Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

# Open water classification with CryoSat-2, ICESat-2, and other altimetry missions

Felix L. Müller, Denise Dettmering, and Florian Seitz

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technical University of Munich, Germany

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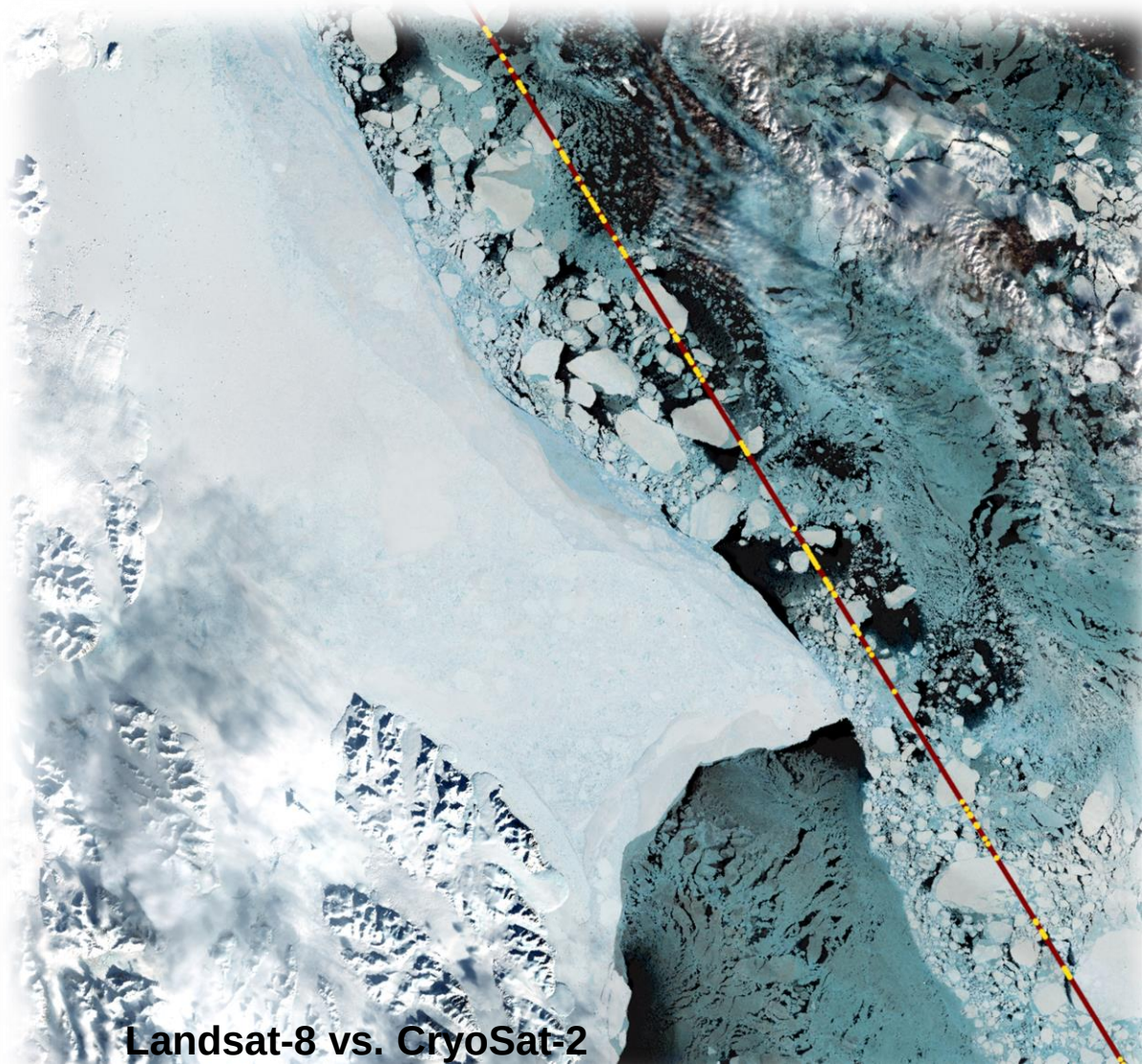


# Open water classification motivation

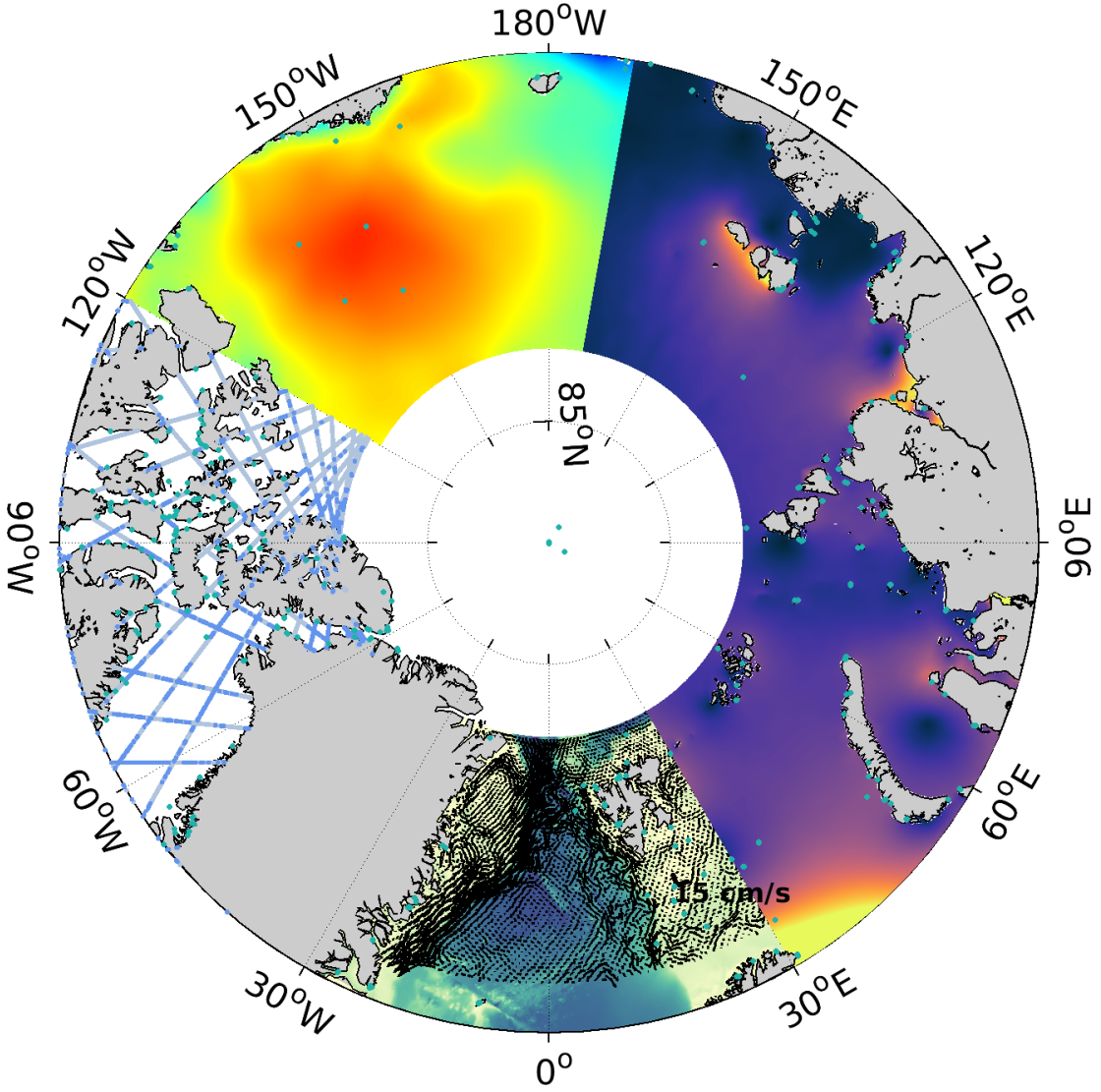
- Automatic detection of open water in the ice-covered ocean for the monitoring of:
  - Polar sea level
  - Polar ocean circulation
  - Spatial lead distribution
  - Sea-ice coverage

- Application of Machine Learning based algorithms

- Implementation of automatic radar waveform classifications for all satellite altimetry missions (ESA, CNES/NASA)

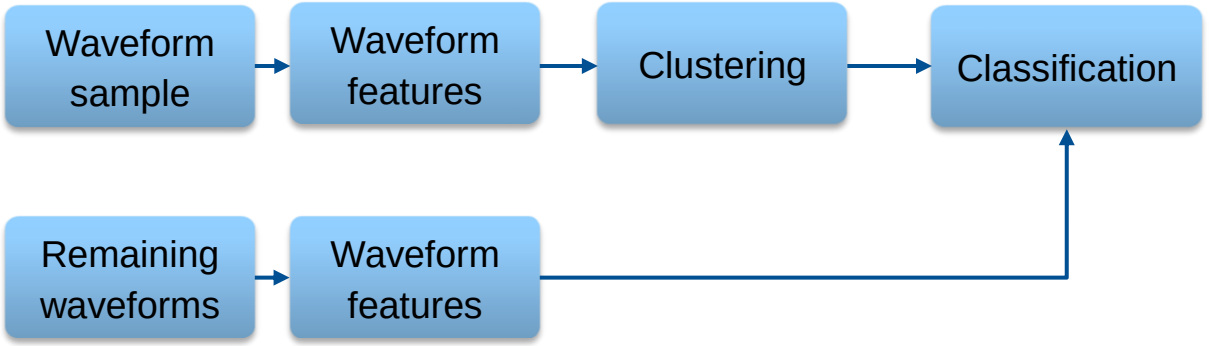
- Provision of improved and reliable altimetry sea surface heights

- Classification work published:
  - Müller et al., 2017: Envisat, SARAL
  - Passaro et., 2018: CryoSat-2 (based on stack data)
  - Dettmering et al., 2018: CryoSat-2 (based on SAR wvf.)
  - Passaro et al., 2020: ERS-2, Jason-1,2,3, Sentinel-3A/B
  - Müller et al., 2023: CryoSat-2, Thin ice detection

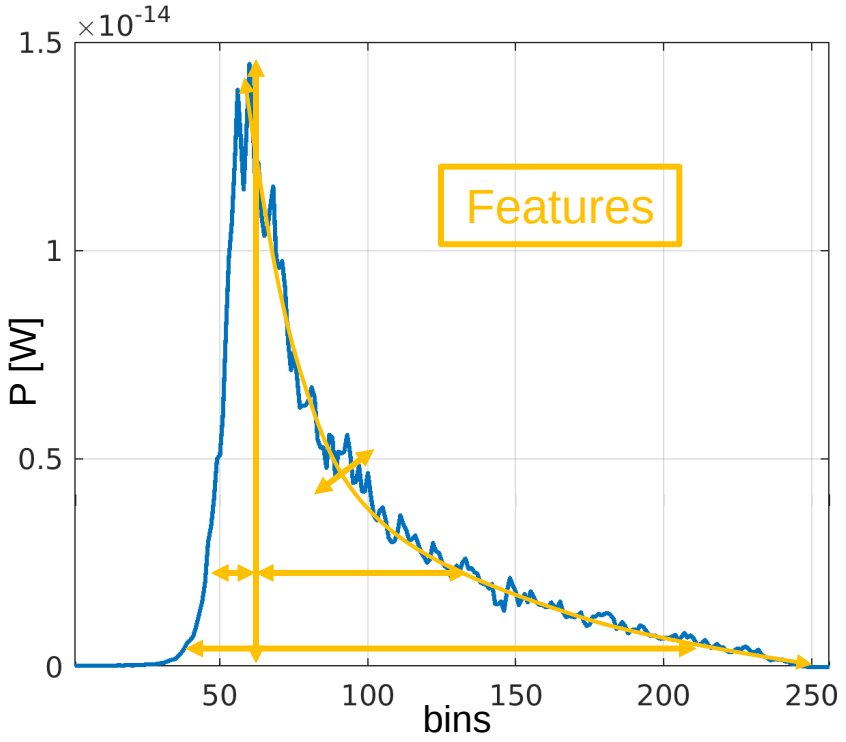


# Unsupervised waveform classification

- Detection of water in leads and polynyas based on radar returns (waveforms)
- No training data needed (unsupervised learning)
- Identification of similarities among waveforms

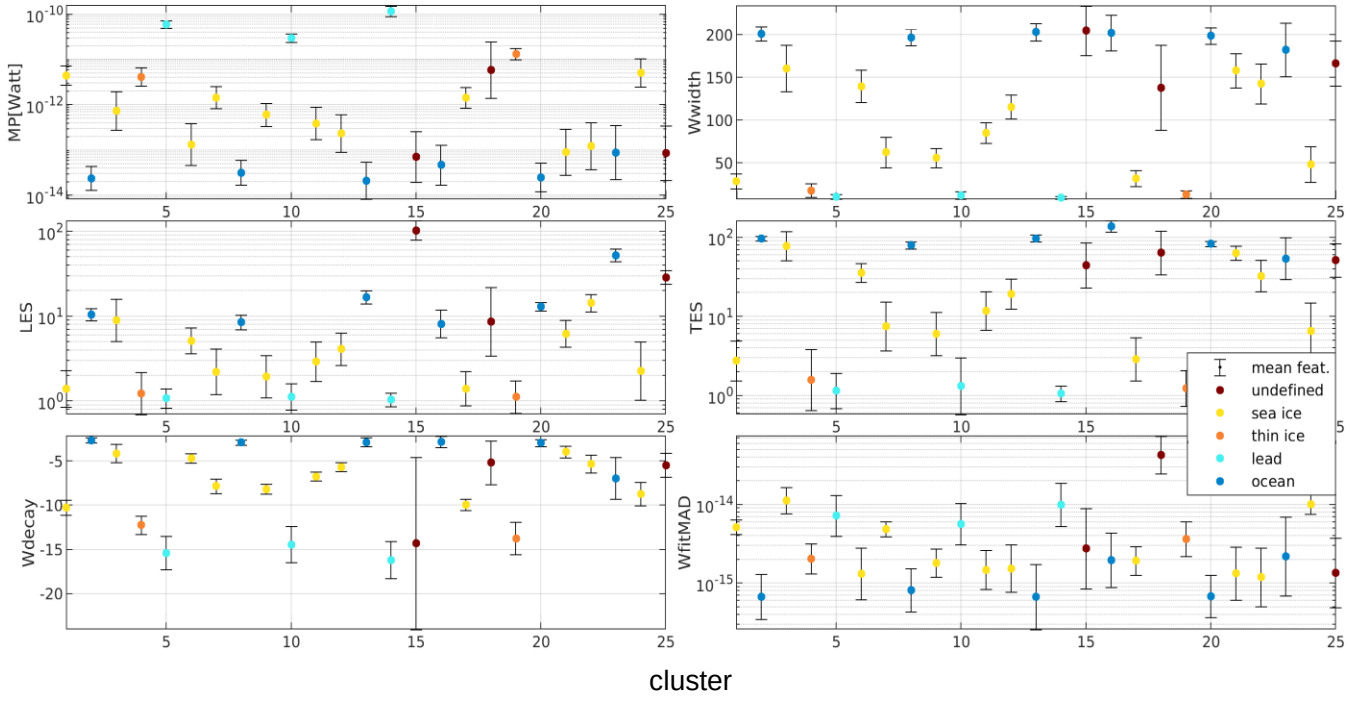


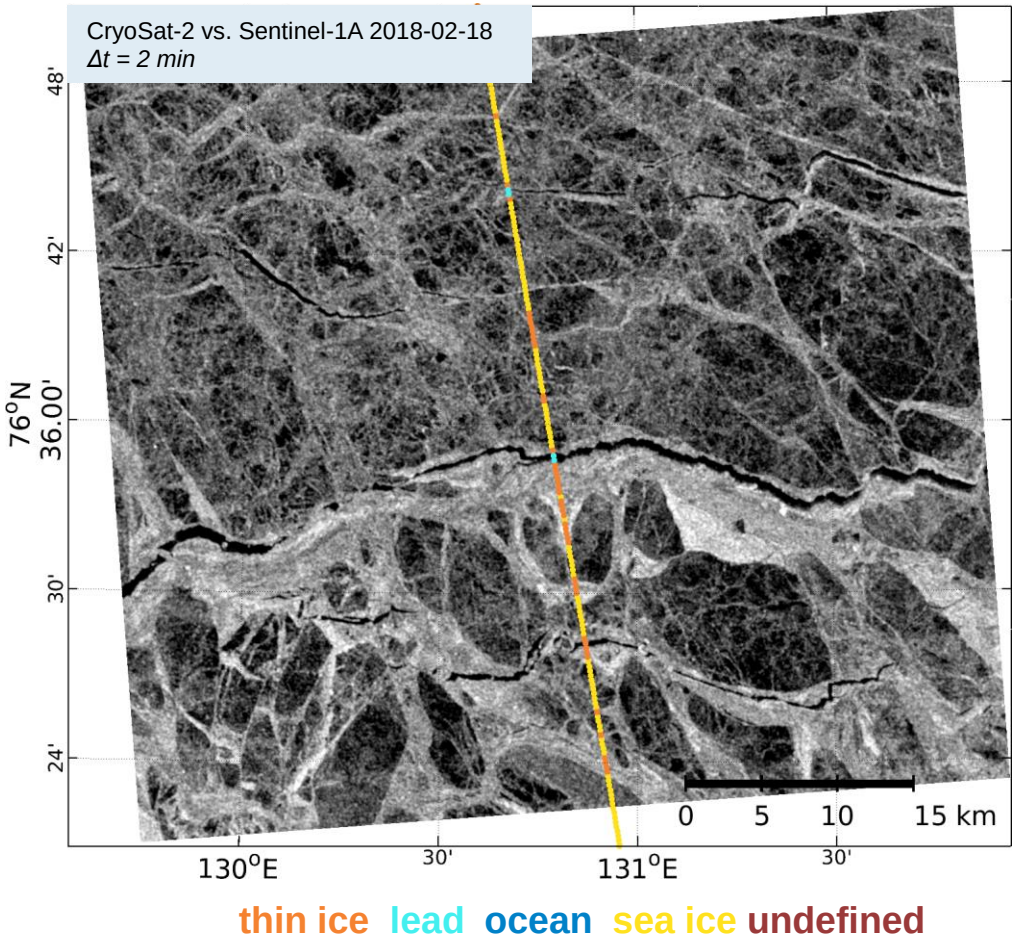

1. Generation of waveform reference model using K-medoids clustering
2. Assignment of waveform clusters to surface conditions
3. Classification of remaining waveforms using reference model and K-nearest neighbor (K-NN)




- Applicable to all altimeter missions
- More info in Müller et al., 2017

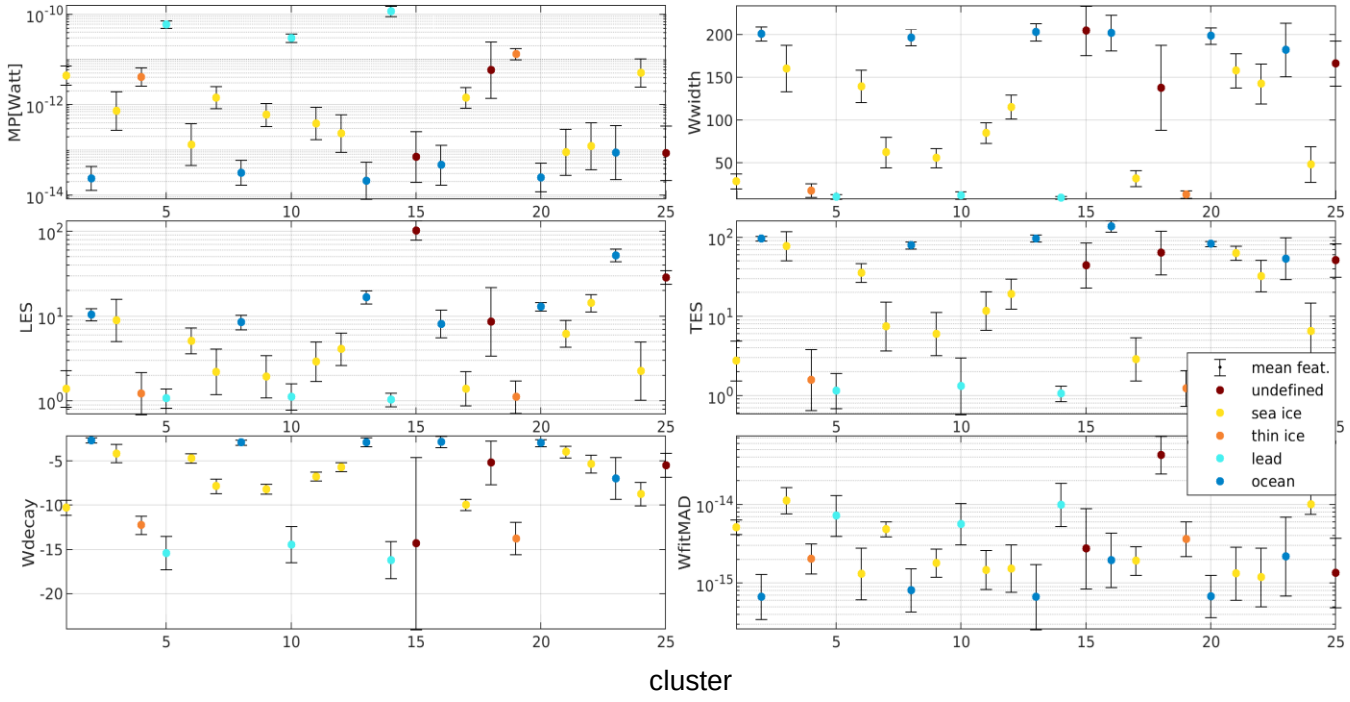
# Unsupervised waveform classification + thin ice extension

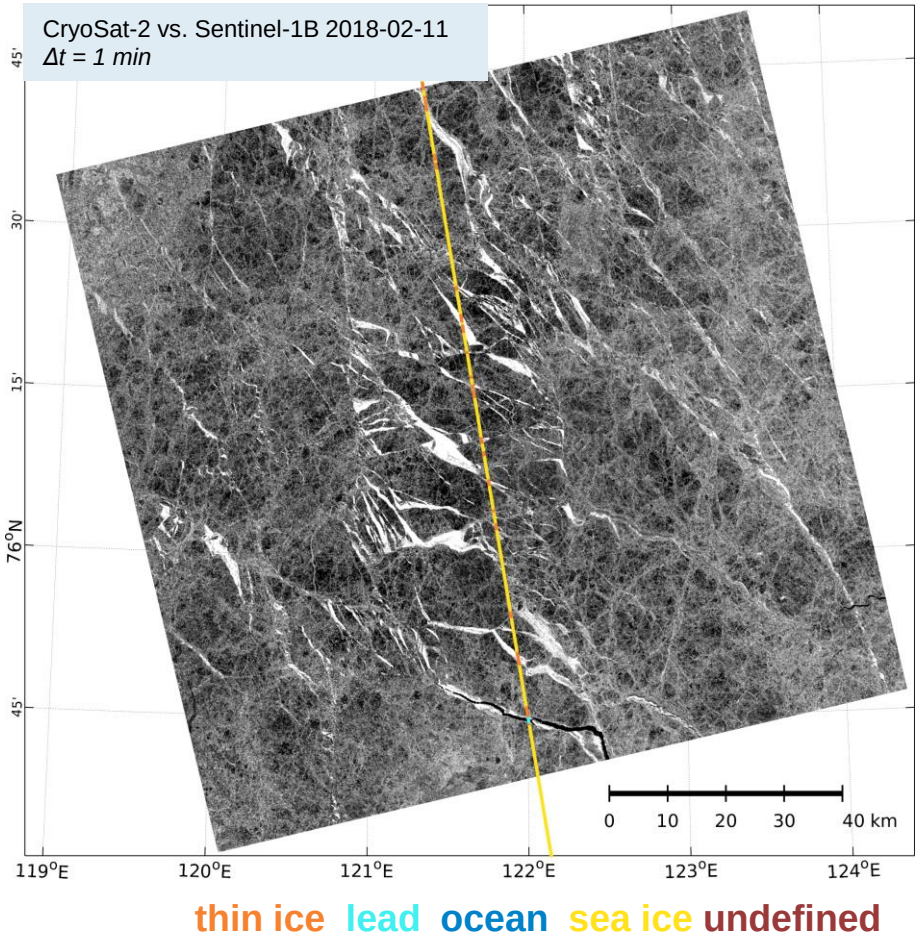



- Clusters are assigned to different surface types
- Extension of open water detection to thin ice surface types (e.g. refrozen leads)
- Comparison with thermal imagery-derived thin-ice thickness reveals strong linear relationships between features and thin-ice thickness

# Unsupervised waveform classification + thin ice extension

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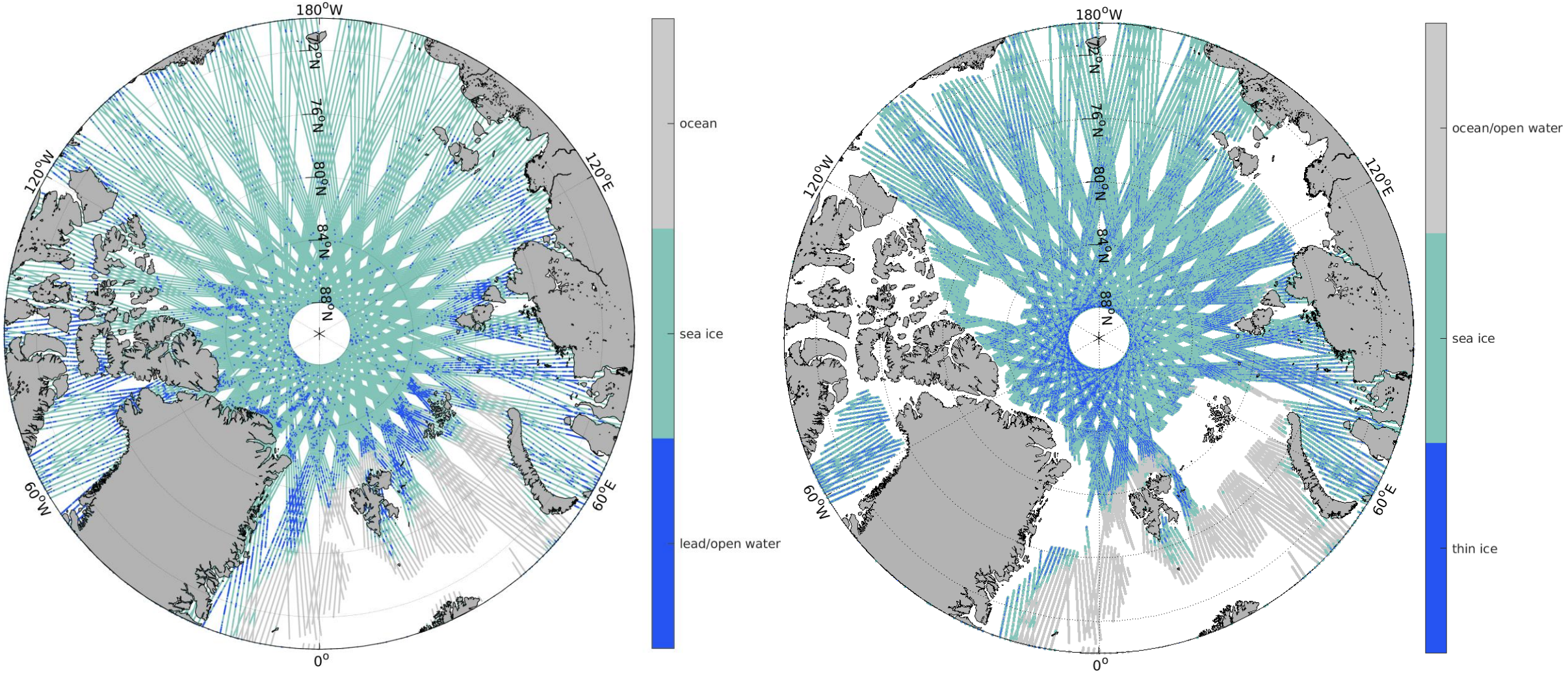
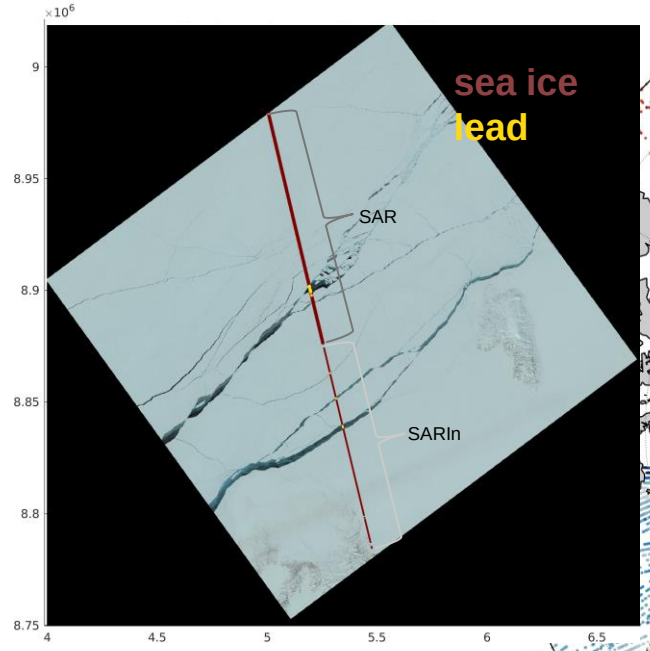
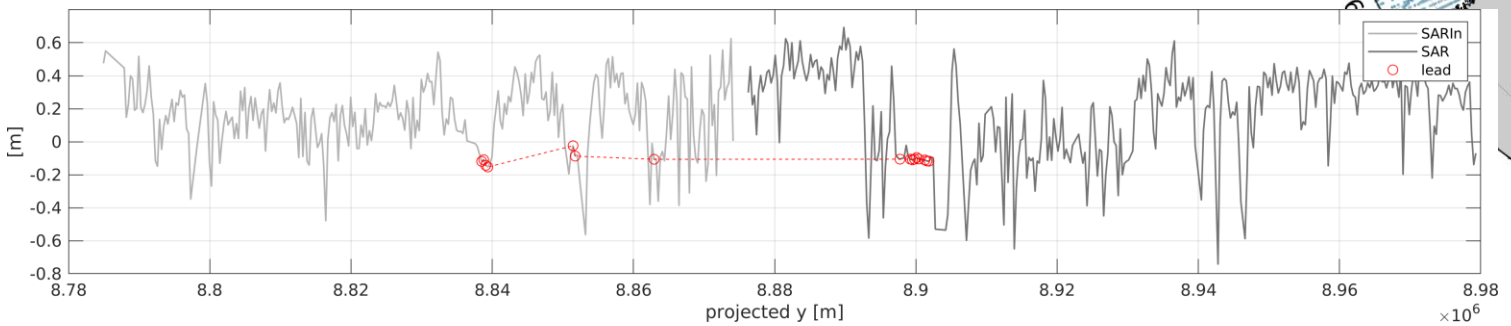



- Surface detections for Cryosat-2 (SAR + SARIn) for the first 15 days in February 2024
- Currently classification of thin ice only available for SAR mode

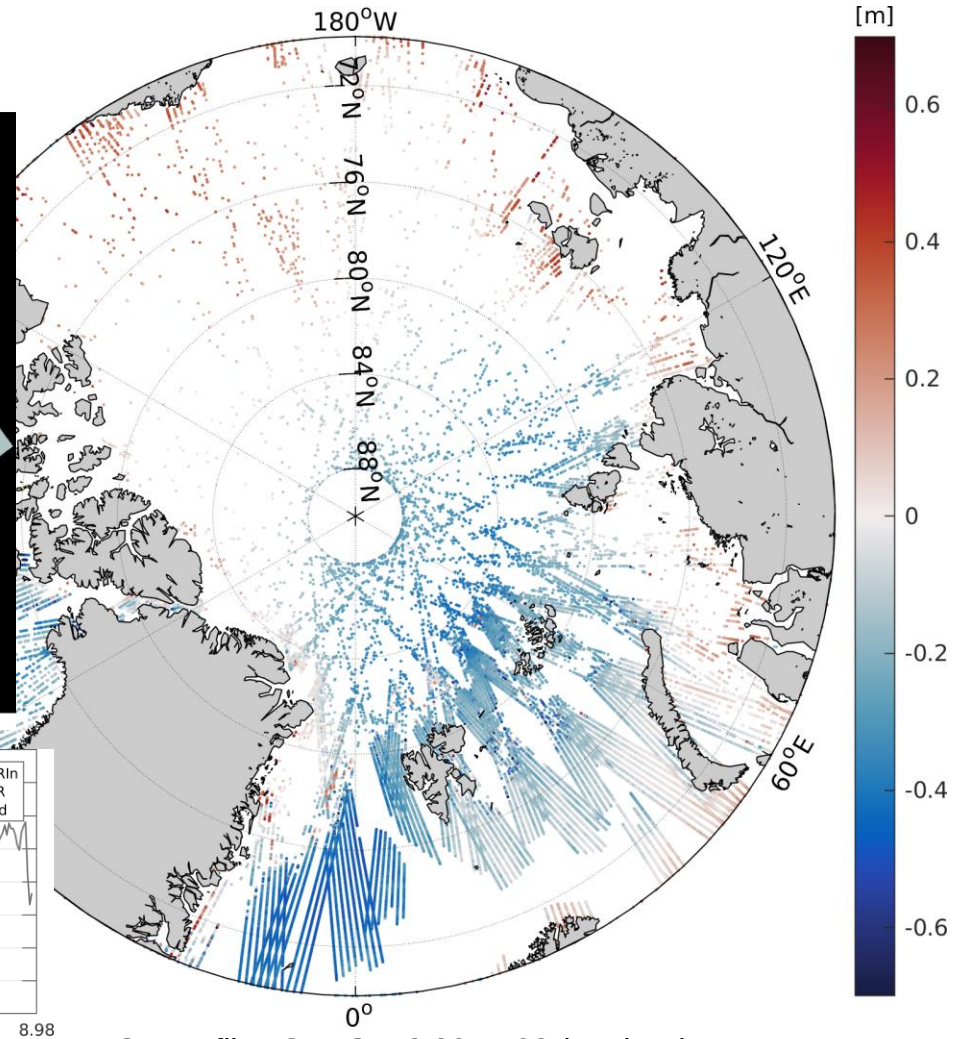
# Unsupervised waveform classification

- Application of classification for polar sea level anomalies (SLA) or dynamic ocean topography (DOT) computation
- Usage of SAMOSA+ (Dinardo et al., 2018) or ALES+SAR (Passaro et al., 2022) retracker



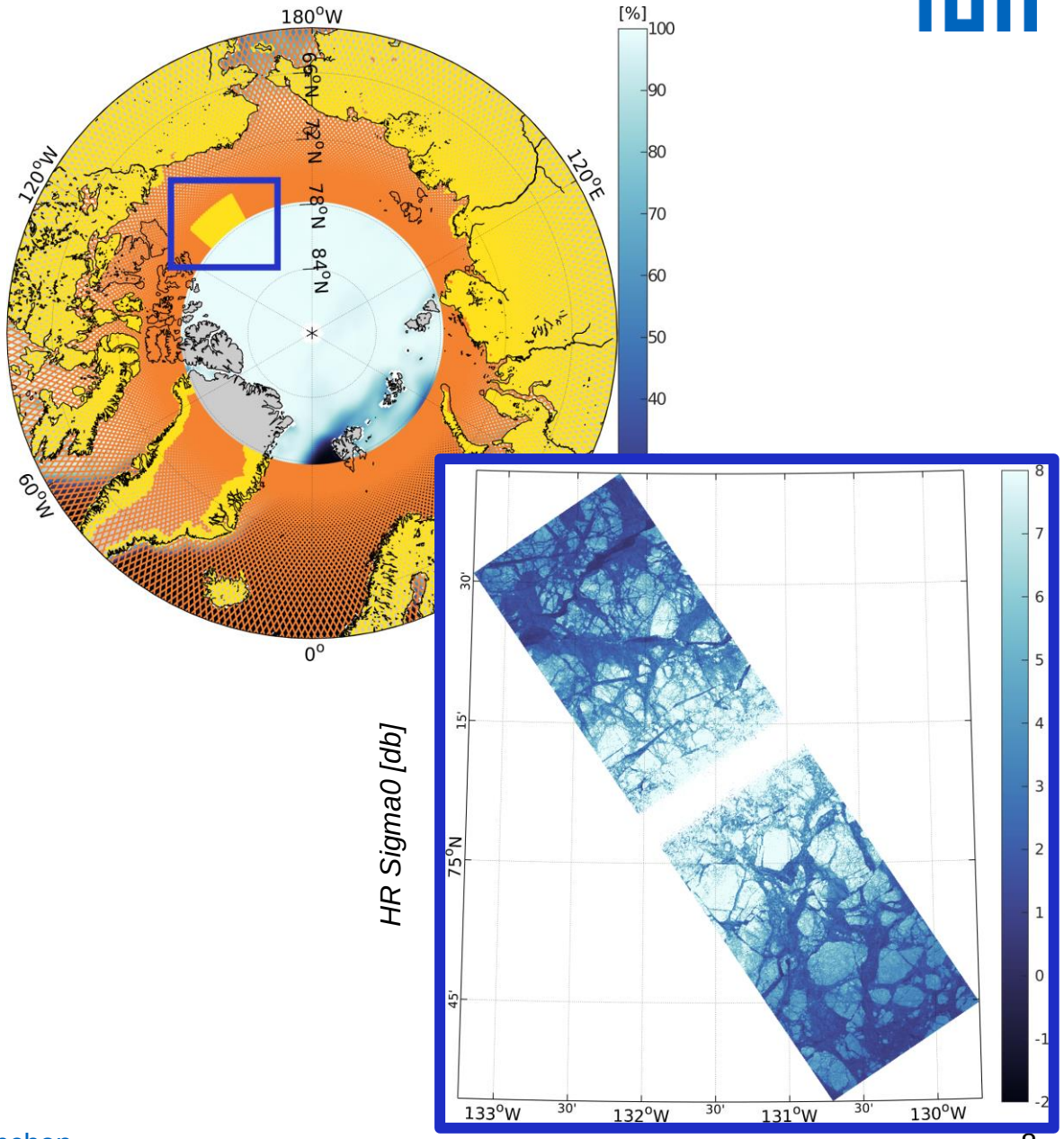

SLA profile CryoSat-2 vs. Landsat-8 2015-04-25 (Δt = 4 std)




DOT profiles CryoSat-2 2017-02 (15 days)

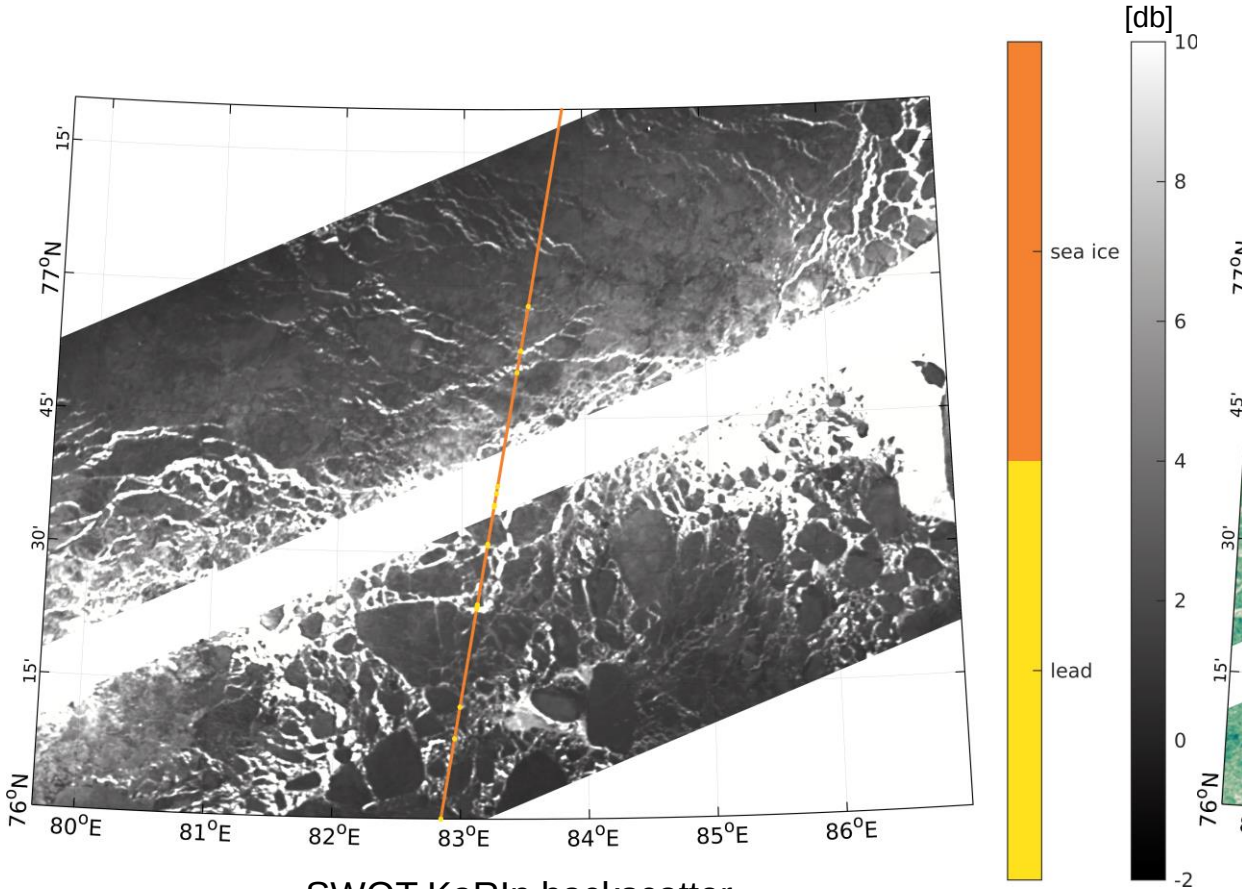
# What comes next?

- Novel near nadir swath altimetry for ocean/sea ice related applications provided by SWOT
- Novel observation techniques by a KaRIn interferometer (swath altimetry)
- Launched in December 2022, different types of datasets (LR, HR) now available
- Spatial resolution ranging from 100 m to 250 m pixel posting
- Enables new insights in:
  - Sea ice and polar ocean dynamics (sea level, ocean currents, sea ice thickness, freeboard etc.)
  - Sea ice drift observations

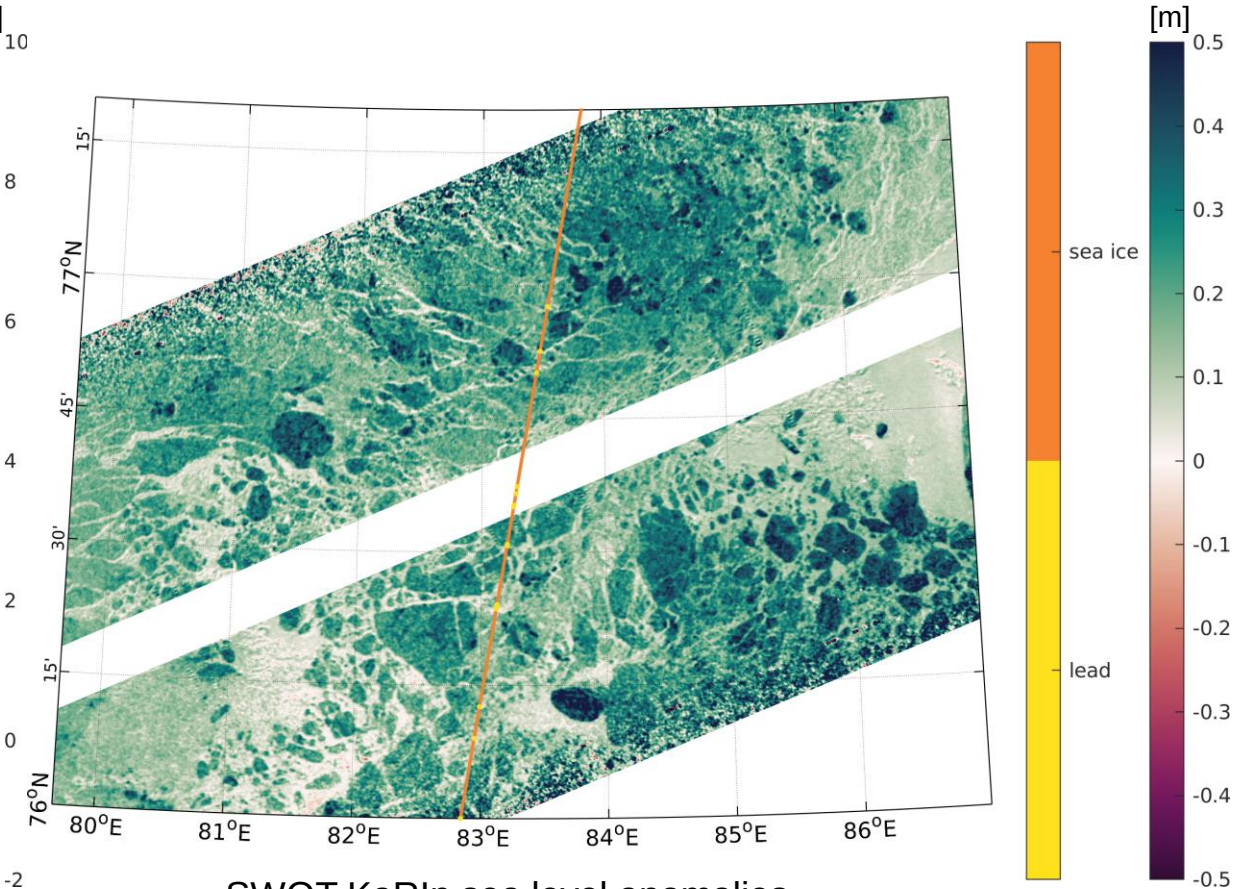


# Comparison CryoSat-2 vs. SWOT

- Comparison of CryoSat-2 unsupervised classification with SWOT LR L2 Unsmoothed (250 m) within 30 minutes time gap




SWOT KaRIn backscatter

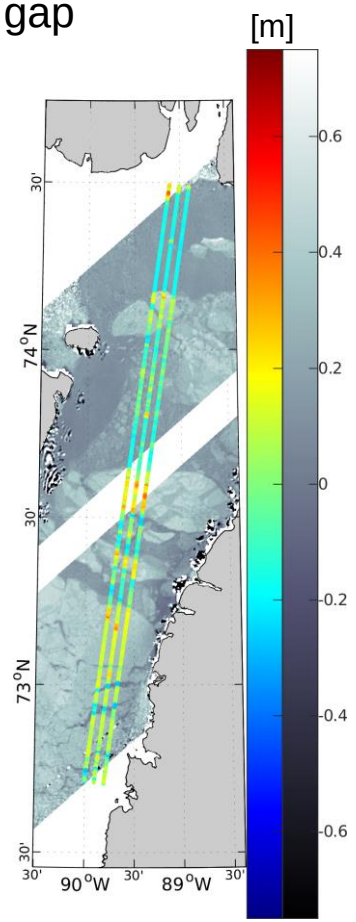


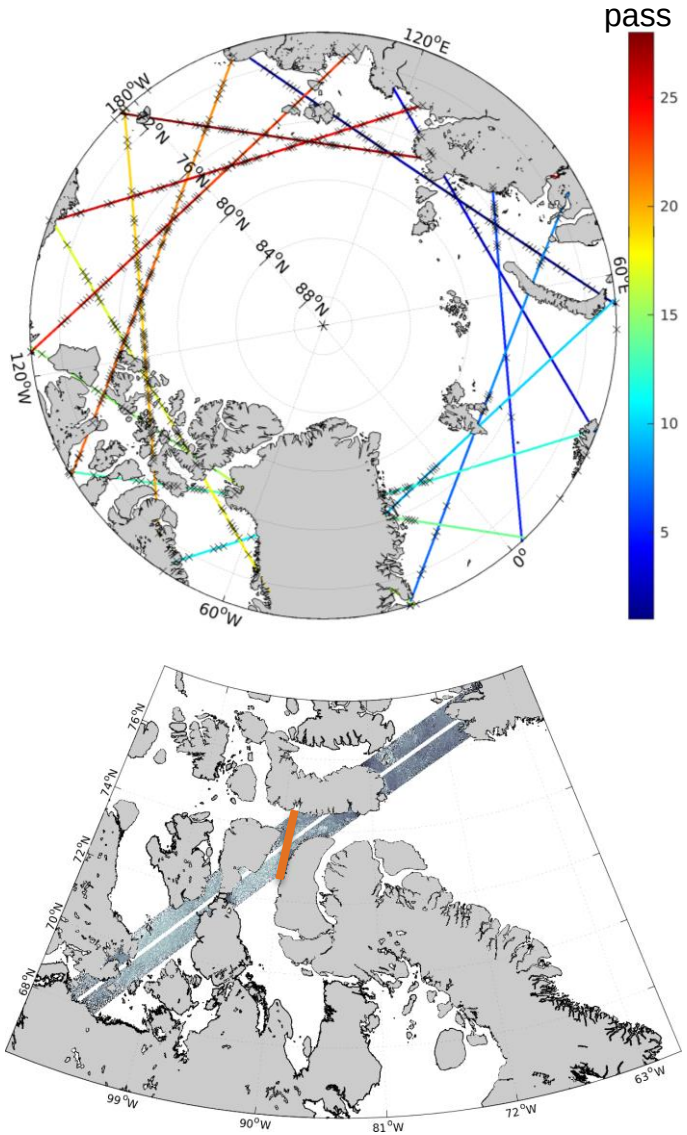

SWOT KaRIn sea level anomalies

# Comparison IceSat-2 vs. SWOT

- Comparison in terms of sea level anomalies (SSH-MSSH)
- Comparison of SWOT L2 LR Unsmoothed 2.0 (250 m) vs. IceSat-2 ATL07 (006)
- ~500 crossovers during SWOT CAL/VAL phase* within 30 min. time gap
- Interpolation of SWOT data to 6 IceSat-2 laser beams


2023-05-09, $\overline{diff.\ std} = 6.7\ cm$

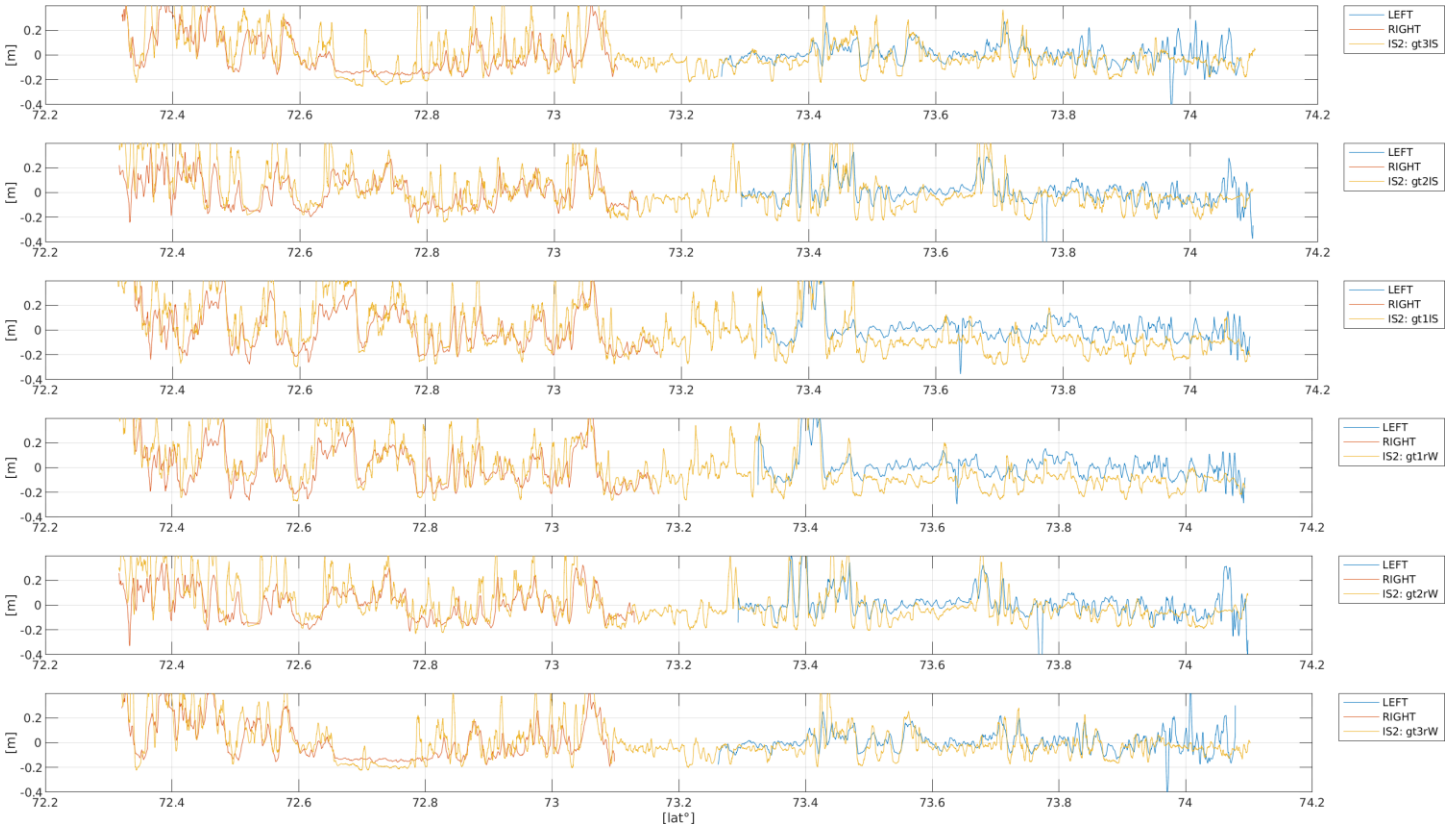


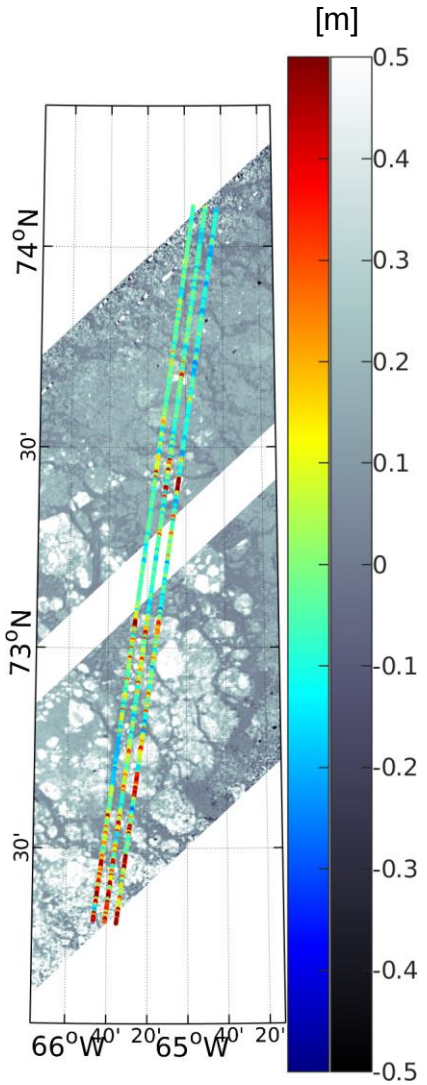

* cal/val from end-of March 2023 → mid July 2024 (1-day repeat orbit)

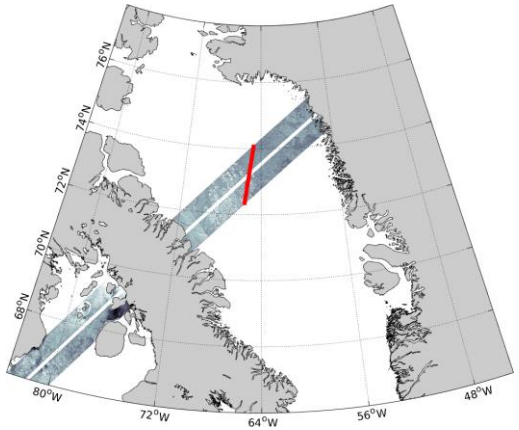
# Comparison IceSat-2 vs. SWOT

- With focus on small leads comparison shows good agreement
- First point-wise analysis of 160 valid tracks (no strong outliers, >500 observations per overlap) reveal a standard dev. of **~ 9 cm**




2023-05-05, $\overline{diff.\ std} = 11\ cm$



# Summary

- Unsupervised waveform classification enables a reliable detection of open water in the ice-covered ocean
- The unsupervised classification approach improves the computation of derived ocean variables (sea level, ocean currents)
- Extending the open water detection for the identification of thin ice opens a variety of possibilities for improving the determination of sea level and for the comprehensive investigation of sea ice development
- First analyses of SWOT pixel-based observations are promising for sea-ice/lead detection
- First comparisons with SWOT and ICESat-2 in terms of SLA show very promising results (small STD)
- Future work focuses on the computation of an improved Arctic sea level and the application of SWOT LR- and HR-mode data

# References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