



HAL
open science

OBSERVING BALTIC SEA EXCHANGES: PRESENTING A NEW MULTI-PLATFORM AUTONOMOUS OBSERVATORY

Bastien y Queste, Sebastiaan Swart, Louise C Biddle, Olle Petersson,
Aleksandra K Mazur, Marcus Melin

► **To cite this version:**

Bastien y Queste, Sebastiaan Swart, Louise C Biddle, Olle Petersson, Aleksandra K Mazur, et al.. OBSERVING BALTIC SEA EXCHANGES: PRESENTING A NEW MULTI-PLATFORM AUTONOMOUS OBSERVATORY. 9th EuroGOOS International conference, Shom; Ifremer; EuroGOOS AISBL, May 2021, Brest, France. hal-03331198v2

HAL Id: hal-03331198

<https://hal.science/hal-03331198v2>

Submitted on 23 Sep 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

OBSERVING BALTIC SEA EXCHANGES: PRESENTING A NEW MULTI-PLATFORM AUTONOMOUS OBSERVATORY

Bastien Y. Queste ⁽¹⁾, Sebastiaan Swart ⁽¹⁾, Louise C. Biddle ^(1,2), Olle Petersson ⁽²⁾, Aleksandra K. Mazur ⁽²⁾ and Marcus Melin ⁽²⁾

⁽¹⁾ Department of Marine Sciences, University of Gothenburg, Gothenburg, Sweden

⁽²⁾ Ocean Knowledge, Foundation Voice of the Ocean, Skeppet Arans Vag 3, 42671 Vastra Frolunda, Sweden

Abstract

The Skagerrak and Kattegat are narrow and shallow channels separating the North Sea and Baltic Sea. This highly dynamic area plays a key role in transforming water masses which flow into and oxygenate deep regions of the Baltic. This site is also a region of important carbon export, through advection down into and out of the Norwegian Trench. This rich and productive ecosystem is strained by intensive human activity and shows strong coupling between biological and physical processes at a range of scales. We present preliminary data from a new autonomous observatory funded by the Voice of the Ocean Foundation along with an outline of the technical infrastructure and innovations of the Voice of the Ocean observatories and how to access its open data.

Keywords: Baltic Sea, gliders, autonomous vehicles, open data

1. Introduction

Over the last 100 years, we have seen a dramatic decline in ecosystem health and an expansion of anoxic zones within the Baltic Sea. The decline and sensitivity of the Baltic is accentuated by its complex bathymetry and the complex interaction of oceanographic processes that occur across multiple spatial and temporal scales. Its circulation is similar to estuarine dynamics: strong horizontal and vertical buoyancy gradients constrain energetic fluxes throughout the basin and limit supply of oxygen to deep basins. This is especially true of the exchanges between the North Sea and the Baltic, which occur via the Skagerrak, Kattegat and through the Danish Straits. Oceanic (i.e. high salinity and oxygen) water occupies most of the water column in the Skagerrak, but its high density is such that it is confined to deeper regions of the Baltic Proper, where low-density surface waters exhibit significant riverine influence (i.e. low salinity).

Sporadic (approximately one per decade), unpredictable, large-scale oceanic inflows are of fundamental importance to the region's physics, biogeochemistry and ecology, and are the principal driver of change in deep regions of the Baltic. Oceanic inflows have a profound effect on the hydrography of the deep Baltic, causing abrupt increases in oxygen and salinity. These inflows regulate deep-water residence times, the strength of stratification and are the primary source of oxygen to bottom waters. The chemistry and biology of the Baltic respond to the hydrographic changes caused by the inflows and to the oxygen they deliver to the deep.

The timing and forcing of oceanic inflows are poorly understood. Similarly, the pathways taken by oceanic water through the Danish Straits, the processes that control this transit, and the effect of water mass transformation processes during this transit are poorly understood. Furthermore, there is evidence of intermittent small-scale inflows – 'leakages' of oceanic water from the North Sea to the Baltic – which cannot be properly resolved by existing mooring networks (low spatial resolution) or monthly ship cruises (low temporal resolution); note the near-bottom layer of high-salinity water visible in Figure 1, that 'spills over' bathymetric sills. The small spatial and temporal scales on which oceanic inflows, leakages and water mass transformation processes operate cannot be adequately captured by existing observation networks. Given the importance of oceanic inflows to the hydrography of the Baltic, understanding the small-scale physical processes that control inflows of oceanic water is crucial to understanding future perspectives for the ecologically and economically significant anoxic region of the Baltic.

The Baltic Sea is surrounded by nine countries that depend on it for fisheries, energy generation and tourism. The EU Marine Strategy Framework Directive requires member states to ensure 'good environmental status' for their territorial waters, providing significant regulatory pressure to advance our knowledge of conditions in the Baltic and to disseminate knowledge to policy makers. Ensuring good environmental status requires long-term monitoring to establish baseline conditions; ship surveys are frequently conducted in the Baltic, and they provide excellent understanding of baseline conditions and large-scale changes when combined with mooring networks. But scientists and policy makers also need an appreciation of high-frequency variability in baseline conditions, the better to separate natural variability from anthropogenic change and resolve processes which may change under future climate scenarios, further tipping the balance.

To address this, we must embrace new tools for ocean observation which can bridge the gap between sparse, long time-series and intense, high resolution but localised process studies. The Voice of the Ocean Foundation (VOTO) currently funds the 'Smart Autonomous Monitoring of the Baltic Sea' project (SAMBA) which aims to collect high resolution long-term datasets using autonomous underwater vehicles in proximity to existing monitoring infrastructure to complement and extend spatial and temporal coverage, as well as collect additional variables to better resolve Baltic Sea ecosystem functioning.

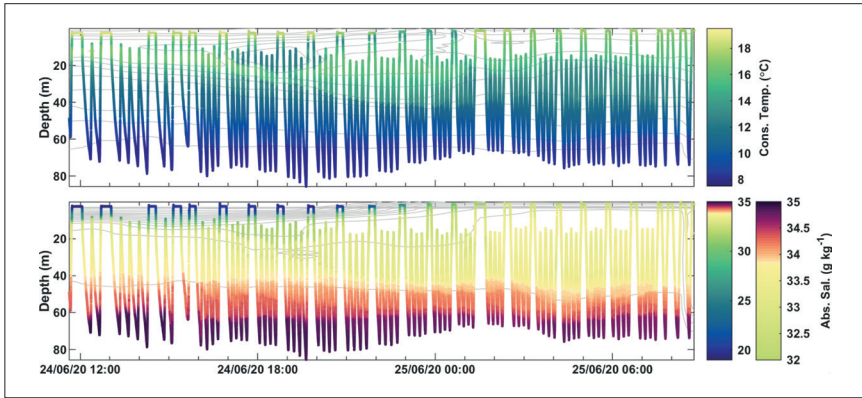


Fig. 1. North-south glider sections within the Kattegat during preliminary instrument trials.

2. Voice of the Ocean Foundation

The purpose of VOTO, founded in 2019, is to conduct, support and promote science, education, information and communication regarding the sea, marine ecosystems, and the marine environment as well as the interaction between humans and the sea, historically, in the present and in the future. VOTO wants to further knowledge, curiosity, and care for the oceans. They strive for a future where the interest and knowledge of marine ecology and history among the general public promotes a sustainable co-existence between humankind and the sea. VOTO aims to influence people's perspectives through knowledge; that is why the foundation seeks to aid in the collection, creation, and dissemination of marine knowledge.

The Ocean Knowledge division of VOTO aims to help scientists understand the sea as a system. This is done through the collection of data useful for research. Ocean Knowledge works along two different timelines: (1) collection of data for current scientific research projects, and (2) establishing long-term observatories to develop our understanding of long term processes and with the aim of helping science in the future (10 years and beyond) to answer questions that may arise over time. Ocean Knowledge wishes to measure baseline conditions in the present for comparison in the future.

One central aim for the foundation is to provide information which can contribute to sound management of the Baltic Sea. VOTO Ocean Knowledge has the equipment and infrastructure to generate data and support the scientific community in addressing current questions about Baltic Sea functioning. Ocean Knowledge works along the following lines: engaging young researchers to use and publish data collected by VOTO infrastructure; encouraging applications to use our fleet of autonomous vehicles in scientific projects; creating a scientific advisory board with international

standing for peer-review of applications; developing best practices and methods for autonomous measuring systems in shallow and dynamic environments; supporting the development of true autonomy for data collection at sea; supporting the development of robust autonomous systems for collection of data over time; and inviting scientists from different fields for cross-disciplinary work to understand the Baltic Sea and its status.

As a first goal, VOTO Ocean Knowledge works towards quantifying a sub-seasonal budget of the horizontal and vertical fluxes of oxygen, salt and nutrients in the Baltic Sea within a five-year period. Data collected by the Ocean Knowledge division at Voice of the Ocean is made available publicly and will soon be available via EMODnet. Further details are available on <http://voiceoftheocean.org/knowledge/>.

3. The Samba Project

3.1 Research aims

SAMBA, or 'Smart Autonomous Monitoring of the Baltic Sea', is a collaboration between VOTO Ocean Knowledge and researchers at the Department of Marine Science at the University of Gothenburg. The project seeks to fundamentally change the landscape of ocean observation in the Baltic Sea by collecting the largest, and highest resolution, physical, biological and chemical dataset of the Baltic Sea to date through a series of observatories continuously surveyed by autonomous vehicles. These observatories will be distributed along the Baltic to monitor conditions and circulation from the North Sea to the upper reaches of the Baltic Sea. Currently, four observatories are planned (Figure 2), from the Skagerrak, the Bornholm Basin, the Gotland region, to the Åland Sea. Both the Skagerrak and Bornholm Basin observatories began March 2021. The following two sites are planned to begin in 2022. These observatories are planned with a minimum 5 year lifetime.

The first two observatories specifically aim to investigate inflows of North Sea water into the Baltic Proper. The Baltic Sea exhibits large expanses of anoxic water at depth which are sporadically, and briefly, reoxygenated by full column overturning or denser water inflow into the Baltic from the North Sea, through the Skagerrak and Kattegat. The currents controlling the surface inflow and outflow of waters between the North Sea and Baltic Sea have been previously described as baroclinic flows, driven primarily by the density gradient of the Kattegat-Skagerrak front and linked to surface wind forcing. However, these studies mostly rely on data collected before 1995, when sampling stations were sparsely positioned with limited resolution, and have little resolution of the processes occurring below the halocline. The Skagerrak-Kattegat front has an influence on the transfer of water masses from north to south, but the temporal and spatial variability of the front, and what drives this variability, is not well understood. The changes that this frontal movement can induce in water mass properties will also have impacts on local biology, with linkages to eel grass meadows, deep coral propagation and fish community structures amongst others.

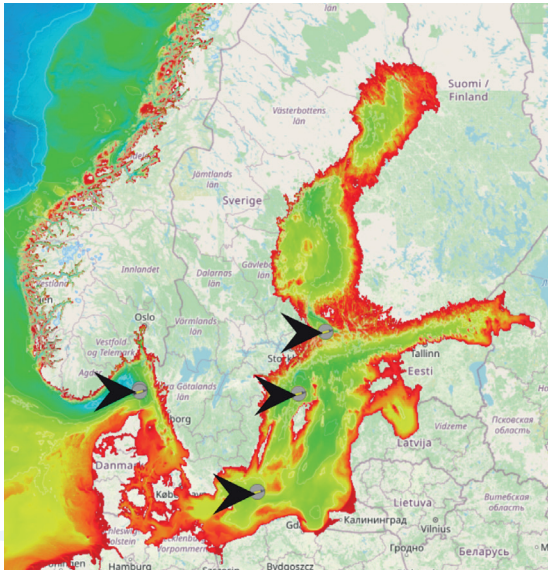


Fig. 2. The location of the four planned SAMBA Project observatories.

These observatories do not seek to answer these aims on their own, but to build on existing ocean monitoring infrastructure by expanding the spatial and temporal coverage with high resolution observations. These observations will help to build a base from which the larger scale project objectives can be achieved over a 5 year timeline:

1. What is the variability of water mass properties and transport across the Danish Straits, and how do these influence both small and large scale Baltic inflows?
2. How do physical processes affect rates of primary production, export of organic matter and remineralisation at depth across the Baltic?
3. How is the upper ocean impacted by heat and momentum fluxes, and how do these affect oxygenation of Baltic deep water?
4. In addition to these scientific questions, the project provides an opportunity to develop best practices for long-term monitoring of shelf seas through the use of autonomous platforms.

3.2 The Skagerrak and Bornholm Basin observatories

The Skagerrak survey line will consist of a right-angled triangle. Its longest leg will capture in- and outflows into the Kattegat while the other two legs extend into the Norwegian Trench to capture the spatial and temporal variability of the Kattegat-Skagerrak front. The survey line coincides with two Baltic Operational Oceanographic System (BOOS) stations (Å14 and Å17) for cross-calibration and reference. The survey

line is approximately 89 km long, with a maximum depth of 375 m, and is surveyed in 4 to 5 days on average by a glider.

The Bornholm Basin survey line is a V-shape, extending outwards from the deepest point to the edges of the basin on either side of the eastern sill. The survey line passes through one BOOS station (BY5) for cross-calibration and reference. The line is 85 km long (one way), with a max depth of 93 m, and is surveyed in 4 to 5 days by a glider.

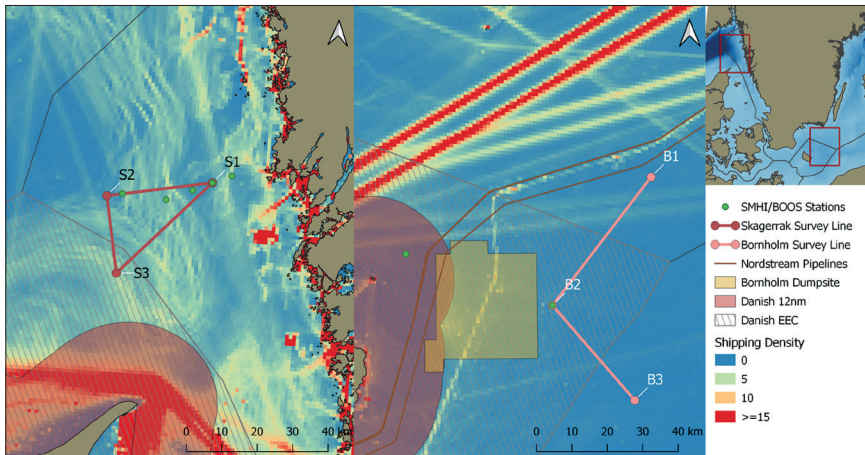


Fig. 3. Detailed view of the two established observatories along with existing monitoring infrastructure, ship track density maps and national borders.

3.3 Infrastructure

Each observatory will be surveyed by the same arrangement of autonomous vehicles: two autonomous underwater gliders (SeaExplorer, ALSEAMAR, France), one with a biogeochemical sensor suite and one with a physical sensor suite, as well as an autonomous surface vehicle (SailBuoy, Offshore Sensing AS, Norway). The SAMBA project runs a fleet of ten SeaExplorer gliders (ALSEAMAR, France). These are equipped with rechargeable batteries and interdisciplinary sensor payloads: RBR Legato temperature and salinity sensors; RBR Coda or JFE Rinko AROD-FT oxygen sensors; Wetlabs Triplet ECOpucks for chlorophyll a, phycocyanin and optical backscatter; SeaBird OCR504i 4-channel PAR sensors; Nortek 1MHz ADCP. The gliders are accompanied by four Sailbuoy surface vehicles (Offshore Sensing AS, Norway). These are equipped with combinations of N.Brown G-CTD, Aanderaa 4319, or RBR Legato temperature and salinity sensors, Airmar 200WX meteorology, FT Technologies FT7 wind sensor, Datawell wave recorder, EK80 WBT mini echosounder, Aanderaa DCPS current profiler.



Fig. 4. A Sailbuoy and two SeaExplorers at the VOTO Ocean Knowledge facility in Nya Varvet, Sweden.

SeaExplorers use changes in buoyancy to drive vertical motion while changing pitch and roll to generate lift from wings which propel the vehicle forward. A glider travels 15 to 20 km a day and profiles the water column at approximately 10 cm per second. For each study site, both gliders will be equipped with temperature and salinity sensors and an oxygen optode. One glider will also measure chlorophyll a and phycocyanin fluorescence, optical backscatter at 700 nm and irradiance at four wavelengths (380, 490, 532 nm, and PAR). The other glider is equipped with a dual-channel chlorophyll a and backscatter sensor and a Nortek Signature 1MHz ADCP for measuring small-scale ocean currents. Sailbuoys on the other hand, stay on the surface, powered using renewable solar panels. The Sailbuoys are equipped to measure surface temperature and salinity, wind speed and direction, air temperature and barometric pressure continuously; the Bornholm Sailbuoy vehicle will also be equipped with an experimental downward-facing ADCP. All vehicles are serviced at approximately monthly intervals and are piloted by VOTO Ocean Knowledge staff, including a team of Masters students employed by the foundation to ensure 24 hour coverage. Together, these platforms provide continuous monitoring across key regions, providing much greater spatial coverage than moorings, greater resolution than Argo floats and longer temporal coverage than ship surveys, at a fraction of the cost.

The autonomous vehicle fleet is supported by VOTO Ocean Knowledge's rapid science vessels. The foundation is going to invest in replacing its current fleet with two to three 22m vessels to aid with logistics on both the east and west coasts of Sweden. The aim is to design an agile vessel capable of performing other tasks along with the vehicle servicing such as oceanographic sampling, smaller surveys with remotely operated vehicles (ROV) and towing equipment. Specifications are geared towards creating a larger open deck space to fit gilders and autonomous vehicles while still having space for a smaller lab and accommodating scientists and crew for up to 72h missions. Between servicing the autonomous fleet the vessels will be available as a resource for oceanographers and scientists around the Baltic.

These vessels serve to quickly and easily service and maintain the autonomous vehicle. The SAMBA project has shown that such infrastructure can be used efficiently in single day missions. Day trips are sufficient to recover the instruments, recharge the batteries, clean the instruments, download the data and redeploy. The additional CTD and rosette configuration that the foundation is adding to the vessels will permit in situ sampling for optimal calibration of the autonomous vehicles. This ability to perform rapid services is crucial to minimising data gaps and ensuring the safety of the autonomous vehicle fleet due to the scarcity of long and clear weather windows, particularly in the winter months.

3.4 Strengths and challenges

Persistent deployments of autonomous vehicles are challenging anywhere in the world. This is particularly true in the Baltic Sea as the vehicles are sensitive to strong density gradients, fast currents, shipping and fishing activity. VOTO Ocean Knowledge seeks to develop Best Practices allowing for easier, more cost-effective monitoring of the Baltic Sea. VOTO, SAMBA and the platform manufacturers have been working together to optimise glider capabilities in this regions Incremental increases in capabilities are being made available to other users through collaborative work in the region. The partnership of academia, industry and the VOTO foundation is a cornerstone of the project and key to future success.

A key challenge and success of SAMBA was demonstrating a sustainable presence in regions of strong currents and density gradients. As underwater gliders use buoyancy as their driving force, they are constrained to a maximum density gradient and their battery consumption is directly tied to the gradients they must overcome. The gliders deployed at the Skagerrak/Kattegat confluence are often affected by the northward, fresh, Swedish coastal current (Figure 6). In this region, the gliders overcame density gradients of 14 kg m^{-3} . This gradient is far greater to that advertised as the limit by the most commonly used gliders' manufacturers. Despite the extreme gradients, battery consumption showed estimated mission durations of a month while sampling all sensors at 1Hz and the ADCP at 0.1Hz.

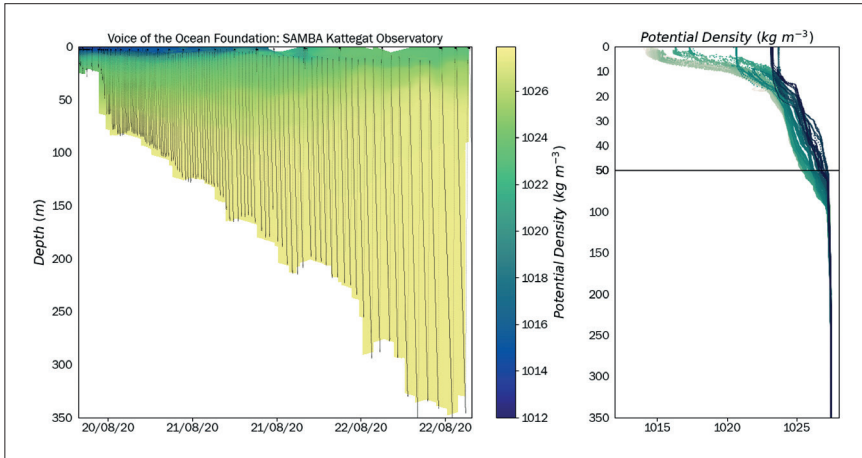


Fig. 6. Example transect of the Swedish coastal current observed by a SeaExplorer highlighting the strong density gradients in the region.

Many cargo ships use the shipping channel past Skagen (Denmark) and down through the Denmark Straits. In addition to these large freighters, close to the Bohuslan coastline there are numerous fishing vessels and pleasure craft which may not always have an AIS signature. To minimize the risk of collision, waypoints are selected to be out of the main shipping channel, so that crossing times are reduced. By having waypoints in 'safe zones', the Sailbuoy will hold position after finishing a transect in a relatively safe location before being directed to the next waypoint. Gliders are often programmed to transit with the top inflection of their dive below the surface (forming a dive profile similar to a W), especially in regions with high currents and high vessel presence.

Near coastal deployments present greater risks from greater human presence, more dynamic processes and strong currents. The availability of pilots 24 hours a day is a necessity. Both the Sailbuoy and the SeaExplorer were selected for their ease of piloting, allowing the foundation to build a large pool of pilots with no prior experience for sustained piloting autonomous vehicles. Several students from the University of Gothenburg are employed during the Masters programme; these pilots are rotated in and out as they start and end their programmes. This provides valuable experience, a welcome supplement to their income, and an exciting way to engage with new oceanographers. The student piloting team has been very successful and beneficial to both the scientists and the foundation.

4. Conclusions

Initial data from the Skagerrak and Bornholm Basin observatories show a wealth of interesting features, many occurring at small temporal and spatial scales hard to resolve through existing means. Figure 7 shows a collection of plots from the first 40 days of the Bornholm Observatory. These figures are composites of 5876 individual profiles, sampled at vertical resolutions of ~10 cm. The observatories are still new, and we do not yet exploit the full capability of the gliders in terms of endurance or resolution. Piloting in such conditions is challenging and significant effort is dedicated to optimising flight to increase endurance. As is always the case in science, a luck component is ever present, and the first glider turnaround at this location occurred during the peak of the spring bloom.

We plan to make all SAMBA data accessible and visible online by the end of the year. Information will be provided on the VOTO website and over @VOTO_Knowledge's twitter. SAMBA's current research component is led by Bastien Queste and Sebastiaan Swart at the University of Gothenburg, Sweden. The SAMBA project will however collect a huge amount of data and welcomes collaborations on all topics. VOTO Ocean Knowledge's remit is to foster international collaboration and this extends to SAMBA. The high resolution observations at these sites can reveal new insights into short term, patchy and submesoscale processes, but real step changes in our understanding of the Baltic will come from combined use of existing long-term infrastructure, new technological developments and collaboration with experts from around the world.

Acknowledgements

We wish to acknowledge the hard work and insight of the pilots, Estel Font, Hanna Rosenthal, Johan Edholm, and Stina Wahlgren. It's easy to pilot a glider, but it's hard to do it in a way that collects good data. We wish to thank Carl Douglas, Ola Oskarsson, and the Voice of the Ocean Foundation for their support and dedication to this project.

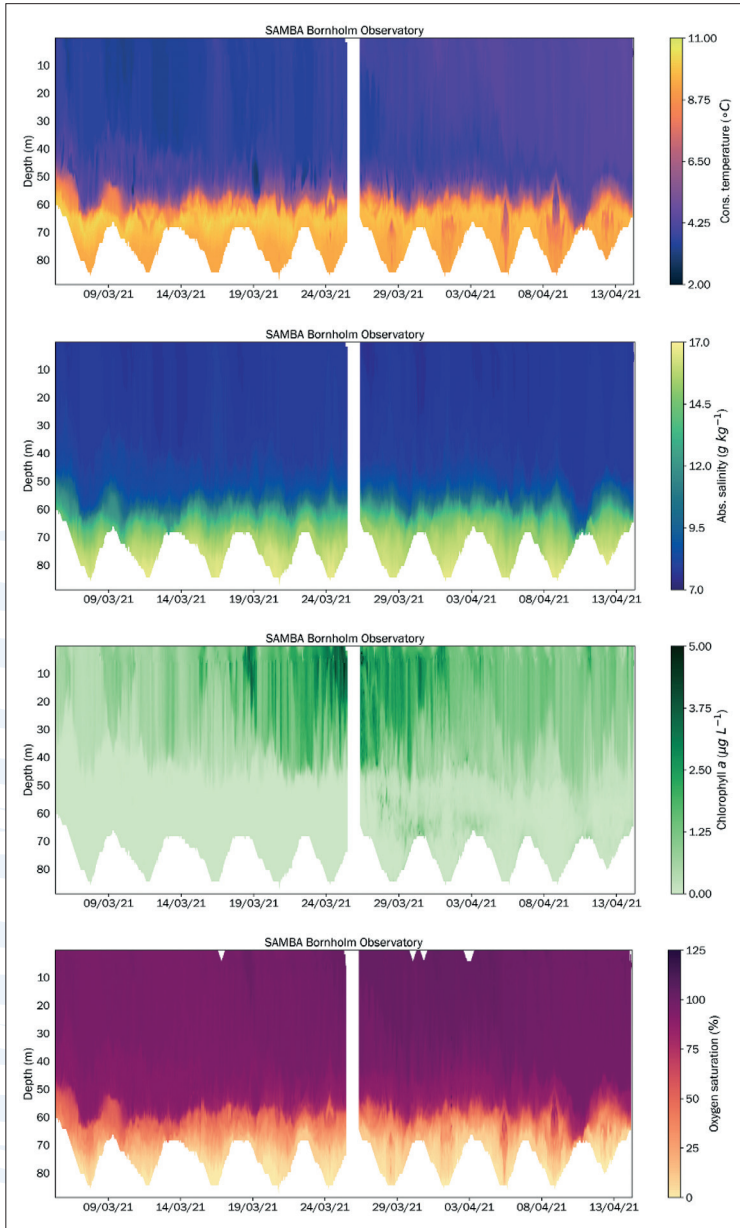


Fig. 7. Composite sections of temperature, salinity, chlorophyll a fluorescence and dissolved oxygen saturation at Bornholm Basin from the first 40 days of the observatory.