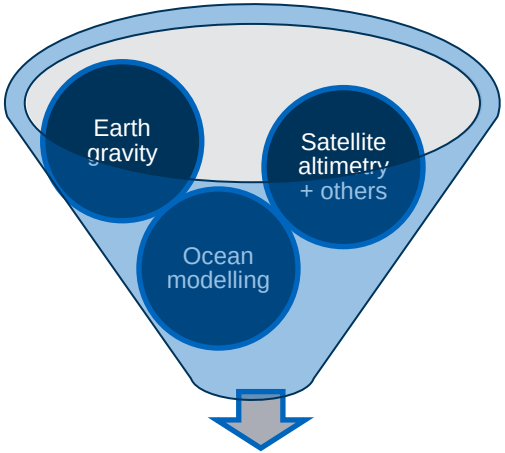
Variations in ocean currents, sea ice concentration, and sea surface temperature along the North-East coast of Greenland (NEG-OCEAN)

Felix L. Müller, Denise Dettmering, and Wolfgang Bosch

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

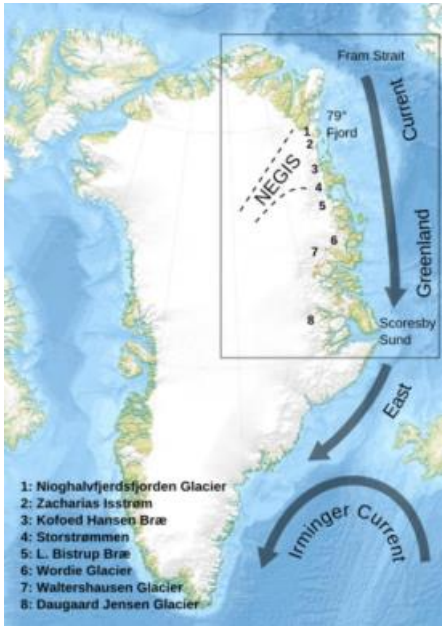
Alfred-Wegener-Institut
Bremerhaven, 20.06.2017

DFG Project- North East Greenland – Ocean (NEG-Ocean)



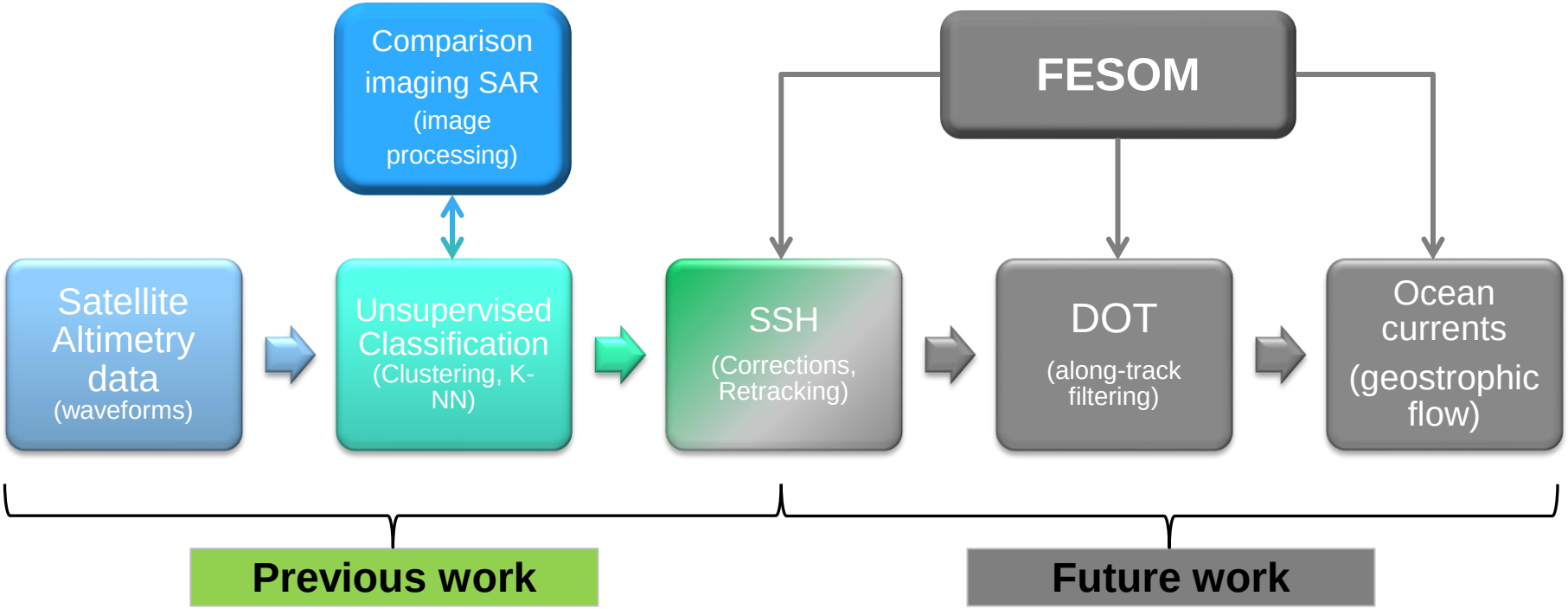
Generation of temporal evolution (1992 – now) of:

- Sea surface heights (SSH)
- Dynamic ocean topography (DOT)
- Ocean surface currents (OSC)
- Sea surface temperature (SST) and salinity (SSS)
- Sea ice concentration (SIC)



study area: Greenland Sea, Fram Strait

Workflow NEG-Ocean (DOT, SSH, OSC)

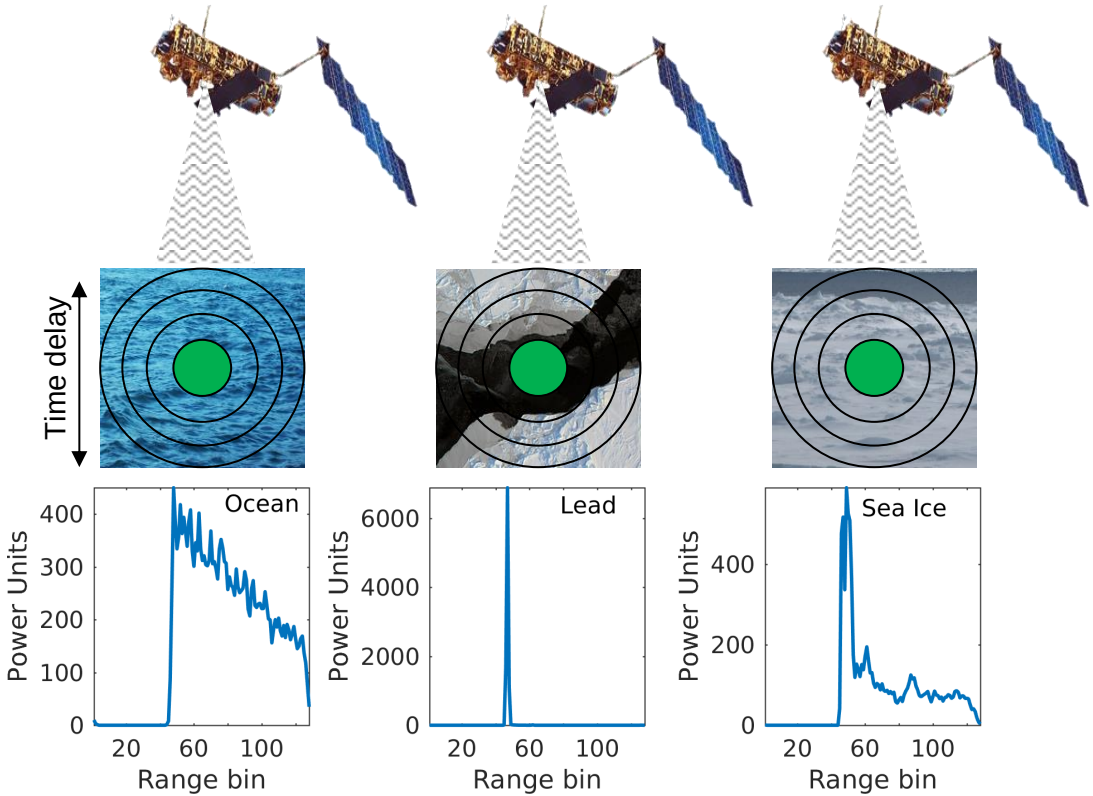


Altimetry: Measurement Principle and waveforms

Altimetry:

- Emitting of radar pulses (nadir)
- Receiving radar echoes 20 – 40 Hz (waveforms)

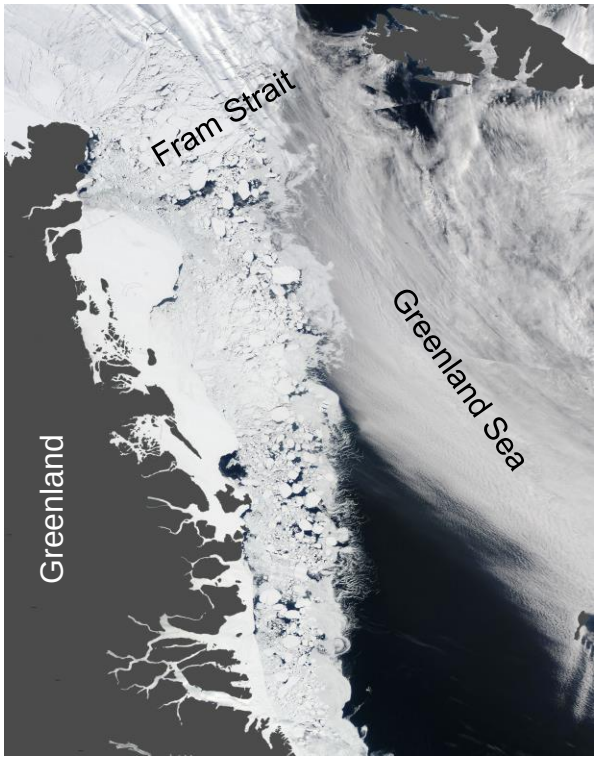
- Estimating distance between satellite and surface by interpreting waveform
- Information about surface conditions by analyzing waveform's shape and back scattered power



Classification – open water detection

Detecting automatically 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



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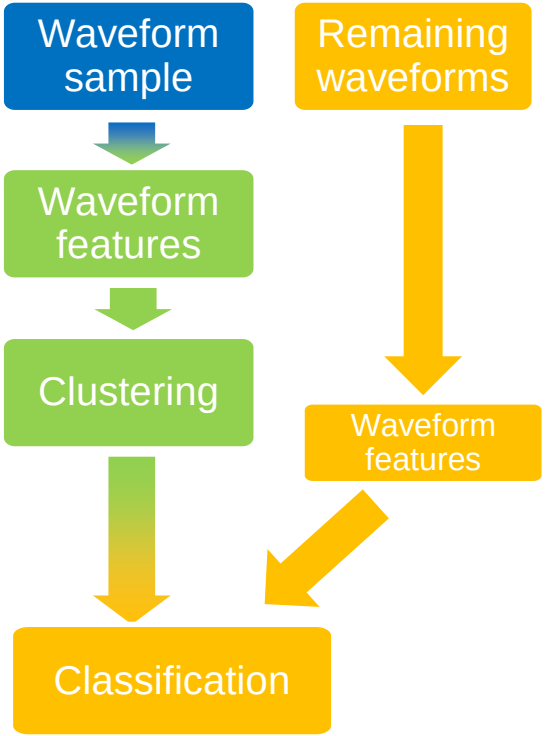
Unsupervised waveform classification

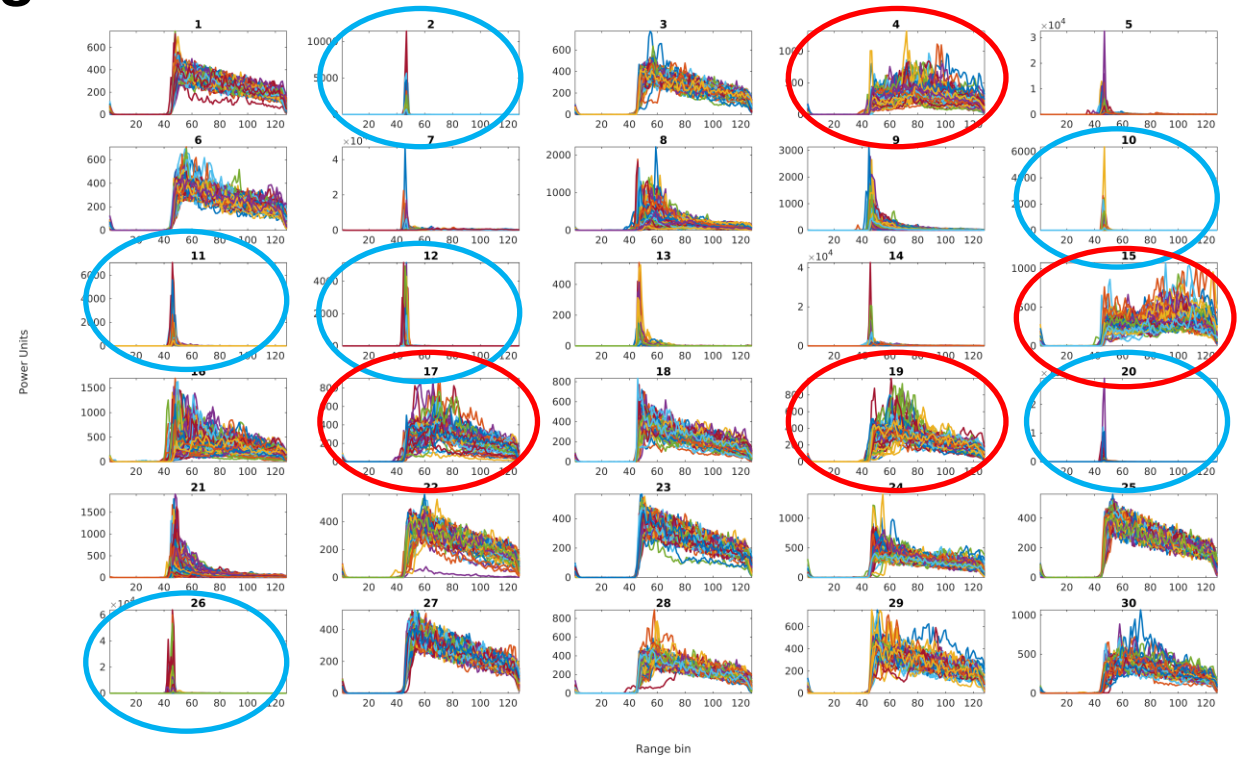
- **Input: Original waveform data**
- Definition and computation of waveform features
  - ➢ Maximum Power, waveform width, decay of trailing edge etc. (Parameters describe the waveform's shape and its features)

- 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 (K-NN)

- **Classification output:** WATER [1] | ICE [0] | UNDEFINED [0] (per measurement)



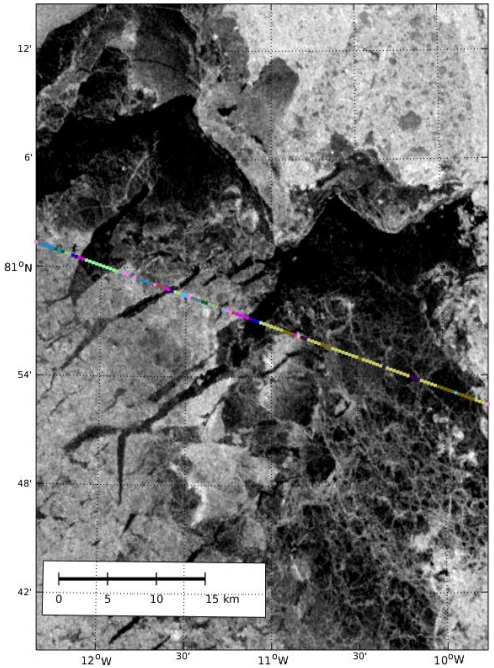
Clustering Results Envisat



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

Classification assignment

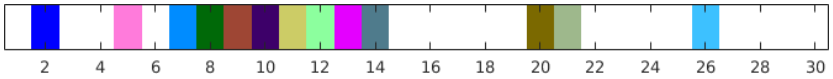
Example: ENVISAT vs. ALOS

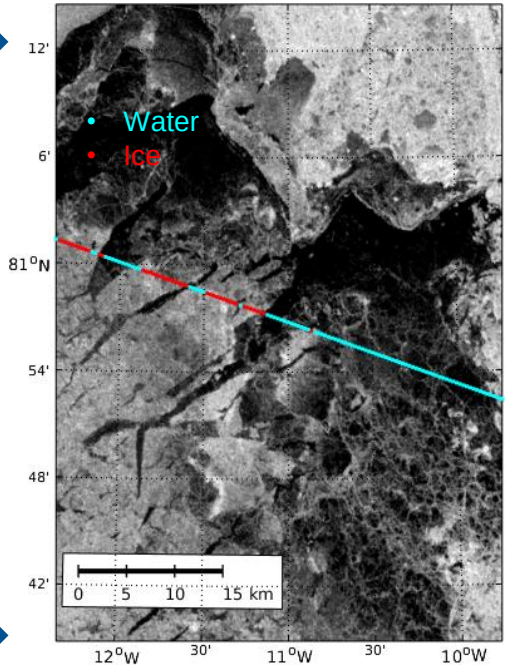


after clustering and K-NN

Cluster assignment:

- Analyzing statistical elements of every cluster center (1…30)
- Integrating physical knowledge about surface scattering
- Comparing questionable cluster with simultaneous available SAR image

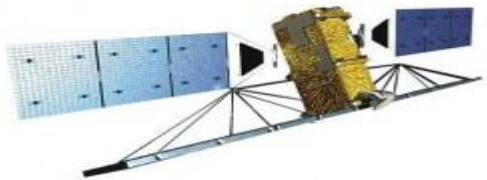




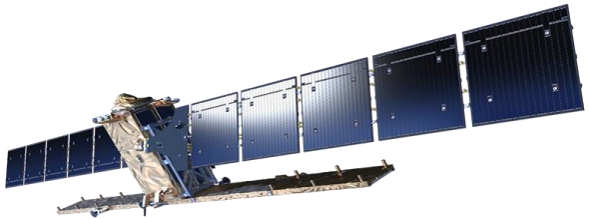
after class assignment

Comparison with imaging SAR

ALOS
(JAXA/METI)



Radarsat-2
(MDA)



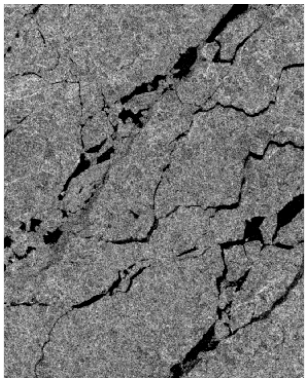
Sentinel-1
(ESA/Copernicus)

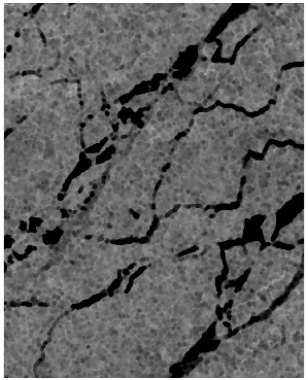
SAR satellite	Band	Mode	Swath width (km)	Pixel size (m)	Period (mm/yyyy)
ALOS	L-Band	Wide Beam	250 - 350	100 x 100	06/2007-05/2008
Radarsat-2	C-Band	Scan SAR Wide	500	50 x 50	06/2008-present
Sentinel-1A	C-Band	Extra Wide	400	40 x 40	10/2014-present

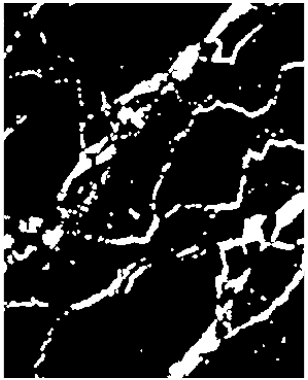
- HH-polarized data (Sentinel-1 offers HH/HV polarization)
- ALOS and Sentinel-1 data is free available
- Radarsat-2 data is available in framework of ESA Third Party Mission Program

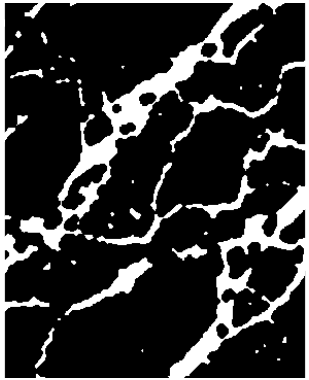
Pre-processing of imaging SAR

Example: Sentinel-1A


Ref:1


Ref:1


Ref:1


Ref: 1

- Noise reduction
- Dark pixel emphasizing

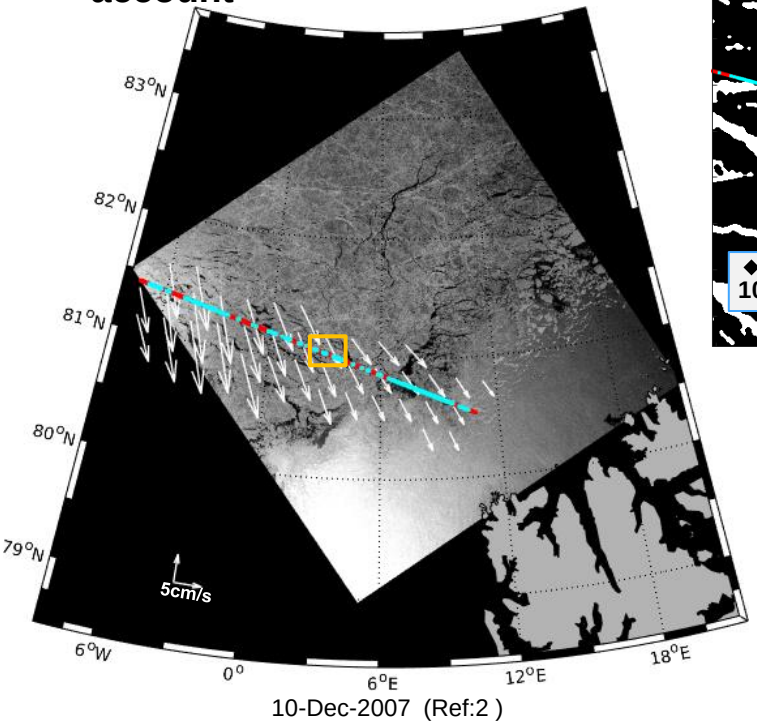
- Considering local SAR illumination changes
- Conversion to binary image

- Linking of segmented lead and polynya fragments

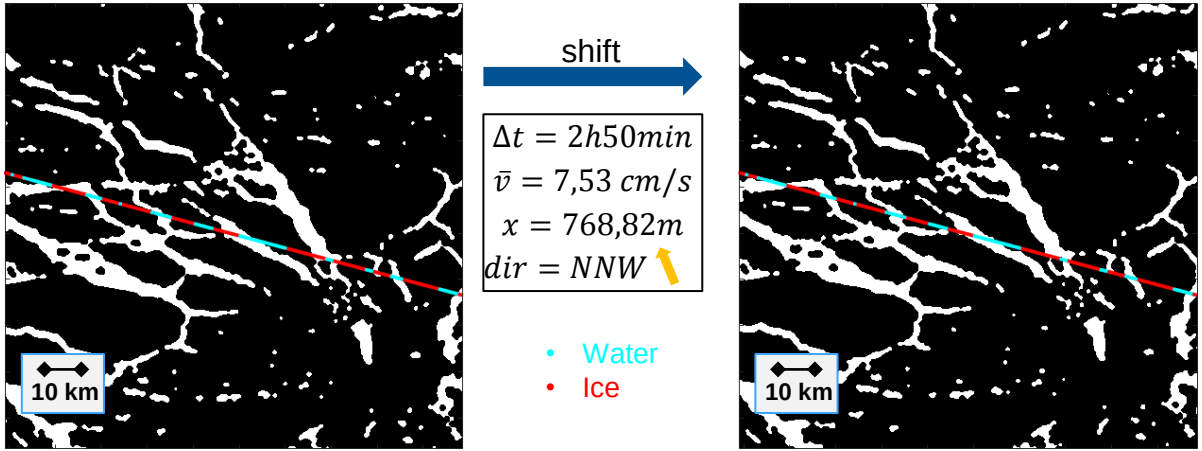
➢ Binarization of grayscaled SAR images

Sea ice motion correction

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



10-Dec-2007 (Ref:2)



before

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)

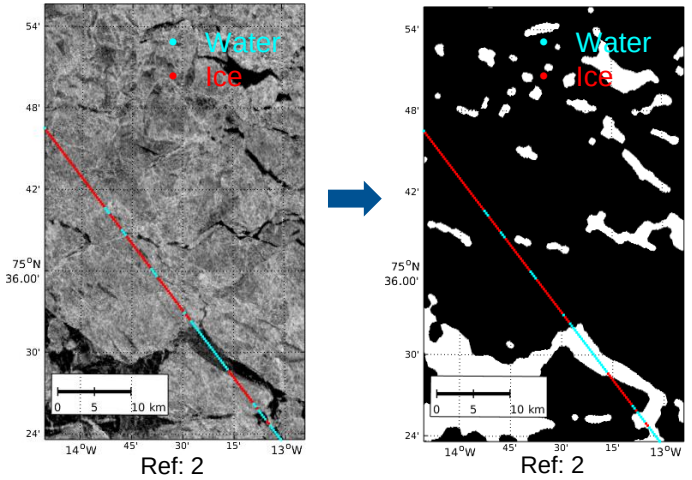
Quantitative comparison with imaging SAR

- 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
  - $P(CR) = 70.7\%$, $\mathrm{P(ALT|SAR)} = 60.0\%$

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

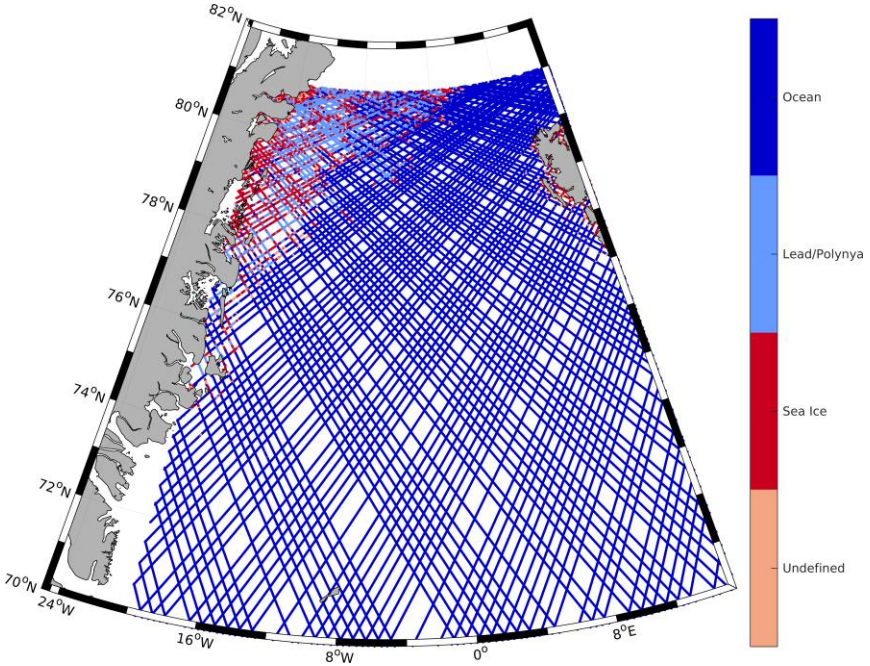


Ref: 2

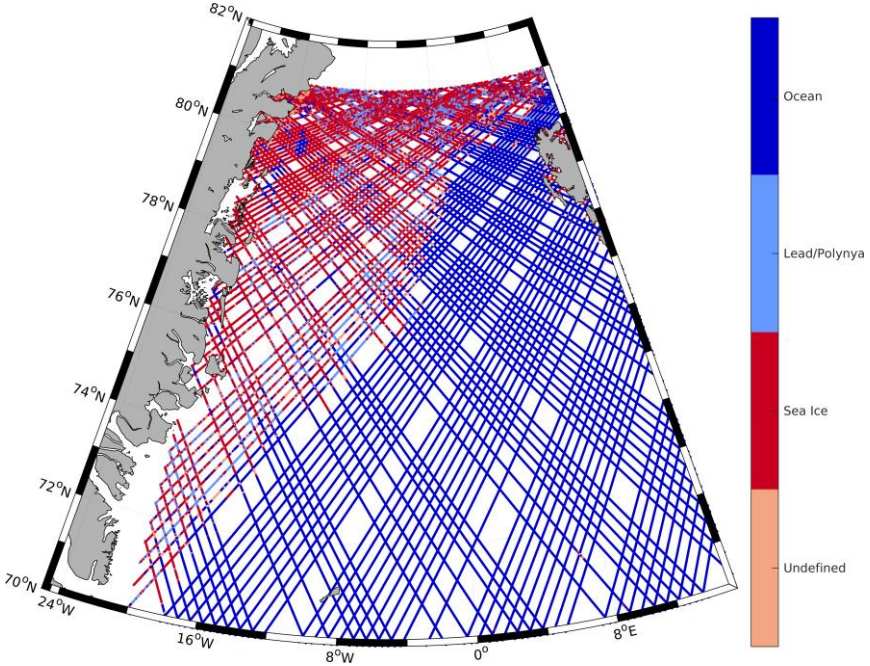
	ALT	ALT	∑
SAR	**31**	4	35
SAR	17	**89**	106
∑	48	93	**141**

contingency table

Spatial distribution of sea-ice and open water areas



09-2004★

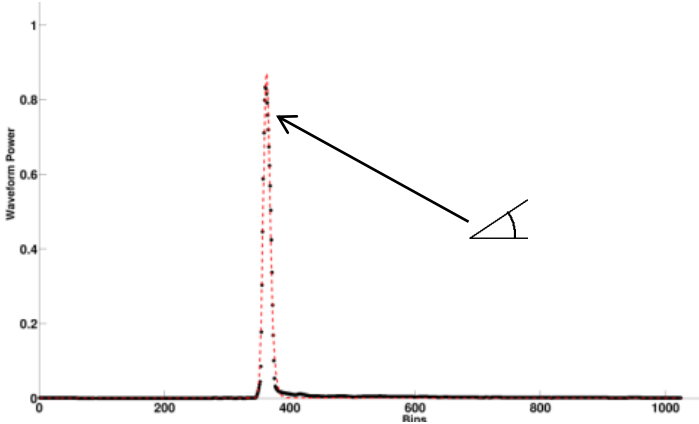


12-2006★

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

ALES+: Retracking of peaky waveforms

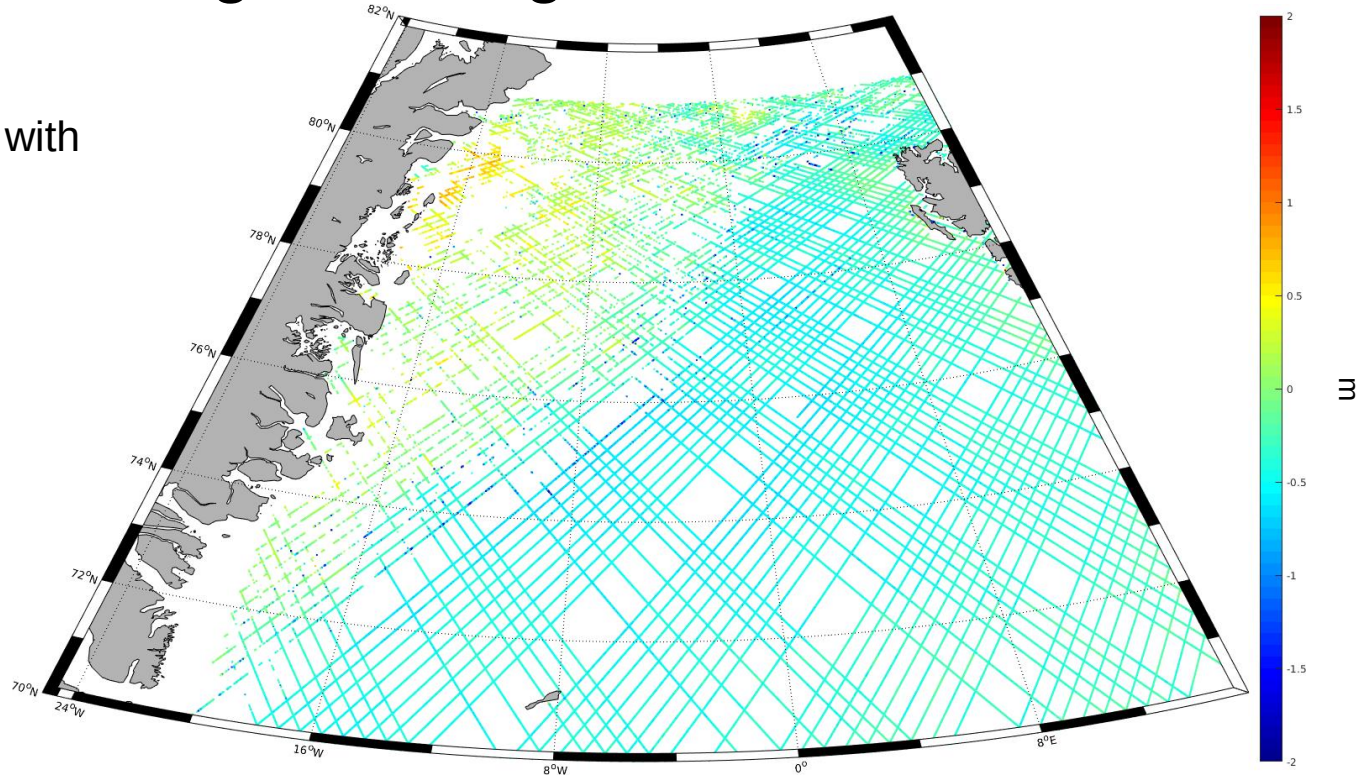
- Build on ALES retracker (see Passaro et. al. 2014)
- ALES+: enables also the fitting of very peaky shaped waveforms
- Developed in the framework of Climate Change Initiative (CCI)
- Preliminary estimation of the trailing edge slope dependent on pulse peakiness threshold
- Homogenous range estimation of lead/polynya, open ocean and coastal waveforms (avoids internal biases)



- More Information: Rose S.K., Andersen O.B., Passaro M., Benveniste J.: An updated 26-year (1991-2017) sea level record from the Arctic Ocean. EGU General Assembly 2017, Wien, 2017-04-28

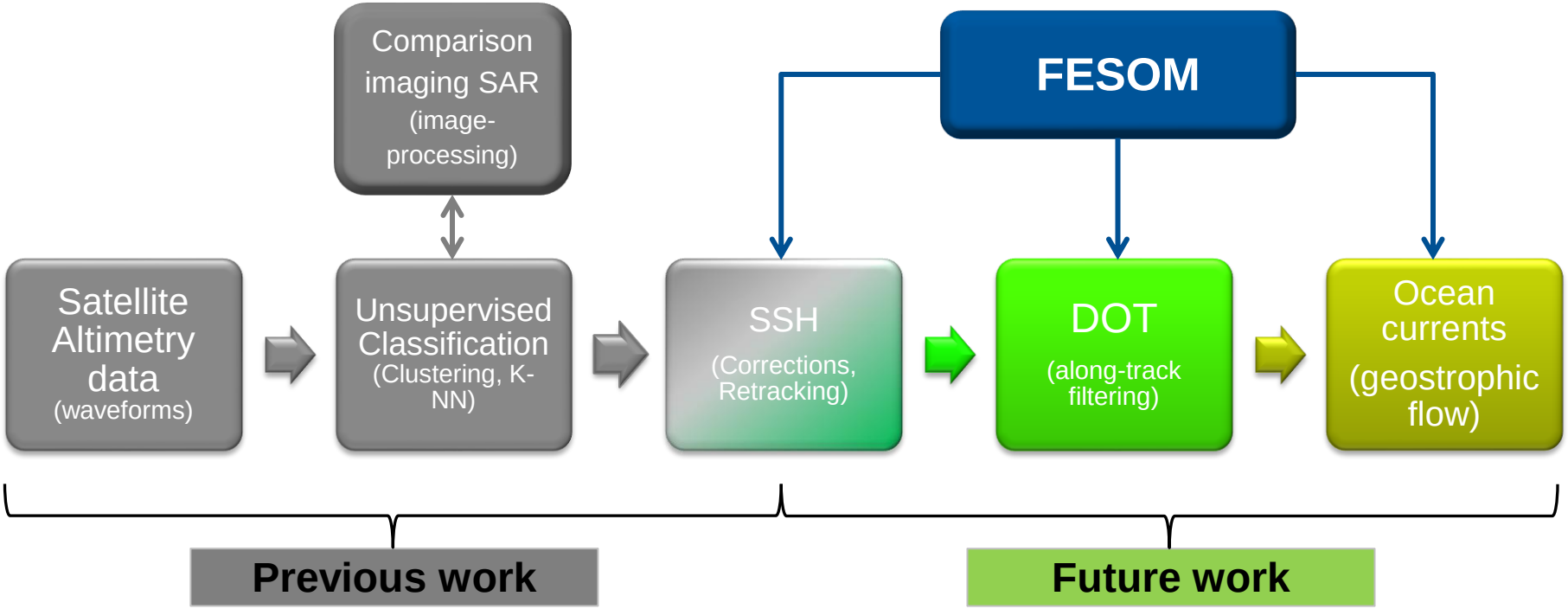
Sea surface heights w.r.t. geoid

- Retracked with ALES+

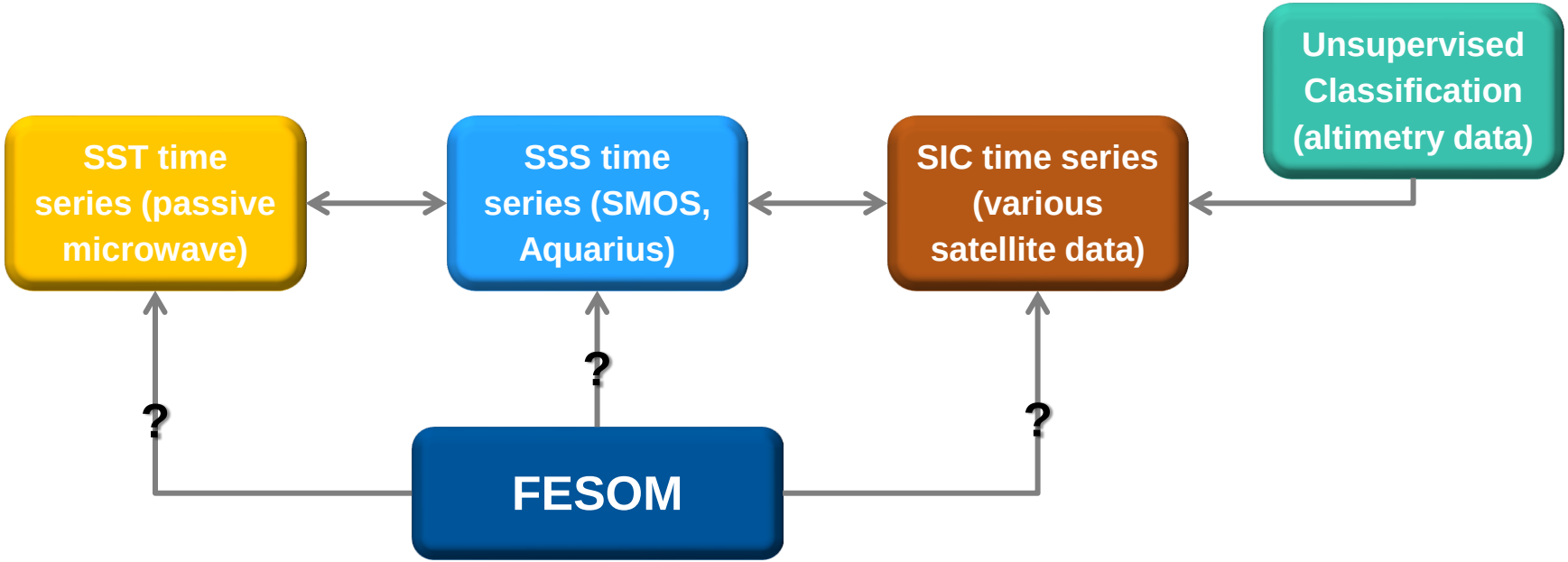


December 2006

Workflow NEG-Ocean (SSH, DOT, OSC)



Workflow NEG-Ocean (SST, SSS, SIC)



Connecting FESOM

How can FESOM contribute to the projects objectives?

1. Providing time series of water levels and horizontal surface velocities
2. Filling the spatio-temporal gaps, where altimetry data is not available
3. Validating and comparing altimetry processing results with FESOM output variables (for example current velocities)

What are the general open questions?

1. How can FESOM be connected with altimetry derived water heights and ocean currents?
2. What further outputs of FESOM can be used to support the studies (temperature, salinity, sea ice concentration)?

Summary

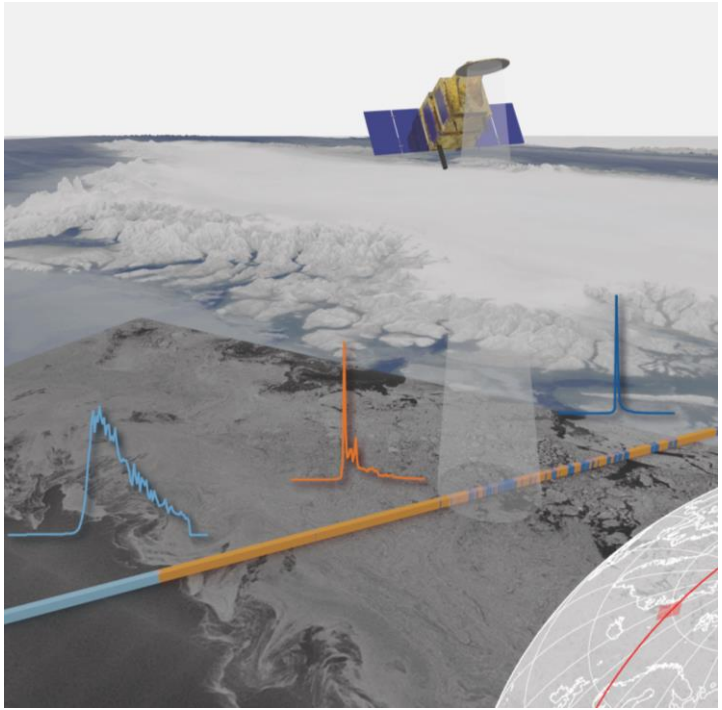
- Assignment strategy of ENVISAT (and SARAL) radar echoes based only on original waveform data has been performed in order to separate different waveforms and surface types
- An automatically running and unsupervised classification approach has been developed
- Quantitative comparison with image processed SAR data shows satisfying results (70% consistency)
- Implementation of single-peaked waveform retracker (ALES+)
- Classified sea surface heights w.r.t. to geoid of ENVISAT and SARAL tracks provide promising results (work in progress)
- Using all conventional altimeter missions + SAR missions (work in progress)

➢ Classification enables the estimation of sea surface heights (SSH), a dynamic ocean topography and geostrophic ocean currents within the ice area

References + more Information

- **Unsupervised Classification - waveforms:**
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, 2017-06-07

- **CryoSat-2 – SAR image processing:**
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)



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Thank you for listening!

Acknowledgements:

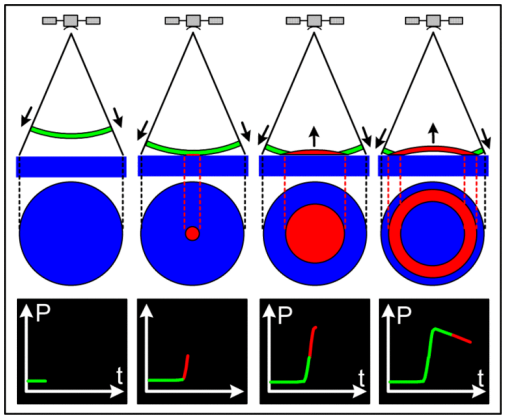
1. **Sentinel-1A data:** Sentinel-1 data provided by ESA, accessed: 28.04.2016
2. **ALOS data:** © JAXA/METI ALOS-1 PALSAR L1.5 2008. Accessed through ASF DAAC https://www.asf.alaska.edu 28.04.2016
3. **ENVISAT data:** ENVISAT SGDR 2.1 data provided by ESA

Comparison datasets:

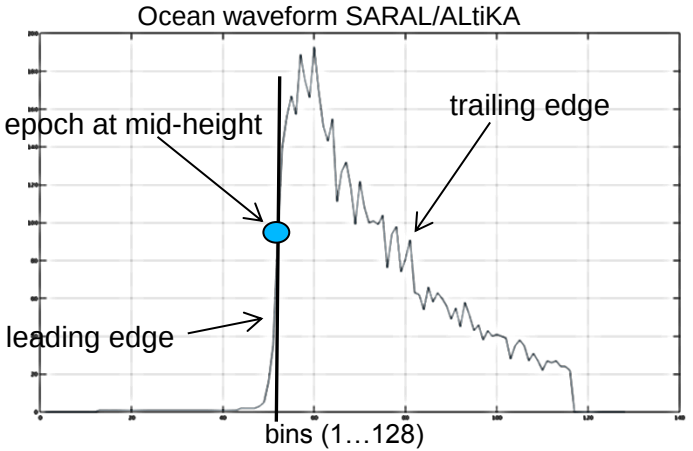
- **ENVISAT Sea Ice Flag:** ENVISAT SGDR 2.1, see: Tran N., F. Girard-Ardhuin, R. Ezraty, H. Feng, and P. Femenias, “Defining a sea ice flag for Envisat altimetry mission”, *IEEE GRS letters*, doi:10.1109/LGRS.2008. 2005275, 6 (1), 77-81, 2009
- **NSIDC Sea Ice Concentration:** Cavalieri, D. J., C. L. 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.

Altimetry: Measurement Principle and waveforms

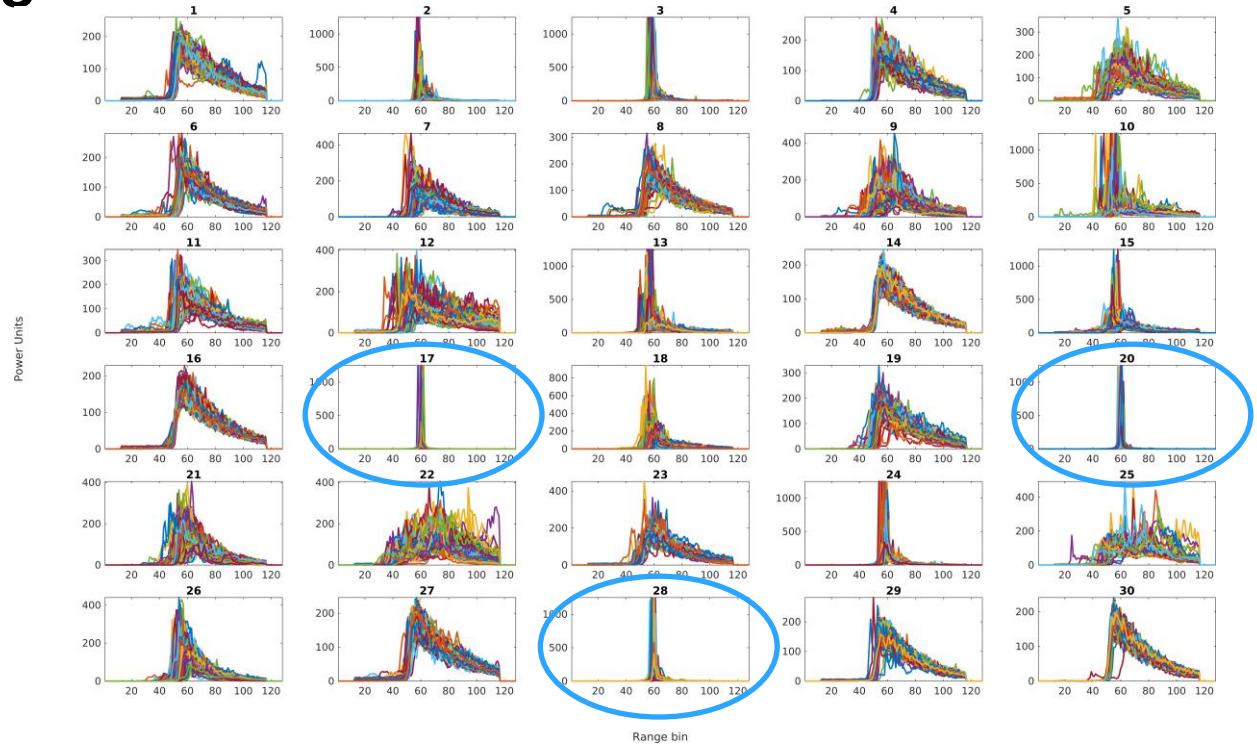
- Estimation of sea surface heights by retracking the returning pulse (waveform) from the satellite
- Postion (t) at the mid-height of the leading edge gives the time delay of the expected return of the radar pulse travelling from the satellite to the surface and back
- Use of high-frequency data (20 Hz – 40 Hz)



http://www.aviso.altimetry.fr/en/techniques/altimetry/principle/pulses-and-waveforms.html



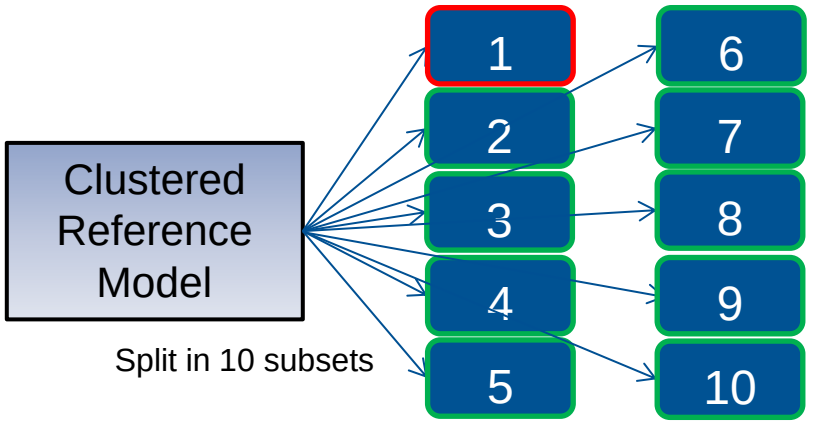
Clustering Results SARAL

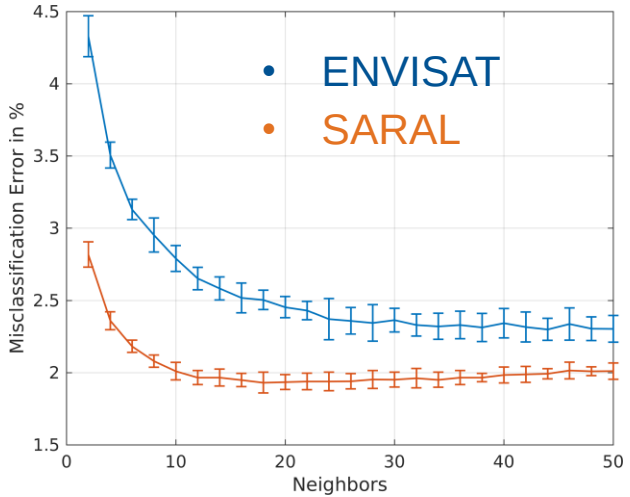


- Input: waveforms from SARAL Cycle 12 (April 2014) in Greenland Sea

Classification Cross-Validation (internal)

- 10 Fold Cross-Validation of clustered reference model (for K neighbors 2-50)

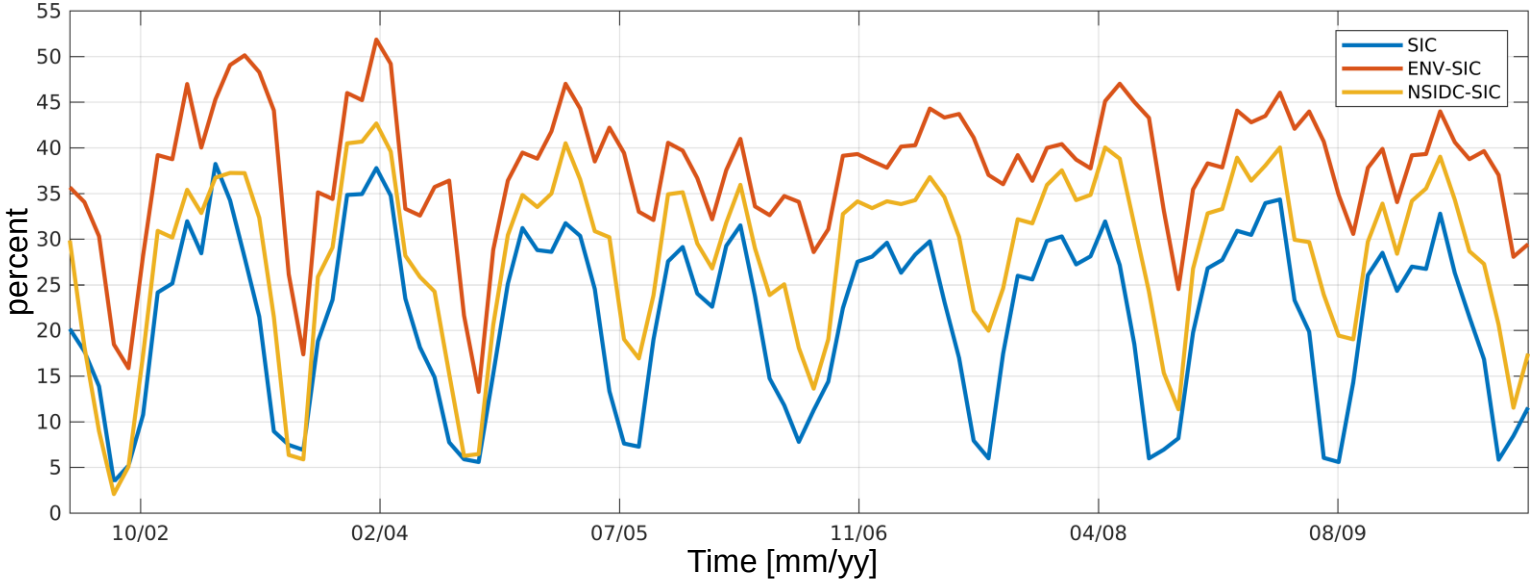




- Classification of subset 1 with 2-10 pre-labeled data, next step sub. 2 vs. sub 1,3-10,…
- Comparison before and after (mean error, std)

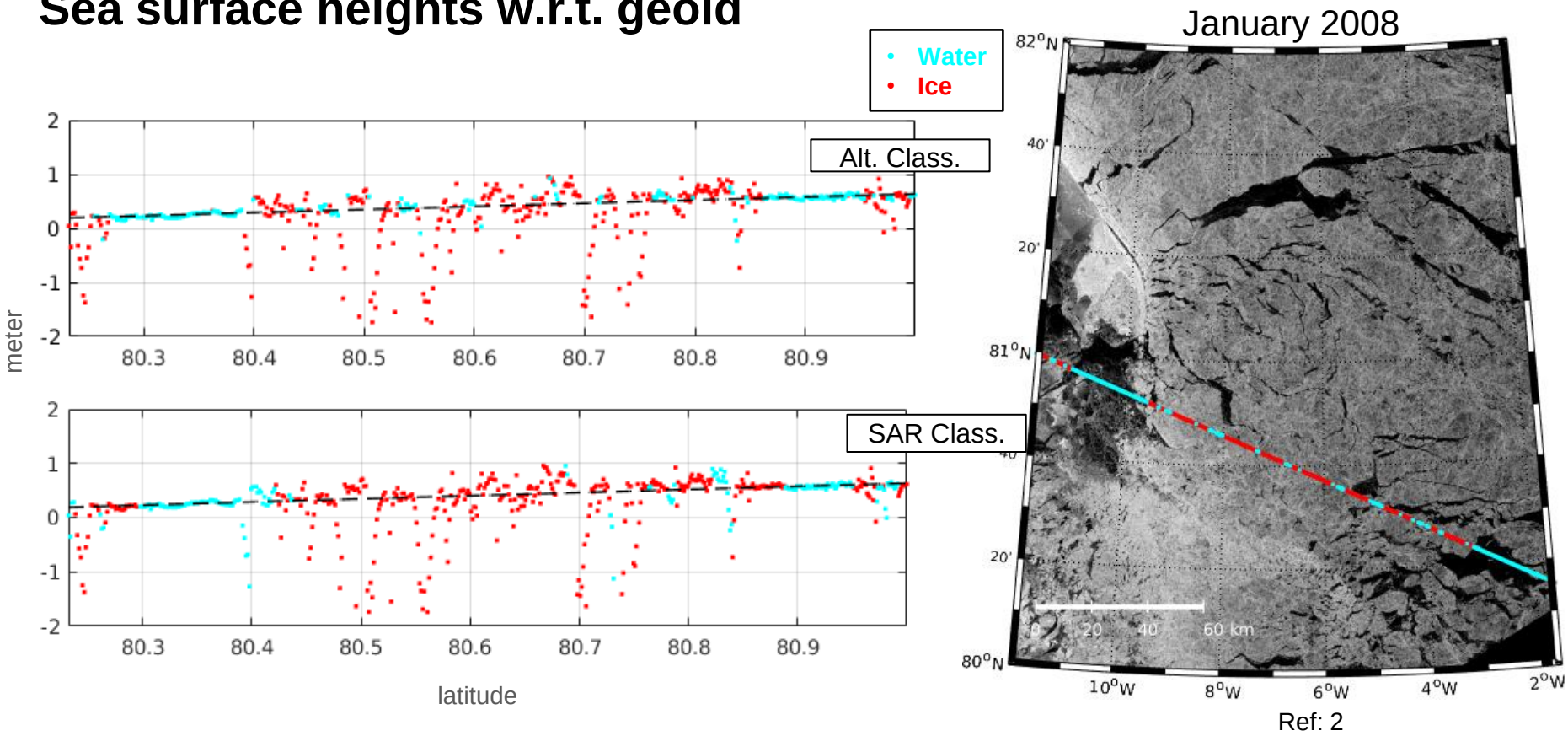
- Internal error of about 2 – 2.25%
- Best results with Envisat K=44, SARAL K=20

Temporal evolution of sea ice concentration (SIC)



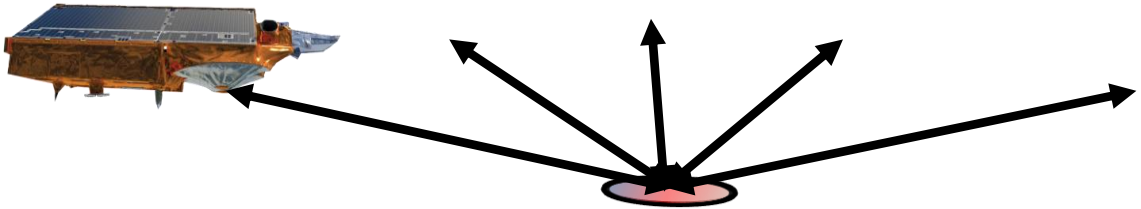
- SIC: Based on unsupervised sea ice classification
- ENV-SIC: Based on ENVISAT sea ice flag (Radiometer-Altimeter Combination)
- NSIDC-SIC: Based on moving average on National Snow & Ice Data Center gridded sea ice concentration (passive microwave + in-situ observations)

Sea surface heights w.r.t. geoid



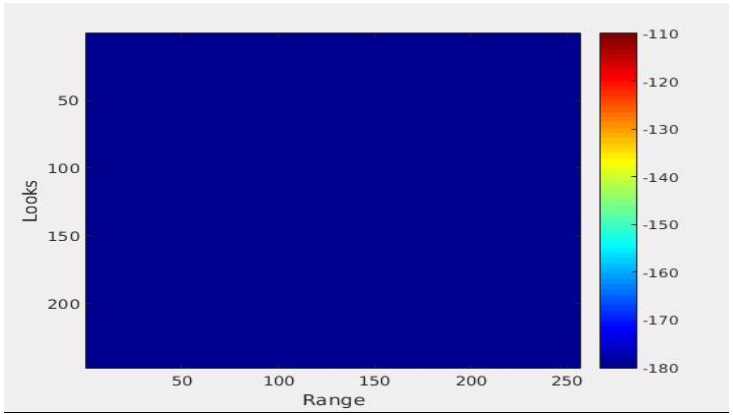
Ref: 2

Stack based classification – CryoSat-2



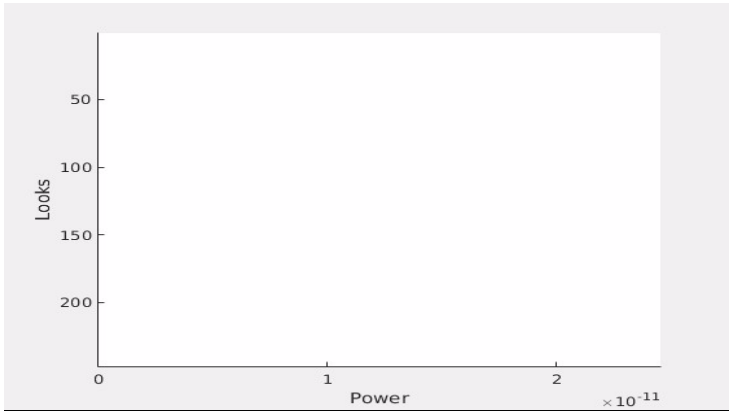
Surface sample

Surface Sample Stack (SSS)



Σ

Range Integrated Power (RIP)



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}