Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Coastal altimetry at high-latitudes: the Baltic SEAL project observing sea level among jagged coastline and sea ice

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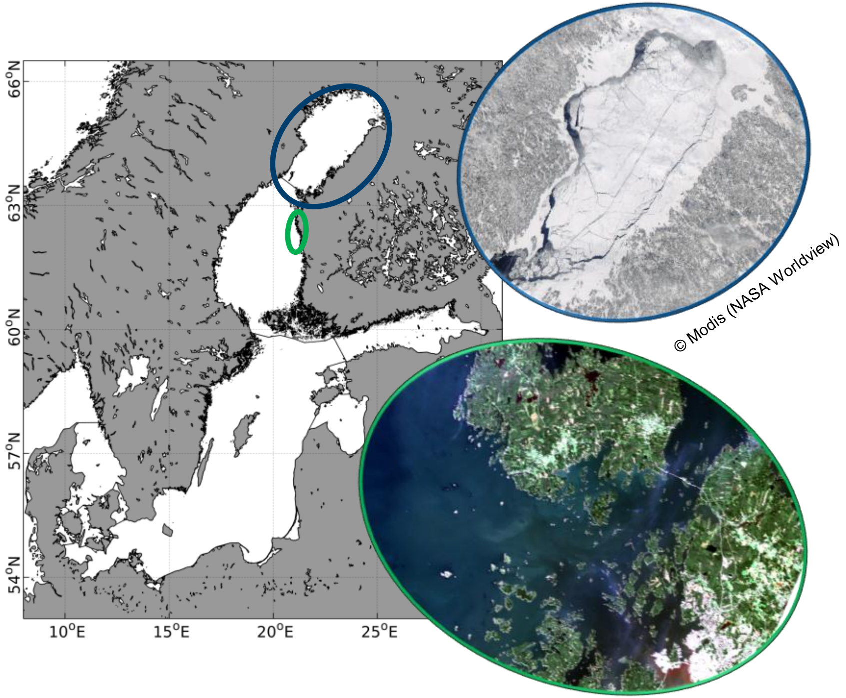
12th Coastal Altimetry Workshop
ESA-ESRIN, 4-7.02.2029

The Baltic Sea – Motivation

What?

- Generation of a novel multi-mission sea level (MMSL) along-track and gridded product



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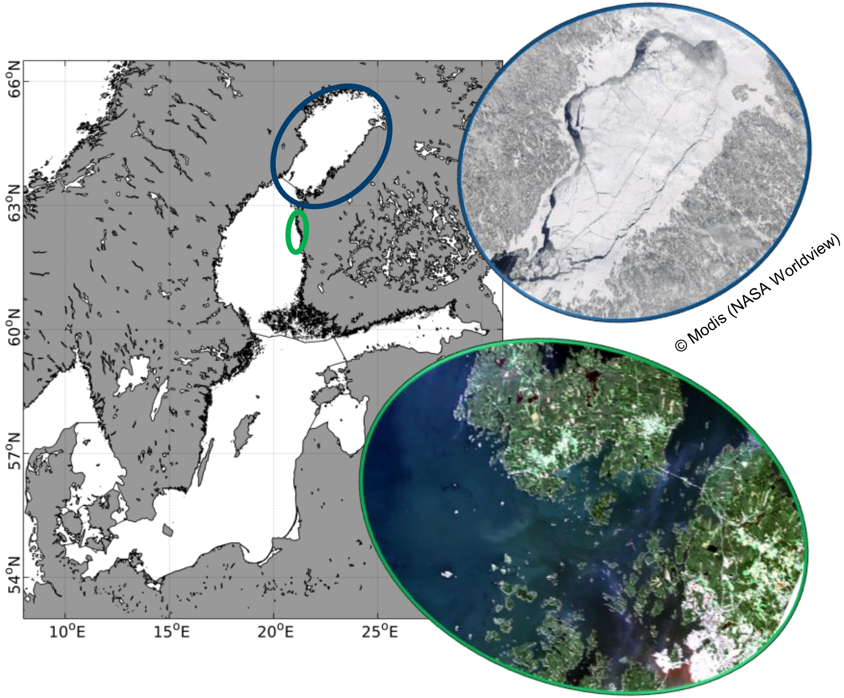
- Previous products show only sparse information in the northern Baltic Sea (no sea-ice treatment)



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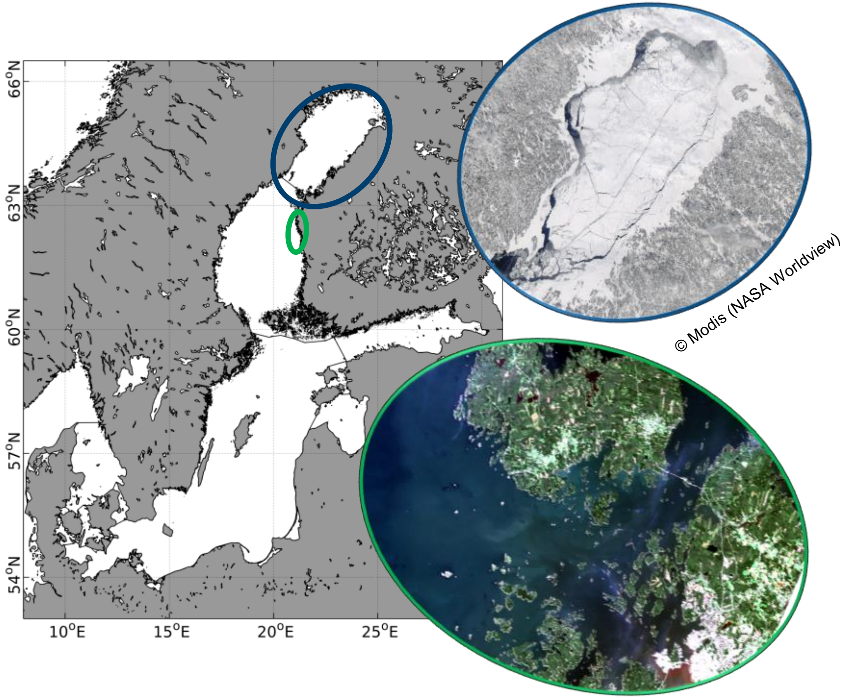

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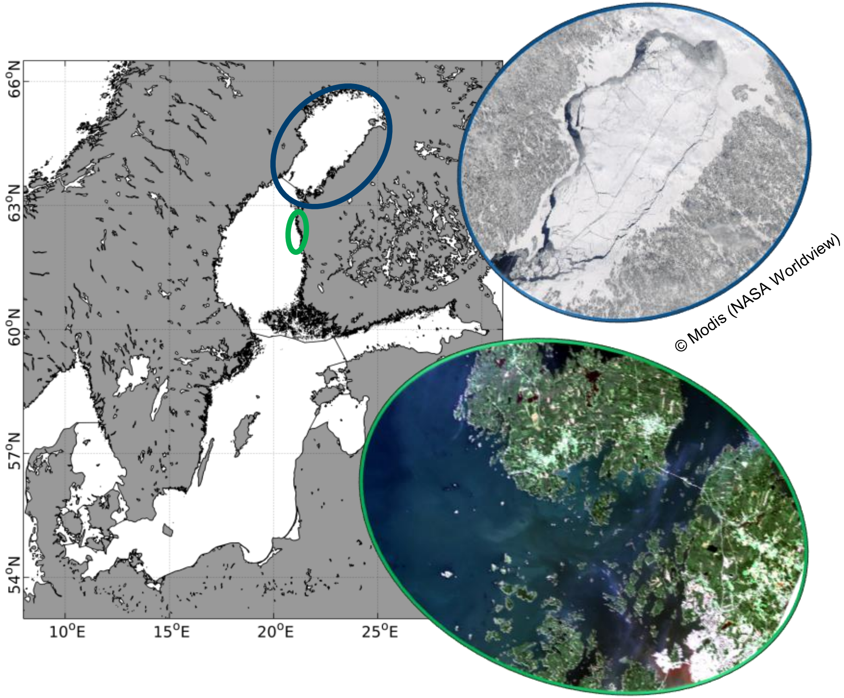
- Improvements in algorithms (classification, retracking), geophysical adjustments and corrections, radar techniques (Delay-Doppler Altimetry)
- Perfect laboratory for Satellite Altimetry (challenging coastlines, sea-ice coverage, small scale variability)



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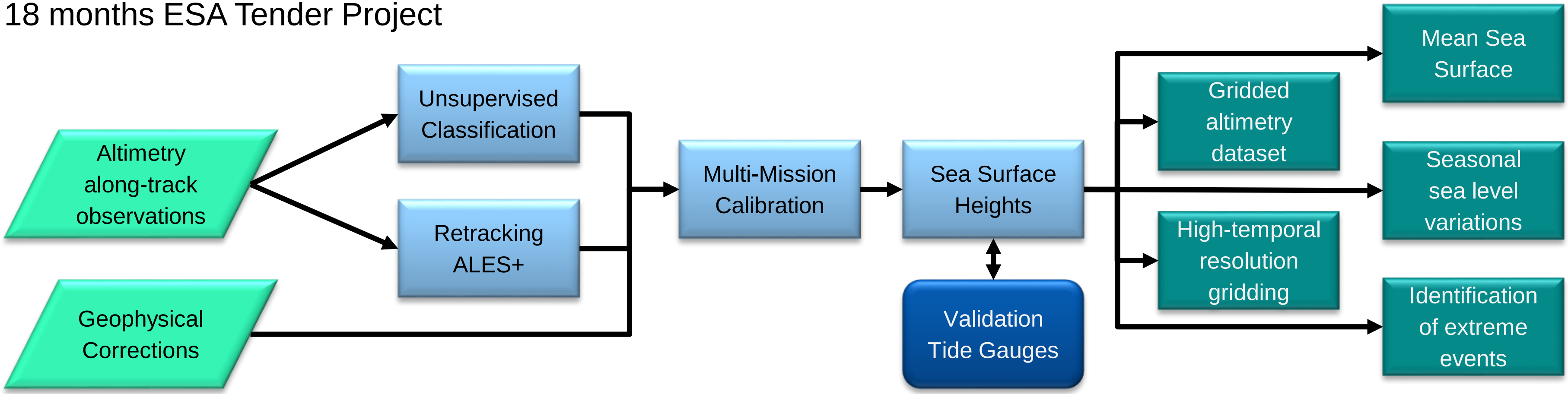
Workflow Baltic+ SEAL

18 months ESA Tender Project



6 Work Packages

1. Scientific Requirements (FMI)
2. Dataset collection (DMI)
3. Algorithm Development and Validation (TUM)
4. Dataset Generation and Impact Assessment (DTU)
5. Scientific Roadmap (UCC)
6. Management and Promotion (TUM)

Unsupervised Classification to detect leads

- Usage of Artificial Intelligence Algorithms (Data-Mining)

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

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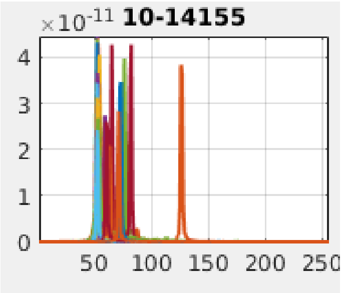
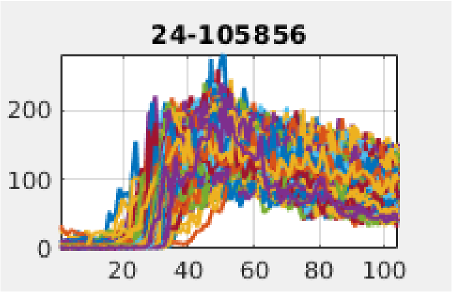
- Clustering of waveforms applying K-medoids
  - ➢ Waveform reference model
- Assigning waveform clusters to surface conditions
  - ➢ 4 classes: lead, ocean, sea-ice and undefined





Example: a Lead cluster (left) and an Ocean cluster in Cryosat-2

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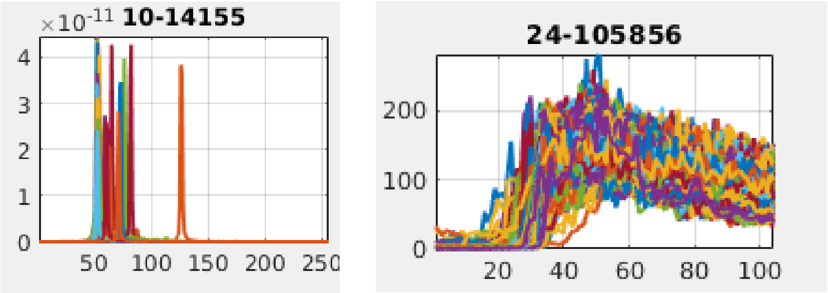

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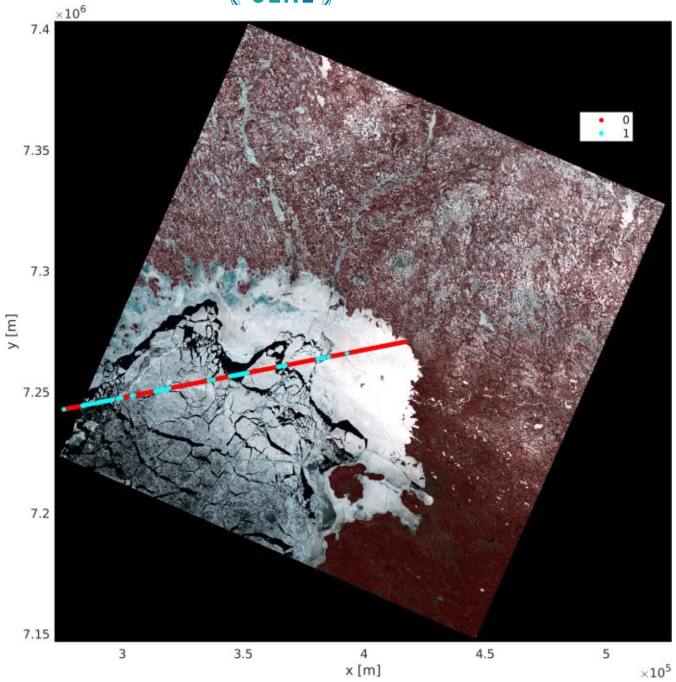
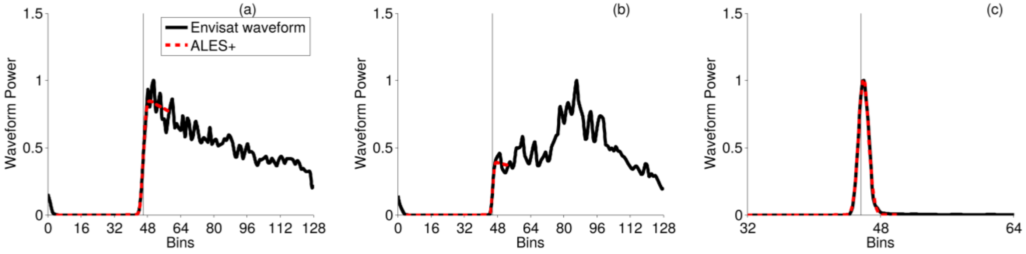


More info: *Müller F.L et al.*: **Monitoring the Arctic Seas: How Satellite Altimetry Can Be Used to Detect Open Water in Sea-Ice Regions**. Remote Sensing, 9(6), 551, 10.3390/rs9060551, 2017c

Retracking

- Sub-waveform retracker to avoid coastal contamination
- Adaptive trailing edge decay to retrack peaky waveforms from leads
- Homogenous range estimation of lead/polynya, open ocean and coastal waveforms (avoids internal biases)



Ocean - LRM **Coastal - LRM** **Lead**

More Information: *Passaro M. et al.* (2017): ALES+: Adapting a homogenous ocean retracker for satellite altimetry to sea ice leads, coastal and inland waters., *Remote Sensing of Environment*

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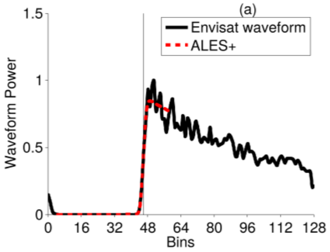
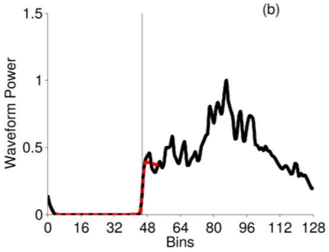
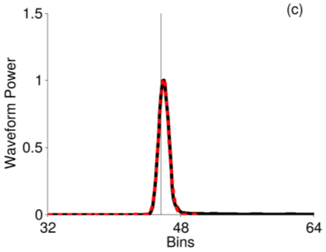


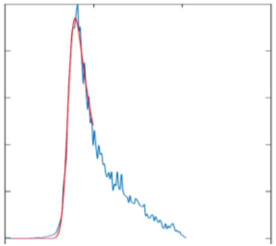
Ocean - LRM



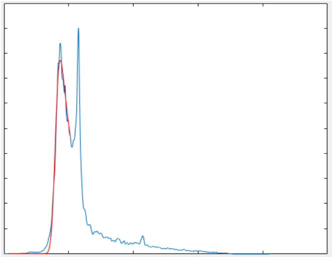
Coastal - LRM



Lead



Ocean - SAR



Coastal - SAR

More Information: *Passaro M. et al.* (2017): ALES+: Adapting a homogenous ocean retracker for satellite altimetry to sea ice leads, coastal and inland waters., *Remote Sensing of Environment*

Sea State Bias

- Correction applied using high-rate ALES+retracked sea state, to decrease intercorrelated errors

- Specific ALES+SAR Sea State Bias model derived

Dataset	XO var before SSB (cm^2)	XO var after SSB (cm^2)	Explained Variance
Gaspar et al. (1994)	127.7	120.4	6%
SGDR Jason Med Passaro et al. (2018)	135.6	108.4	20%
ALES+ SAR	106.0	84.9	20%

Variance at crossover locations before and after the application of the sea state bias correction

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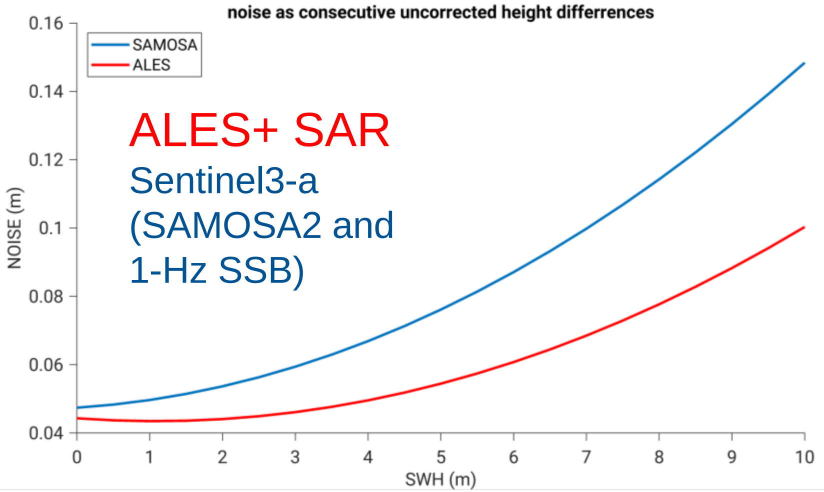

More info: *Passaro M. et al..*: **Improving the precision of sea level data from satellite altimetry with high-frequency and regional sea state bias corrections**. Remote Sensing of Environment, 245-254, 10.1016/j.rse.2018.09.007, 2018

Cross-Calibration

- Offset not always time-constant => drifts!
- Differences in sea level heights can have large-scale geographical pattern
- A location-dependent cross-calibration between all missions is needed
- Output: time series of radial errors => applied as corrections to each measurement

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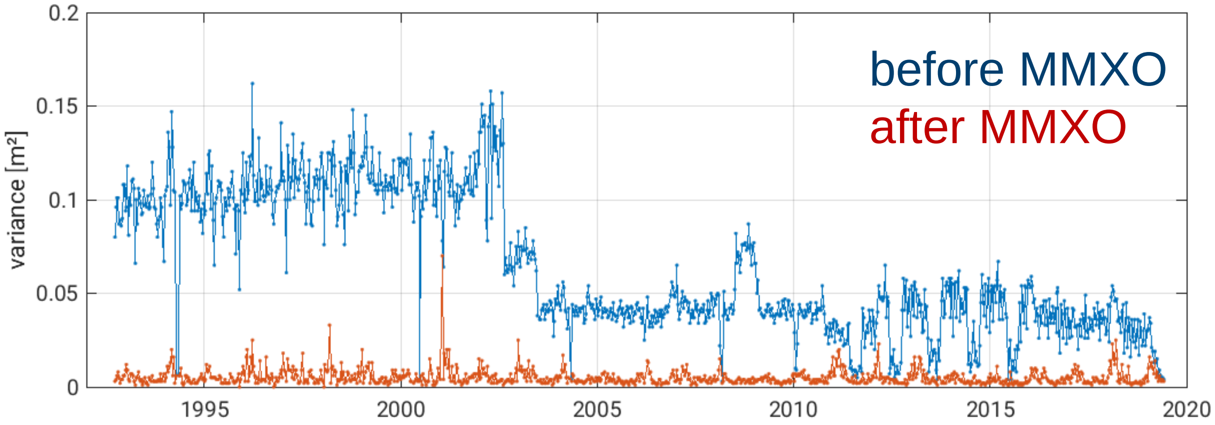
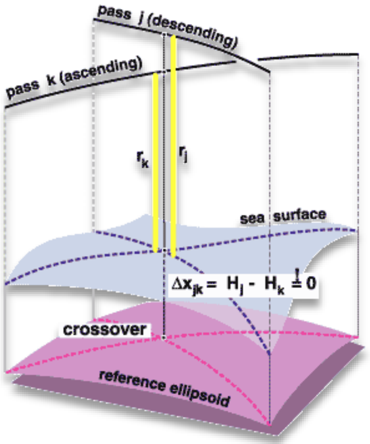


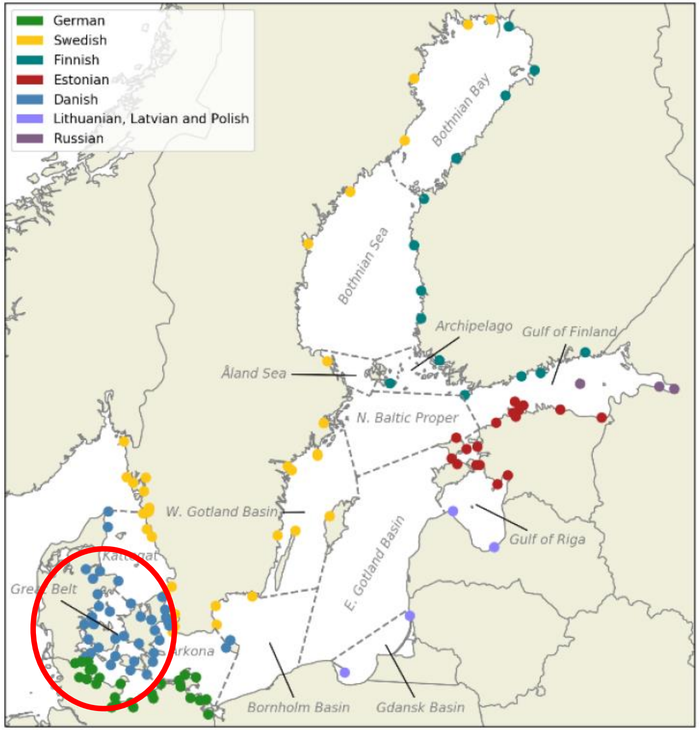


More Information: *Bosch W. et al.*: **Multi-mission cross-calibration of satellite altimeters: constructing a long-term data record for global and regional sea level change studies**. Remote Sensing 6(3): 2255-2281, [10.3390/rs6032255](https://doi.org/10.3390/rs6032255), 2014

BALTIC SEAL | esa | TUM | DMI | DTU | FMI | UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

First validation

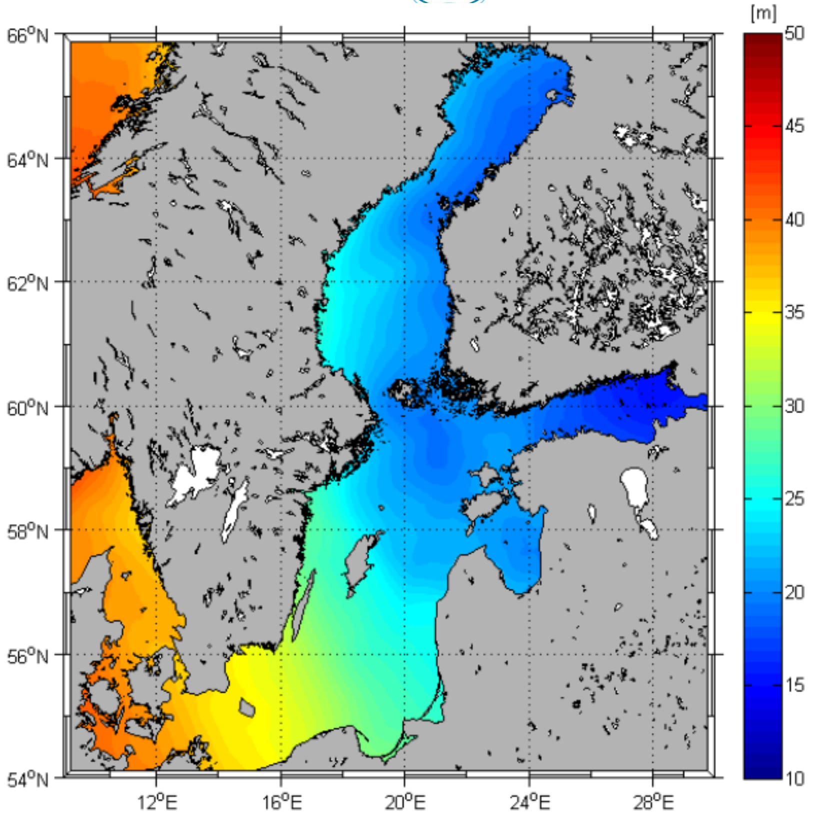
	ALES+	SAMOSA2
Valid Points	727	<690
Median Correlation (only of valid points)	0.93	0.88



- 31 cycles of Sentinel-3a
- Points within 5 km from the coast averaged and compare to Tide Gauges
- Outlier check based on Tide Gauges

Mean Sea Surface

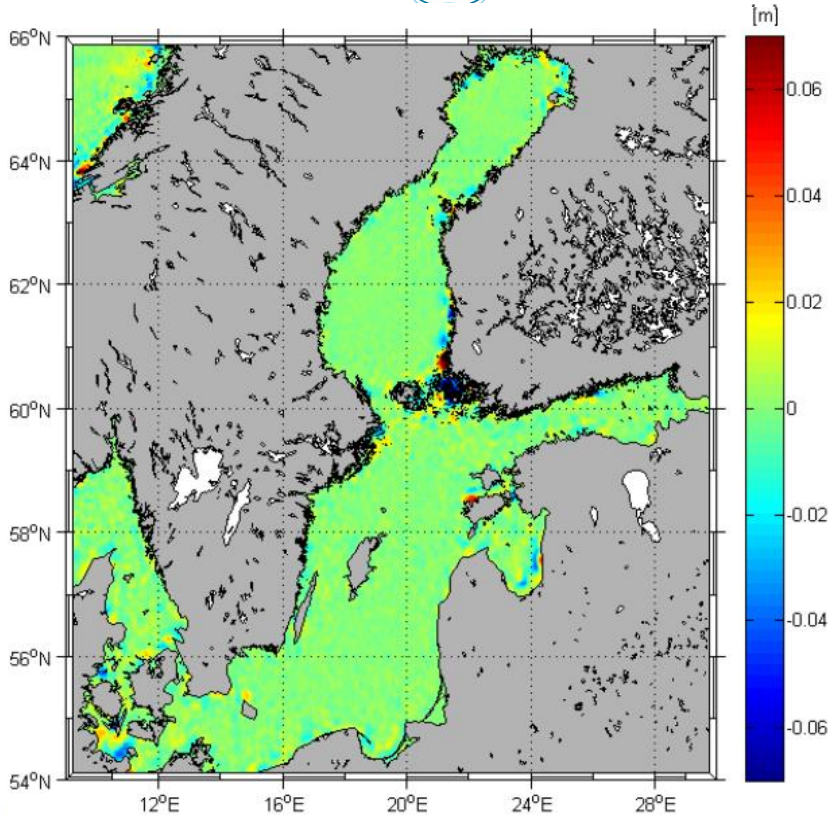
- A new Mean Sea Surface is being produced within the project
- In the current version, leads among sea ice and SAR altimetry not yet included
- …and yet, if we consider the differences with DTU15…



Mean Sea Surface

…the secret lies in the details!

Shown are differences between new MSS and DTU15 model



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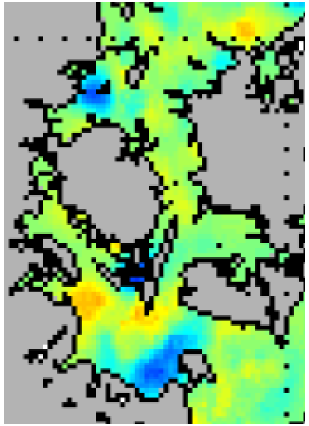
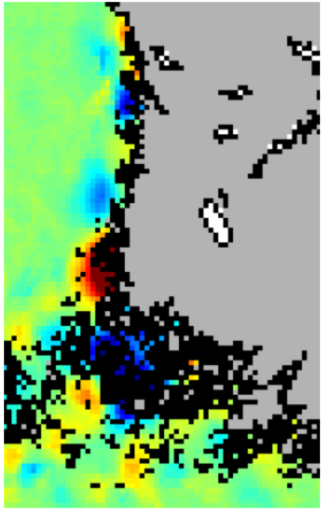
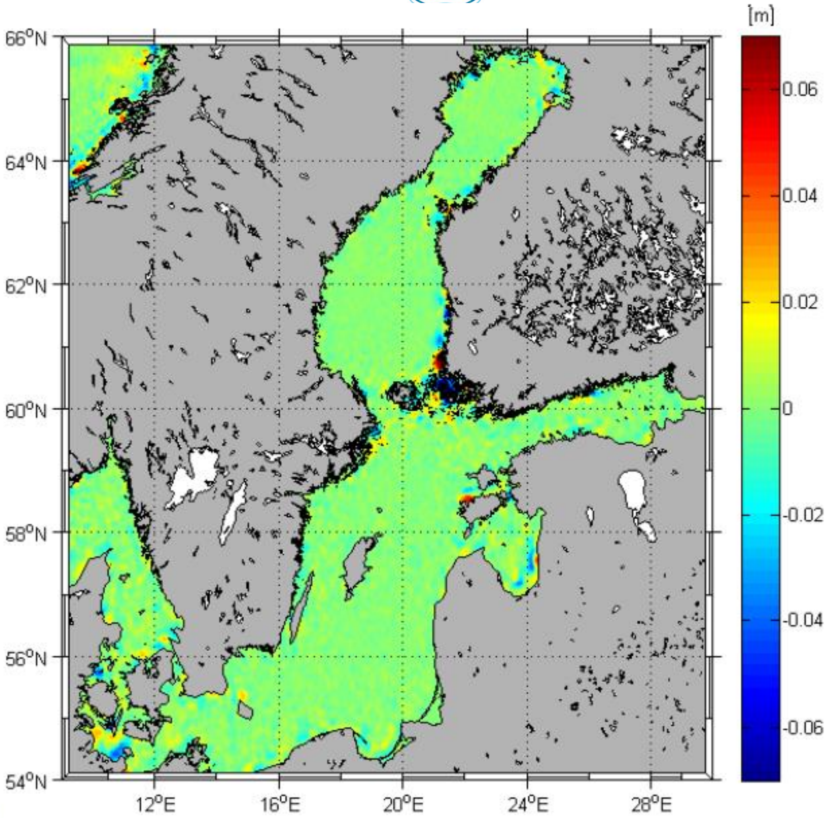


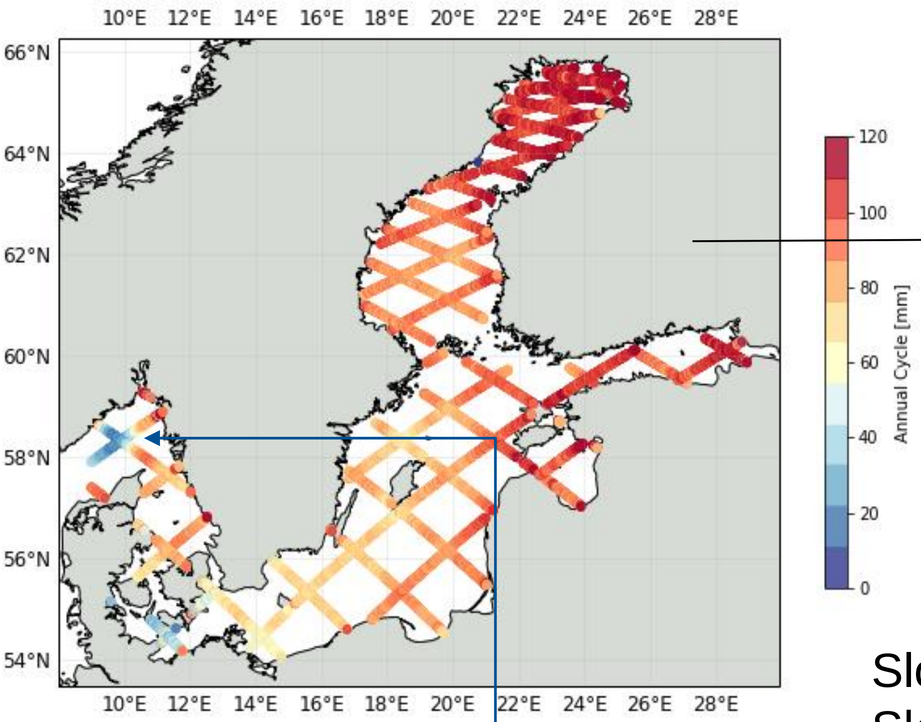
Danish Straits



Finnish Coast



Sea Level Analysis: First Results -> Amplitude of annual cycle

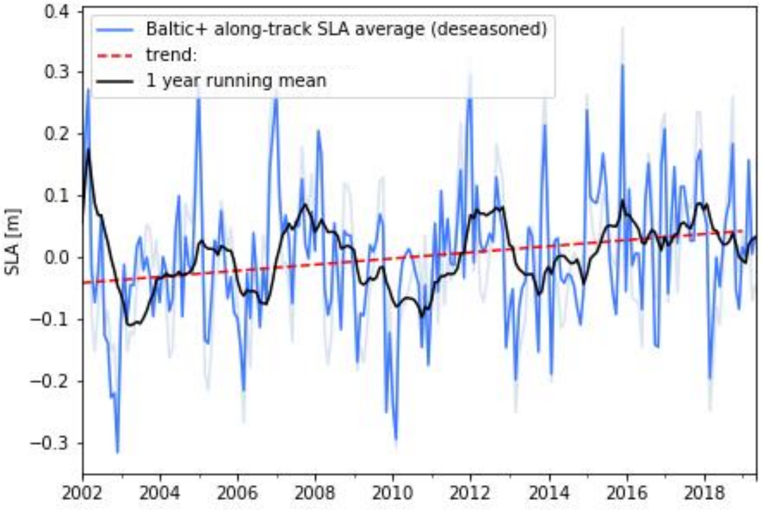


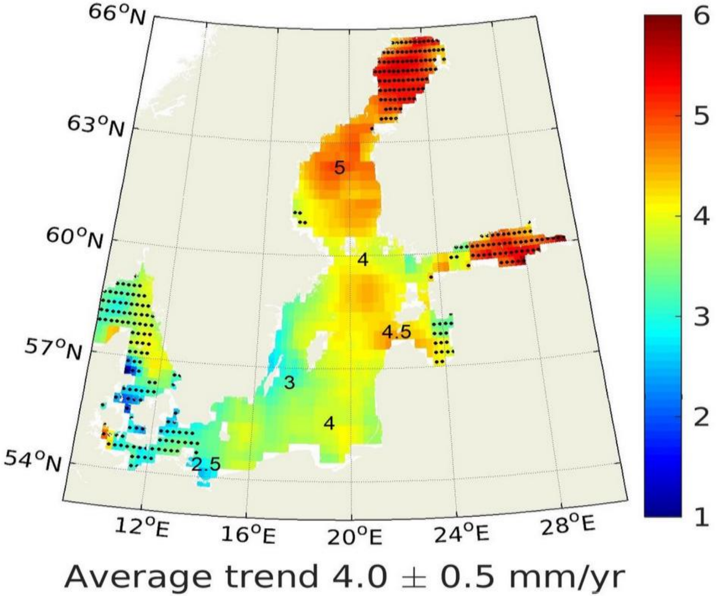
Mean annual cycle amplitude: 9cm

consistent with Stramska, M., and Chudziak, N. (2013)

Sloping annual cycle amplitude in the Skagerrak Sea [Passaro 2015]

Sea Level Analysis: First Results





Average trend 4.433 +- 2.21 mm/year

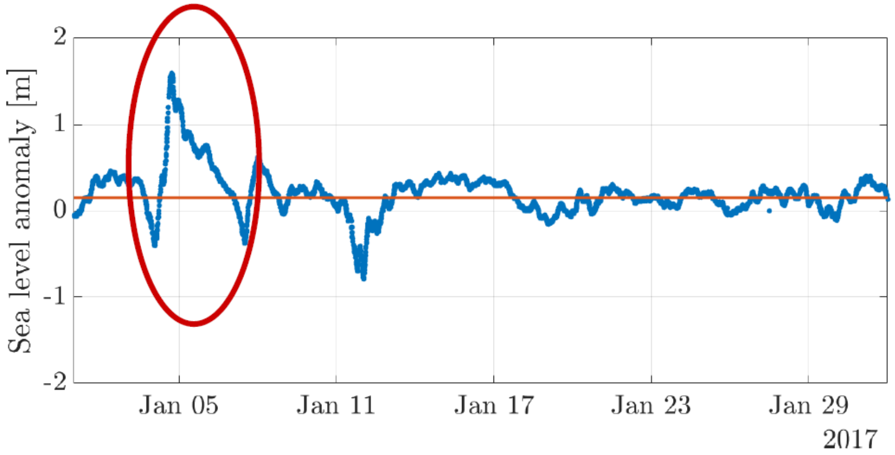
Madsen et al. 2019

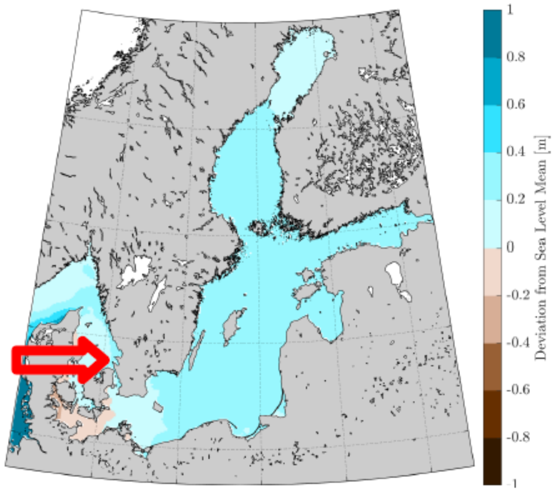
Higher uncertainty: just Jason mission for now and shorter time series

Additional products: experimental high-temporal resolution gridding

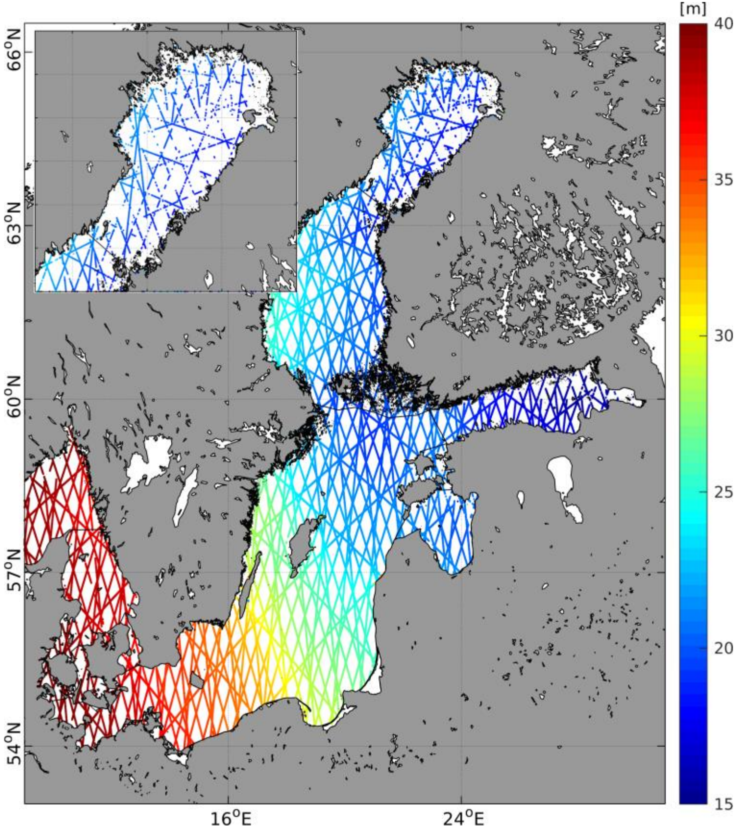
- The recent availability of several altimeters opens new possibilities for optimal interpolation every few days

- The objective is to provide a storm surge model with the best possible initial state (SSH BEFORE the surge)

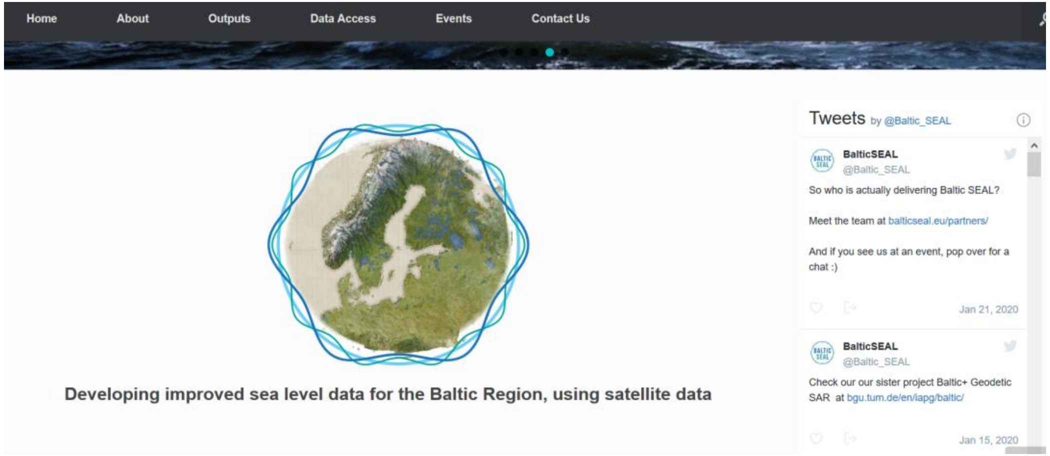




Conclusions



- Baltic SEAL is a laboratory for advanced satellite altimetry
- Regionally-dedicated analysis, featuring the latest advances at different level of products (from classification to gridding)
- By the end of 2020, a multi-mission cross-calibrated along-track product, a monthly gridded product, a new mean sea surface will be available to all users
- The techniques exploited in this framework can be easily transferred to other regions



Thank you!

Stay tuned and visit:

balticseal.eu

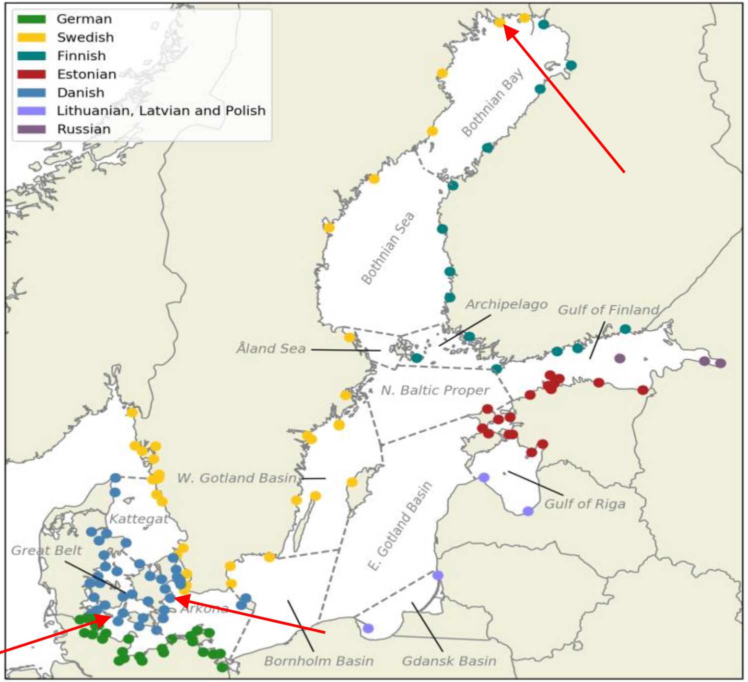
SPARE SLIDES

Validation

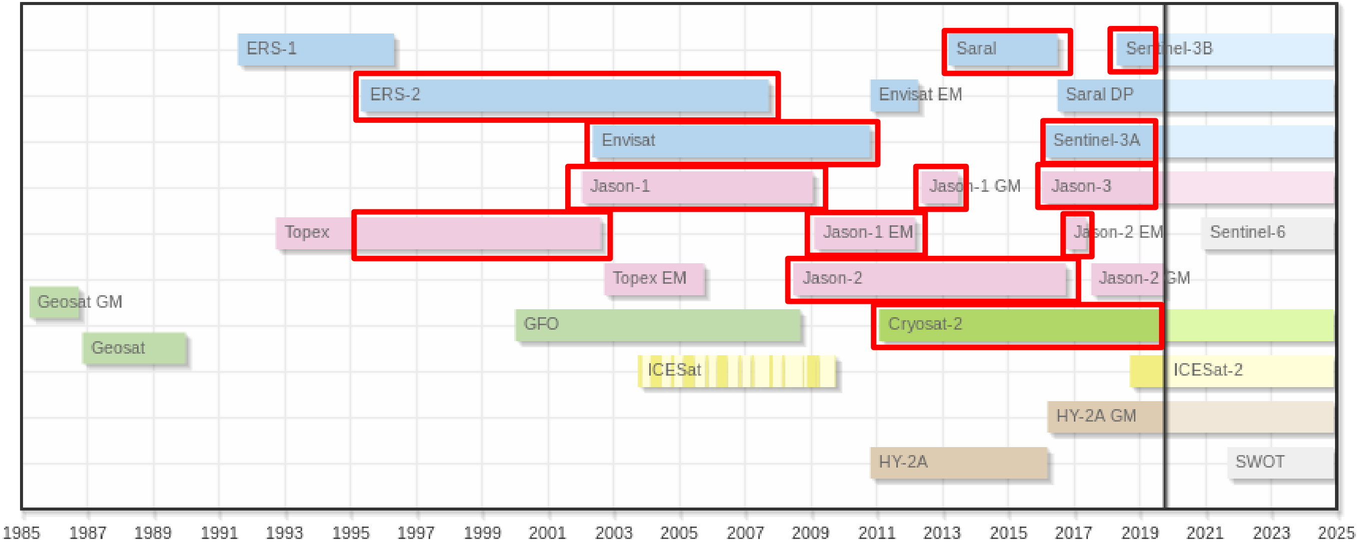
- Data averaged in the last 10 km

- ALES+ increases the valid cycles in the sea-ice covered areas

TG	RMSE (m)	r	n	SAMOSA2	ALES+
Bagenkop	0.05	0.95	27	x	
Bagenkop	0.05	0.95	28		x
Kalix-Storön	0.18	0.71	23		x
Rodvig	0.07	0.94	29	x	
Rodvig	0.07	0.95	29		x



Dataset collection (Altimetry)

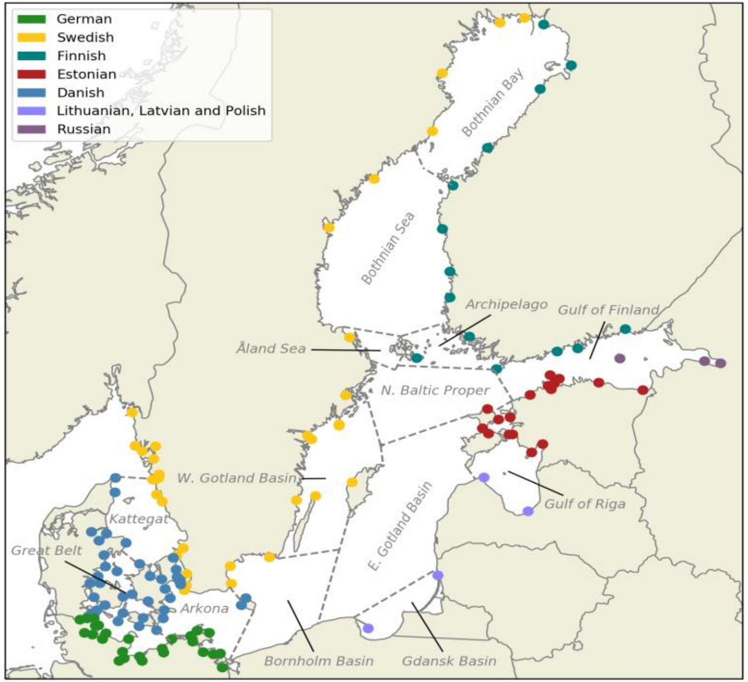


© Open Altimeter Database (OpenADB) DGFI-TUM

- ~ 25 years Multi-mission altimetry data (LRM & SAR)
- Usage of ALES+ retracked high-frequency along-track observations
- Multi-mission cross calibrated Sea Surface Heights
  - Regional cross calibration based on high-frequency along-track observations

Dataset collection (Sea Surface Height Validation)

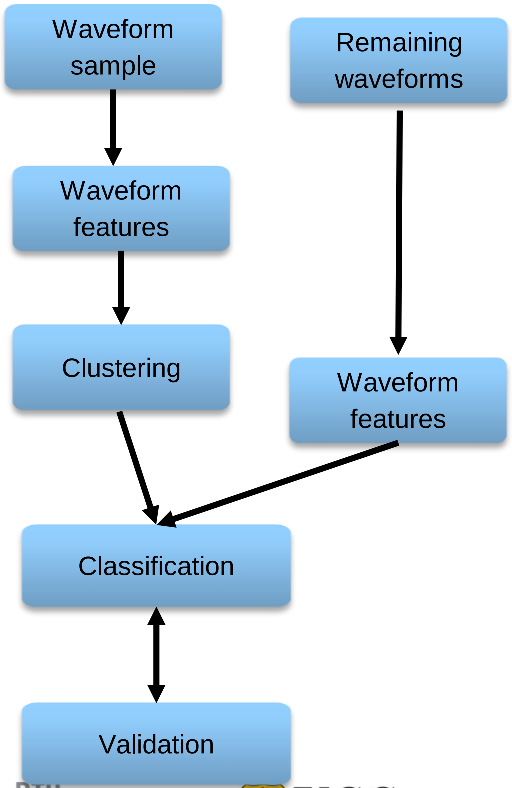
- Spatially comprehensive distribution of tide gauge stations
- All shown tide gauge stations available via CMEMS
- More tide gauge data can be requested from Finnish Meteorological Institute and Swedish Meteorological and Hydrological Institute
- Height conversion from national reference heights to EVRF2007



Tide gauge station locations

Algorithm Development and Validation (Unsupervised Classification)

- Usage of Artificial Intelligence Algorithms (Data-Mining)
- Application of unsupervised (no training data) classification for detecting leads (water openings within the ice) → see Müller et al. 2017
- **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 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)
- Same method for LRM and SAR missions, but slightly different feature space



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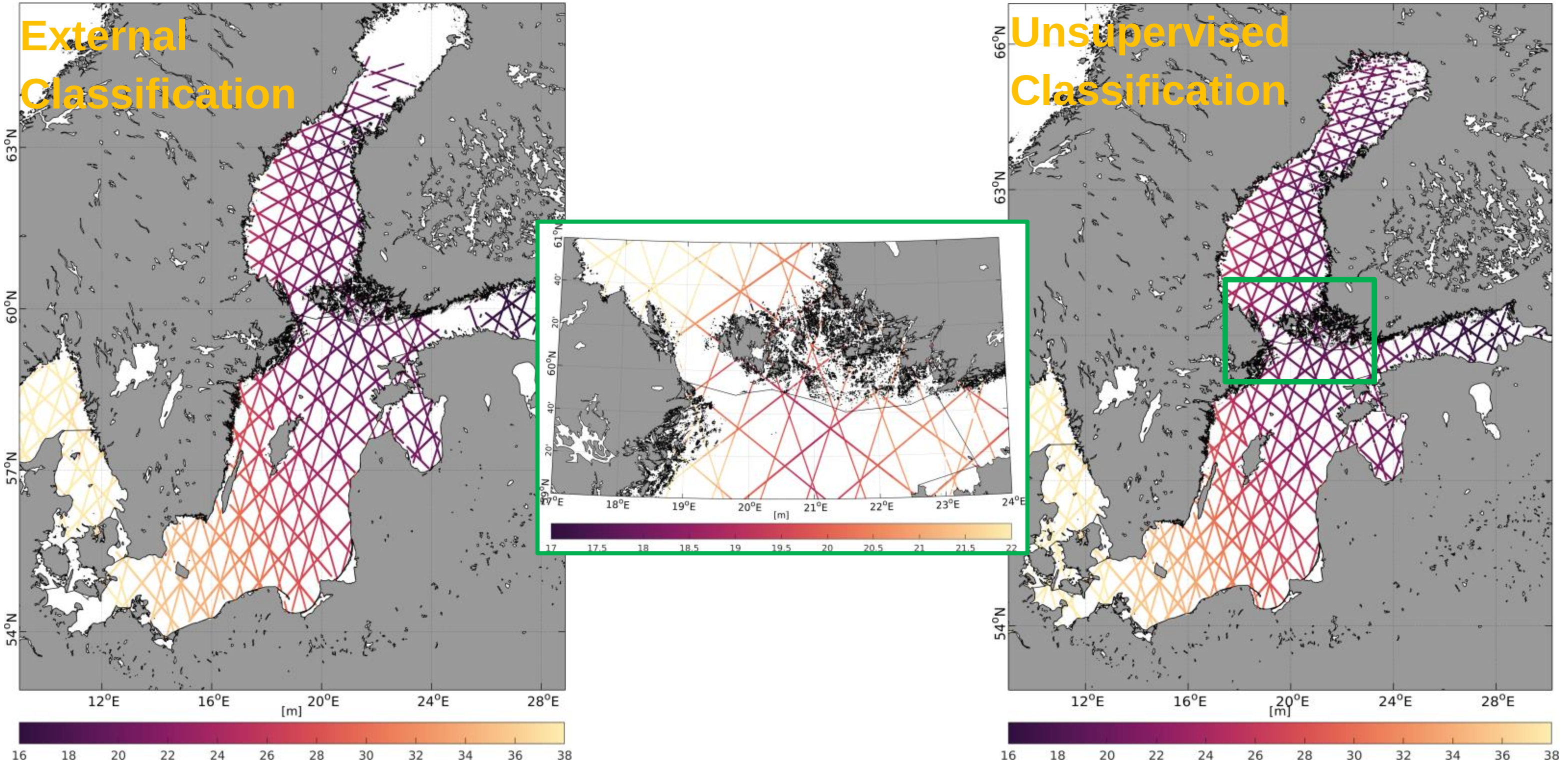


Sea Surface Heights ALES+ 2009-04 (J1-EM,J2,ENV)

Dataset Generation and Impact Assessment (Gridded/Meshed altimetry dataset)

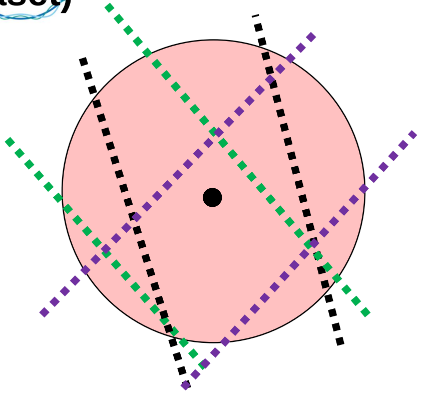
- Generation of a meshed altimetry dataset (TUM)

- Gridding profiled SSH data on an unstructured, triangulated grid
- Monthly temporal resolution 7,5 km spatial resolution
- Using least-square approach with spatio-temporally Gaussian weighting
  - Fitting a plane to the individual grid nodes
  - Defining proper weights and circular cap size

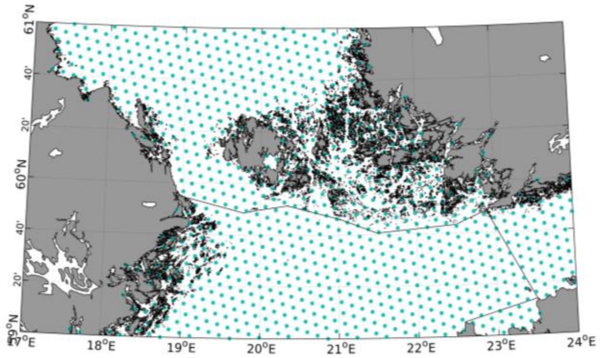
$$h(x,y) = c_0 + c_1 x + c_2 y$$

- Production of high-temporal resolution gridding (DTU/DMI)

- Development of a high-temporal (1-3 days) gridded dataset
- Combination of altimetry, tide gauges observations and the output of a hydrodynamic ocean model
- Based on Optimal Interpolation and error covariance statistics

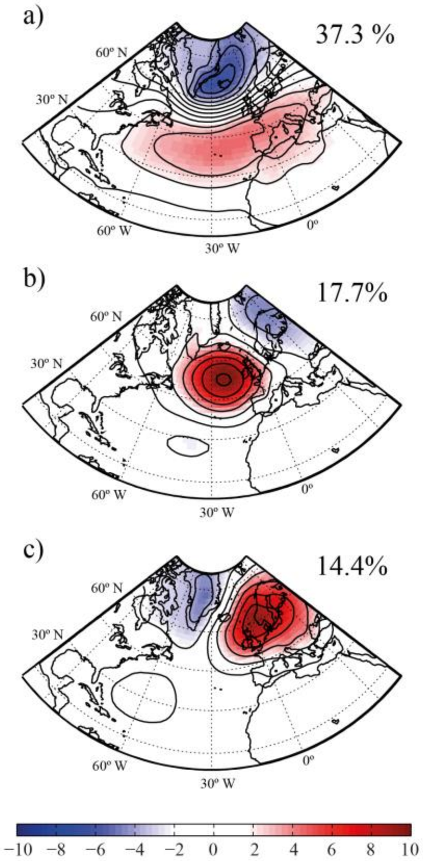


Grid-node with cap size and sea surface height distribution



Unstructured grid

Appendix



DJF – SLP leading modes
[mb]

NAO

EA

From Comas-Bru and McDermott, 2013