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BALTIC+ Theme 3

Baltic+ SEAL (Sea Level)

Requirements Baseline Document

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CONTENT

LIST OF ABBREVIATIONS

ALES: Adaptive Leading Edge Subwaveform
ASL: Absolute sea level
BAL MFC: The Baltic Monitoring and Forecasting Center
BOOS: Baltic Sea Operational Oceanographic System
BS: Baltic Sea
CMEMS: Copernicus Marine Environment Monitoring Service
DD: Delayed-Doppler
DMI: Danish Meteorological Institute
EMODNET: The European Marine Observation and Data Network
ESA: European Space Agency
EU: European Union
FMI: Finnish Meteorologial Institute
GIA: Glacial Isostatic Adjustment
GPS: Global Positioning System
HZG: Helmholtz-Zentrum Geesthacht
MBI: Major Baltic Inflow
MMSL: Multi-Mission Sea Level
MVA: Multi-Version Altimeter
NRT: near real time
RBD: Requirement Baseline Document
RSL: Relative sea level
RT: Real Time
SAR: Synthetic Aperture Radar
SLA Sea Level Anomaly
SGDR: Sensor Geophysical Data Records
SL: Sea Level
SL_cci: Sea Level Climate Change Initiative
SMHI: Swedish Meteorological and Hydrological Institute
SSH: Sea Surface Height
TG: Tide Gauge
VLM: Vertical Land Motion
WCRP: The World Climate Change Research Programme

1. INTRODUCTION

1.1 SCOPE OF THIS DOCUMENT

This document holds the Requirement Baseline Document (RBD) prepared by Baltic+ SEAL team, as part of the activities included in the WP1 of the Proposal (Task 1 from SoW ref. EOP-SDR/SOW/086-17/DFP).

The objective of this document is to consolidate the preliminary scientific requirements for the project.

1.2 STRUCTURE OF THE DOCUMENT

The RBD is structured as follows:

Section 1 covers the introduction and the description of this document.

Section 2 introduces the scientific background and presents a review of the knowledge gaps and scientific problems addressed in this project.

Section 3 presents the initiatives and projects operating at the Baltic region that could be potential stakeholders for the new product and also introduces the user survey.

Section 4 defines the test regions used for the development and testing of the proposed methodologies.

Section 5 analyses the various technical risks associated to the project, with their corresponding proposed mitigation strategies.

2. SCIENTIFIC BACKGROUND

The goal of work described in this RBD is to create and validate a novel multi-mission sea level (MMSL) product for the Baltic Sea (BS). The aim is to improve the performances of the current state-of-the-art of the ESA efforts in the Sea Level Climate Change Initiative (SL_cci). The BS provides a number of challenges that require specific attention and procedures. In particular, the BS includes the two main areas in which the use of satellite altimetry has been severely limited since the start of the "altimetry era": the presence of sea ice and the proximity of the coast. The advantage of focusing on the BS is that it is a semi-enclosed area, in which marine observations have been done decades before the advent of satellite altimetry. This means that work done in the BS can be considered as a laboratory in which advanced solutions in the preprocessing and postprocessing of satellite altimetry can be tested before being transferred to global initiatives, such as the future phases of SL_cci.

The BS can be depicted as an estuary that drains brackish water into the North Sea via the Danish Straits. The BS region is as defined by the Marine Strategy Framework Directive to be bounded by the parallel of the Skaw in the Skagerrak at 57°44.43', thus including the Danish Straits. The Baltic Sea is shallow, with mean depth of 54 m. However, there are deeper sub-basins with maximum depths up to 459 m.

The sea level variability in the Baltic Sea is influenced by irregular fluctuations of atmospheric pressure, precipitation, river-runoff, wind strength and standing wave oscillations (seiches). The tidal component is limited, except in the northern Danish Straits, where the tidal range can be up to 0.5 m (Myrberg et al. 2006; Chap. 9). This is an important consideration, since the difficulty of tidal modelling in areas with complex coast and bathymetry severely impacts the quality of altimetry data in other areas. Compared to other semi-enclosed seas, the salinity variations play an important role and have a significant gradient from the North Sea entrance to the inner gulfs (Liebsch et al., 2002).
In particular, waters of the BS are brackish, but intrusions of salty water from the Skagerrak Sea through the Danish Straits occur on an irregular basis. The largest amount of saline water comes to the BS during Major Baltic Inflows (MBIs, Matthäus and Frank 1992). The MBIs are driven by sea level gradient patterns across the Danish Straits and control the deep water salinity in the Baltic Sea.

There is a weak cyclonic mean circulation with mean current speeds of 5 to 10 cm/s (e.g. Feistel et al. 2008; Meier, 2007). There are two persistent cyclonic gyres within the Baltic Proper and in the Bothnian Sea. Moreover, the generation of Kelvin Waves travelling along the coast creates downwelling and upwelling events. The main factors that generate the currents are wind stress and sea level differences between the North Sea and the Baltic Sea at the Danish Straits. In particular, winds are very variable in the area and therefore transient currents play a more important role in the circulation than long-term wind-driven oceanic currents. A reliable satellite altimetry dataset could definitely improve the characterisation of the circulation in the area.

Figure 1.1 Geographical map of the Baltic Sea region showing the surrounding countries, drainage area and different subbasins.

The inter-annual sea level changes in the BS vary geographically: Previous studies have associated changes in the central and eastern BS to sea level pressure (in particular the North Atlantic Oscillation) and changes in the southern

BS to precipitation patterns (Hünicke et al., 2008). The seasonal cycle has been mapped using AVISO open water altimetry product, highlighting the high variability of the winter sea level, but also the need for dedicated coastal product with better temporal and spatial resolution (Stramska et al. 2013).

In the Baltic Sea, it is fundamental to distinguish between absolute (ASL) and relative sea level (RSL). BS is strongly impacted by Vertical Land Motion (VLM) and in particular by the glacial isostatic adjustment (GIA). BS has the advantage of being an area very well sampled by tide gauges (TG), which measure RSL. RSL data shows strongly negative trends around -8 mm/yr in the northern BS, which are justified by the VLM motion measured by GPS sensors and is opposite to the strong trends registered since the satellite altimetry era of up to 15 mm/yr (e.g. Madsen, 2011; Olivieri and Spada, 2016). Nevertheless, in Figure 2 from Madsen (2011) it is shown how the mean trend derived by the current satellite altimetry products is strongly affected by uncertainty. In any case, it is based on a gridding of very sparse data, which are completely missing in a large area for several months of the year and do not include data close to the coast.

Storm surge is a major natural hazard in the Baltic Sea, and large parts of the coastline are storm surge risk areas (Schmidt-Thomé, 2006). Historic events show that storm surges have the potential to cause large and even devastating damages today, and the risk e.g. for cities like Copenhagen will significantly increase with future sea level change unless adaptation measures are taken (Hallegatte et al. 2011). Storm surges have durations of hours to days, and are therefore not always caught by altimetry. However, examples from e.g. the Xaver storm surge show that when a storm surge is observed by altimetry, this gives detailed information on the height and extent of the surge (Shutler et al. 2014, Figure 3).

To overcome the limited sampling frequency of altimetry, a blended altimetry and tide gauge product was developed within the ESA eSurge project, and assimilated into a sea level model of the Baltic Sea (Madsen et al. 2015). This blended product was shown to improve the overall sea level of the assimilated model, but was challenged in storm surge situation.

2.1 Knowledge gaps and scientific problems to be addressed in the project

The main scientific problem addressed in this project is the quality of the current altimetry products in the Baltic Sea. The latest reference in these terms is the global SL_cci product, which needs a strong improvement in both ice and coastal regions (Legeais et al., 2018). Passaro et al. 2015 analysed the time series of sea level anomaly (SLA) in the intersection area of North Sea and BS, including the Danish Straits and the Arkona Basin, considering the Envisat mission and comparing the ALES coastal altimetry product with the SL_cci. They found that Envisat SL_cci has gaps in the straits and Arkona basins, as well as within 15 km of the coast in the whole domain. Moreover, the Envisat SL_cci data set shows evident signs of corrupted estimation. Any altimetry product is obtained starting from a pre-processing of the signal. The altimetric waveforms are in fact routinely fitted with functional forms in order to retrieve range (distance between satellite and reflecting surface), significant wave height and backscatter coefficient in a process called retracking. The range has subsequently to be corrected for various instrumental and geophysical effects in order to derive the sea level.

The accuracy of altimetry measurements in the coastal areas is affected by the local departure of the radar signal from the known ocean response (due to inhomogeneities of the illuminated area) and the inaccuracy of the corrections, as well as of the tidal models, needed to isolate anomalies in the sea level variability (Vignudelli et al., 2011). In the sea-ice covered regions, the only way to measure sea level is by exploiting returns coming from the openings in the ice (leads), whose shape differ strongly from the known shape of radar reflections from the open ocean (Passaro et al., 2018). In order to do this and given the small size of the leads, high frequency radar signals have to be classified, i.e. the returns from leads have to be isolated from the surrounding ice.

3. Survey of Current and on-going initiatives and projects and user requirements

3.1 Description of existing initiatives of the projects

3.1.1 Baltic Earth

The Baltic Earth is an international research community that works with “Grand Challenges”, which are identified as fundamental research issues in order to improve our understanding on the Baltic Sea system. These “Grand Challenges” include Sea level dynamics in the Baltic Sea. The aim of this “Grand challenge” is to gain more detailed knowledge of dynamics of short term sea level variations, in particular on their climatology and their long-term variability and change. Another aim is to improve understanding of the connections between Baltic Sea, North Sea and North Atlantic sea level.

Project website: www.baltic-earth.eu/organisation/bewg_sealevel/index.html
Person to contact: Ralf Weisse (HZG, Chair), ralf.weisse@hzg.de
Funder: The World Climate Research Programme (WCRP)

Project Status: Active

3.1.2 BOOS

The BOOS (Baltic Sea Operational Oceanographic System) aims to promote and develop operational oceanographic infrastructure in the Baltic Sea. The tasks include routine collection, interpretation and presentation of in situ and satellite data. BOOS has 22 institutes as partners around the Baltic Sea BOOS. The operational observing system in the Baltic Sea provides real time (RT) and near real time (NRT) observations by BOOS members to fit for the purpose of model validation and data assimilation for the improvement of the operational forecasting and reanalysis. One of the foundations of the BOOS work and exchange of data and information have been the tide gauge observations and sea level forecasts at tide gauge locations.

Project website: http://www.boos.org/
Person to contact: Jun She (DMI, BOOS Chair)
Funder: Member institutes
Project Status: Active since 1997

3.1.3 CMEMS

The Copernicus Marine and Environmental Monitoring Service (CMEMS) provides oceanographic in-situ, satellite, forecast and reanalysis products for the European marginal seas. The Baltic Monitoring and Forecasting Center (BAL MFC) produces forecasts and reanalyses for the Baltic Sea as a part of the CMEMS services. The products include forecasts and reanalyses of sea level, ice concentration and thickness, temperature, salinity and currents made with a 3D ocean-ice model. The sea level dataset produced in this project can be used for assimilation in the reanalysis and also in the validation work performed both for the analysis and forecast system and the reanalysis system.

Project website: http://marine.copernicus.eu/
Person to contact: Mercator Ocean International (www.mercator-ocean.eu), servicedesk.cmems@mercator-ocean.eu, communication@mercator-ocean.fr
Funder: EU Copernicus Programme
Project Status: Active since 2015

3.1.4 EMODNET

The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy. More than 150 organisations are involved in the EMODnet programme. EMODnet established a series of checkpoints for European seas. The Baltic Sea CheckPoint focused on studying the present data collection, observation, surveying, sampling and data assembly programs in the Baltic Sea basin and how they can fit into purpose of different challenge areas in terms of data uncertainty, availability, accessibility and adequacy. The findings are described in the Literature review:

http://www.emodnet-baltic.eu/Portals/0/LiteratureReview/Baltic%20checkpoint%20literature%20survey%20report.pdf

and Data Adequacy Report:

http://www.emodnet-baltic.eu/Portals/0/DAR/BSCP_DAR1_Version_20161202.pdf.

3.1.5 BALTIC+ THEMES 2, 4 AND 5

Baltic+ Theme 2 (Sentinel-2 and 3 synergy for land-sea biochemical linkages), Theme 4 (Baltic Sea 4D Reconstruction), Theme 5 (Geodetic SAR for Baltic Height System Unification and Baltic Sea Level Research) provide information that is potentially valuable to this project and also the results from this project may be utilised in other Baltic+ Themes.

3.2 USER REQUIREMENTS

A user survey will be conducted to get information about the user needs. The questionnaire is presented in Appendix 1. Results of the user survey will be presented in a separate report in Autumn 2019.

3.3 ADDED VALUE OF THE WORK CARRIED OUT

Providing a new good quality Sea level product for the Baltic Sea will greatly benefit the different activities. It can be used in addition to other datasets to assess the long-term trends in the SSH.

The sea level product can also benefit the Baltic Sea modelling activities performed by the BOOS partners and the CMEMS BAL MFC. The modelling efforts will benefit from the new good quality dataset that has been validated against TG data that can be used for model validation and data assimilation.

Co-operation with Theme 2 (Sentinel-2 and 3 synergy for land-sea biochemical linkages) will possibly enable identification of Sentinel-3 tracks located close to the deltas or estuaries of rivers, and could provide useful local sea level time series to assess the impact of river fluxes.

Sea Level data is valuable for ocean modelling both for validation and assimilation. A close collaboration between Theme 3 and Theme 4 would be essential to improve the knowledge of the full ocean dynamics in the BS and provide realistic future predictions that would be beneficial for the BS coastal community.

Cooperation with Theme 5 (Geodetic SAR for Baltic Height System Unification and Baltic Sea Level Research) improves our understanding of the VLM in the BS, which is essential to correctly interpret the output of Theme 3, improve our possibility of validation by means of TGs and put our results in a useful context for the coastal communities in the region. At the same time, the development of satellite altimetry in areas close to the in-situ measurements is a key factor to provide an estimation of VLM by means of differentiation between the relative and the absolute sea level trends and to close the observational gaps between TGs and satellite altimetry.

4. Test areas

4.1 Identification of test areas

The test areas will be used as a testbed for research and development as well as for initial validation and initial impact analysis. Four test areas were selected based on the scientific, past knowledge on the challenges in sea level retrieval and availability of auxiliary data:

1. The Danish straits and the Western Baltic: Baltic Sea – North Sea transition zone is an important area for the Baltic Sea physics (e.g. Major Baltic Inflows)
2. Bothnian Bay: A coastal area of the northern Baltic Sea where fast ice is present
3. Gulf of Finland: A complicated coastal area to test with land-sea-land transition (e.g. Gulf of Finland)
4. An area where GPS station exists close to tide gauge

The location of the sub-basins of the Baltic Sea are presented in Fig. 1.1.

4.2 Available data in the test areas

The Danish straits are dynamic areas through which the water exchange between the Baltic Sea and North Sea occurs. The surplus of less saline water, by voluminous river discharges exits the Baltic Sea and the more saline water of North Sea enters the Baltic Sea. Occasionally large volumes of saline water enter the Baltic Sea, called the Major Baltic Inflows. An MBI event is preceded by an outflow of water from the Baltic to the North Sea and a decrease in the sea level. During the inflow period, a large amount of saline water enters the Baltic Sea followed by a rise in the sea level that can be even up to 1 m. The area has a good coverage of tide gauge data (Fig 4.1). There are also good records of the MBI's available with data from moorings and field campaigns (e.g. Mohrholtz, 2018). The latest strong MBI was recorded in December 2014. The last strong one before that was recorded in January 2003.

Figure 4.1 Tide gauges in the Danish Straits (53°48'00.0"N, 9°11'16.8"E, 56°19'48.0"N, 12°30'00.0"E)

The Bothnian Bay has ice cover every winter. FMI and SMHI ice services provide daily ice charts, which are based on satellite data, in-situ measurements and expert evaluation. The ice charts are available in digital format for the past 10 - 20 years. The ice charts contain information about the ice extent, ice concentration and ice thickness. The area has 9 tide gauges, five on the Finnish coast and 4 on the Swedish coast (Fig. 4.2). In this area, it is possible to evaluate the sea level estimates from the leads together with the tide gauge data.

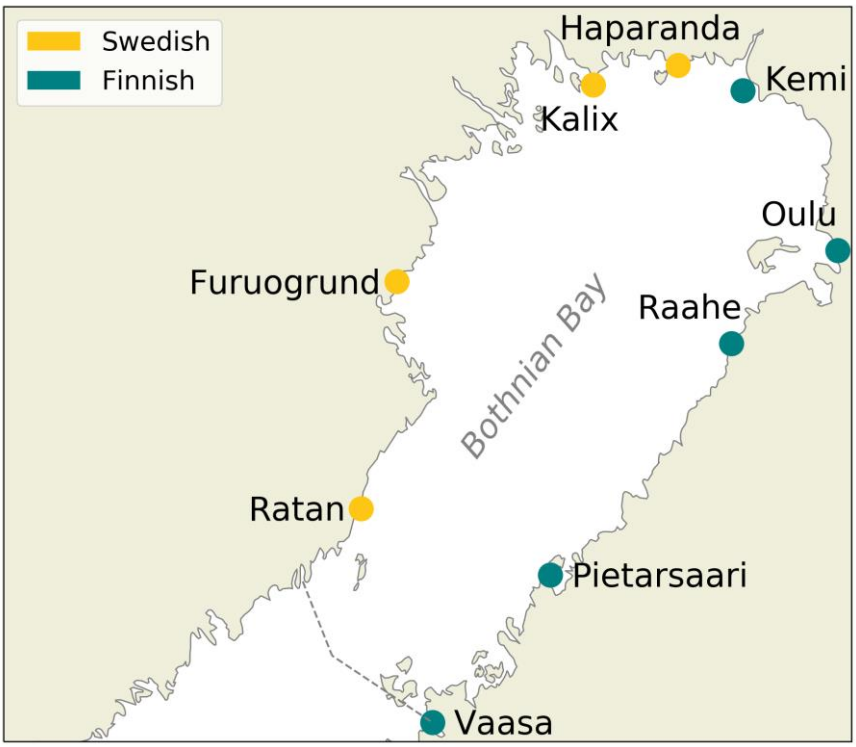

Fig 4.2 Tide gauge stations in the Bothnian Bay (63°00'00.0"N, 17°30'00.0"E, 66°06'00.0"N 26°00'00.0"E)

The Gulf of Finland is an elongated gulf, about 400 km long and the width varies between 60 to 130 km (Fig.4.3). The southern and northern coasts are quite different. The Finnish coast has an irregular structure and is covered by thousands of small islands and islets, whereas the Estonian coast has a smoother shoreline. The irregular structure and the archipelago in the Finnish coast gives a possibility to evaluate how near to the shoreline it is possible to get reliable estimates of SSH in such areas. There are also 4 tide gauges on the Finnish coast, which can be used for validation.

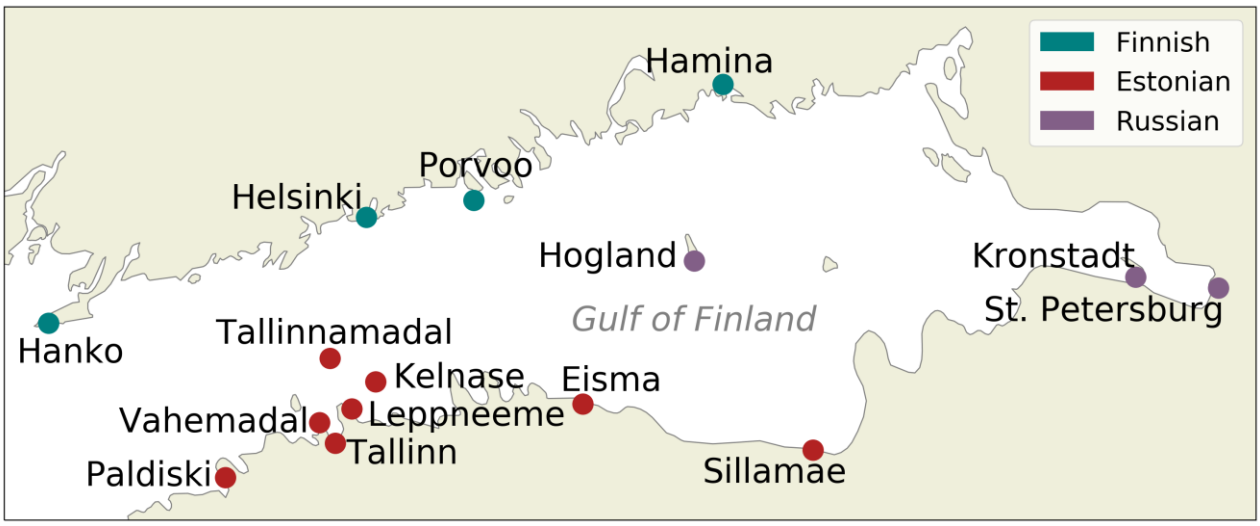

Figure 4.3 Tide gauges in the Gulf of Finland (59°12'00.0"N, 22°42'00.0"E, 60°48'00.0"N, 30°30'00.0"E)

There are few areas in the Baltic Sea where there is a GPS **station** located in the vicinity of a tide gauge. The potential test areas include the Quark, Danish Straits and Kattegat (Fig 4.4). The location of the most suitable test area will be decided after more thorough data search and data quality analysis have been performed.

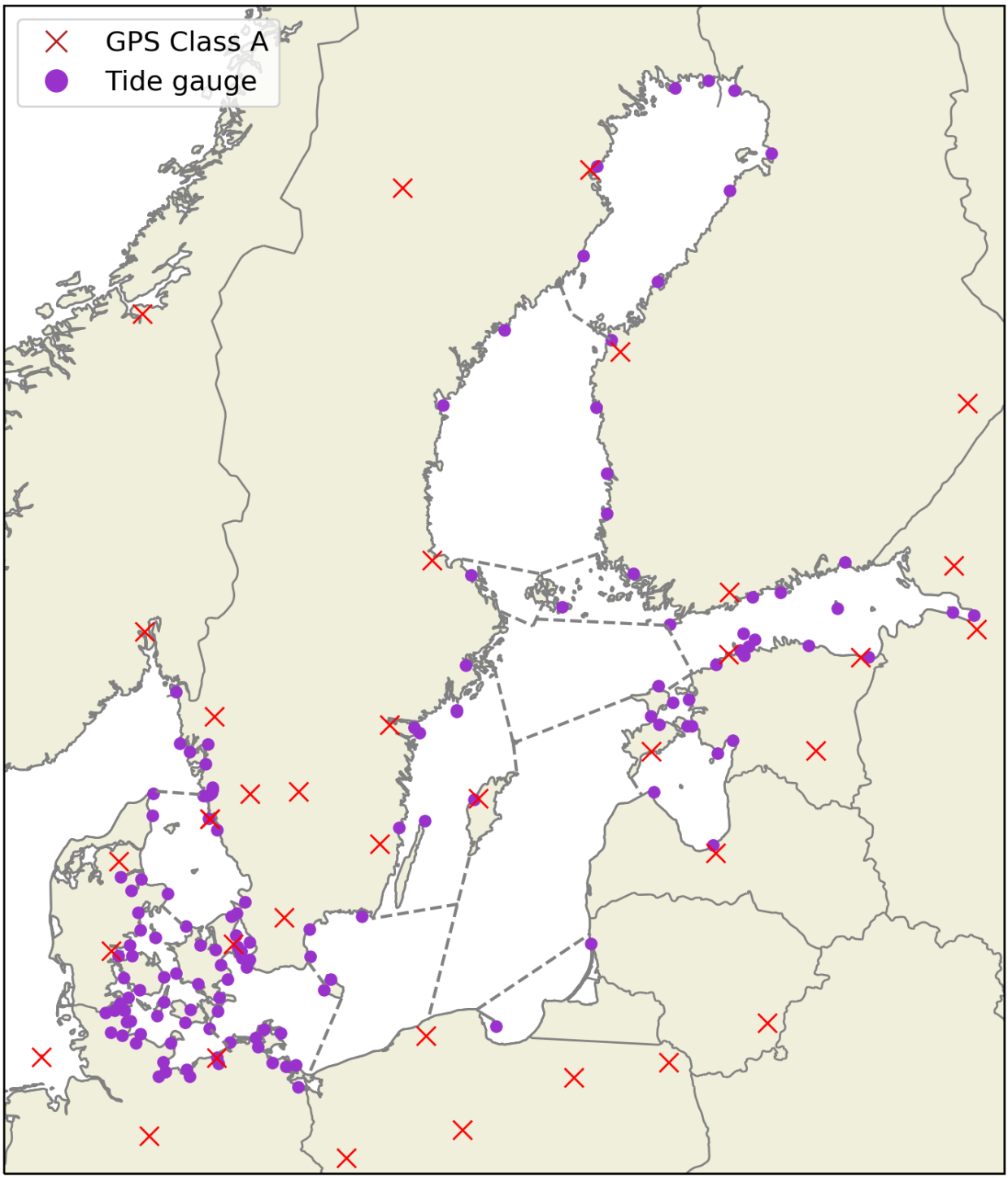

Fig 4.4 Location of GPS stations (A class) and tide gauges in the Baltic Sea

5. Risk elements of the project

5.1 Risks for the execution of the project

Following points list limitations in execution of the project:

1. The SGDR of TOPEX mission (1992-2006) are not suitable for retracking. In several meetings this problem has been raised, but as of today the repository does not provide a satisfactory documentation to analyse the waveform data.
2. In its current formulation, ALES+ data have shown to be superior to SGDR data (both ocean and sea-ice retracker) in terms of precision (Passaro et al., 2018). Nevertheless, due to the compromises needed to have

such an adaptive solution, the standard ALES solution (which cannot retrack signals from sea-ice covered areas) performs better than ALES+ in the coastal zone.

3. Even it is sought to provide a single retracker solution, it is not guaranteed that ALES+ fitting of DD waveforms keeps the performance of the current SAMOSA approach
4. The Wet Tropospheric Correction available in the SGDR and computed using model data in order to avoid the problems of land corruption in the radiometer might not provide a satisfactory space-time resolution.
5. Annual cycle estimation on the ERS-Envisat-SARAL/AltiKa repeating tracks: we are generating time series with a frequency of one measurement every 35 days, the estimated annual cycle will include the contribution coming from any error in the tidal correction for the K1 constituent (which has an aliasing period of 365.24 days) (Volkov et al., 2012)

5.2 Mitigation strategies

The identified risks can be solved by the following actions:

1. The current version of TOPEX SGDR will be nevertheless included in the MVA system in its current version, in order to be able to evaluate the TOPEX-Jason time series in its full length. The validation against in-situ data will assess the reliability of SGDR TOPEX data when approaching the coast. It was already demonstrated (Passaro et al., 2014; Roblou et al., 2011) that altimetry data, even if retracked with a standard open-ocean procedure, have several good sea level retrievals even in the coastal zone, provided that the outlier detection effectively removes or flags most of the wrong estimations.
2. As a possible improvement to ALES+, we will seek a better strategy for the leading edge detection in order to avoid the peaks in the trailing edge, typical of coastal waveforms, be interpreted as peaky leading edges (as in signals reflected back from leads) by the algorithm.
3. In the context of this project, our prime objective for DD altimetry will be the adaptation of ALES+ to DD waveforms (see description of Task 3). This is the most desirable of the solutions, since it would guarantee a higher level of consistency among the different missions. Passaro et al., 2016 and Cipollini et al., 2017 have shown that DD data without any specific coastal retracker are reliable up to 3 km to the coast, which is also the suggested limit of reliability of ALES data. For these reasons, the official output from SAMOSA retracker will be provided to the partners at least for Sentinel3a and b, in order to establish through validation whether or not the use of the ALES+ adaptation brings an added value.

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Appendix 1. User requirements survey

Baltic+ SEAL survey of user requirements

Welcome to the Baltic+ SEAL online survey, funded by European Space Agency (ESA). We greatly appreciate you taking the time to provide us with any insights regarding your present and future use of altimeter sea level data.

The goal of the Baltic+ SEAL project is to create and validate a novel multi-mission sea level product for the Baltic Sea in order to improve the performances of the current state-of-the-art of the ESA efforts in this sense: the Sea Level Climate Change Initiative (SL_cci).

The new dataset will consist of time series of sea surface height distributed as a multi-mission gridded product and the along-track data from each satellite mission is taken into account. The time span covers the full altimetry era up to the present (over 25 years of data). Data will be distributed for free in NetCDF format. The objective is to provide users with no previous experience of altimetry data handling with the possibility of exploitation of a sea level dataset which is up to date with the current advances of the field (such as dedicated processing of coastal and sea-ice covered areas).

The Baltic+ SEAL project is conducted by five partners: Technical University of Munich, Technical University of Denmark, Finnish Meteorological Institute, Danish Meteorological Institute and University College Cork.

The aim of this survey is to identify potential applications for the new sea level dataset, reinforce ties with the user community and possibly optimise our procedure according to their needs. We very much appreciate your involvement through completing this survey, and look forward to analysing the results and the suggestions.

Please answer all questions in English.

What type of organisation are you based at?

- Public sector organisations
- University
- Private company
- Foundation, Association
- Other:

Country of your organisation?

Which marine sectors are you active in? (multiple answers possible)

- Marine environmental monitoring
- Maritime security
- Transport
- Instrumentation/sensor deployment
- Renewable energy
- ICT industry
- Fisheries
- Aquaculture
- Oil & Gas
- Tourism
- Blue Technology
- Public research
- Other:

Which kind of Ocean Remote Sensing data have you used (if any)? (multiple answers possible)

- Sea Surface Temperature
- Sea Ice Concentration
- Sea Surface Salinity
- Sea Level Height
- Derived Geostrophic Currents
- Ocean Colour
- Significant Wave Height
- None of the above
- Other:

Which kind of Sea Level data have you used?

- Tide Gauge data
- Along Track Altimetry data
- Gridded Altimetry data
- Model data
- Other:

Which are the sources of sea level data you have used? (multiple answers possible)

- ESA Sea Level Climate Change Initiative
- AVISO/Copernicus
- RADS (Radar Altimetry Database)
- Permanent Service of Mean Sea Level (PSMSL)
- GESLA
- Other:

Which applications do you use sea level data for (in your past, present or future work)? (multiple answers possible)

- Sea level trend/variability analysis
- Circulation studies
- Validation studies
- Data assimilation in models
- Teaching purposes
- Synergy with other remotely-sensed oceanic variables
- Coastal engineering/ Coastal planning
- Operational Oceanography
- Maritime safety & security
- Other:

Which area of the Baltic Sea are applying to your research or products? (multiple answers possible)

- The whole Baltic Sea
- Bothnian Bay
- Bothnian Sea
- Åland Sea
- Gulf of Finland
- Northern Baltic Proper
- Gulf of Riga
- Western Gotland Basin
- Eastern Gotland Basin
- Gdansk Basin
- Bornholm Basin

Arkona Basin
Bay of Mecklenburg
Kiel Bay
Great Belt
The Sound
Kattegat
Other:

What is the spatial scale of your applications?

Mention two main issues with the sea level datasets you are currently using, or have used in the past.

Name two features that you like about sea level datasets you are currently using, or have used in the past.

What is an acceptable spatial resolution of a sea level dataset useful for your application?

Along-Track altimetry data at maximum resolution (~300 m spacing)
Along-Track altimetry data at low resolution (7 km spacing)
Gridded data at 25 km resolution
Gridded data below 25 km resolution
Other:

What is an acceptable time resolution of a sea level dataset useful for your application?

monthly
weekly
3 days
daily
Other:

Which is an acceptable distance to the coast at which the sea level data should be reliable for your application?

< 100 m
< 1 km
< 10 km
< 50 km
Other:

What format do you prefer sea level datasets to be delivered in?

Please indicate if you are interested in the provision of the following additional datasets (multiple answers possible):

atmospheric pressure component of the sea level "dynamic atmosphere correction"
ocean tide component
mean sea surface
gridded sea level trend map
gridded annual cycle amplitude and phase map

Any other comments?

If you would like to be added to our mailing list, for occasional updates, event notifications and project news, please provide your email address below: