Sea Ice Leads and Polynya Detection using Multi-Mission altimetry in the Greenland Sea

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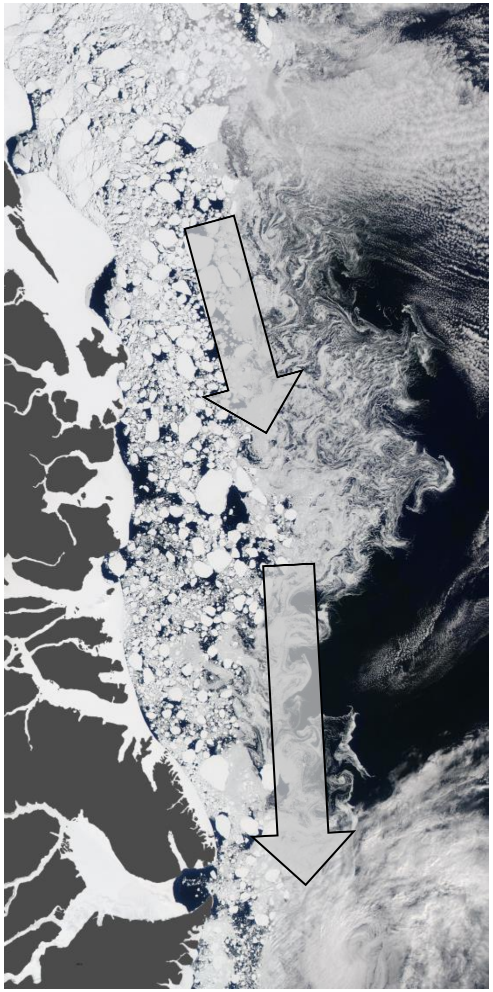
Introduction

- Finding open water (lead, polynya) to estimate sea surface heights with multi-mission altimetry data along the coast of Greenland Sea

- Unsupervised classification of waveforms without the use of selected training data for pulse-limited altimetry data (example ENVISAT)

- Classification of CryoSat-2 waveforms based on the Surface Sample Stack

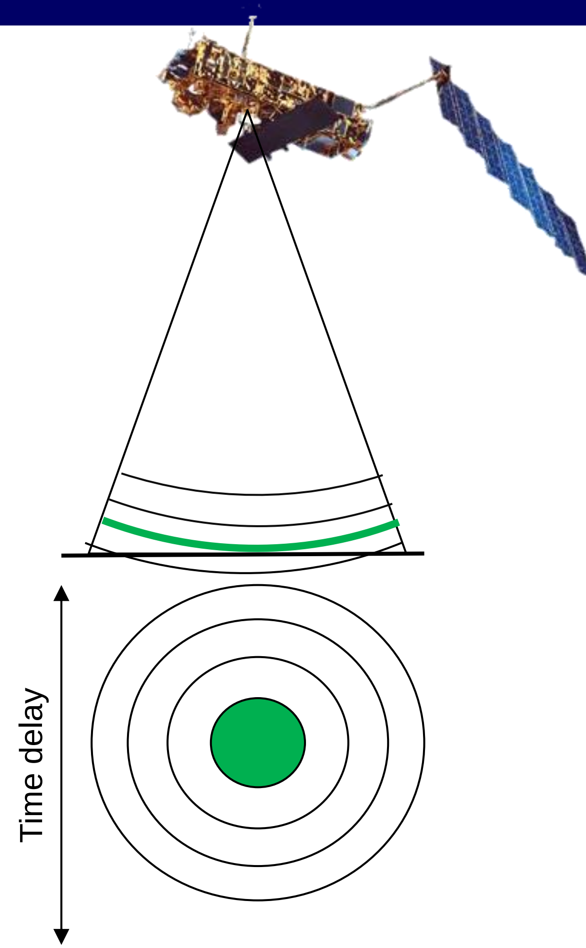
- Comparison of classification using imaging SAR taking into account sea ice motion

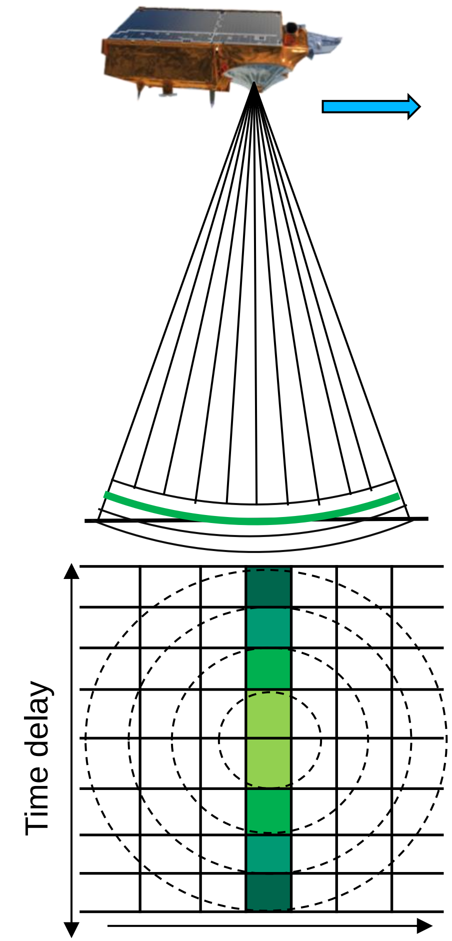


Altimetry: Measurement Principles

Altimetry:
- Emitting and receiving of radar pulses
- Estimating distance between satellite and surface by interpreting reflected radar pulse

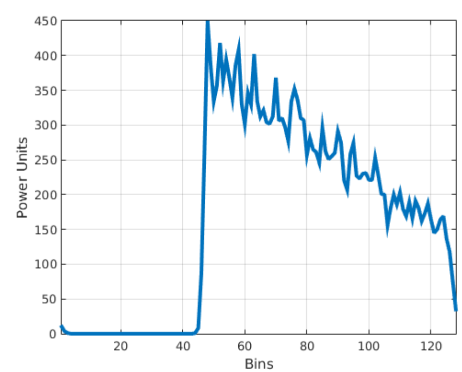
Example: ENVISAT



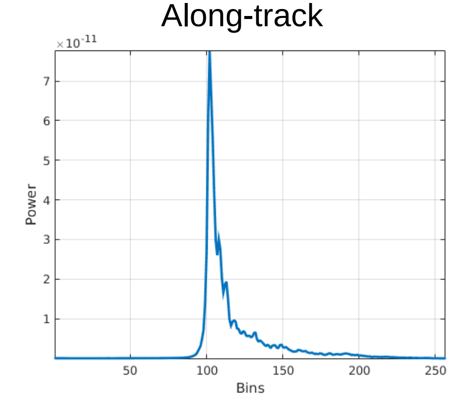


Delay-Doppler:
- Use of Doppler shift obtains higher number of looks on a smaller footprint
- Provides multi-look processing in along-track and across-track direction
- Higher accuracy

Example: CryoSat-2



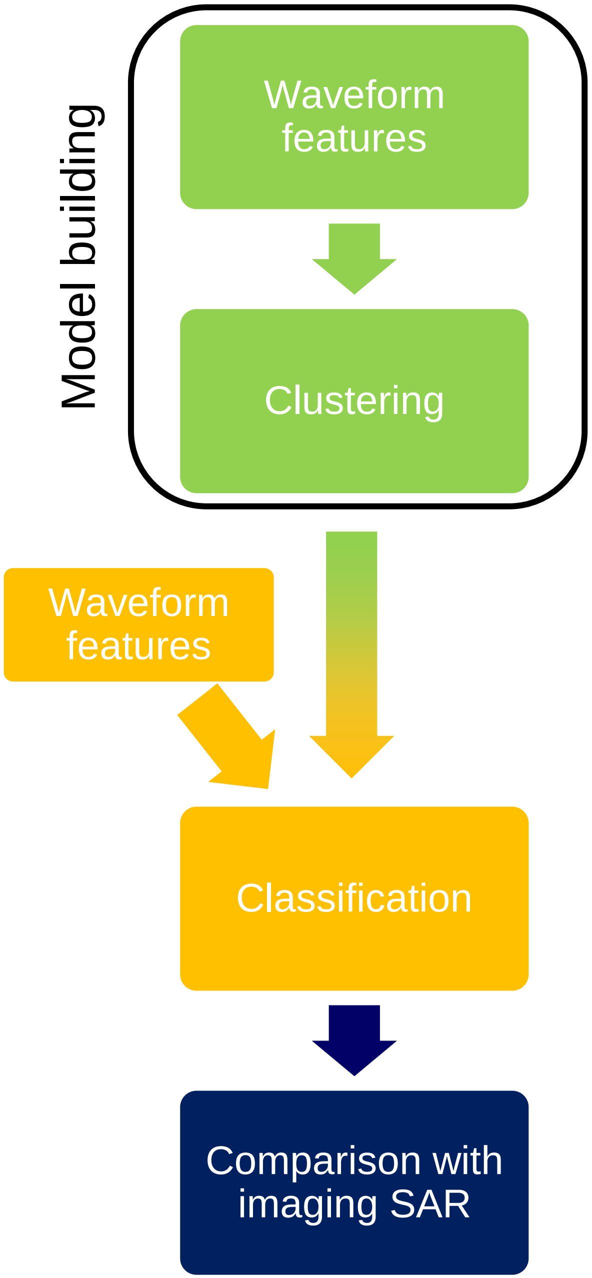
Waveform



Waveform

Unsupervised classification - ENVISAT

- Parameters describe the waveform shape and its features
  - Maximum Power
  - Peakiness
  - Decay of trailing edge
  - …
- Parameters are input of a K-medoids based cluster algorithm
- Clustering creates the model for the classification relating to a certain altimetry mission
- The detection of open water bodies is done by a nearest-neighbor classification

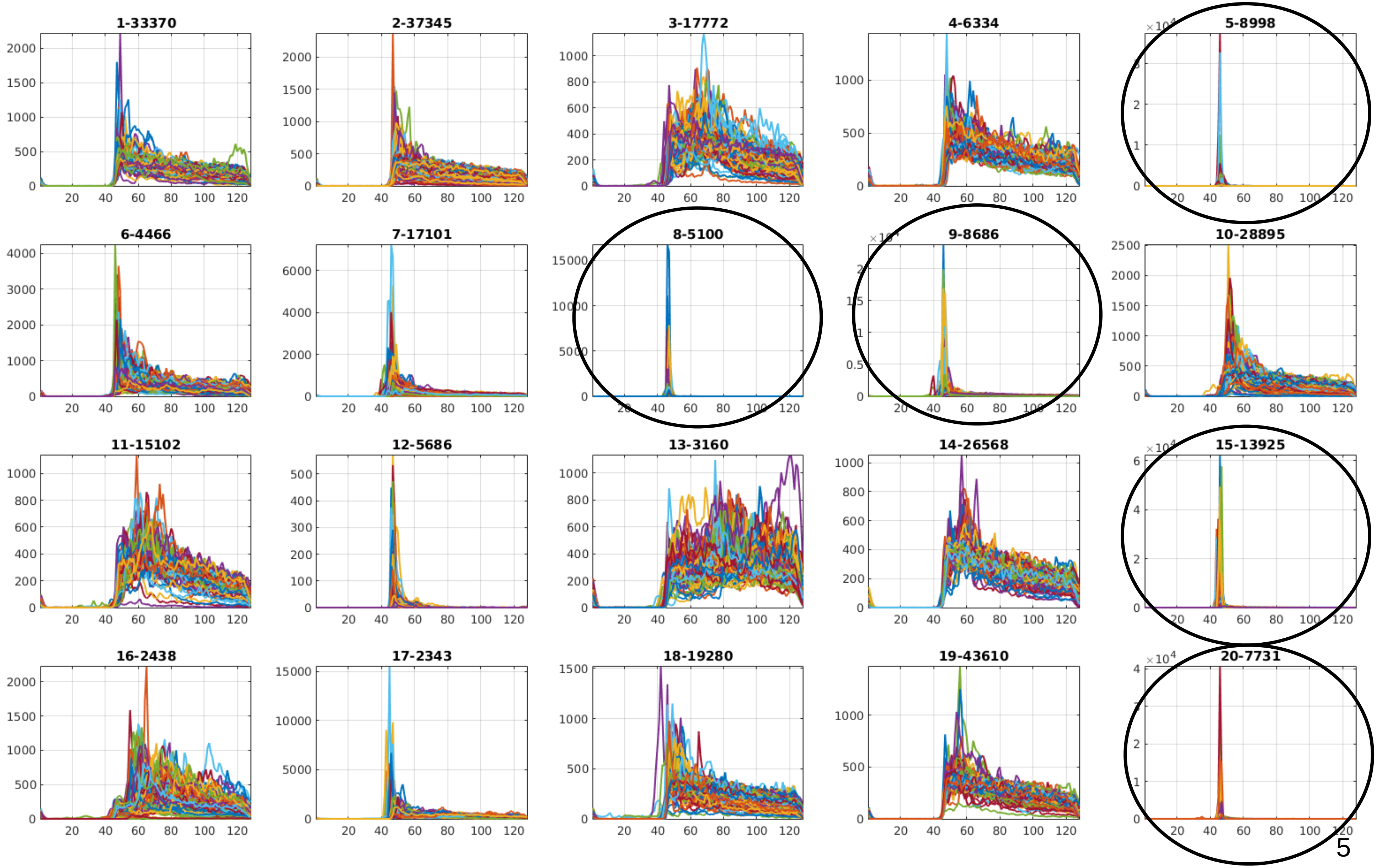


Challenges:
- find suitable parameters
- make the parameters comparable
- set the right number of clustering classes

➢ 6 parameters, 20 classes

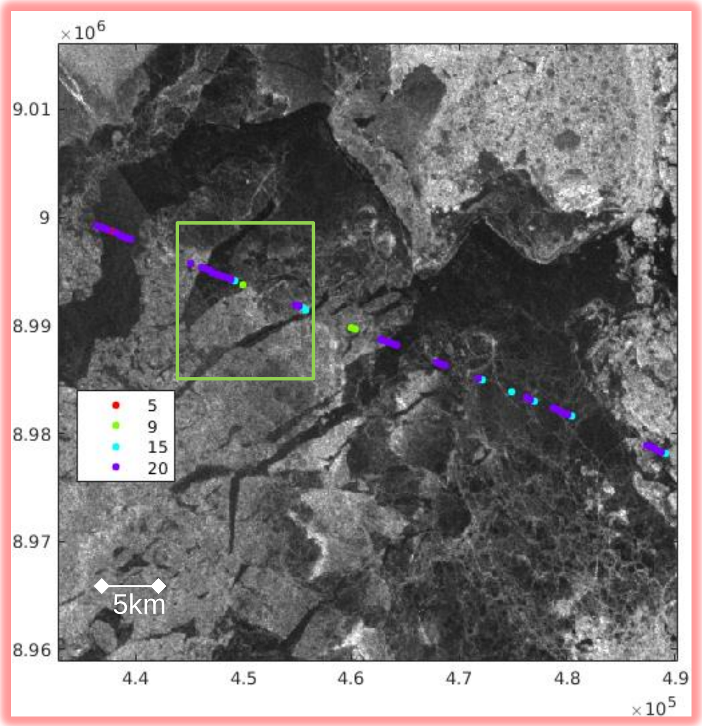
Unsupervised classification - clustering

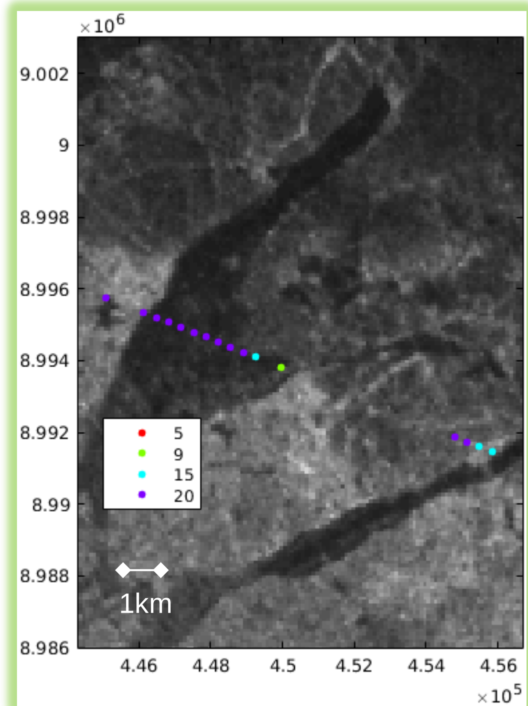
- Results of K-medoids clustering
- Input: waveforms from ENVISAT Cycle 57 (April 2007) in Greenland Sea

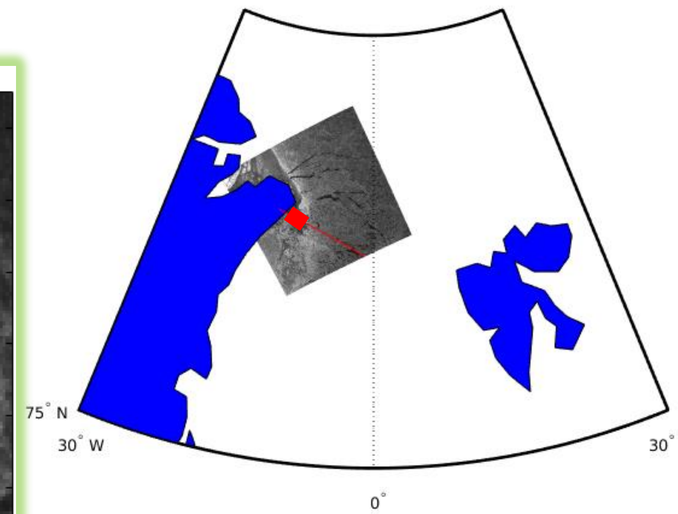


Unsupervised classification – result 1

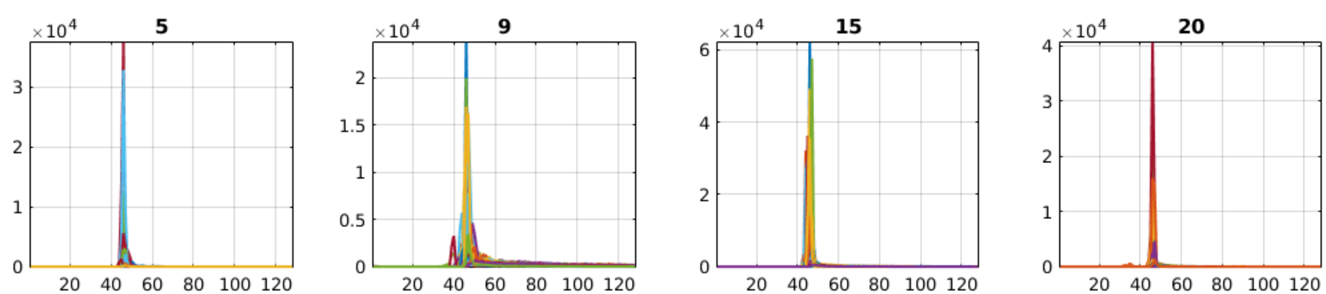
- Comparison with ALOS SAR data



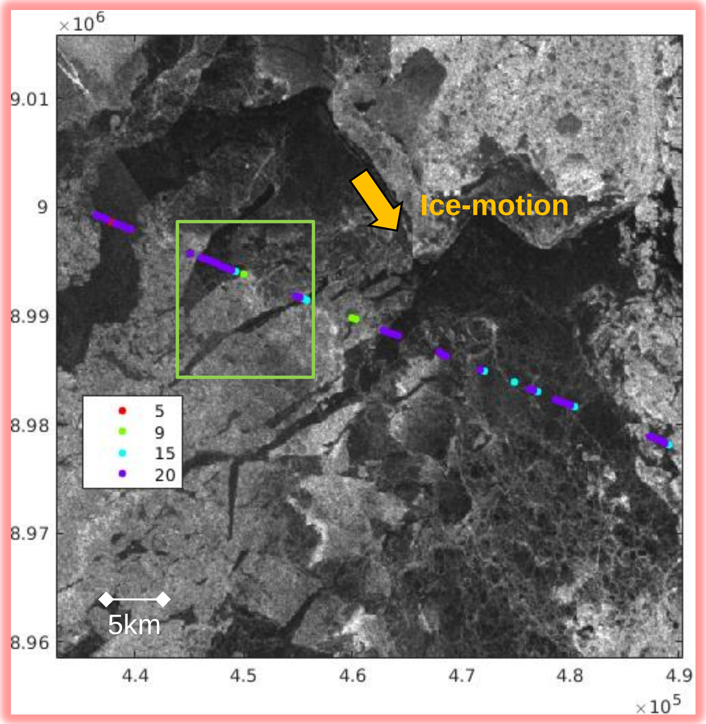


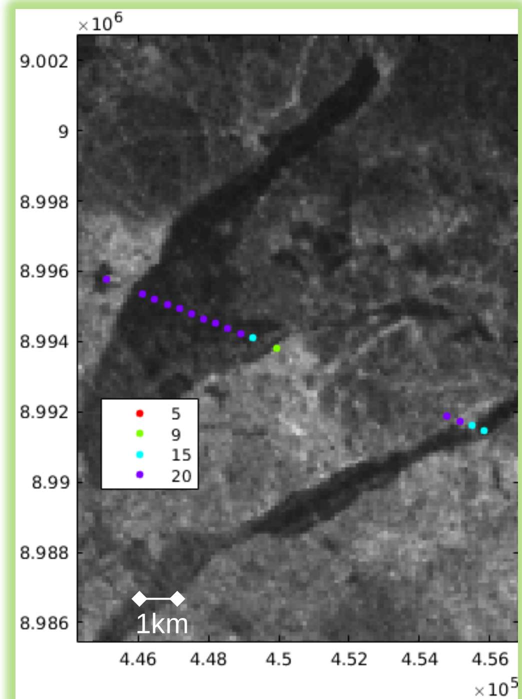


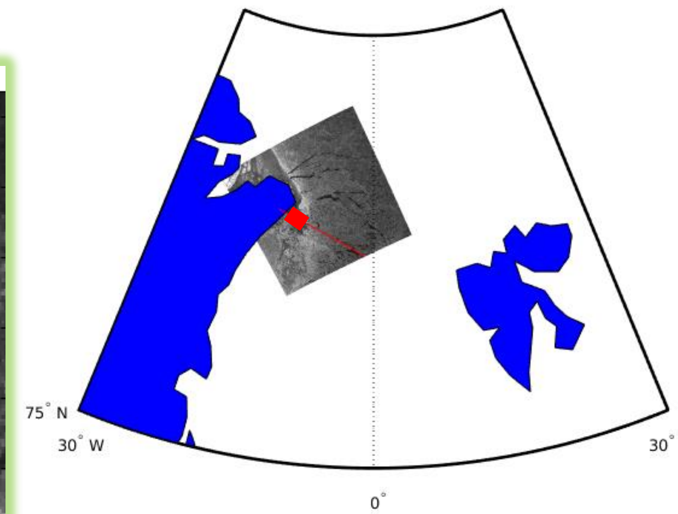
- ALOS SAR image spatial resolution: 100m



Unsupervised classification – result 1



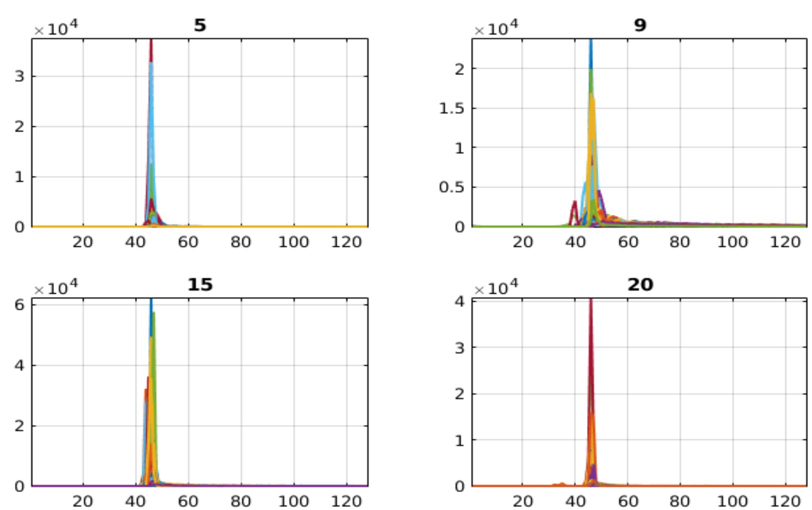




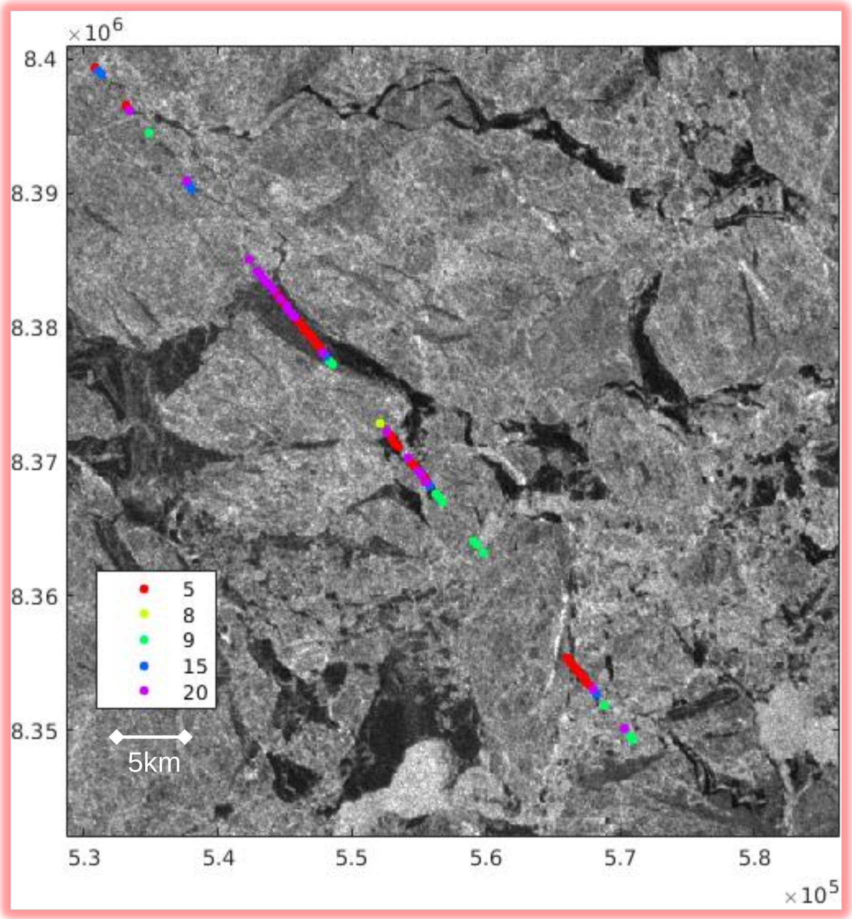
- ALOS SAR image spatial resolution: 100m
- Acquisition date: 12-01-2008 20:54 UTC
- ENVISAT Track: 18:04 UTC

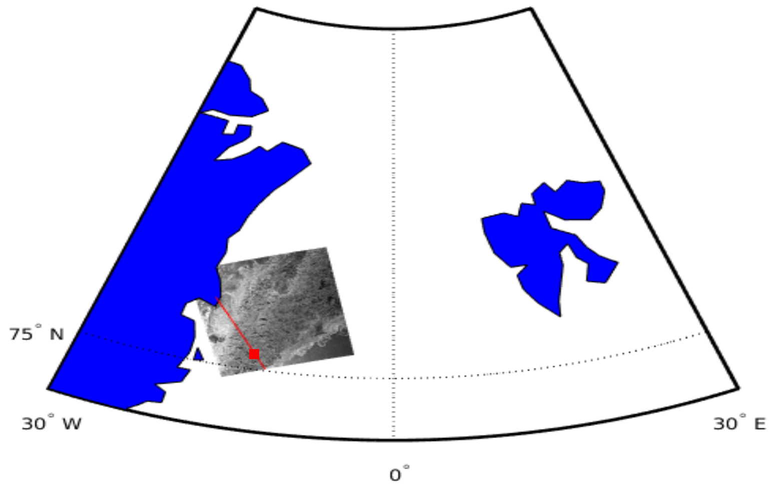
- Considering the ice motion with pixel-based shifting
- NSIDC Daily Polar Pathfinder 25 km EASE-Grid Sea Ice Motion Vectors

- Ice motion velocity: $4.99\,\frac{cm}{s}$
- Time-shift:
  - $\Delta t = 2h50min$
  - $s \approx 508.57m$

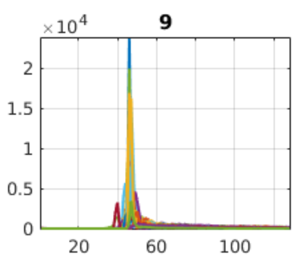


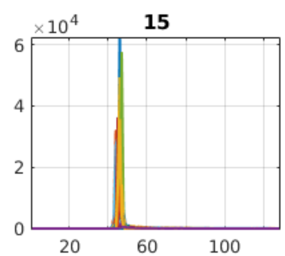
Unsupervised classification – result 2

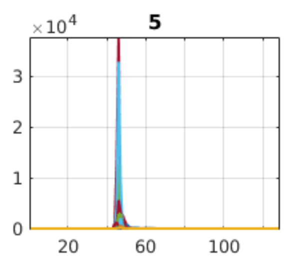


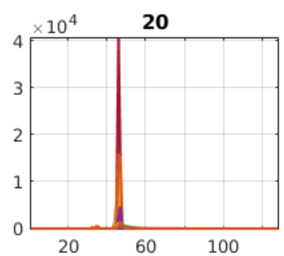


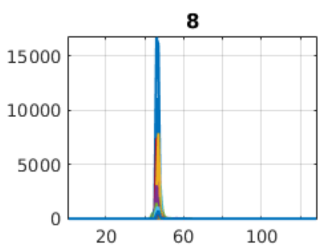
- ALOS SAR image spatial resolution: 100m
- Acquisition date: 04-05-2008 21:58 UTC
- ENVISAT Track: 20:32 UTC
- Ice motion velocity: $1.25\frac{cm}{s}$
- Time-shift:
  - $\Delta t = 1h26min$
  - $s \approx 64.5m$



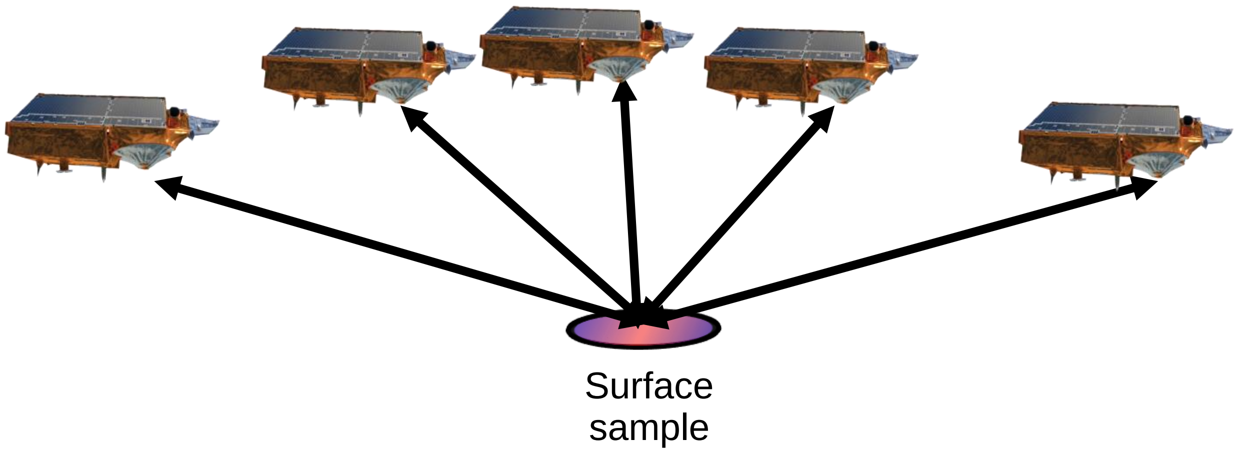


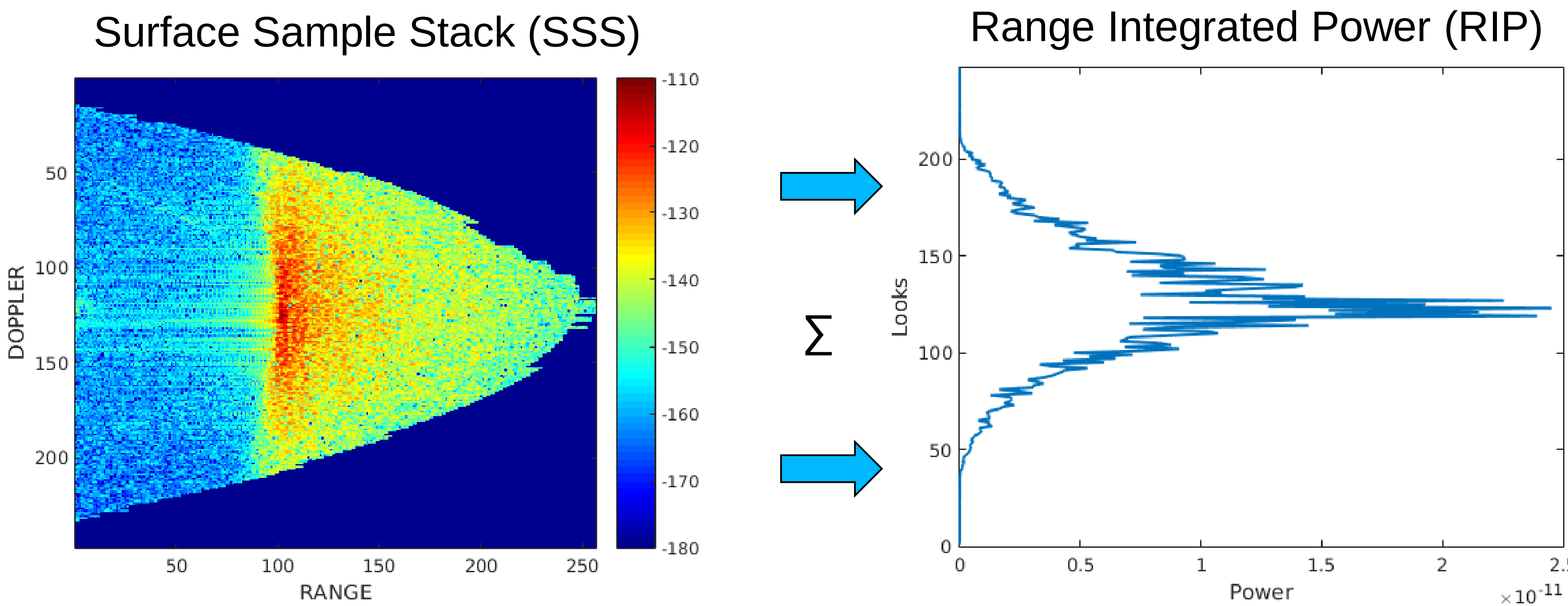






Stack based classification – CryoSat-2



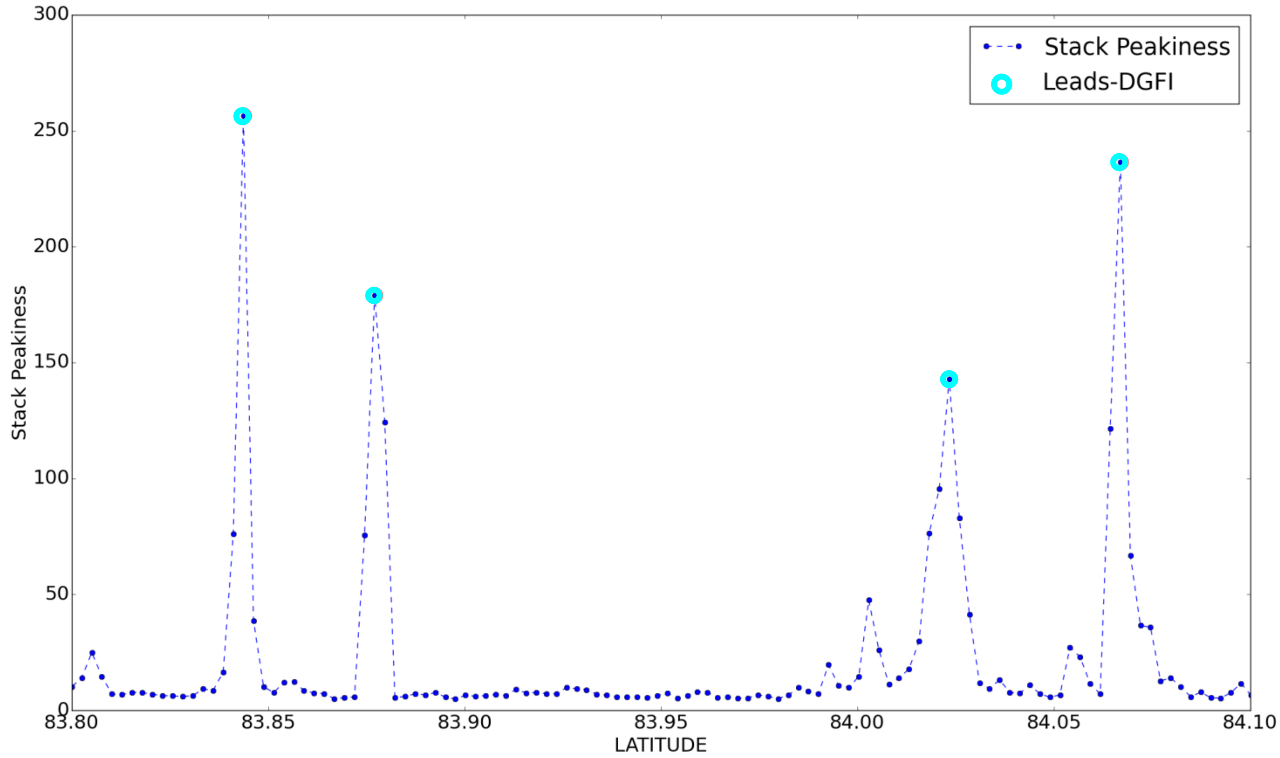


Stack based classification – CryoSat-2

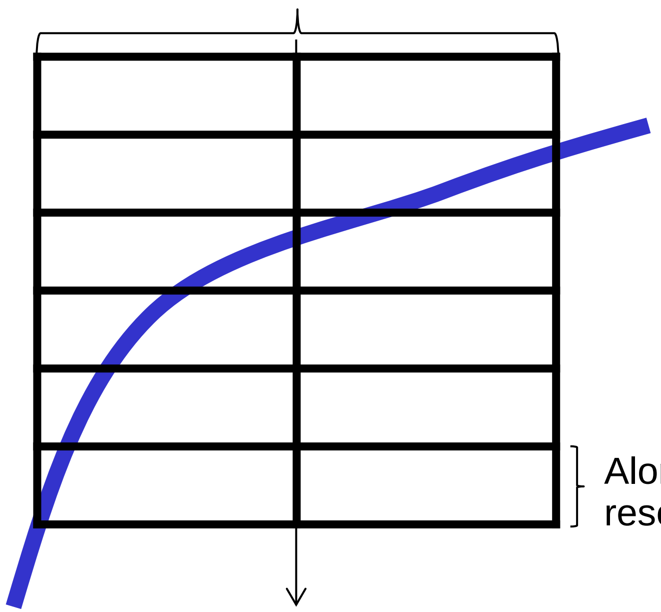
- Data: CS-2 L1b data from ESA G-POD (https://gpod.eo.esa.int/)
- Classification based on the Stack Peakiness PP_{stack} and the RIP $P(i)_{l,r}$:

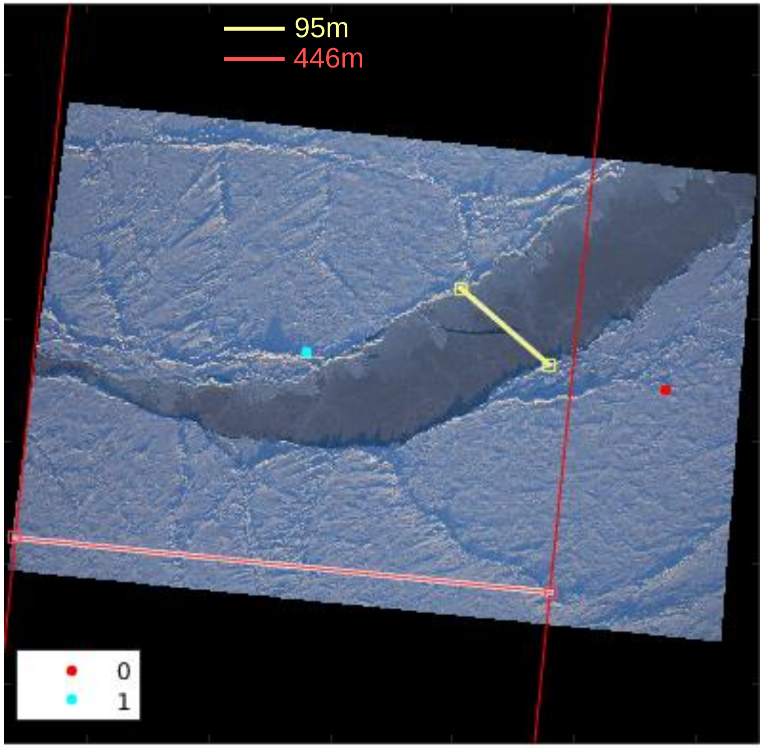
$$PP_{stack} = \frac{1}{\overline{P_{l,r}}}, \text{with } \overline{P_{l,r}} = \frac{\sum_{i=1}^{N} P(i)_{l,r}}{N}$$

- Assuming when the satellite flies over the lead, the specular return from the lead will be maximum when the lead is in nadir
- Using of an empirical threshold on min. PP_{stack}



Stack based classification – CryoSat-2

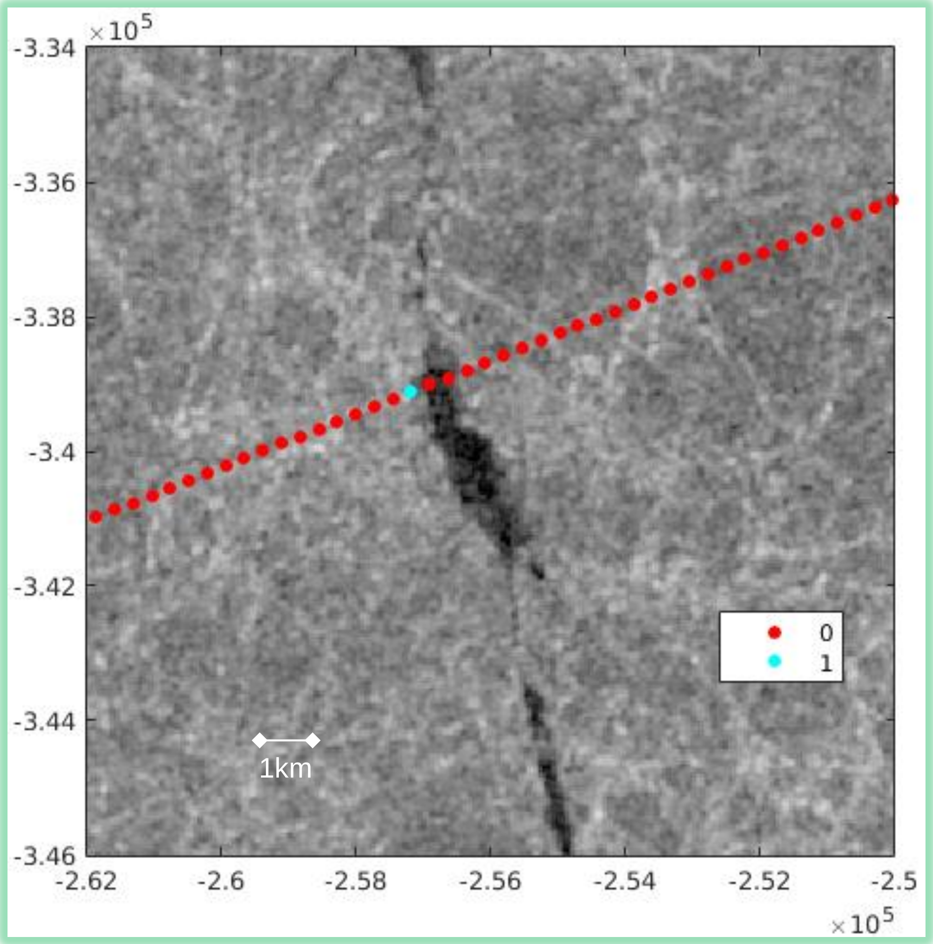


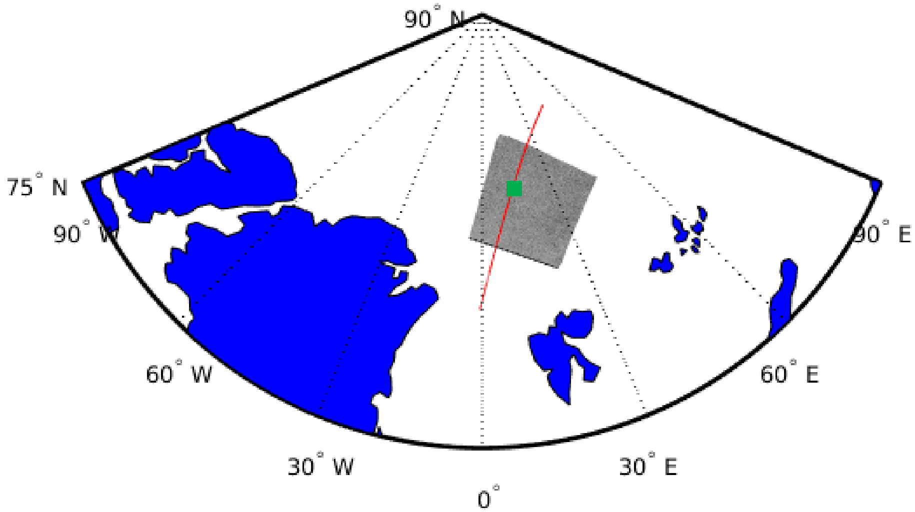


0 No lead
1 Lead

Stack based classification – result 1

- Comparison with Sentinel-1 SAR data



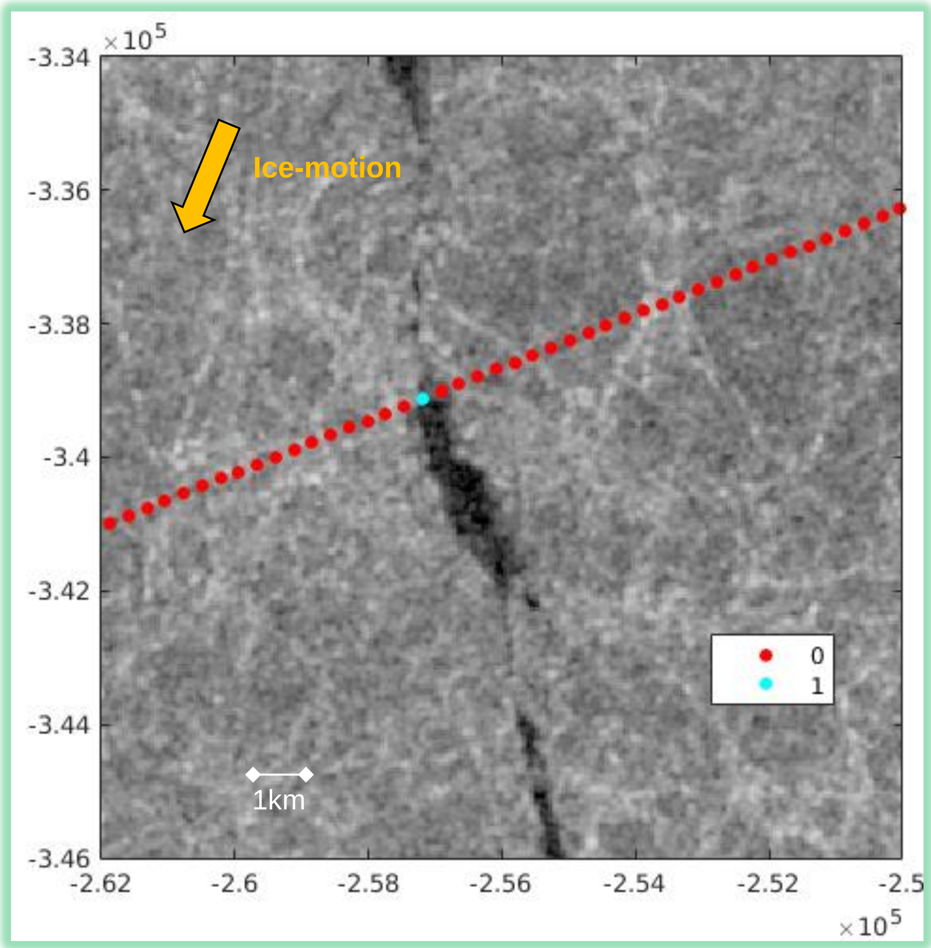


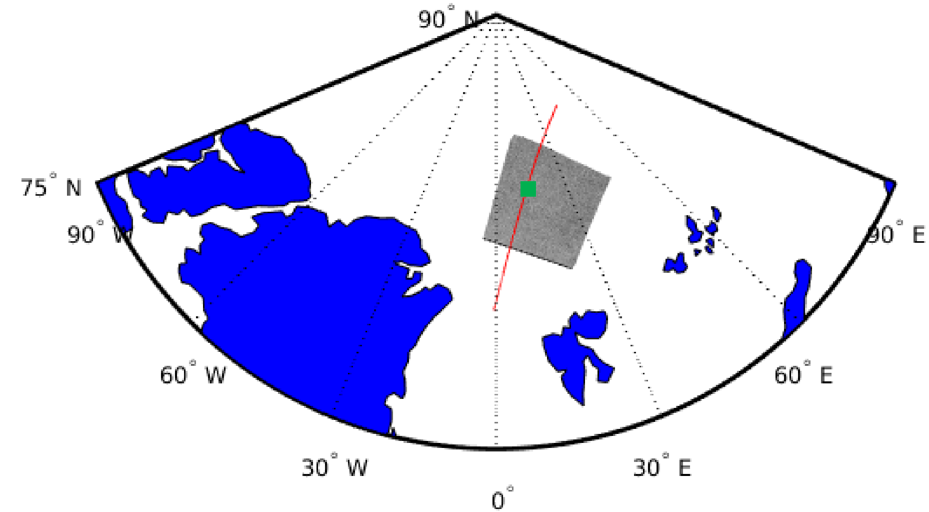
0 No lead
1 Lead

- Sentinel-1 image spatial resolution: 40m
- Without ice motion pixel-shift

➢ Thanks to E. Rinne for providing Sentinel-1 data

Stack based classification – result 1

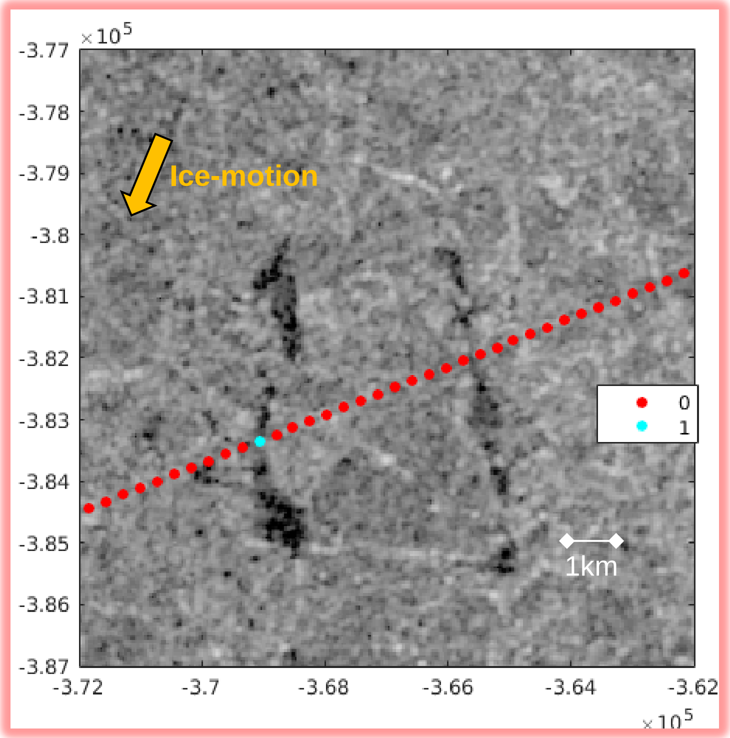




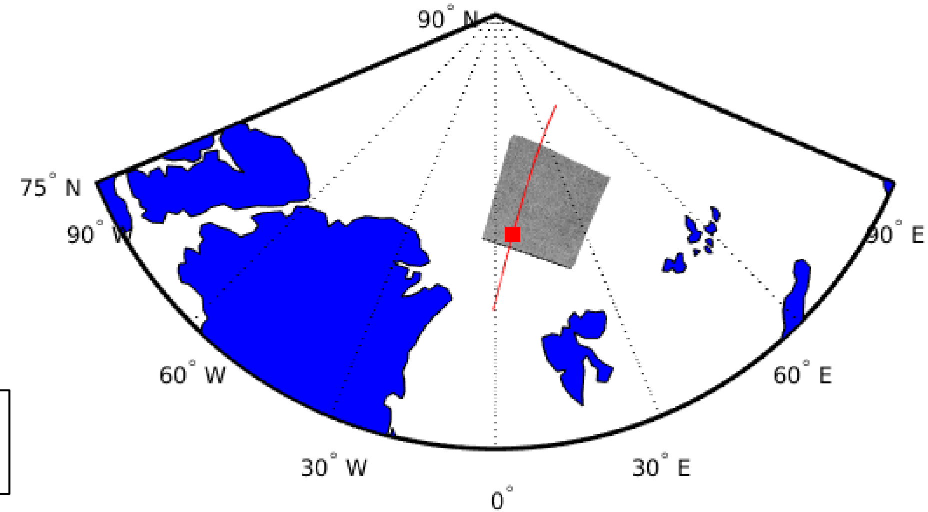
0 no lead
1 Lead

- Sentinel-1 image spatial resolution: 40m
- Acquisition date: 15-09-2015 13:02 UTC
- CS-2 Track: 16:24 UTC
- Mean Ice motion velocity 2004 - 2014: $3.72\,\frac{cm}{s}$
- Time-shift:
  - $\Delta t = 3h22min$
  - $s \approx 450.48\ m$

Stack based classification – result 2



0 No lead
1 Lead



➢ Thanks to Ricker, R. et al. (2014)

- Sentinel-1 image spatial resolution: 40m
- Acquisition date: 15-09-2015 13:02 UTC
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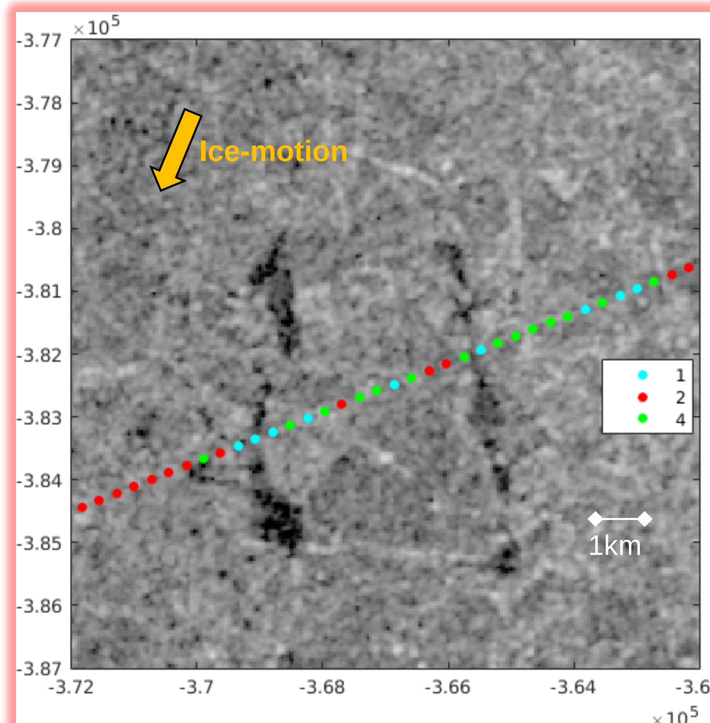
- Time-shift:
  - $\Delta t = 3h22min$
  - $s \approx 450.48\ m$

1 Lead
2 Ice
3 Ocean
4 Undefined



Classification results

Summary - Conclusion - Outlook

Summary:
- Unsupervised classification of ENVISAT waveforms based on K-medoids and K-nearest neighbor has been performed
- Threshold based classification of CryoSat-2 stack data
- Comparison of classification results with imaging SAR data
- Taking into account ice motion with daily ice velocity vectors

Conclusion:
- Waveform classification provides reliable results in oceanic regions affected by rapid climate change
- Unsupervised classification allows separation of different waveform and surface types
- Analysis of consecutive Delay-Doppler stacks identifies narrow leads at nadir
- Necessity of taking ice motion for realistic validation into account

Outlook:
- Quantitative validation of classification results
- Applying classification method for all conventional altimetry and Delay-Doppler missions covering arctic area
- Improving classification method by sensitizing classification for off-nadir returns
- Unsupervised classification of CryoSat-2 stack data

➢ Waveform classification will be used to improve accurate sea surface height estimation

Thank you for listening!

Acknowledgements:

ALOS data: © JAXA/METI ALOS-1 PALSAR L1.5 2008. Accessed through ASF DAAC https://www.asf.alaska.edu 28.04.2016
CryoSat-2 data: CS-2 Stack data provided by ESA G-POD https://gpod.eo.esa.int/ 28.04.2016
ENVISAT data: ENVISAT SGDR 2.1 data provided by ESA
Sentinel-1 data: Sentinel-1 data provided by ESA, reprocessed by E. Rinne

Comparison classification: Ricker R, Hendricks S, Helm V, Skourup H, Davidson M (2014) Sensitivity of cryosat-2 arctic sea-ice freeboard and thickness on radar-waveform interpretation. Cryosphere 8(4):1607–1622. http://www.thecryosphere.net/8/1607/2014/. doi:10.5194/tc-8-1607-2014