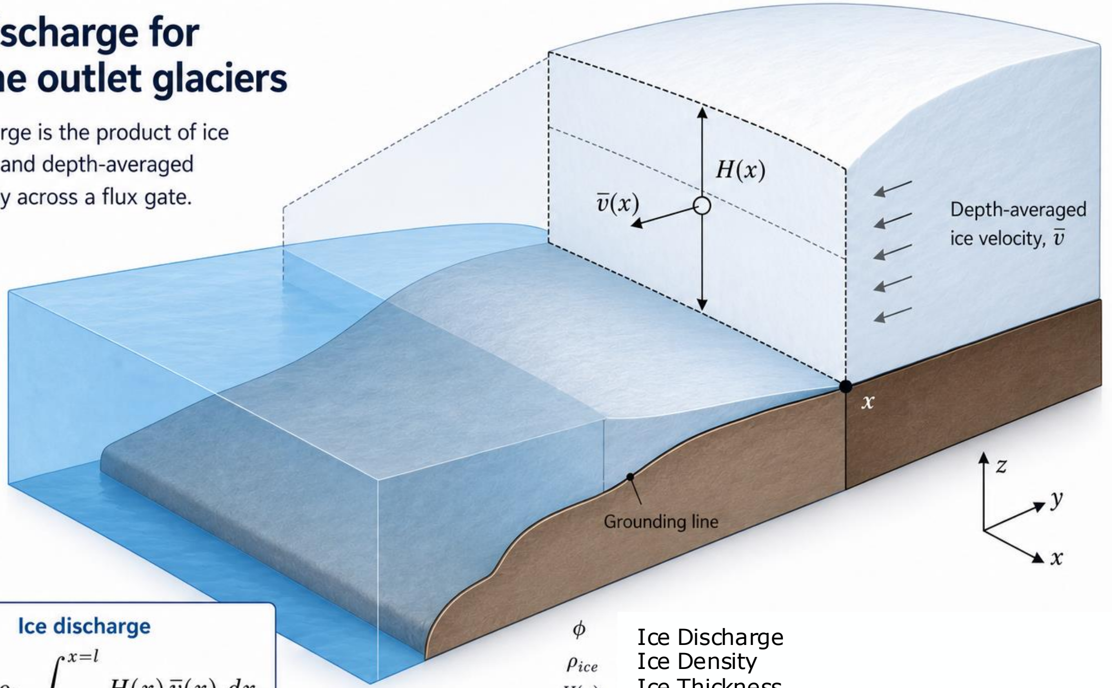
Ice discharge for marine outlet glaciers

Ice discharge is the product of ice thickness and depth-averaged ice velocity across a flux gate.

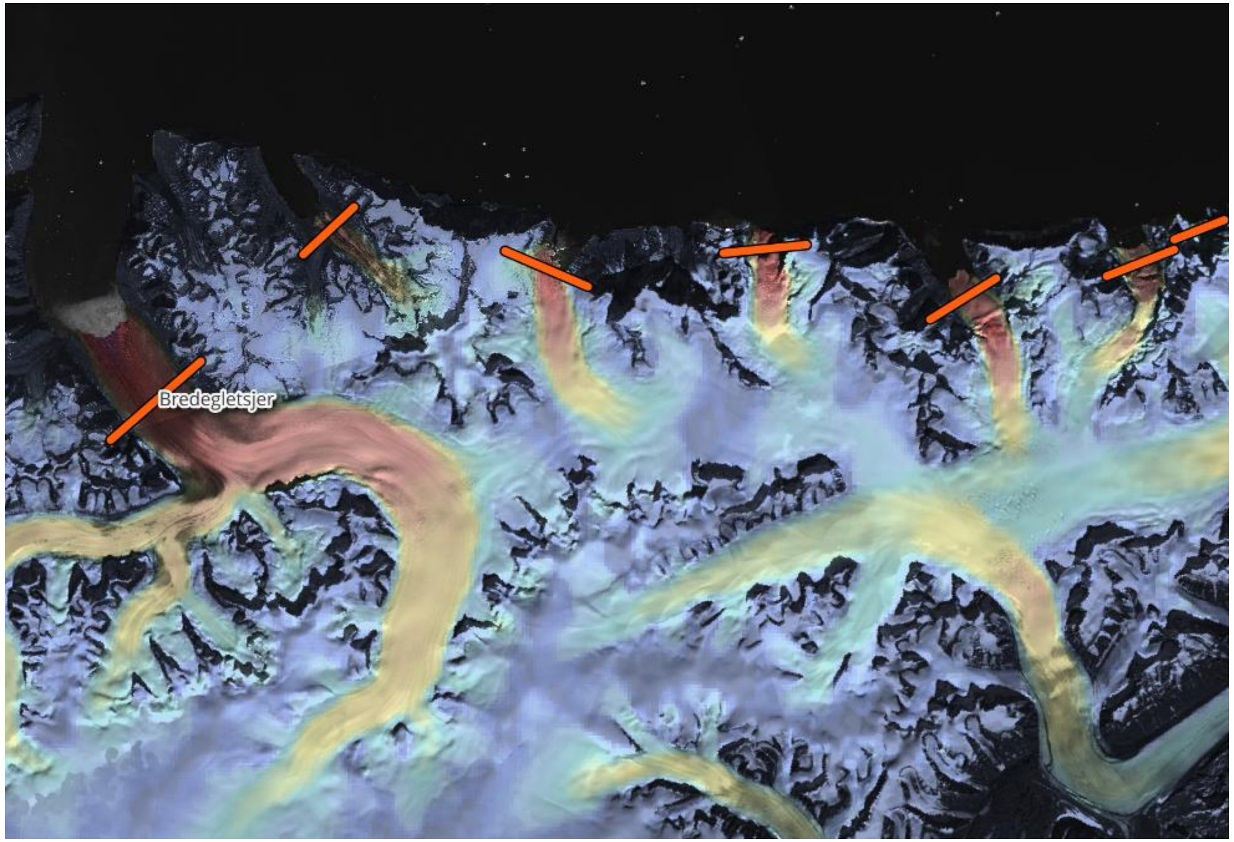


Ice discharge

$$\phi = \rho_{ice} \int_{x=0}^{x=l} H(x)\,\overline{v}(x)\,dx$$

Ice discharge ϕ is the product of ice density ρ_{ice} and the integral across the flux gate of ice thickness $H(x)$ times depth-averaged velocity $\overline{v}(x)$.

ϕ Ice Discharge
ρ_{ice} Ice Density
$H(x)$ Ice Thickness
$\overline{v}(x)$ Depth-averaged ice velocity



- ❑ Ice velocity primary input for calculating solid ice discharge
- ❑ Monthly ice discharge is calculated by combining ice velocity and ice thickness
- ❑ Flux gates for >250 marine terminating outlet glaciers around the Greenland Ice Sheet margins
- ❑ Ice thickness corrected for surface elevation changes

Greenland Solid Ice Discharge

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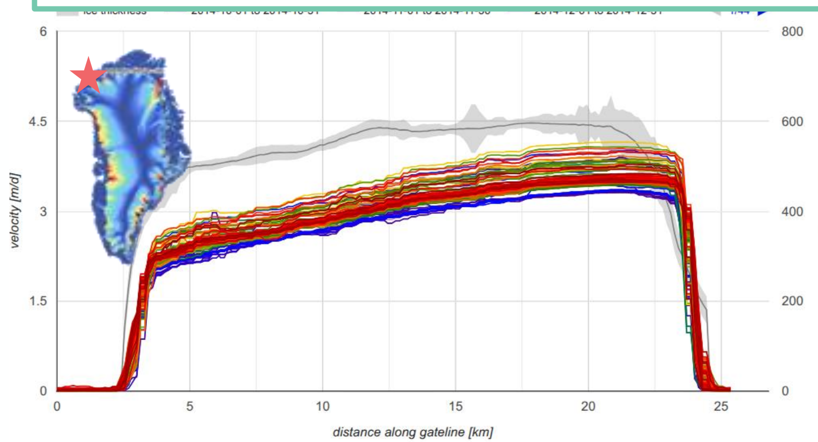
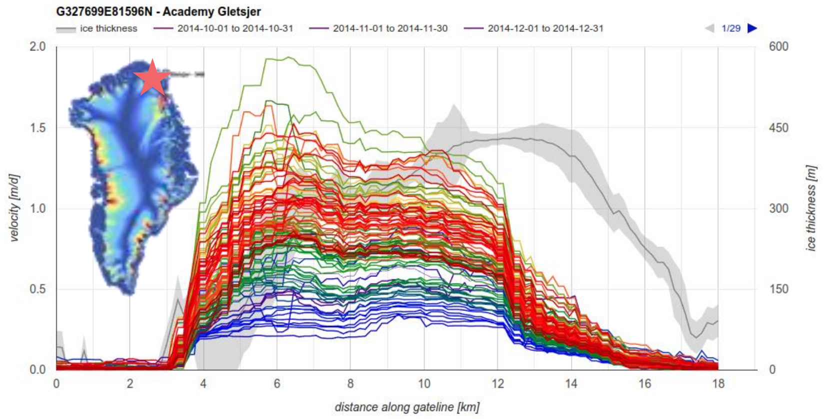
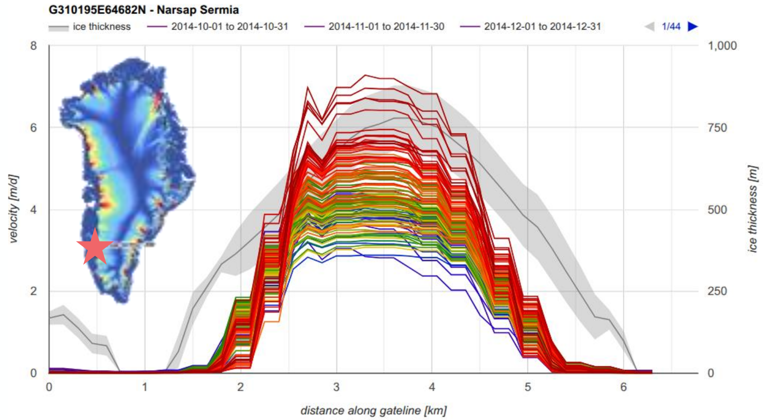
Cross profiles (Velocity and Ice Thickness)

Ice Thickness: IceBridge BedMachine Greenland, Version 6





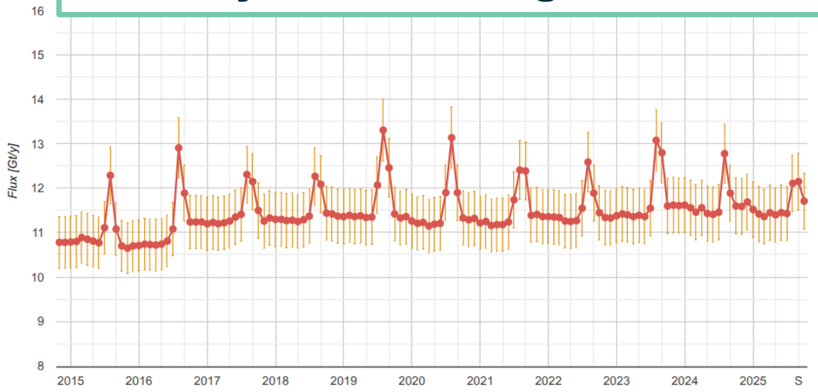


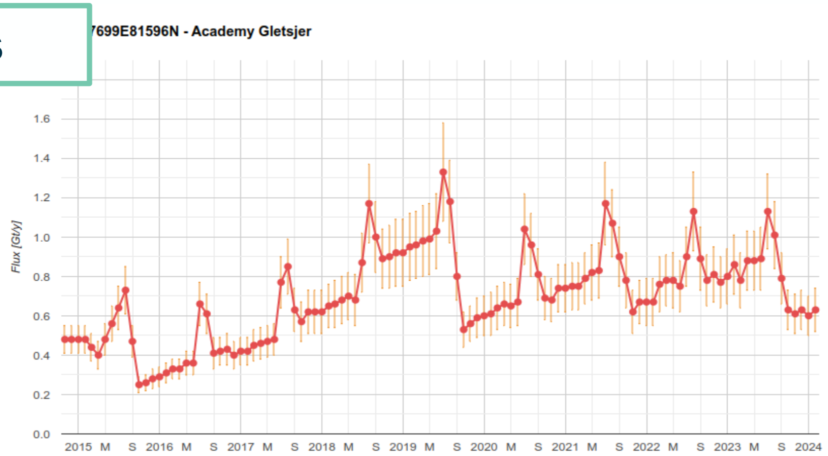
Petermann Glacier

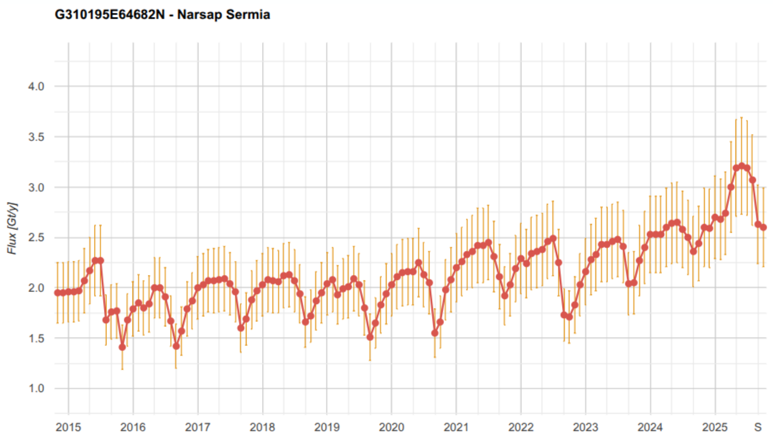
Academy Glacier

Narsap Sermia

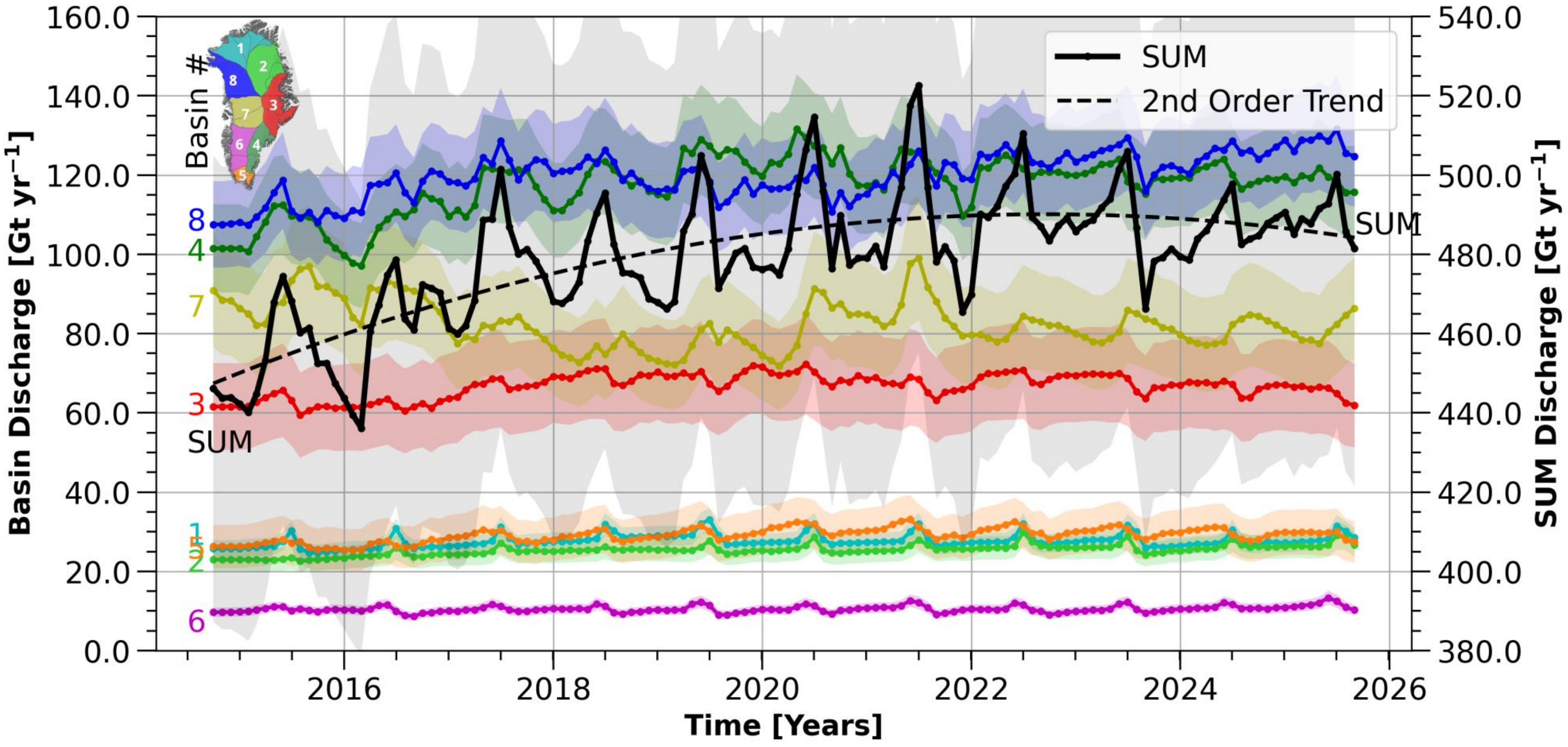
Monthly Ice Discharge time series





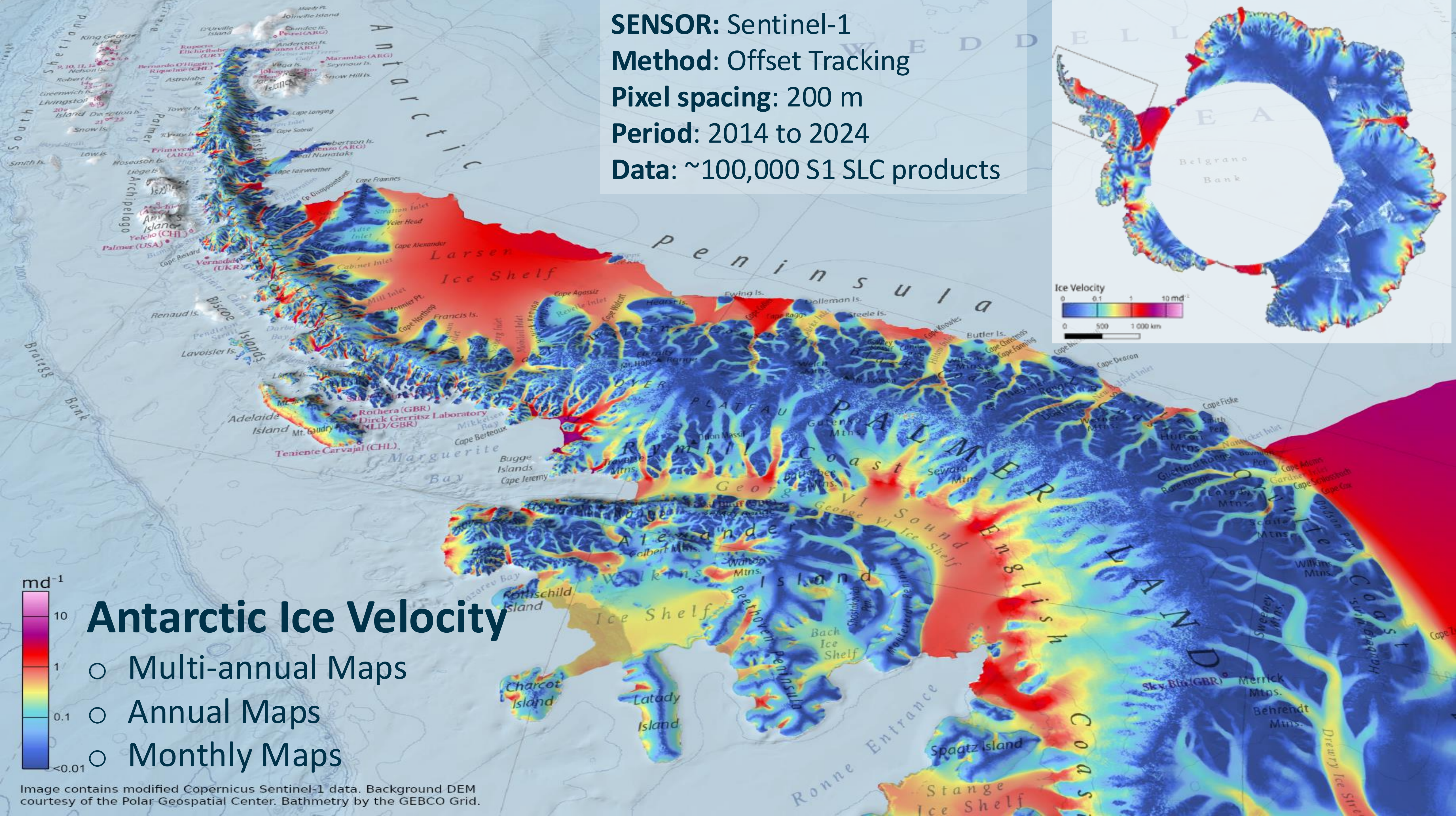


10+ years of Greenland Monthly Ice Discharge



YEAR	ANNUAL SOLID ICE DISCHARGE (Gt/Y)
2014-2015	450.49 ± 59.18
2015-2016	453.12 ± 59.08
2016-2017	472.71 ± 61.01
2017-2018	474.71 ± 60.92
2018-2019	475.35 ± 60.99
2019-2020	482.63 ± 61.09
2020-2021	485.96 ± 61.89
2021-2022	479.38 ± 60.24
2022-2023	485.65 ± 60.88
2023-2024	480.83 ± 60.40
2024-2025	485.14 ± 61.14

+6.5%



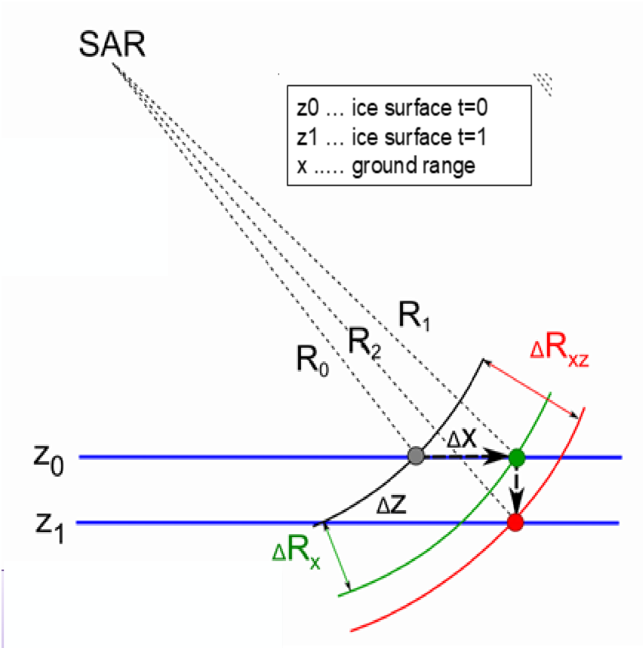
Antarctic Ice Velocity

- Multi-annual Maps
- Annual Maps
- Monthly Maps

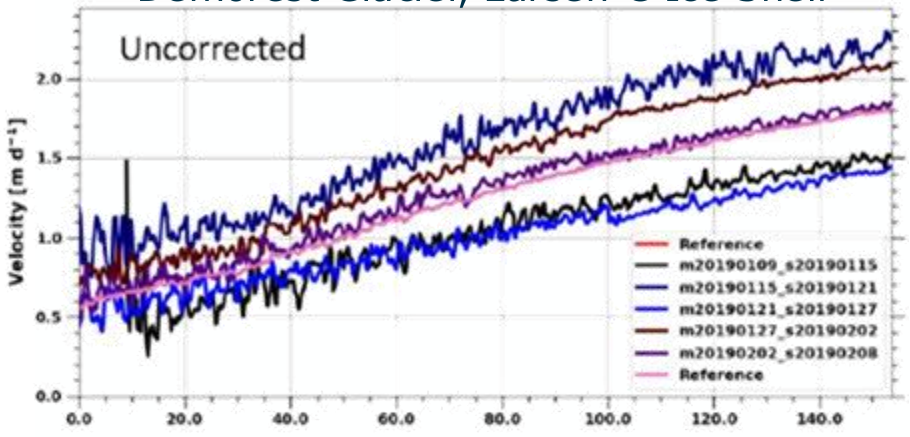
SENSOR: Sentinel-1
Method: Offset Tracking
Pixel spacing: 200 m
Period: 2014 to 2024
Data: ~100,000 S1 SLC products

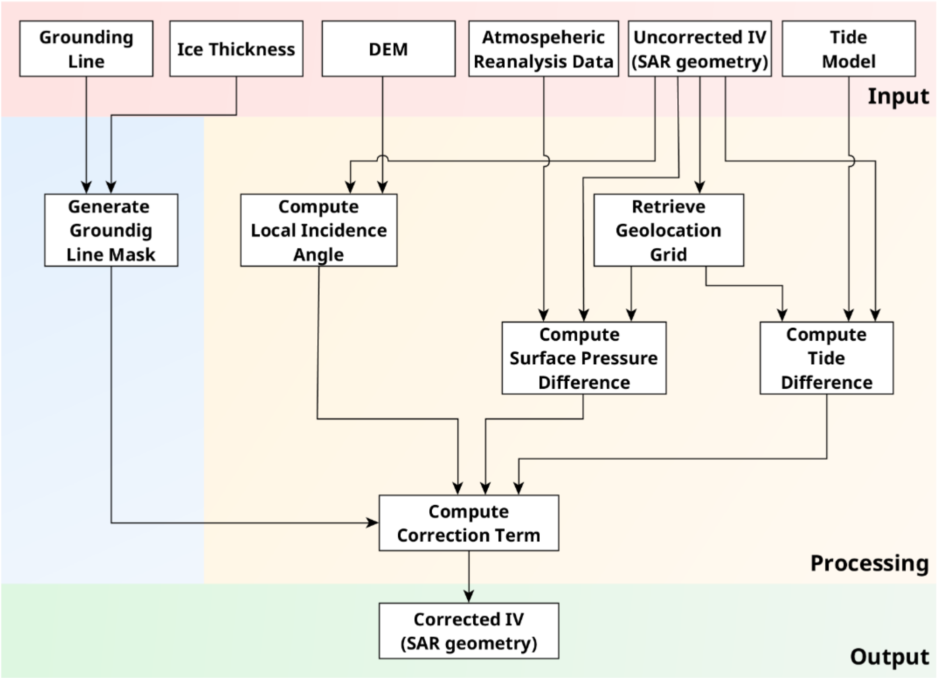
Image contains modified Copernicus Sentinel-1 data. Background DEM courtesy of the Polar Geospatial Center. Bathmetry by the GEBCO Grid.

Tidal Correction on Floating Ice



Uncorrected Velocity Profiles on Demorest Glacier, Larsen-C Ice Shelf





$$iv_{corr} = iv_{uncorr} + \left(\frac{(\Delta h + \Delta p\, c_{IBE})\, \cos(\Theta)\, w}{sz_{rg}}\right)\frac{1}{(t_1 - t_0)}$$

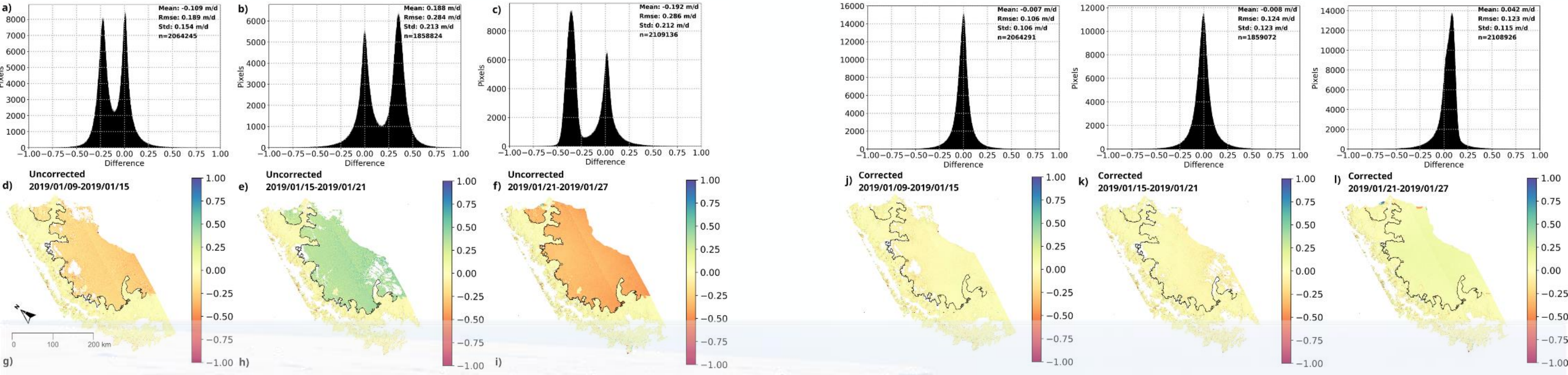
Processing line computes vertical displacements on floating ice and corrects velocity using a tide model, ERA5 pressure data, and an elastic beam model

Tidal Correction on Floating Ice

Uncorrected

Tide Corrected

Larsen C Ice shelf



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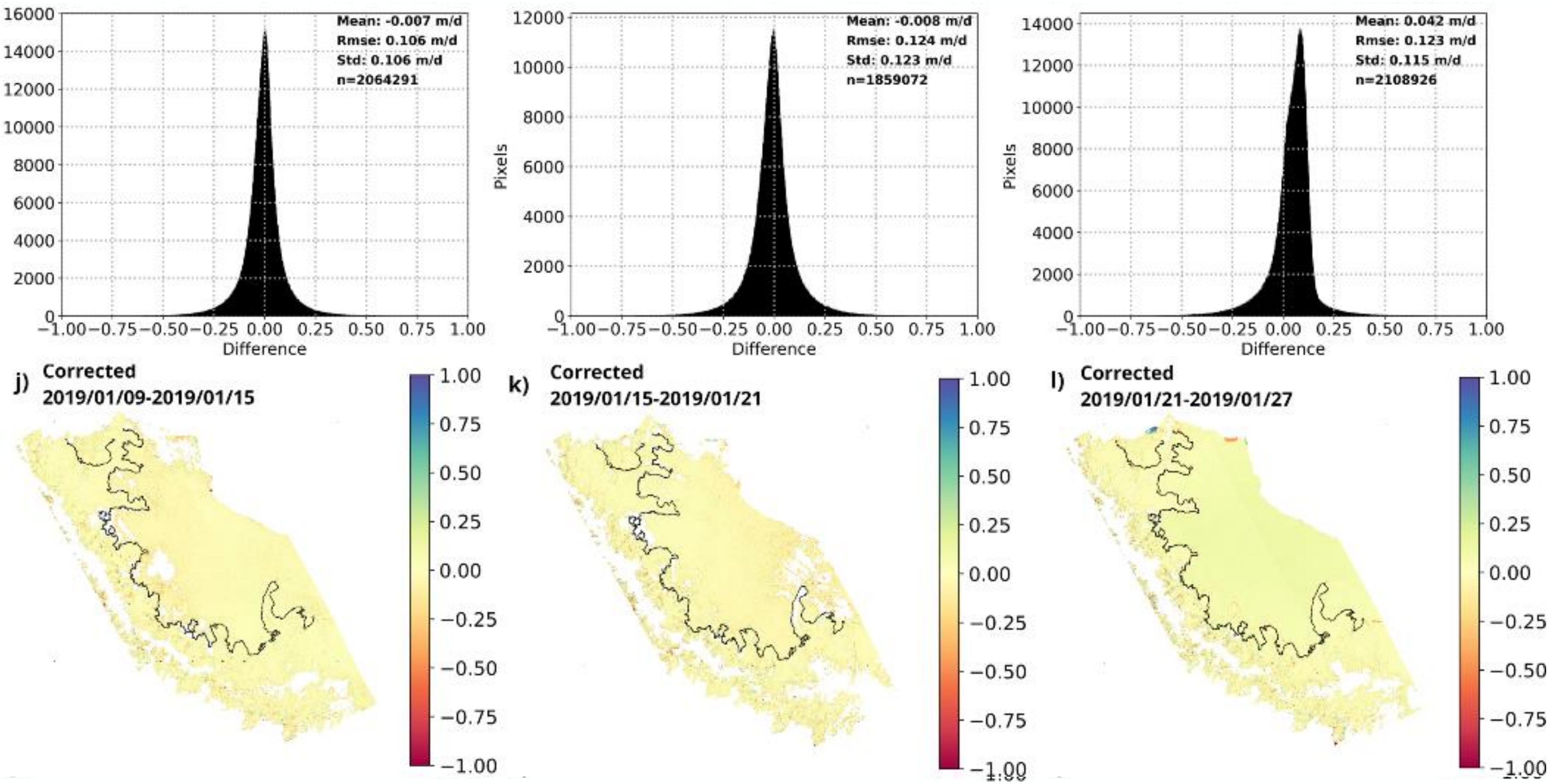
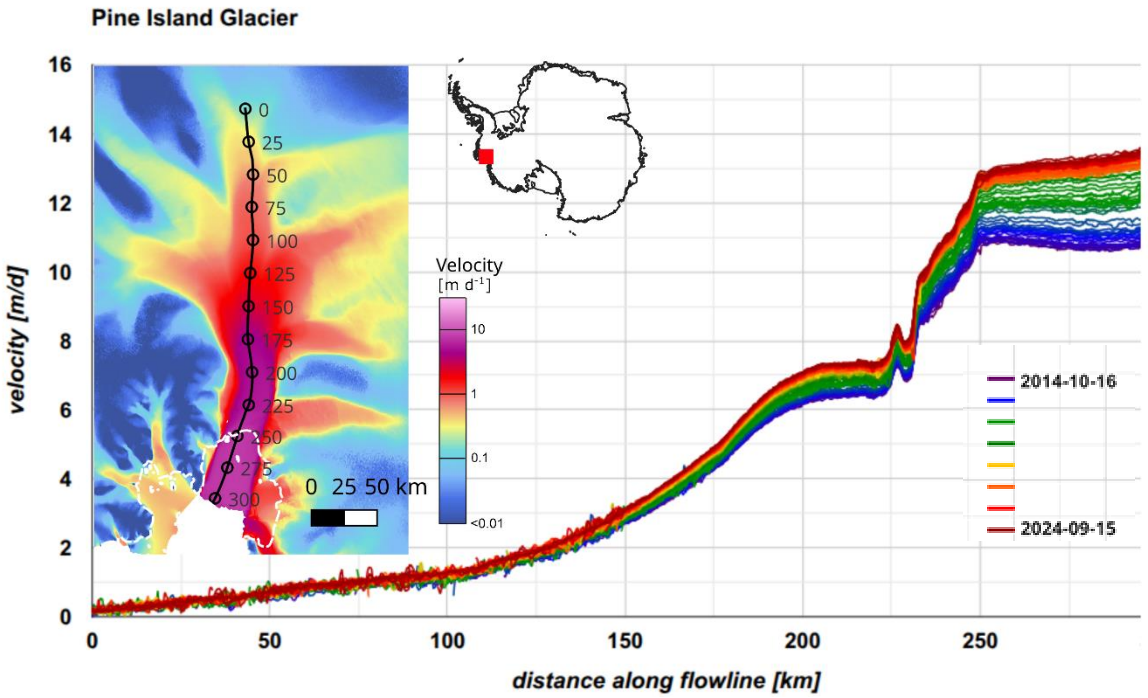
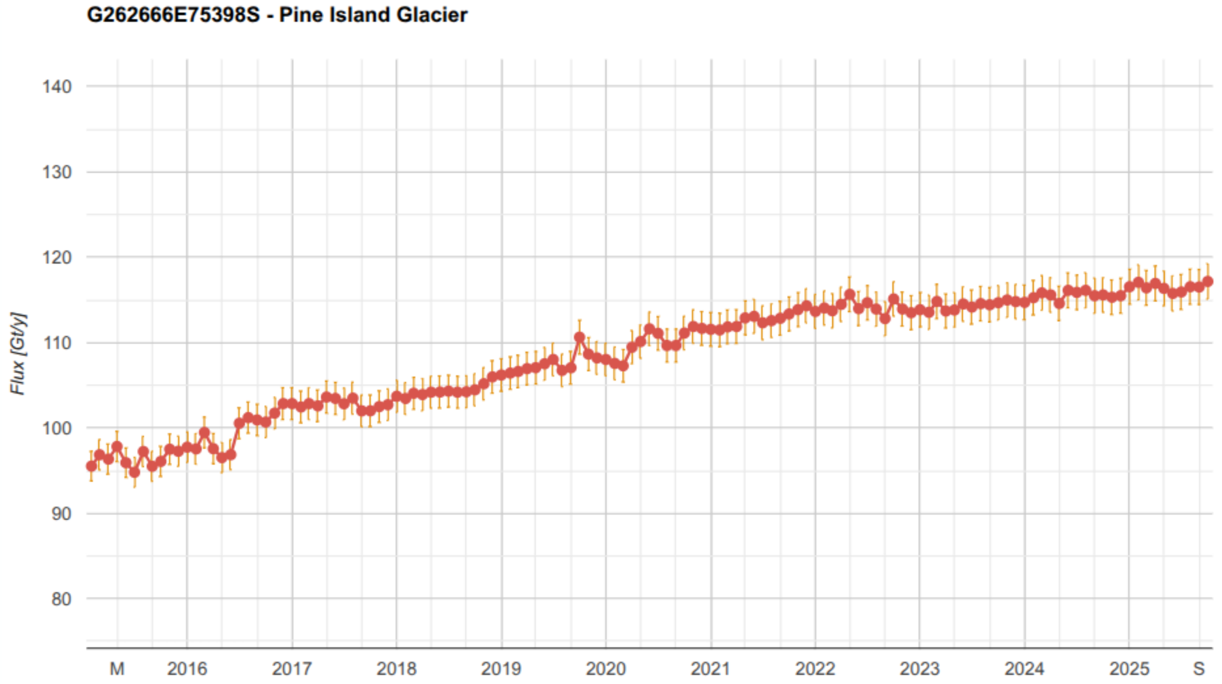
Larsen C Ice shelf

Tide Corrected



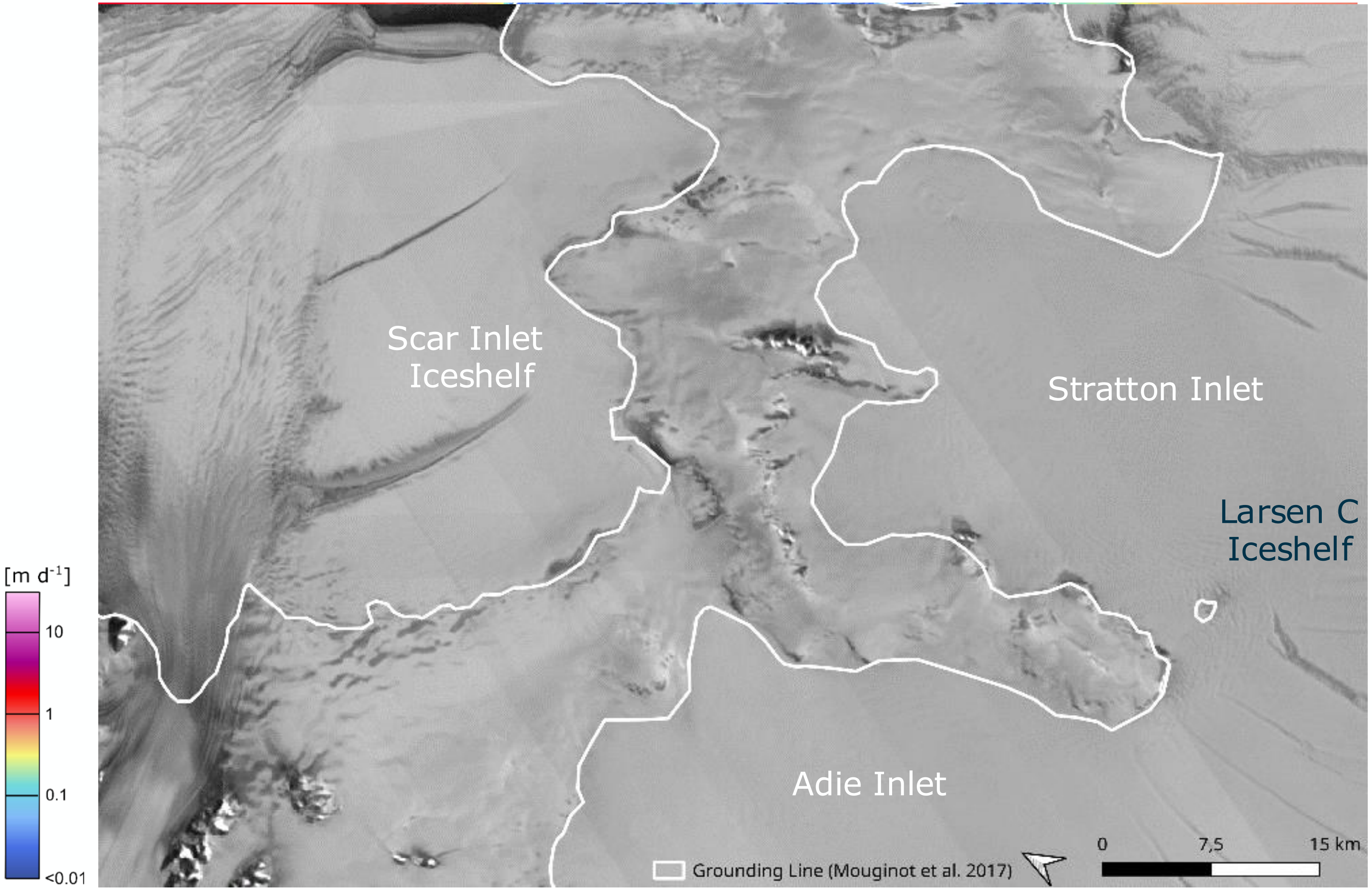
10+ years of Ice Velocity and Discharge on Pine Island Glacier

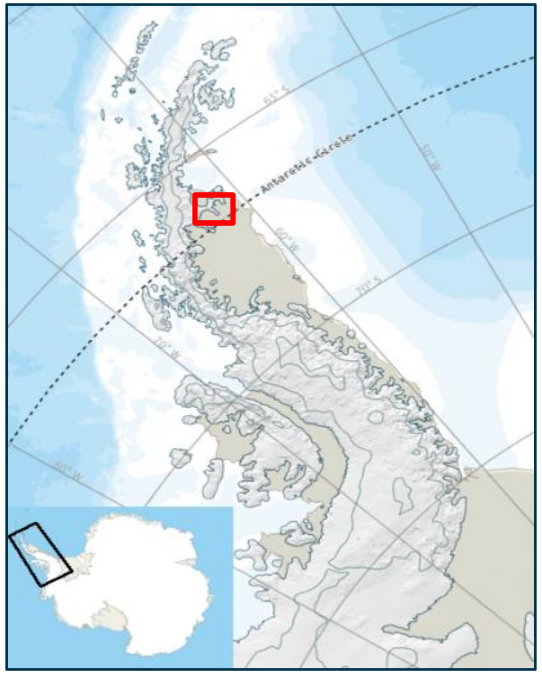




Pine Island Glacier shows a continuous near-linear increase in ice velocity and discharge at the grounding line from 2015-2025: ~20% (Wuite et al., 2025)

S1/SAOCOM InSAR (Xorbits-tidecor) + SAOCOM INSAR with Flowdir



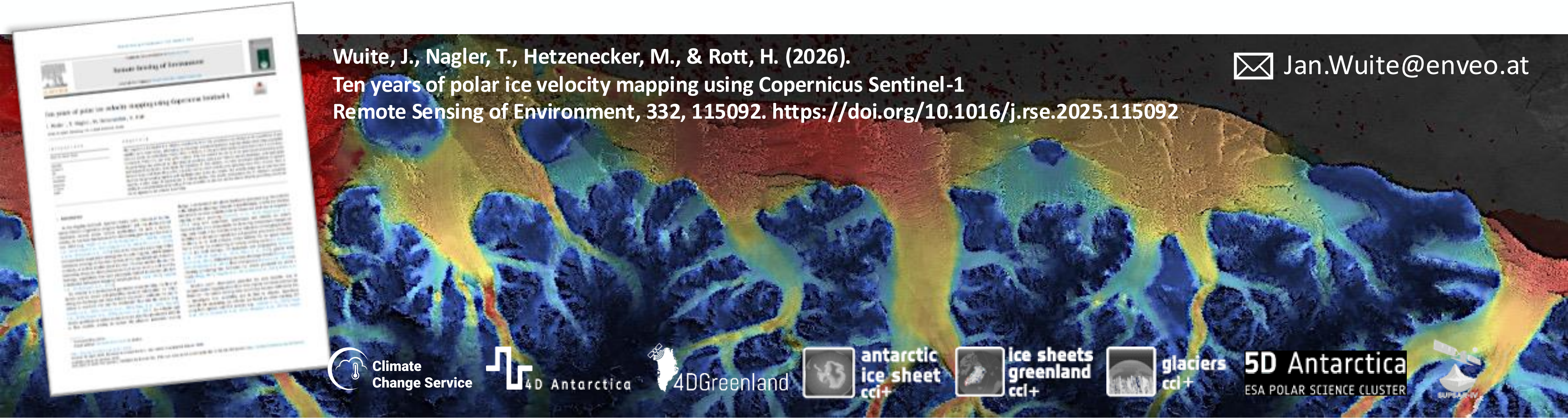


SAOCOM: 2021/08/20 – 2021/09/05
Sentinel-1: 2021/09/07-2021/09/13

Summary and Conclusions

Sentinel-1 fundamentally changed the way we are able to monitor ice sheets and ice caps by systematically acquiring dense time series of SAR data in the polar regions

- Continuous detailed velocity maps covering Greenland, Antarctica and polar ice caps and glaciers since 2014 at high spatial and temporal resolution
- Time series enables to detect fluctuations and trends in ice velocity and discharge at various time scales providing new insight into the changing dynamics of glaciers and ice sheets
- Future opportunities for velocity retrieval emerge with new and upcoming missions (e.g. NISAR, ROSE-L, S1 NG) which will deliver new data over ice sheets that can be used in synergy with Sentinel-1 for comprehensive polar monitoring



Wuite, J., Nagler, T., Hetzenecker, M., & Rott, H. (2026).
Ten years of polar ice velocity mapping using Copernicus Sentinel-1
Remote Sensing of Environment, 332, 115092. https://doi.org/10.1016/j.rse.2025.115092

Jan.Wuite@enveo.at