INVESTIGATION OF TIDAL GROUNDING LINE MIGRATION USING SAR LINE-OF-SIGHT OFFSET TIME SERIES

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DLR

Motivation

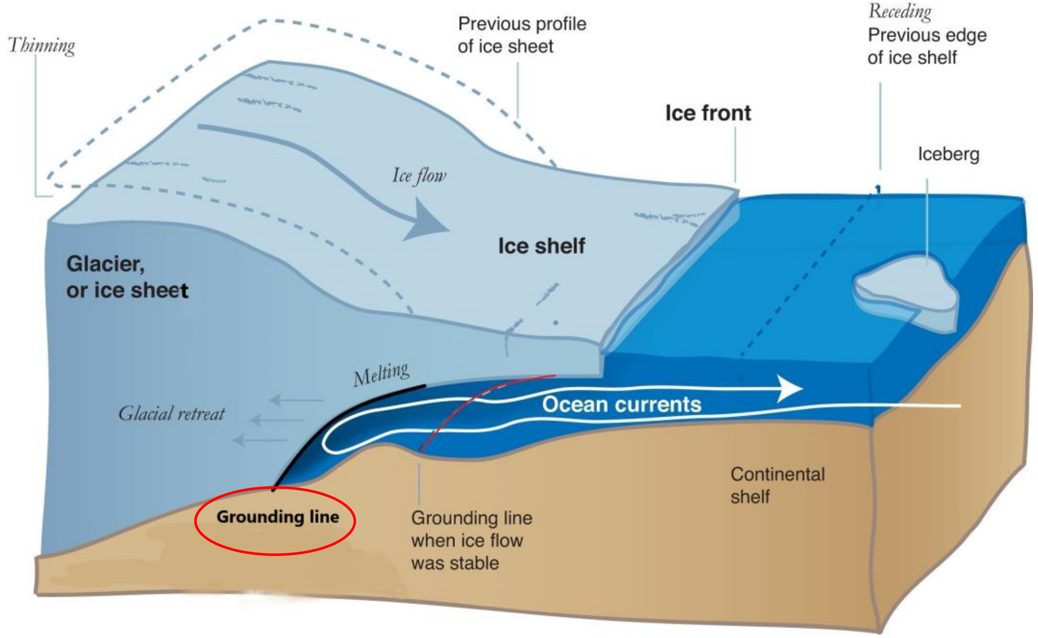
The grounding line (GL) marks the boundary where an outlet glacier starts to float over open water

Significance:

- Accurate GL locations are needed to compute ice mass loss budget
- Knowledge of melt processes at GLs are essential to understanding the evolution of ice sheets [Rignot, 2023]

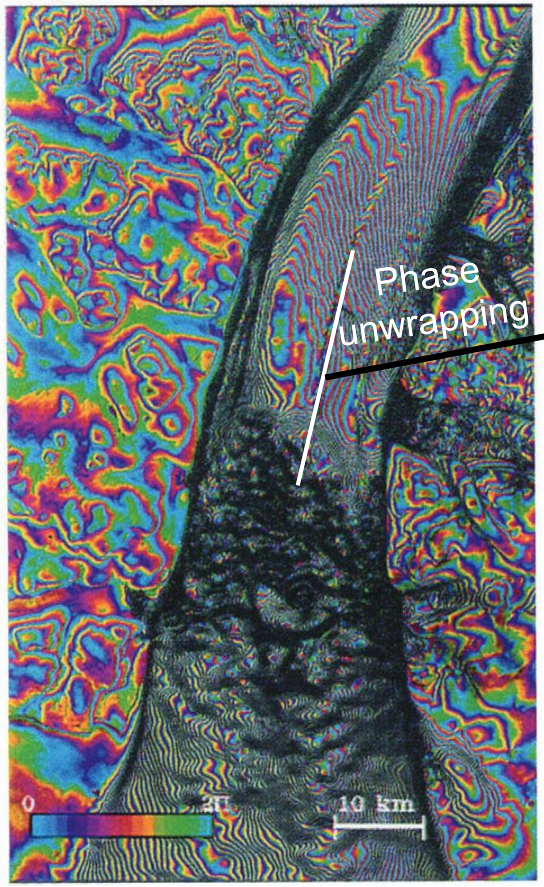
Challenges:

- GLs are not visible on the surface → difficult to detect!
- Heterogenous and out of phase movement with tides [Freer et al., 2023], [Milillo et al., 2019]

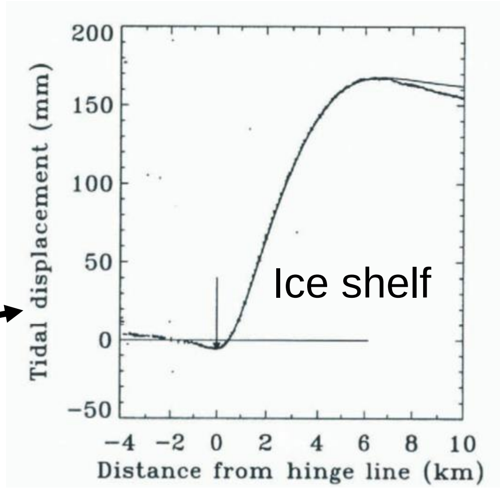


National Snow and Ice Data Center, NASA

Grounding line detection with Synthetic Aperture Radar: modeling approach



ERS **Interferometric SAR** phase, Petermann glacier, Greenland

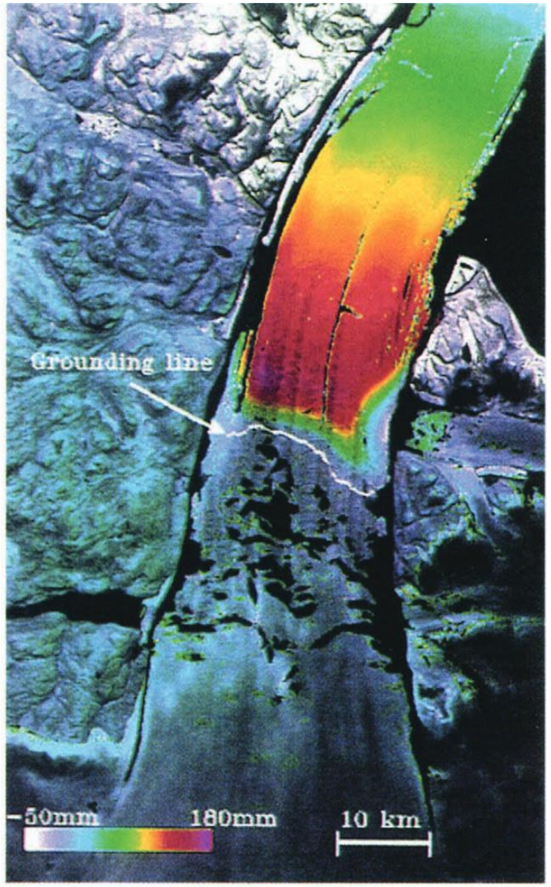


$$w(x) = A_0(t)[1 - e^{-\beta x}(\cos\beta x + \sin\beta x)]$$

x: horizontal axis
$w(x)$: tidal deflection
$A_0(t)$: level of ice shelf if floating in isostatic equilibrium

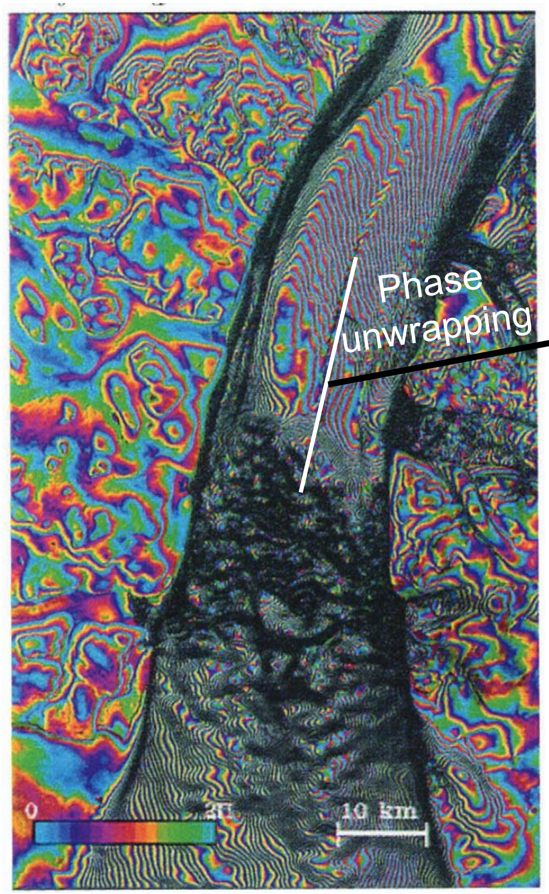
$$\beta = \sqrt[4]{\frac{3\rho_{sea} g(1-\nu^2)}{Eh^3}}$$

h: ice thickness
ν: Poisson's ratio
E: Young's modulus



Rignot E, 1996

Grounding line detection with Synthetic Aperture Radar: modeling approach



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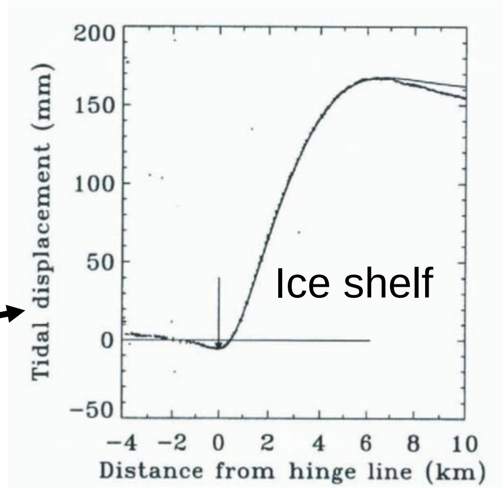

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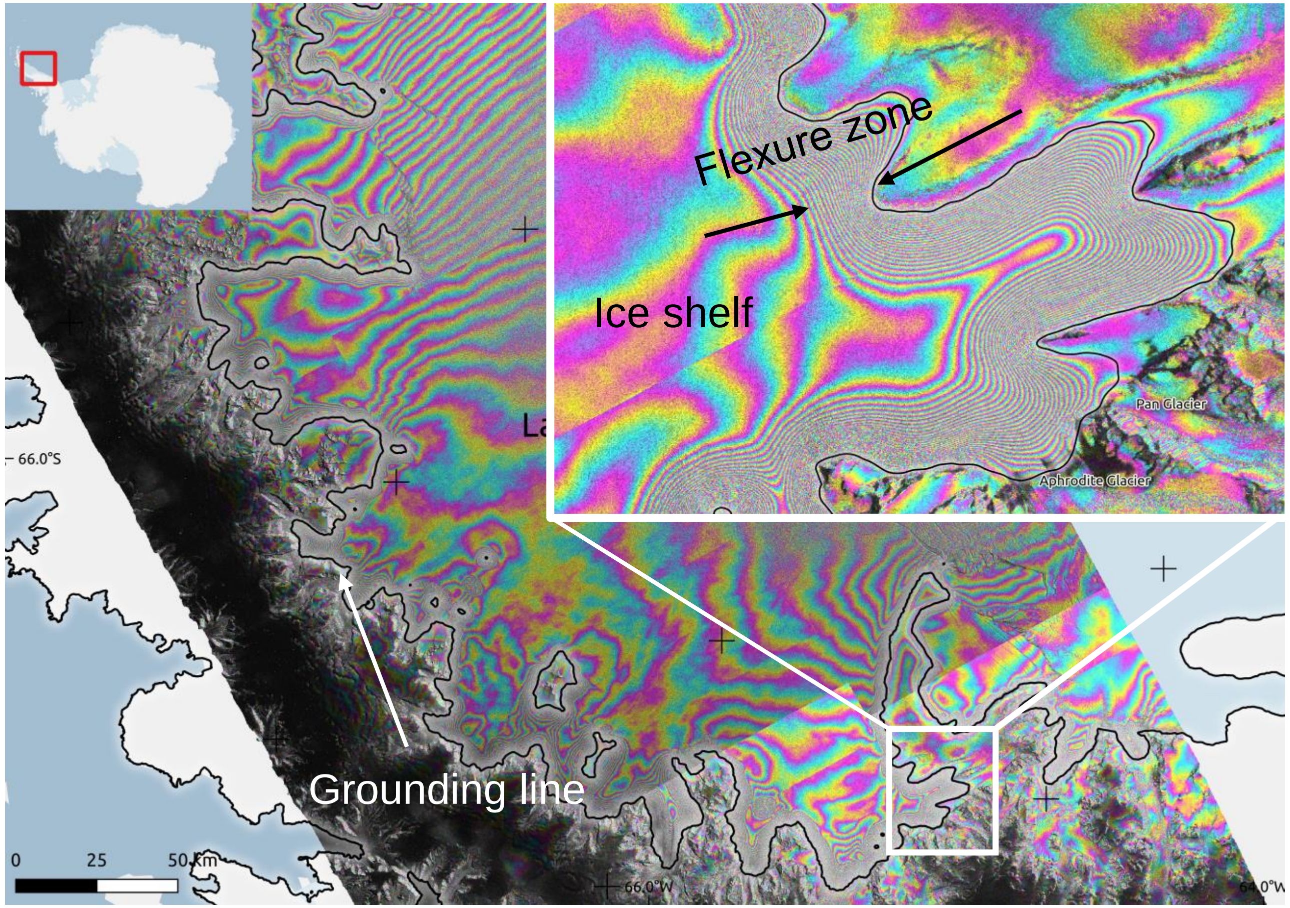
- Currently no open source SAR data with < 6 days temporal repeat
- Large variation in E (0.1 – 10 GPa)
- Difficult to constrain the model due to uncertainties in ice thickness and tide elevation

Grounding line detection with Synthetic Aperture Radar: heuristic approach

Differential Interferometric SAR (DInSAR):
- difference of two interferograms to remove horizontal ice motion
- requires 3-4 acquisitions → mixed tidal state
- difficult to get coherent interferograms for fast flowing glaciers

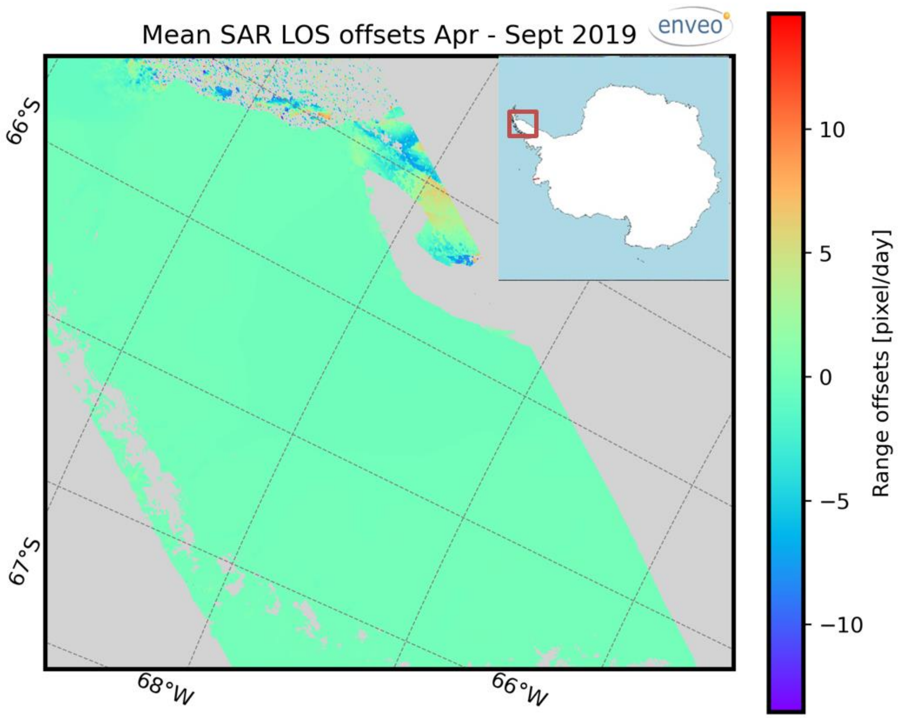
SAR LOS (range) offsets:
- are computed by cross-correlating 2 SAR intensity images → not dependent on coherence!
- Less precise than DInSAR

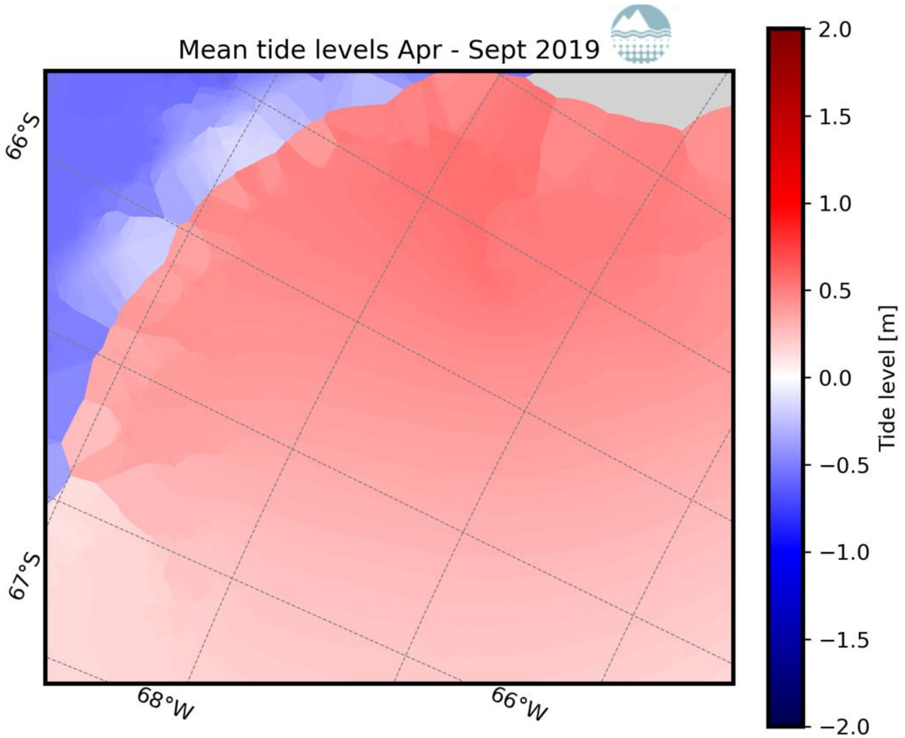
Goal: Create a dense time series of GLs to facilitate the study of tidal migration



Interferograms from Wallis et al., 2024

Datasets and test site

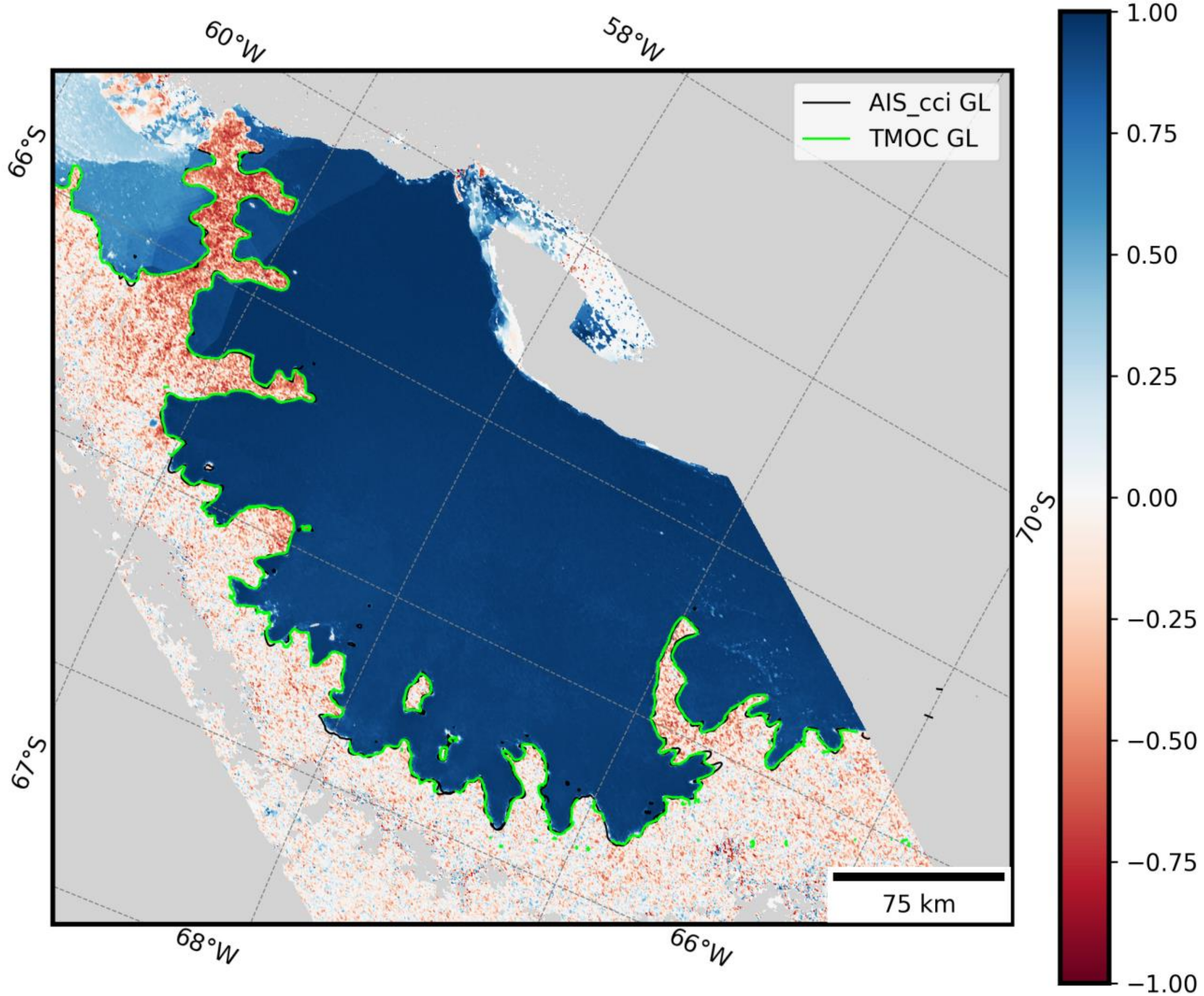




Variable	Dataset	Spatial resolution	Temporal extent
Sentinel-1 LOS offsets	ENVEO IT [Nagler et al., 2015]	200 m	Apr – Sept 2019
Tide elevation	CATS2008_v2023 [Howard et al., 2024]	2000 m	Coincident with LOS offsets
4 x daily surface level pressure	NCEP/NCAR Reanalysis, NOAA [Kalnay et al., 1996]	2.5°	Coincident with LOS offsets
Grounding lines	Antarctic Ice Sheets climate change initiative (AIS_cci) GL [Floricioiu et al., 2019]	-	1994 - 2022

Tidal motion offset correlation grounding line (TMOC)

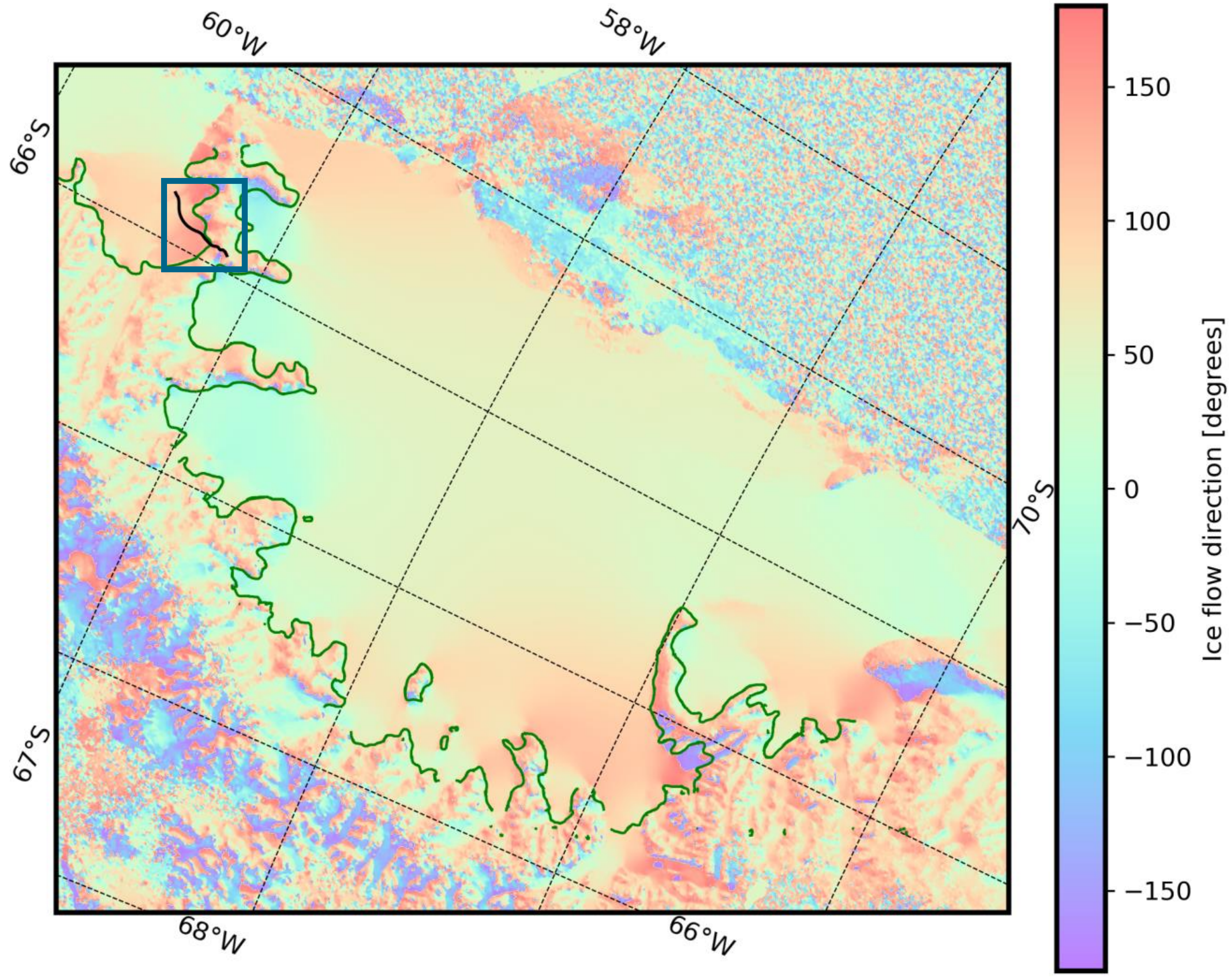
Pearson's correlation between LOS offsets and tide elevation



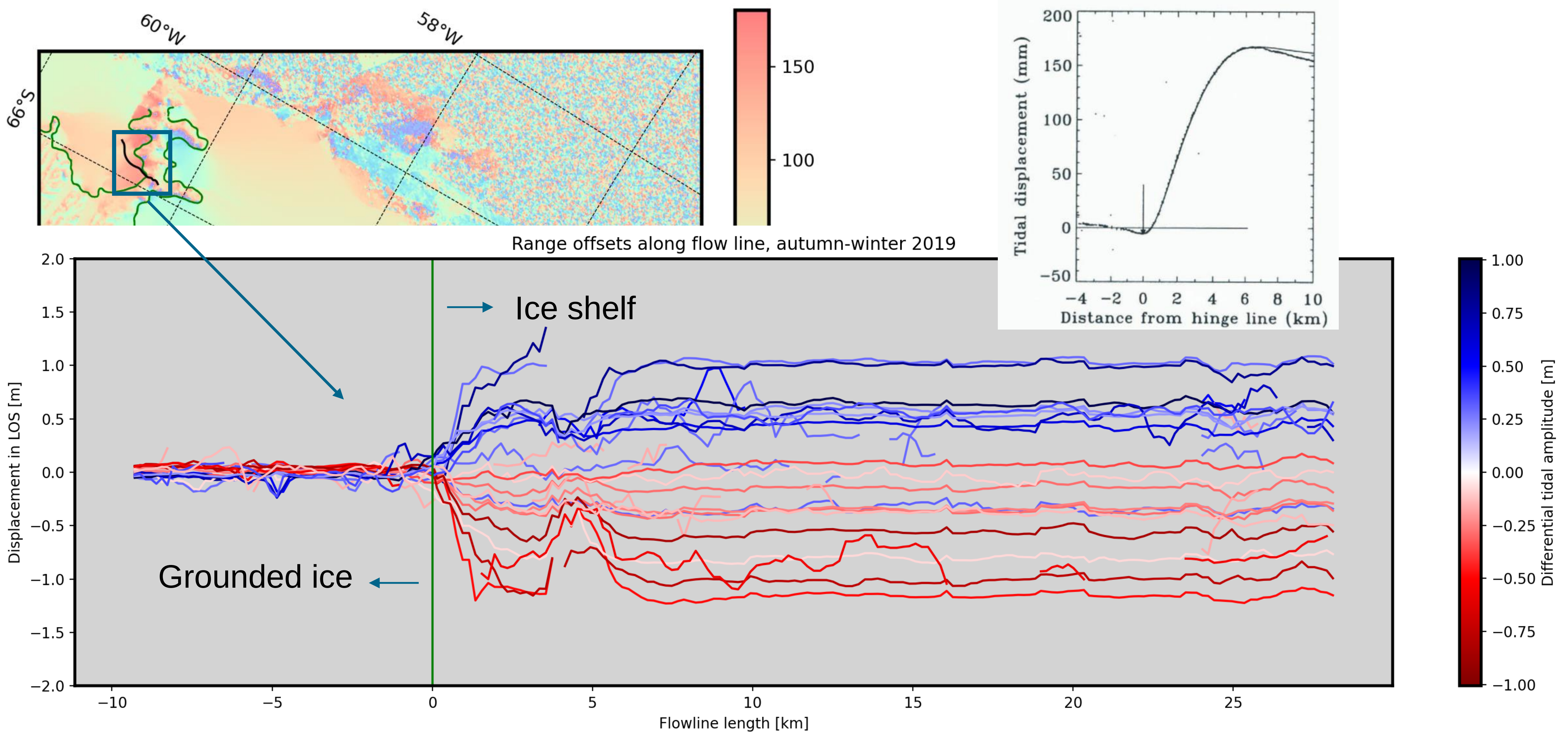
- The average GL was derived from Apr – Sept 2019 acquisitions using TMOC as detailed in Wallis et al., 2024

- TMOC GL is on average biased seawards of the AIS_cci GL by 438 ± 502m

LOS offsets along flowline

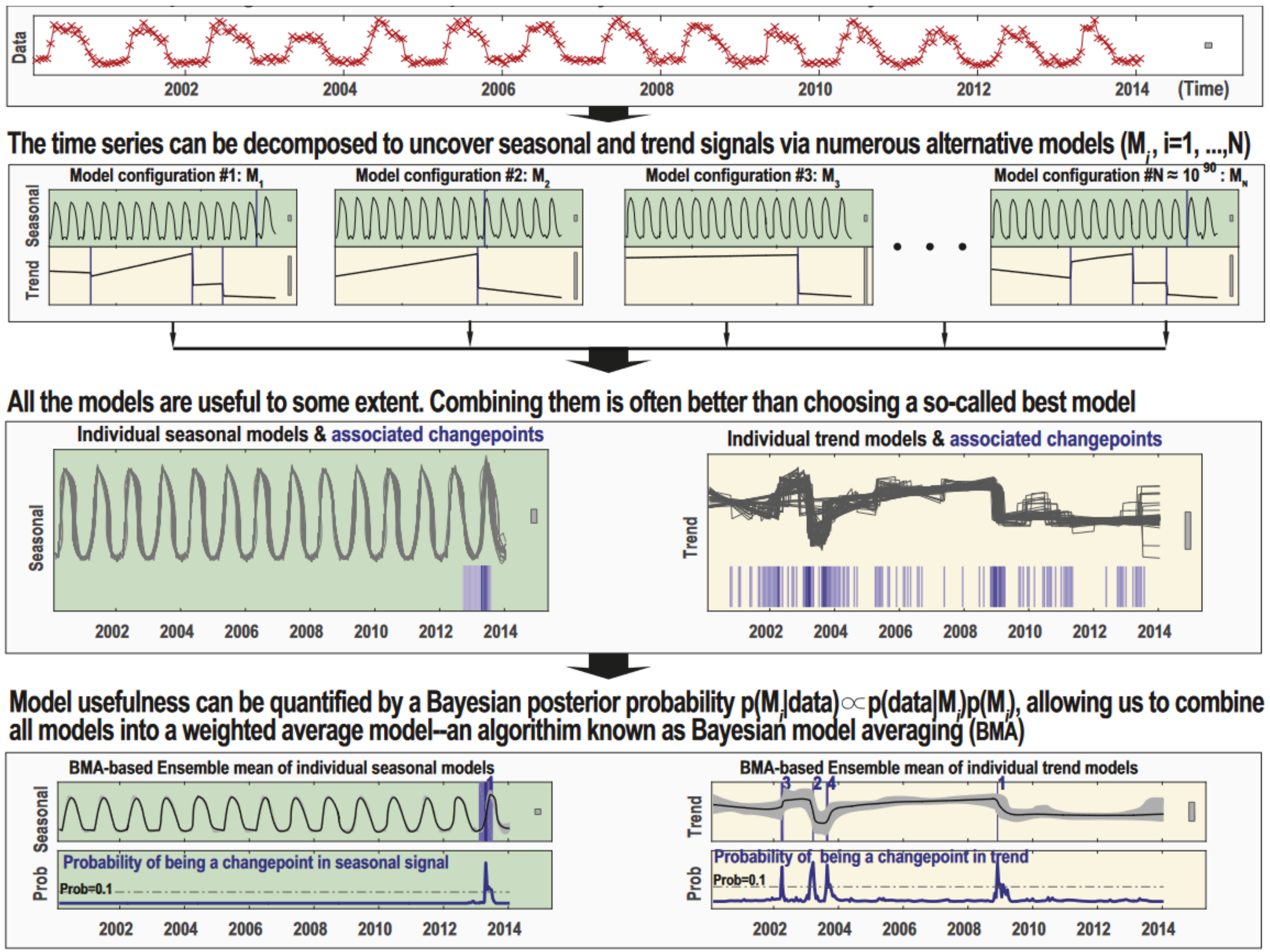


LOS offsets along flowline



Change point detection with BEAST

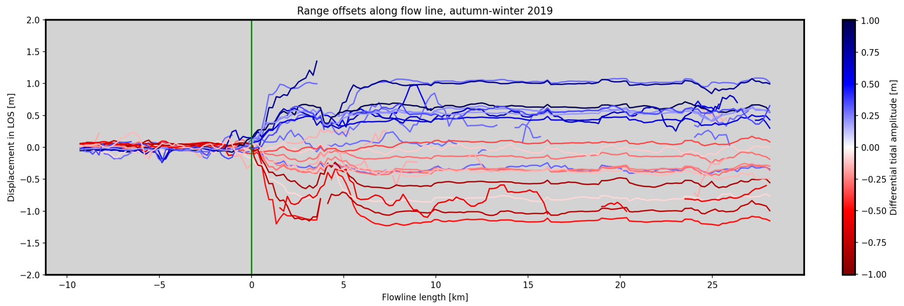
Bayesian Estimator of Abrupt change, Seasonal change, and Trend (BEAST) [Zhao et al., 2019]



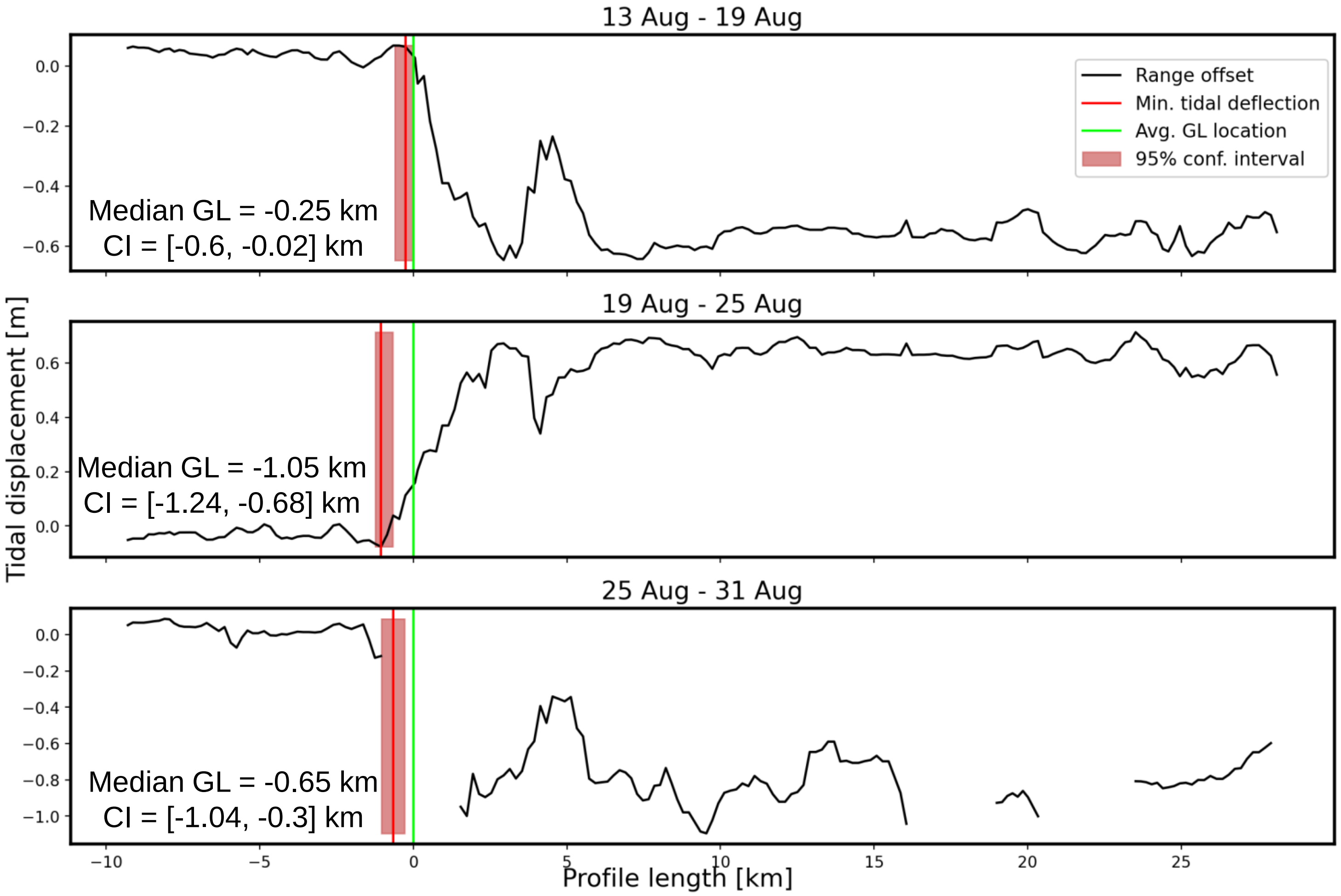
- Detects trends, seasonality and change points
- Provides uncertainties!
- Physical model agnostic

Workflow

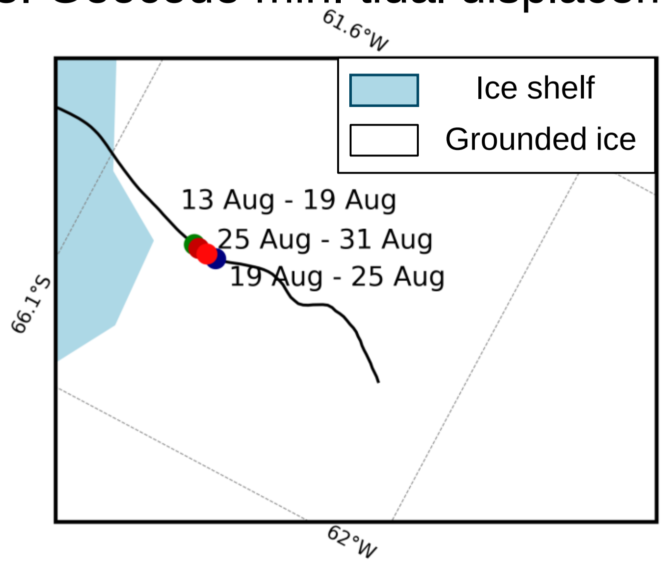
1. Extract offsets along ice flow direction



2. Identify min. tidal displacement using BEAST

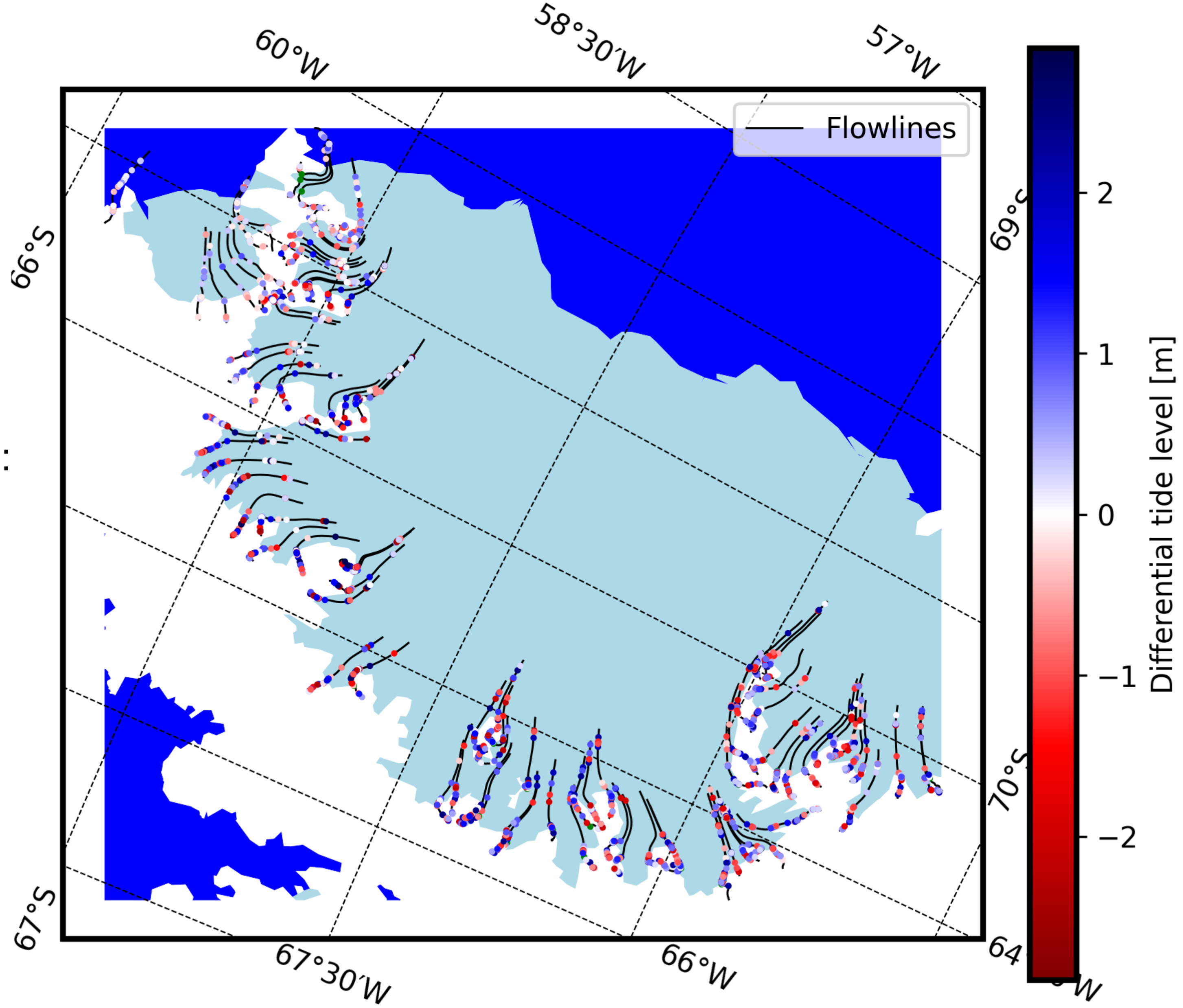


3. Geocode min. tidal displacement



Tentative results for 101 flowlines

If the GL moves in phase with the tides:
- blue points → grounded ice
- red points → ice shelf



Outlook

- Develop an **effective outlier detection algorithm**
- Generate **spatially continuous** grounding lines
- **Validate derived GLs** with those derived by unwrapping contemporaneous interferograms
- **Quantify the tidal migration** across the whole ice shelf
- Investigate the cause for the non-linear and out-of-phase migration, accounting for bed topography and slope

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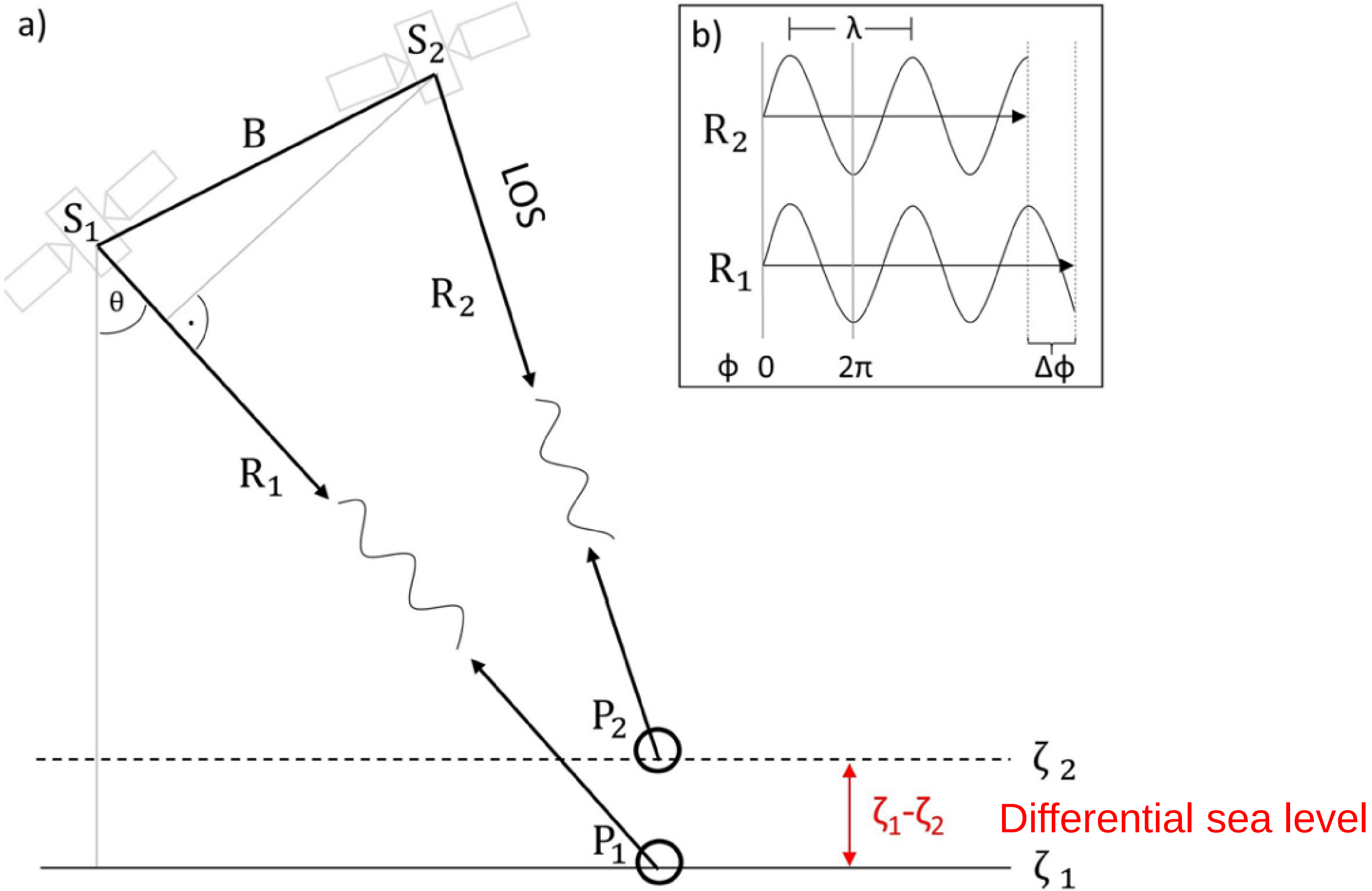
SAR geometry



Adapted from Rott H, 2009