Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Baltic SEAL: Building a Sea Level Product for Climate Research in a Region Featuring Jagged Coastline and Sea-ice Coverage

Felix L. Müller[1], Marcello Passaro[1], Adili Abulaitijiang[2], Ole B. Andersen[2], Denise Dettmering[1], Jacob L. Høyer[3], Milla Johansson[4], Kristine Skovgaard Madsen[3], Laura Rautiainen[4], Ida M. Ringgaard[3], Eero Rinne[4], Jani Särkkä[4], Rory Scarrott[5], Christian Schwatke[1], Florian Seitz[1], Eimear Tuohy[5], Laura Tuomi[4], Americo Ambrozio[6*], Marco Restano[6**], Jérôme Benveniste[6]

[1] Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany
[2] SPACE National Space Institute, Technical University of Denmark, (DTU), Denmark
[3] Danish Meteorological Institute (DMI), Denmark
[4] Finnish Meteorological Institute (FMI), Finland
[5] MaRei Centre, Environmental Research Institute, University College Cork (UCC), Ireland
[6*] DEIMOS, c/o ESA-ESRIN, Italy
[6**] SERCO, c/o ESA-ESRIN, Italy
[6] ESA-ESRIN, Italy

Ocean Surface Topography Science Team Meeting (OSTST), 2019
Chicago, IL, USA, 23.10.2019

The Baltic Sea – Motivation

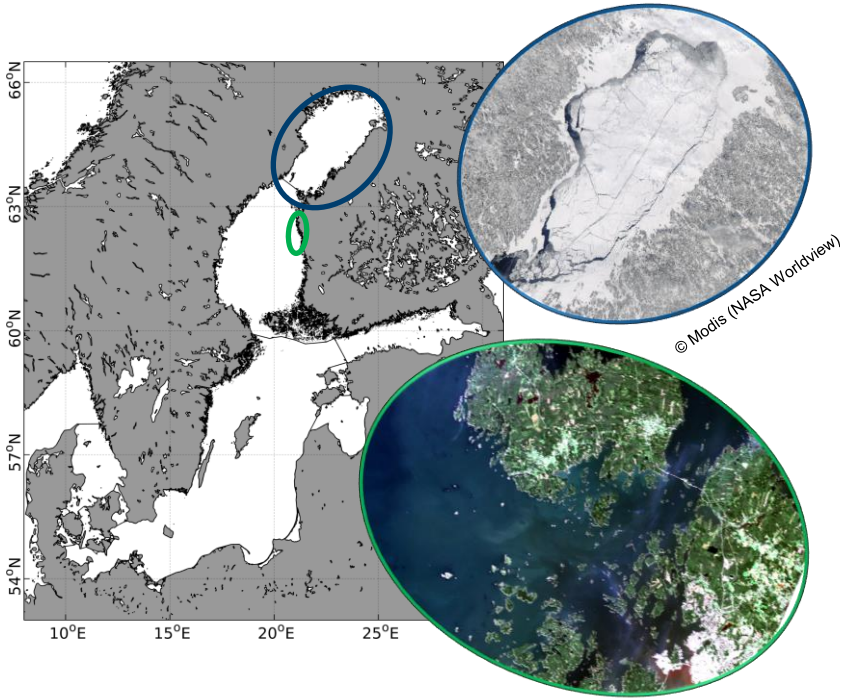
What?

- Generation of a novel long-term multi-mission sea level (MMSL)

Why?

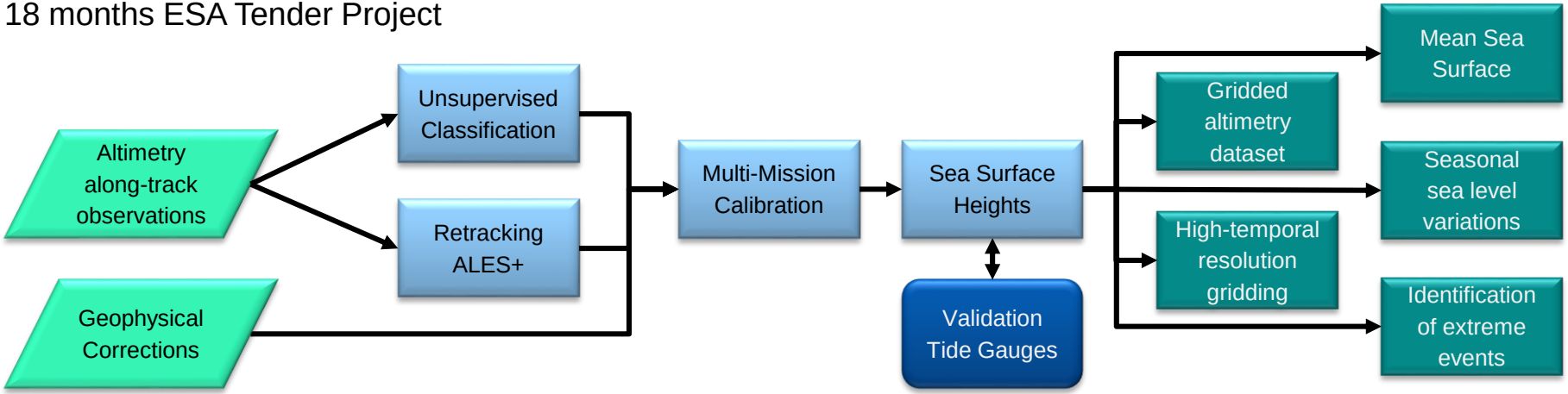
- No or sparse long-term sea-level information in the Baltic Sea
- Previous products show only sparse information in the northern Baltic Sea (no sea-ice treatment)
- New altimetry missions (e.g. Sentinel-3)
- Improvements in retracking solutions (closer to the coast), geophysical corrections etc.

- Perfect playground as laboratory for Coastal Altimetry (challenging coastlines and sea-ice coverage)
- Exploiting Artificial Intelligence Algorithms (Unsupervised Radar Waveform Classification, Clustering, K-Medoids)
- Good validation possibilities (large number of tide gauges, optical and SAR image comparisons etc.)



Workflow Baltic SEAL

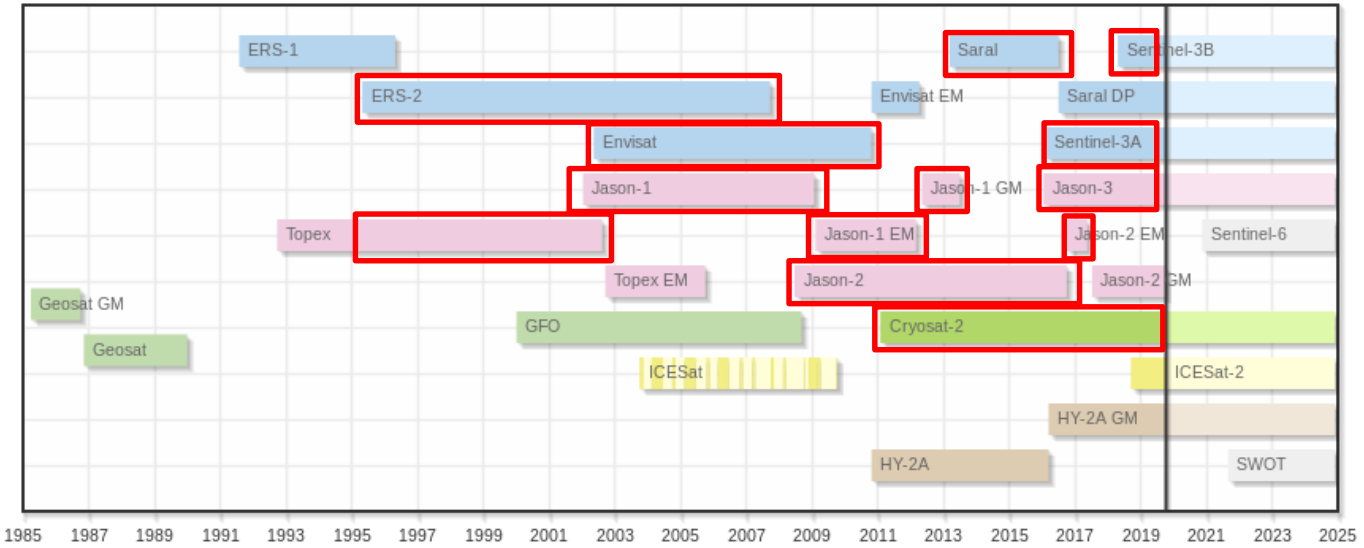
18 months ESA Tender Project



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)

Dataset collection (Altimetry)

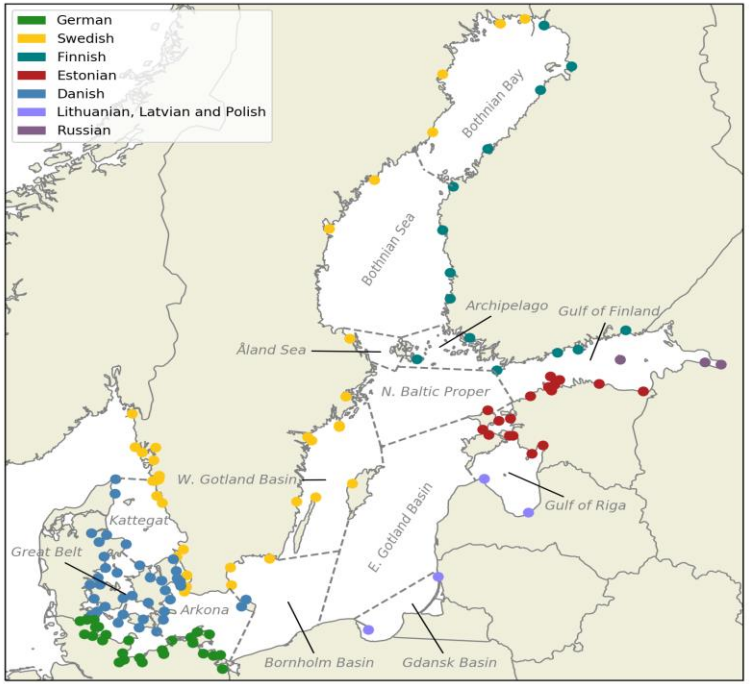


© Open Altimeter Database (OpenADB) DGFI-TUM

- ~ 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

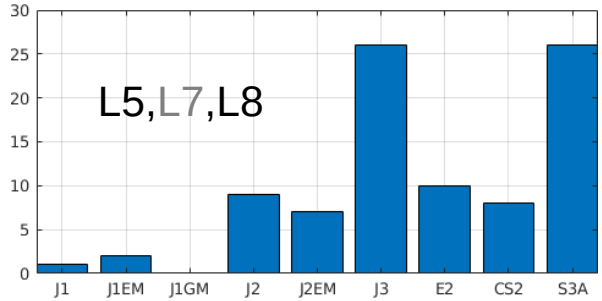
Dataset collection (Unsupervised Classification Validation)

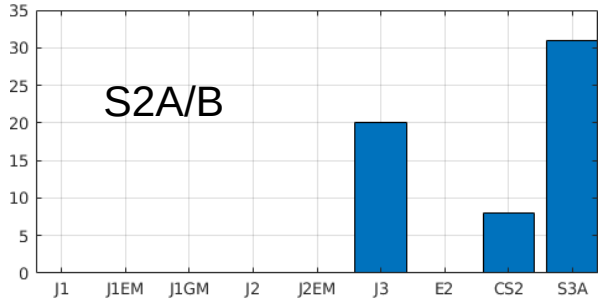
- Comparison open water classification vs. optical/SAR images
- Theoretical availability of comparison pairs 1995-05→2019-05:
  - Bay of Bothnia (most northern part of the Baltic Sea)
  - Only during sea-ice period [January – April]
  - Max $\Delta 1h$ time difference
  - Max 44% Cloud coverage (only optical)

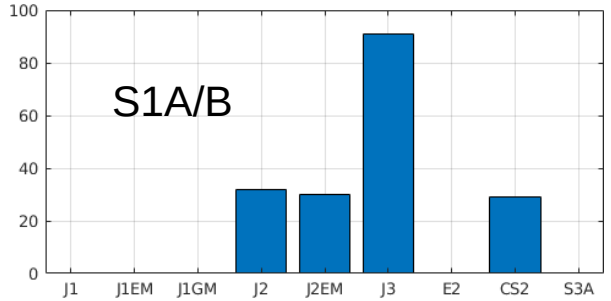
© Modis (NASA Worldview)

- **Landsat** · Pixel Resolution: 30m · Total Number Scenes: ~420
- **Sentinel-2A/B** Pixel Resolution: 30m · Total Number Scenes: ~450
- **Sentinel-1A/B** Pixel Resolution: 40m (Extra Wide Swath) · Total Number Scenes: ~970

Number of scenes w.r.t altimetry missions







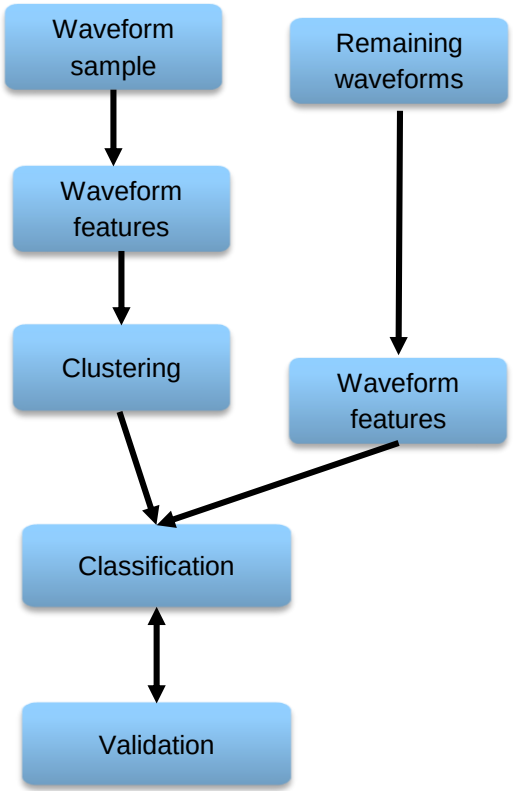
L7: Not all images are usable, due to instrument issues

Algorithm Development and Validation (Unsupervised Classification)

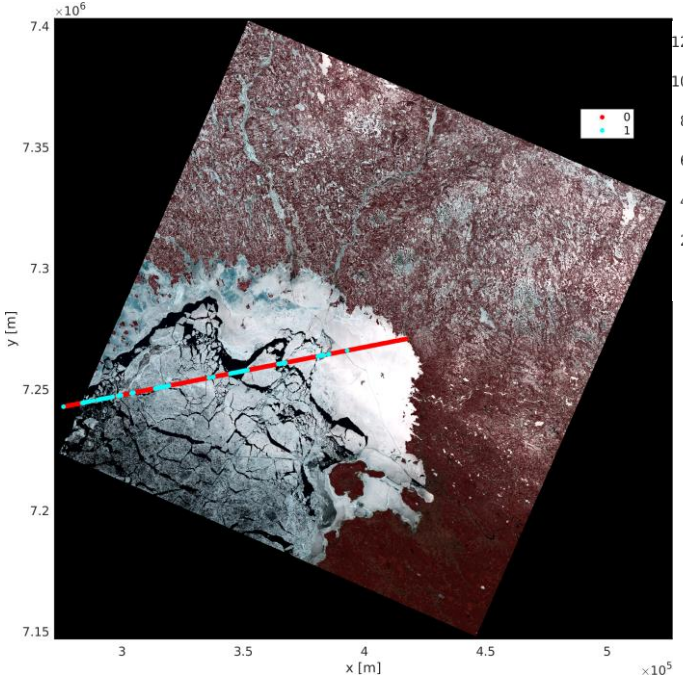
- Usage of Artificial Intelligence Algorithms (Data-Mining)
- Application of unsupervised (no training data) classification for detecting leads (water openings within the ice) → see Müller et al. **2017**
- **Input: Original waveform data**
- Definition and computation of waveform features
  - ➢ Maximum Power, waveform width, decay of trailing edge etc.
    (Parameters describe the waveform's shape and its features)

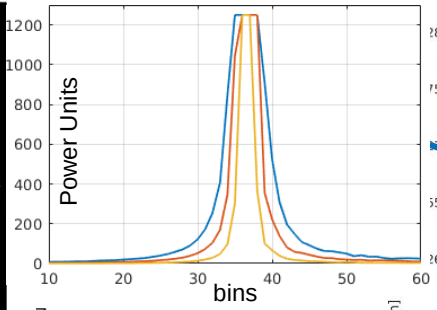
- Clustering of waveforms in clusters applying K-medoids
  - ➢ Waveform reference model
- Assigning waveform clusters to surface conditions
  - ➢ 4 classes: calm water, ocean, sea-ice and undefined
- Classification of remaining waveforms using reference model and K-nearest neighbor (K-NN)
- **Classification output:** WATER [1] | ICE [0] | UNDEFINED [0] (per measurement)

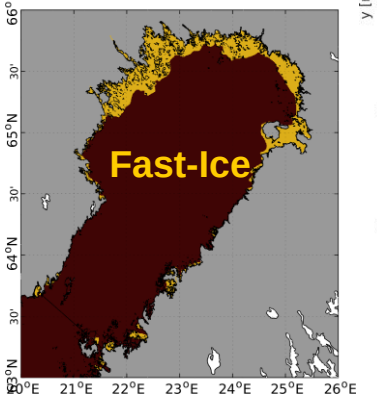
- Same method for LRM and SAR missions, but slightly different feature space

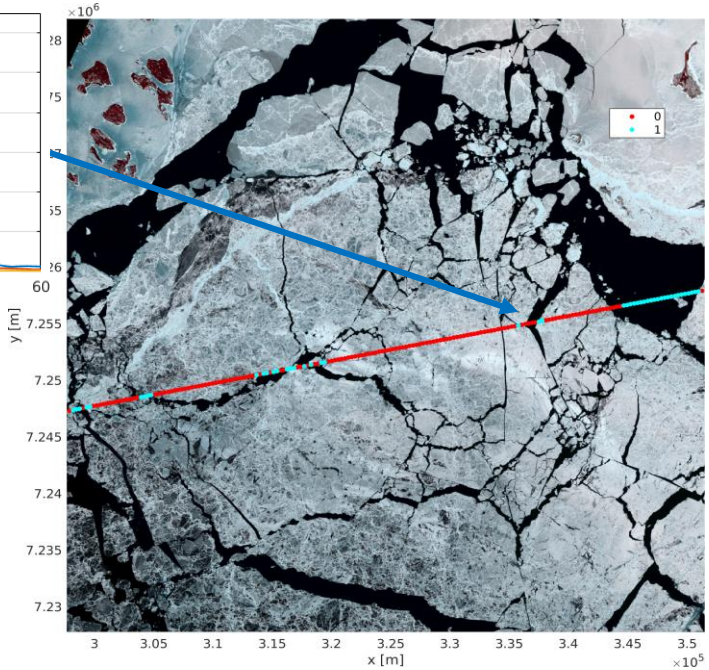


Algorithm Development and Validation (Unsupervised Classification)









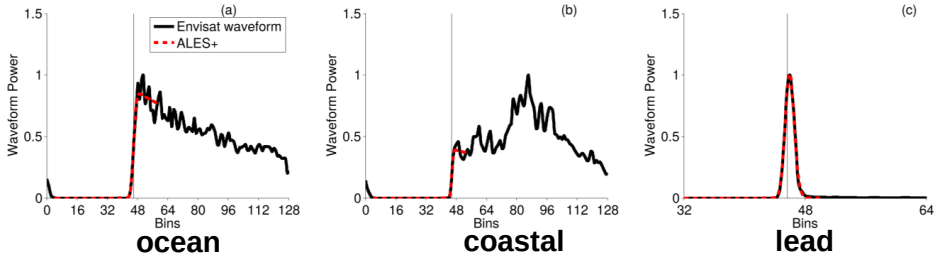
2016-04-14 / $\Delta t = 21min$

Jason-3 vs. Landsat 8

- Classification not always possible due to truncated waveforms (SARAL, Jason 1…3, CryoSat-2)
- Fast Ice surface conditions cause open ocean like radar echoes → Ambiguities (ext. sea-ice charts required)

Algorithm Development and Validation (Retracking)

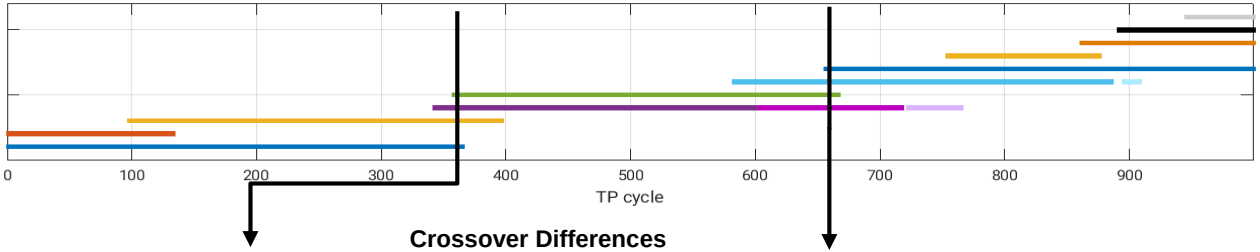
- ALES+: Retracking of peaky waveforms (only LRM)
- Build on ALES retracker (see Passaro et. al. 2014)
- ALES+: enables also the fitting of very peaky shaped waveforms
- Developed in the framework of Climate Change Initiative (CCI)
- Preliminary estimation of the trailing edge slope dependent on pulse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



More Information: *Passaro, M., Kildegaard, R. S., Andersen, O. B., Boergens, E., Calafat, F. M., Dettmering, D., and Benveniste, J.* (**2017**): ALES+: Adapting a homogenous ocean retracker for satellite altimetry to sea ice leads, coastal and inland waters*., Remote Sensing of Environment*

Algorithm Development and Validation (Multi-Mission Cross Calibration MMXO)

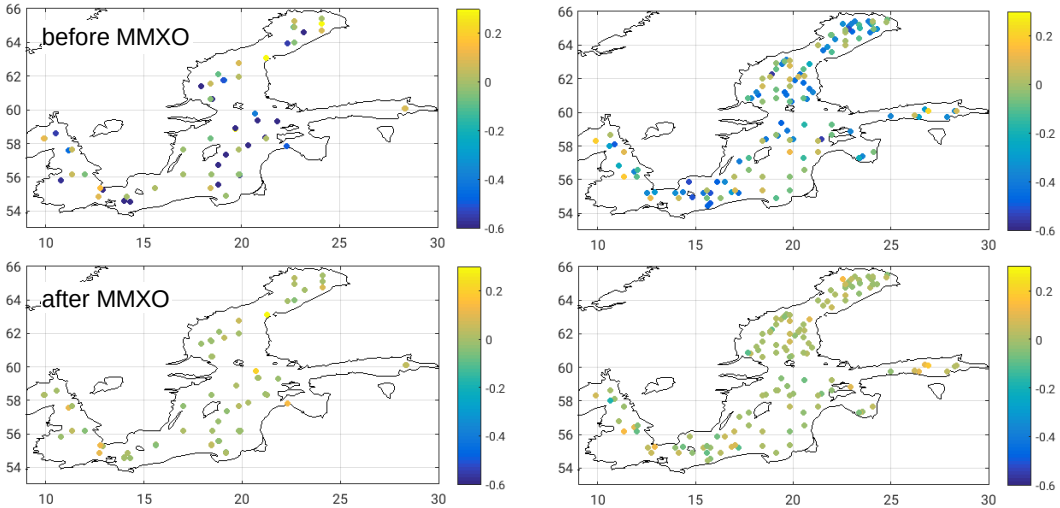
- Multi-mission crossover analysis: regional approach based on high-frequent SSH observations
  - Two – four missions per 10 day cycle / max. time differences = 3 days



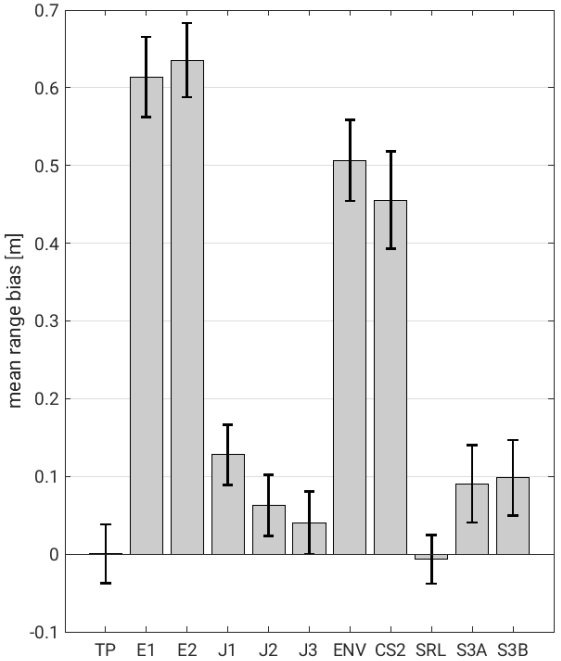
Crossover Differences

TOPEX/ERS-2/Jason-1/Envisat

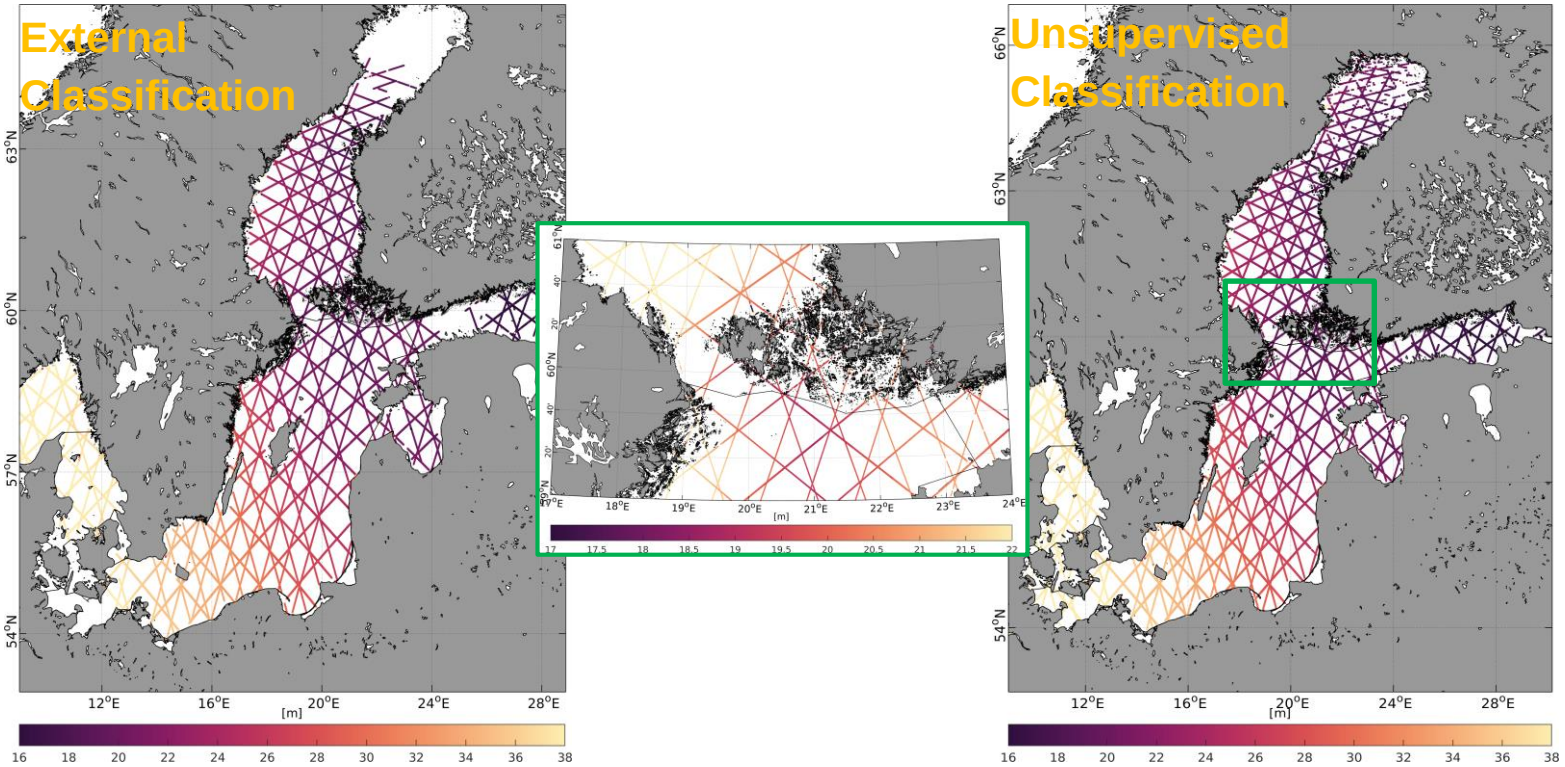
Jason-2/Jason-1 EM/Envisat/Cryosat



Mean range biases wrt TOPEX



Algorithm Development and Validation (Sea Surface Heights)



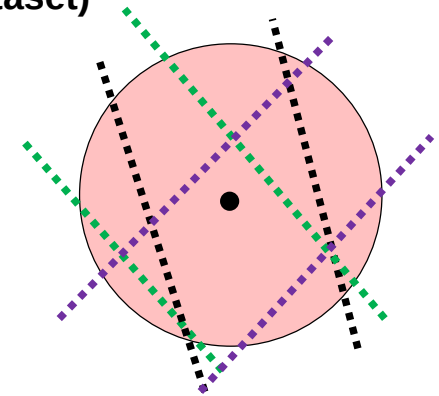
Sea Surface Heights ALES+ 2009-04 (J1-EM,J2,ENV)

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

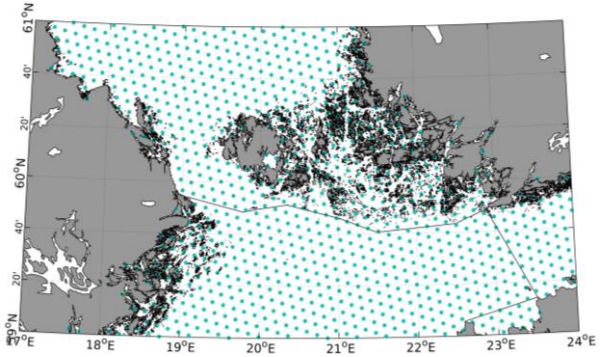
$$h(x, y) = c_0 + c_1 x + c_2 y$$



Grid-node with cap size and sea surface height distribution

- 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



Unstructured grid

Summary and Conclusions

- Baltic SEAL is a project designed to:
  - Exploit high-frequency multi-mission altimetry observations (LRM & SAR)
    - Very close to the coast (~ 3km)
    - Within the sea-ice layer
  - Improve and update the mean sea level in the entire Baltic Sea in the vicinity of jagged coastlines and sea-ice
  - Provide various temporal variable datasets
    - Monthly triangulated meshes
    - High-temporal resolution grids
  - Generate a 25-year long dataset
  - Investigate seasonal/annual sea level variability and absolute trends
  - Analyze and identify extreme events
  - Validate the results with tide gauge data

Thank you!

Stay tuned and visit:

balticseal.eu