Satellite altimetry in sea ice regions- detecting open water for estimating sea surface heights

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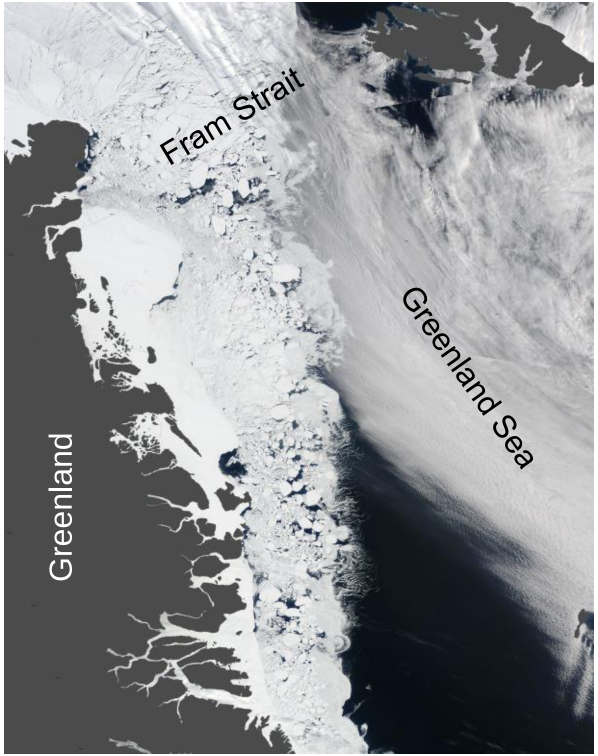
Introduction

Detecting open water (lead, polynya) to estimate sea surface heights (SSH) with multi-mission altimetry data in the Fram Strait and Greenland Sea

- Unsupervised classification approach of pulse-limited radar echoes without the use of a-priori known training data
- Automatic and quantitative evaluation of classification performance with pre-processed SAR images
- Mapping sea ice extent and its variation with radar altimetry
- Improving SSH estimation within the sea ice area

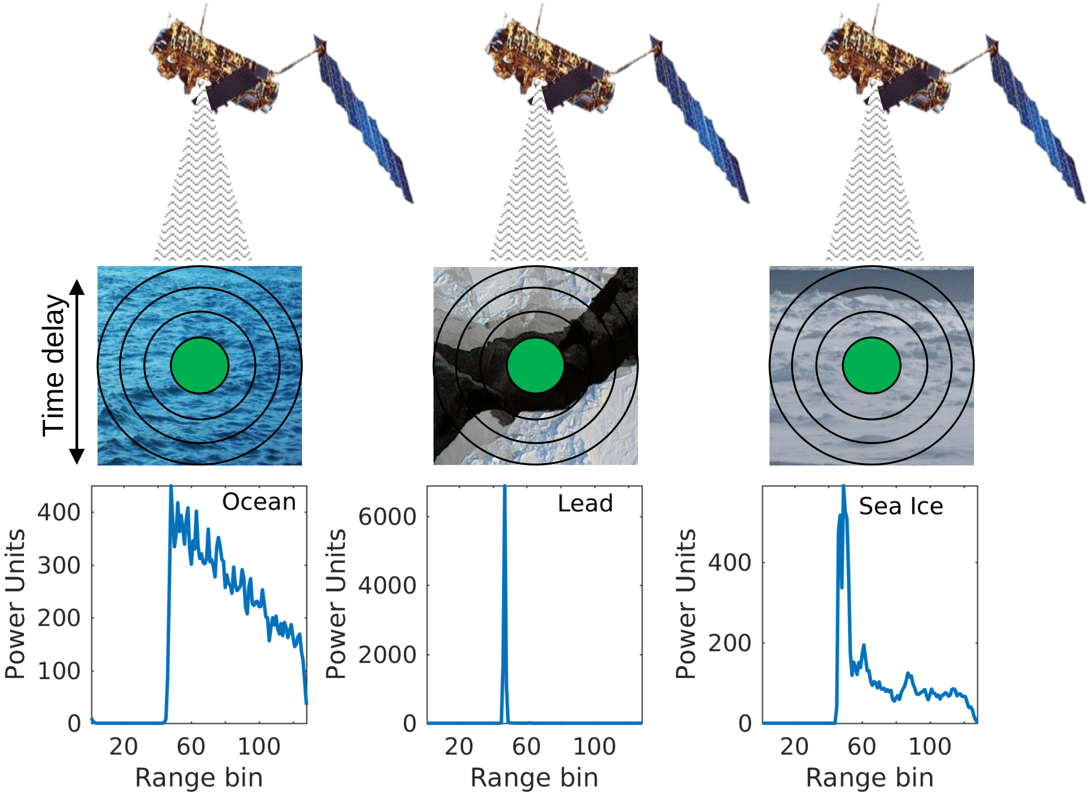


Altimetry: Measurement Principle and waveforms

Altimetry:

- Emitting of radar pulses (nadir)
- Receiving radar echoes (waveforms)
- Estimating distance between satellite and surface by interpreting waveform
- Information about surface conditions by analyzing waveform’s shape and back scattered power

Mission: ENVISAT (ESA)



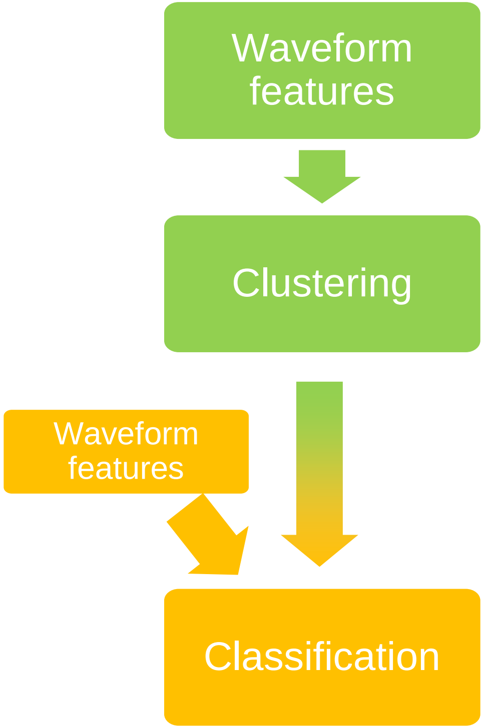
Unsupervised classification

- Definition of waveform features
  - ➢ Maximum Power, Waveform width, Decay of trailing edge etc.

    (Parameters describe the waveform’s shape and its features)

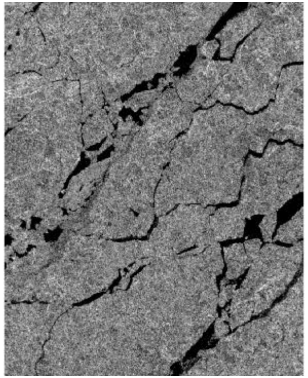
- Clustering of waveforms in 30 clusters applying K-medoids
  - ➢ Waveform reference model
- Assigning waveform clusters to surface conditions
  - ➢ 4 classes: calm water, ocean, sea-ice and undefined
- Classification of remaining waveforms using reference model and K-nearest neighbor

➢ Classification result: WATER [1] | ICE [0] | UNDEFINED [0] (per measurement)

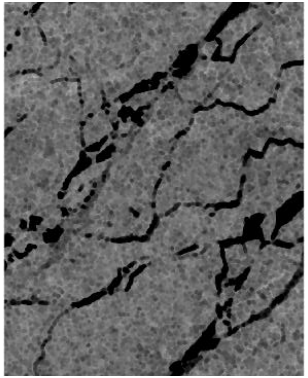


Pre-processing of imaging SAR

Example: Sentinel-1A



Ref:1



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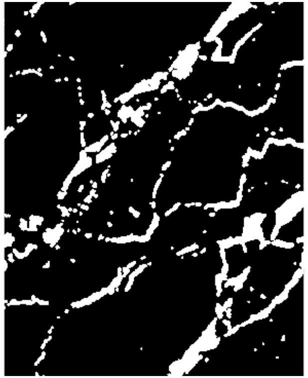

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Ref: 1

- Noise reduction
- Dark pixel emphasizing

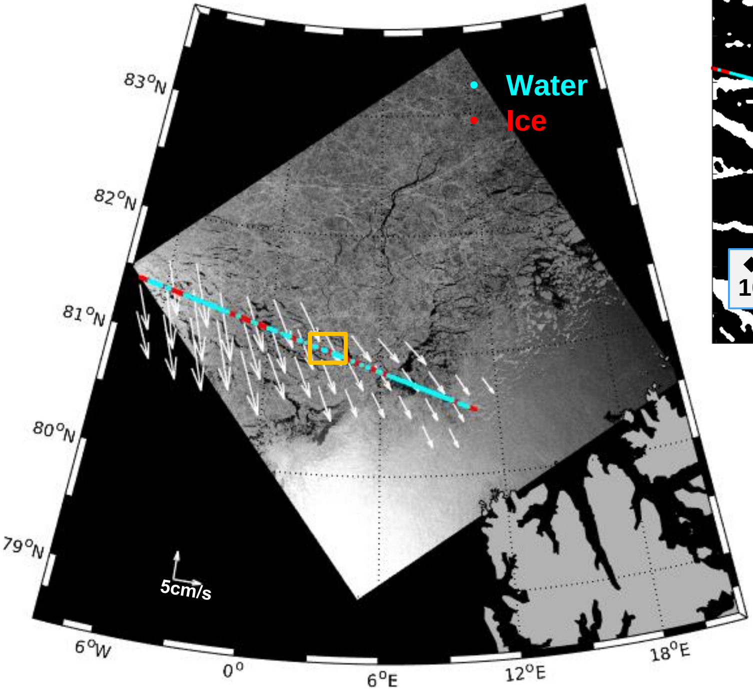
- Considering local SAR illumination changes
- Conversion to binary image

- Linking of segmented lead and polynya fragments

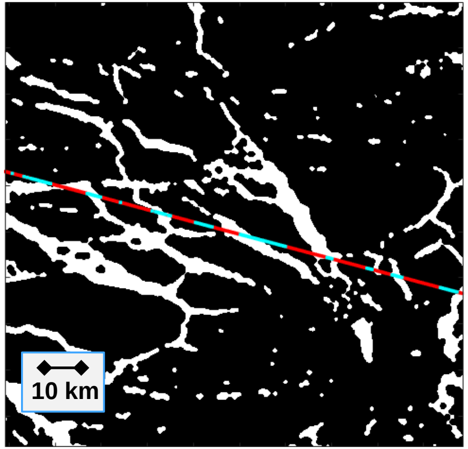
➢ Binarization of grayscaled SAR images

Sea ice motion correction

- **Purpose: Taking ice motion into account**



10-Dec-2007 (Ref:2)



before

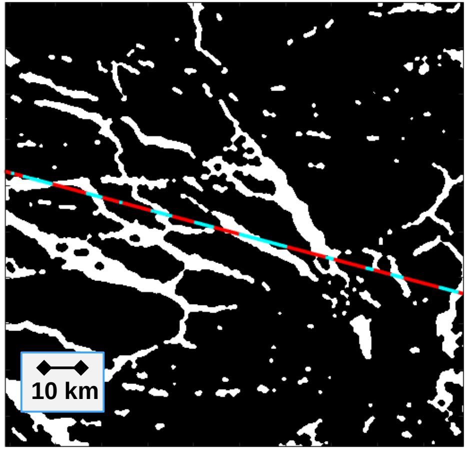
shift

$\Delta t = 2h50min$

$\bar{v} = 7{,}53\ cm/s$

$x = 768{,}82m$

$dir = NNW$



after

- Considering a mean sea ice motion with pixel-based shifting
- National Snow & Ice Data Center Daily Polar Pathfinder 25 km EASE-Grid Sea Ice Motion Vectors

➢ Improving the consistency between altimetry and SAR classification

➢ Applicable only for short acquisition time gaps (~3h)

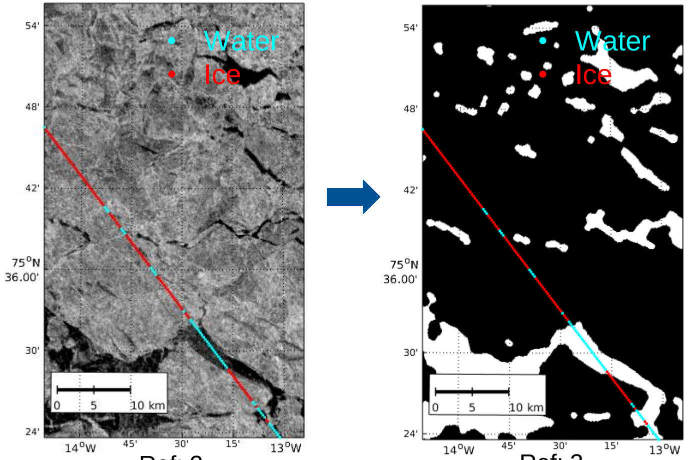
Quantitative comparison with imaging SAR

- Comparison between the altimetry and SAR classification results
- Computation of relative and absolute statistical information (contingency table)
  - Example: $P(CR) = \frac{31 + 89}{141} \approx 0.85$ consistency rate

    $P(ALT|SAR) = \frac{31}{35} \approx 0.89$ true water classification rate

- Processing of 19 image pairs (Radarsat-2/ALOS, 15025 altimetry observations) for Envisat classification located in the Fram Strait and Greenland Sea
  - $P(CR) = 70.7\%$, $P(\mathrm{ALT}|\mathrm{SAR}) = 60.0\%$

- Possible causes: misclassification SAR/altimetry, acquisition time differences/sea ice motion,



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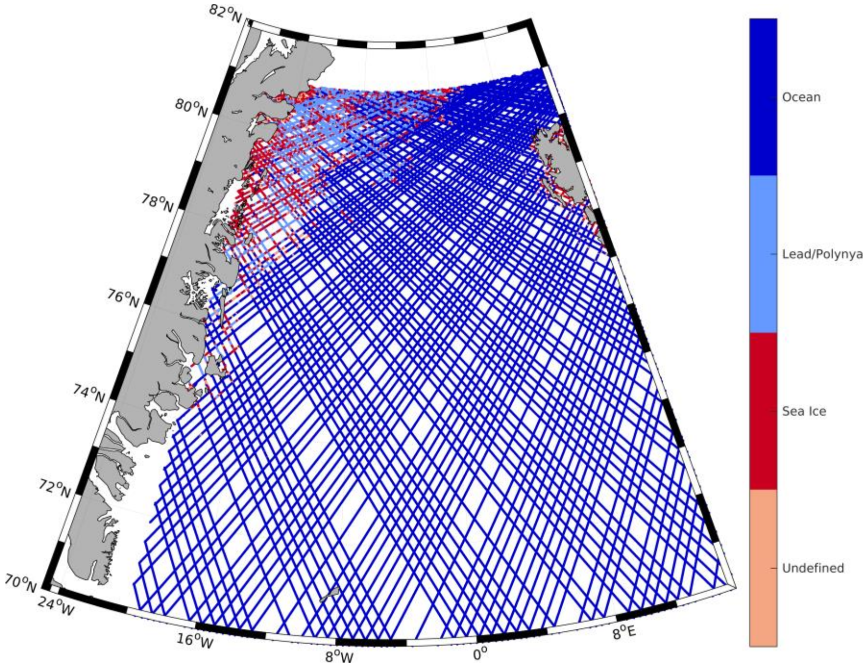
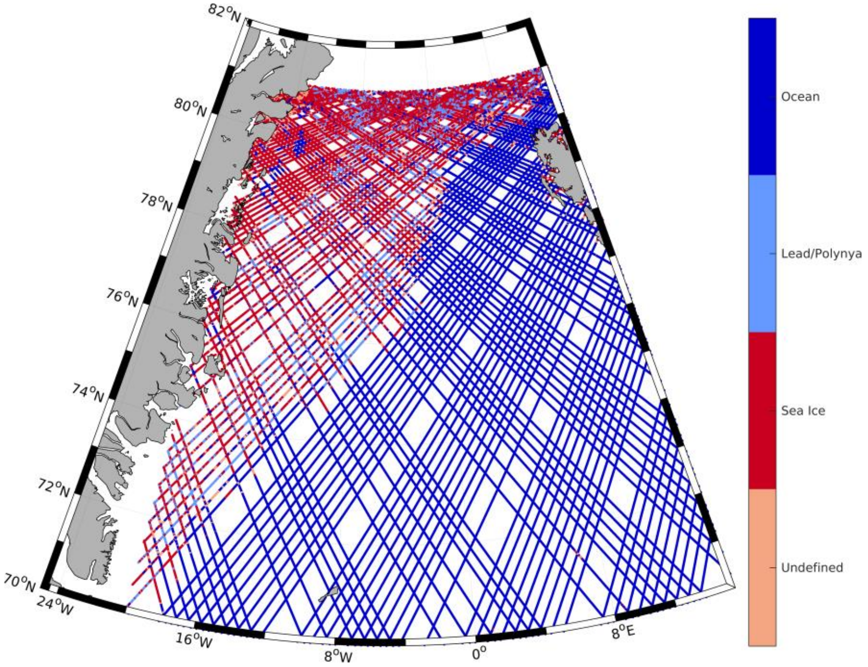
	ALT	ALT	∑
SAR	**31**	4	35
SAR	17	**89**	106
∑	48	93	**141**

contingency table

Spatial distribution of sea-ice and open water areas



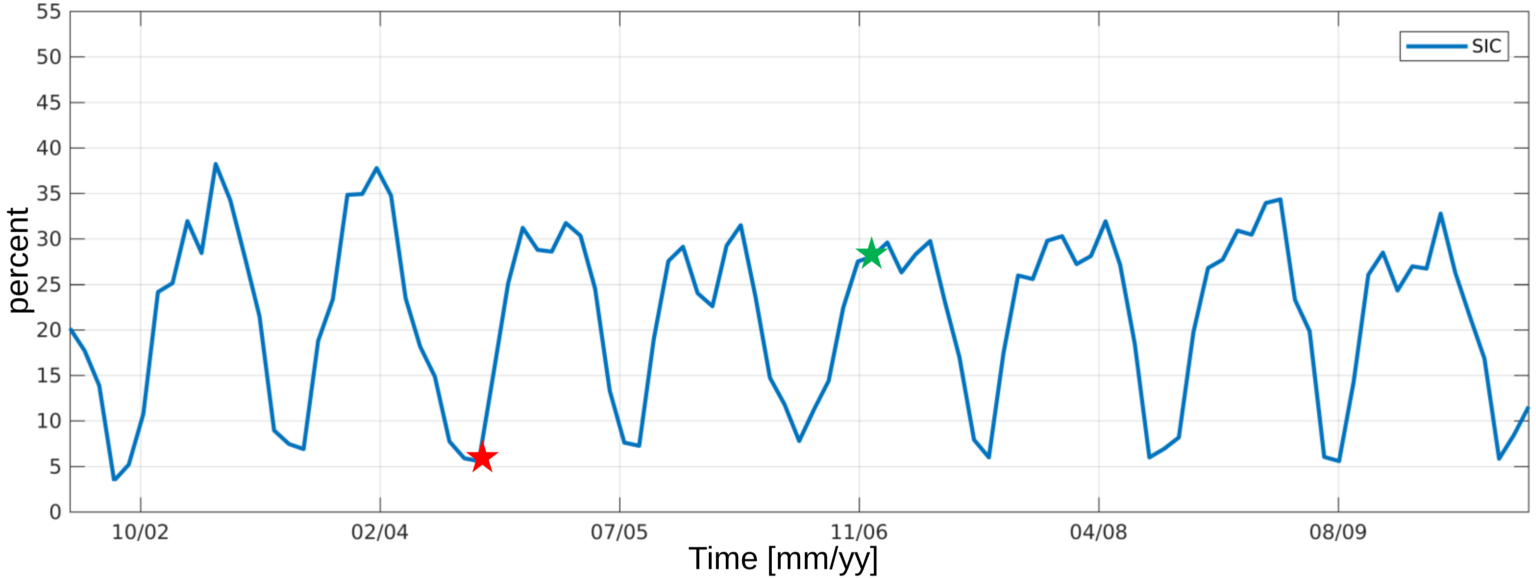
09-2004★



12-2006★

- Classification results: Ocean, Lead/Polynya, Sea ice and Undefined classes

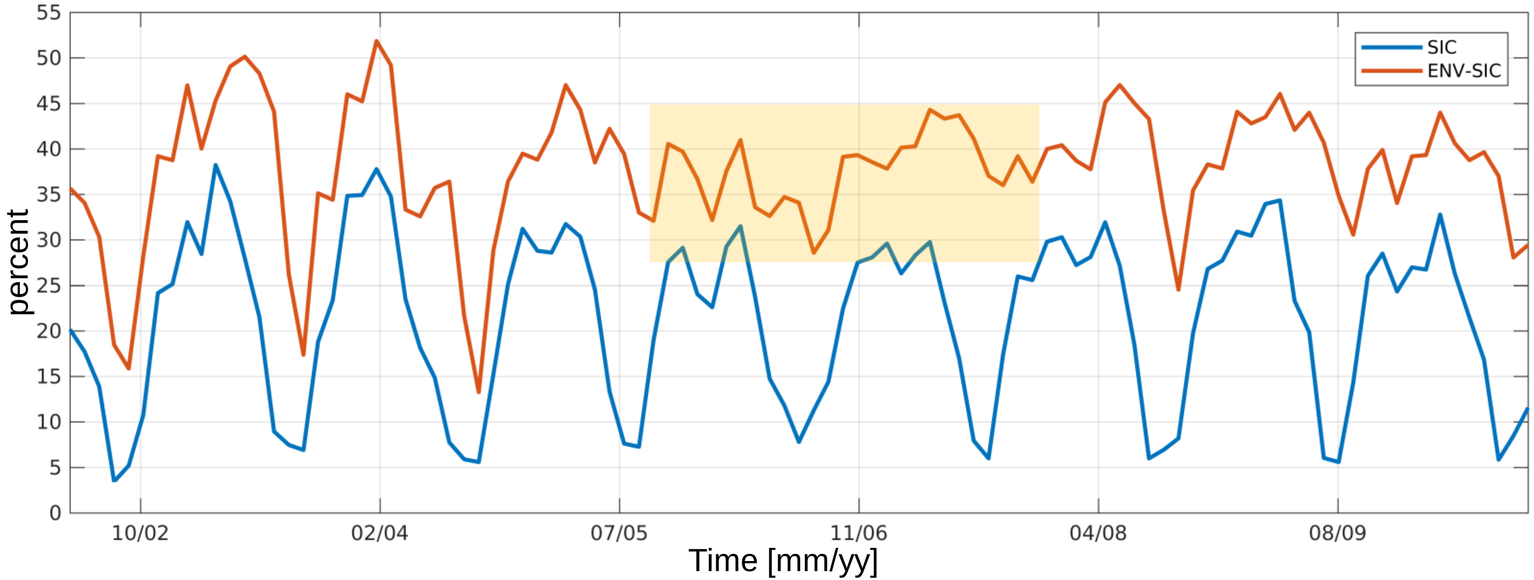
Temporal evolution of sea ice concentration (SIC)



- SIC: Based on unsupervised sea ice classification

➢ Significant seasonal variations
➢ Max. SIC of about 40% due to large ocean area

Temporal evolution of sea ice concentration (SIC)

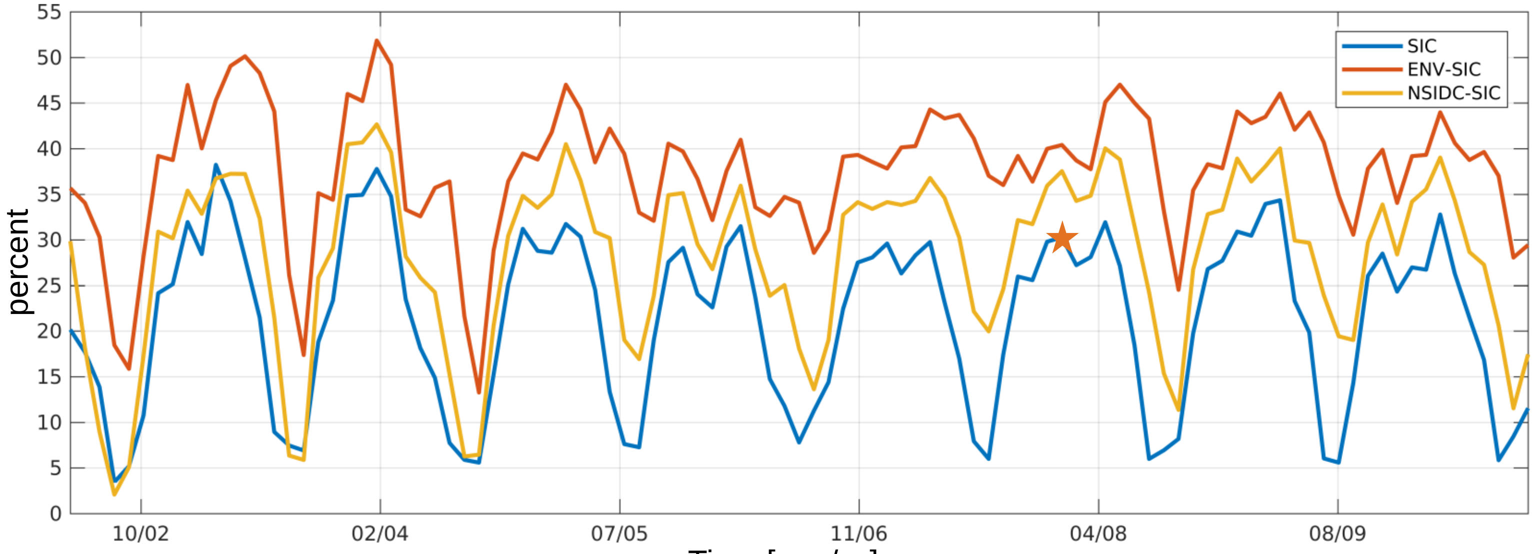


- SIC: Based on unsupervised sea ice classification
- ENV-SIC: Based on ENVISAT sea ice flag (Radiometer-Altimeter Combination)

➢ Higher SIC due to lower spatial resolution (leads/polynyas are missed)

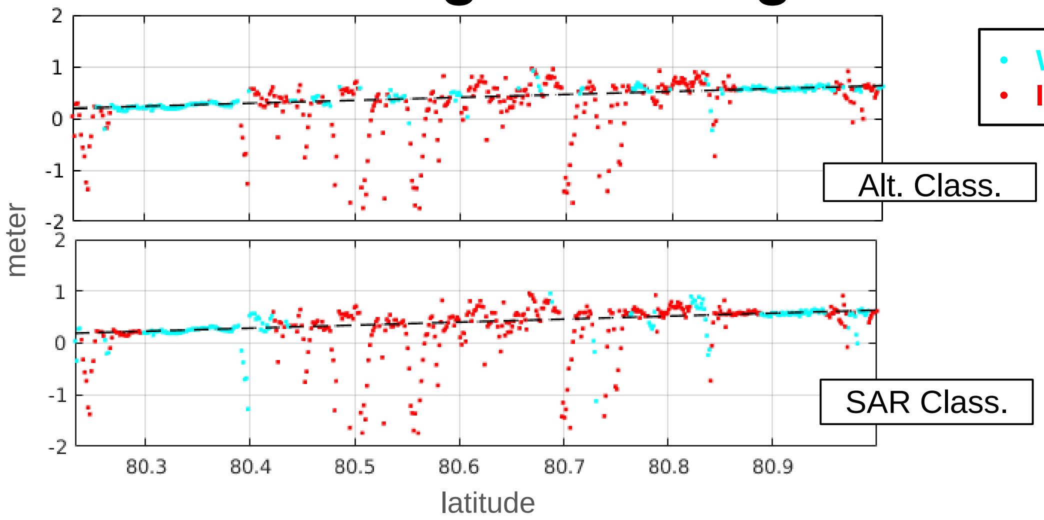
➢ No seasonal effect in 2005 – 2007

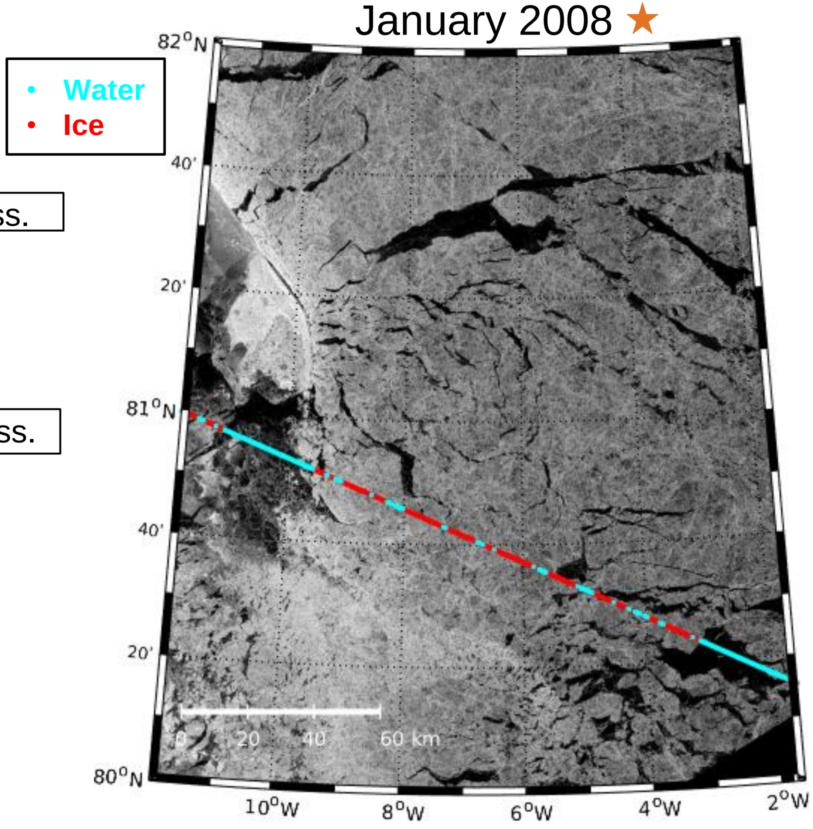
Temporal evolution of sea ice concentration (SIC)



- SIC: Based on unsupervised sea ice classification
- ENV-SIC: Based on ENVISAT sea ice flag (Radiometer-Altimeter Combination)
- NSIDC-SIC: Based on moving average on National Snow & Ice Data Center gridded sea ice concentration (passive microwave + in-situ observations)

Sea surface heights w.r.t. geoid





Ref: 2

- SSH based on ALES+ retracker
- RMS of SSH residuals w.r.t. linear fitted altimetry water observations

RMS_{all}	$RMS_{SAR\ water}$	$RMS_{Alt.\ water}$
0.462 [m]	0.260 [m]	0.103 [m]

Conclusion

- Unsupervised classification of ENVISAT (and SARAL) waveforms based on K-medoids and K-nearest neighbor has been performed in order to separate different waveforms and surface types
- Quantitative comparison with imaging SAR shows satisfying results (70% consistency)
- Classification allows for computation of sea ice concentration (SIC) and enables the estimation of sea surface heights (SSH) within the ice area
- Comparison with ENVISAT sea ice flag shows a lower total SIC and a higher sensitivity to seasonal sea ice variations
- Comparison with NSIDC SIC data shows good accordance to seasonal sea ice variability
- Classified sea surface heights w.r.t. to geoid of single ENVISAT tracks provide promising results (work in progress)

Thank you for listening!

More Information coming soon:

- Müller, F.L.; Dettmering, D.; Bosch, W.; Seitz, F.; Monitoring the Arctic seas: How satellite altimetry can be used to detect open water in sea-ice regions. Remote Sensing. (under review)

- Passaro, M.; Müller, F.L.; Dettmering, D. Lead Detection using Cryosat-2 Delay-Doppler Processing and Sentinel-1 SAR images. Advances in Space Research. (under review)

Acknowledgements:

1. **Sentinel-1A data:** Sentinel-1 data provided by ESA, accessed: 28.04.2016
2. **ALOS data:** © JAXA/METI ALOS-1 PALSAR L1.5 2008. Accessed through ASF DAAC https://www.asf.alaska.edu 28.04.2016
3. **ENVISAT data:** ENVISAT SGDR 2.1 data provided by ESA

Comparison datasets:

- **ENVISAT Sea Ice Flag:** ENVISAT SGDR 2.1, see: Tran N., F. Girard-Ardhuin, R. Ezraty, H. Feng, and P. Femenias, “Defining a sea ice flag for Envisat altimetry mission”, *IEEE GRS letters*, doi:10.1109/LGRS.2008. 2005275, 6 (1), 77-81, 2009
- **NSIDC Sea Ice Concentration:** Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. J. Zwally. 1996, updated yearly. Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1. [Greenland Sea]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: http://dx.doi.org/10.5067/8GQ8LZQVL0VL. 19.04.2017.