Project information	
Project full title	EuroSea: Improving and Integrating European Ocean Observing and Forecasting Systems for Sustainable use of the Oceans
Project acronym	EuroSea
Grant agreement number	862626
Project start date and duration	1 November 2019, 50 months
Project website	https://www.eurosea.eu

Deliverable information	
Deliverable number	D6.2
Deliverable title	**Demonstration of annual/quarterly assessments and description of the production system**
Description	This task set out to increase communication between the ocean monitoring and modelling communities in the Baltic Sea area. Through these improved communications, the goal was to advance and improve the HELCOM marine environmental assessments. To gain confidence in the numerical model outputs, an effort was undertaken to ensure ocean observing *in-situ* data, collected by multiple nations in the Baltic Sea, was assimilated into a numerical model. Here, we report on the development of indicators, as requested by our stakeholders, and we discuss if the Baltic Sea numerical modelling efforts are ready to augment regional environmental status reports, and can our results help guide environmental management in the region.
Work Package number	6
Work Package title	Ocean Health Demonstrator
Lead beneficiary	TalTech
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Due date	31.10.2022
Submission date	30.10.2022
Comments	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862626

https://doi.org/10.3289/eurosea_d6.2

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Executive summary

Historically, the coordination of operational oceanography and the environmental health monitoring activities in the same sea area has been misaligned and fragmented, e.g., the Baltic Operational Oceanographic System (BOOS) and the Helsinki Commission (HELCOM) in the Baltic Sea area. In this case, HELCOM assessments are produced with some delay and, generally, do not contain all available near-real time data, while operational products would benefit from the timely delivery of ocean health data that has been not agreed upon previously in the context of operational oceanography.

This EuroSea task aims at integrate efforts from both the BOOS and HELCOM monitoring networks, resulting in a more fit-for-purpose operational oceanography system and enhanced environmental assessments in the Baltic Sea. The following steps were implemented in the EuroSea project:

1) the timeliness (latency) of ship data delivery according to operational oceanography requirements was promoted in HELCOM;

2) interim reanalysis by assimilating both BOOS and HELCOM data for a selected period was conducted;

3) indicator assessments based on integrated products for the selected period were produced for both eutrophication status and marine extreme events.

Products were designed in close consultation with the HELCOM community and introduced at relevant HELCOM meetings and will be published on the BOOS and HELCOM websites.

1. Introduction

In the past, operational oceanography and the environmental health monitoring activities in the same sea were uncoordinated in the Baltic Sea. HELCOM assessments are produced with some delay and, generally, do not contain all available near-real time data, while operational products would benefit from timely delivery of ocean health data that has been not agreed earlier.

To improve the assessment system and demonstrate the value of Copernicus Marine Environmental Monitoring Service (CMEMS) products for environmental assessments, this activity was carried out in the framework of the EuroSea project. For this, increased cooperation between the BOOS and HELCOM monitoring networks in order to enhance and support a more fit for purpose operational oceanographic system leading to improvements of environmental assessments in the Baltic Sea, was initiated.

Consultations were conducted with the relevant HELCOM working groups (WGs) to select useful indicators/products of value for the HELCOM assessments. A number of eutrophication indicators were selected. Hydrography/extreme event indicators were considered and tested. Where the quality/confidence of indicator results was high, the CMEMS products were deemed appropriate to use. Regarding indicators that rely on (stratification-dependent) water column parameters, interim reanalysis using rapidly available ship CTD casts / monitoring data was required.

An effort was made to ensure ship data delivery in accordance with operational oceanography requirements. The success of this approach was heavily dependent on starting cooperation with individual institutes and promotion in HELCOM. Based on the acquired additional data, interim reanalysis was run by assimilating both BOOS and HELCOM data for a demonstration period (2020). The impact of interim reanalysis is presented comparing CMEMC products, interim reanalysis outcome and *in-situ* data. Relevant indicators were recalculated to demonstrate the benefits of how the integration efforts improve operational products and environment assessments.

All products were presented at the HELCOM State & Conservation WG meetings and will be published on BOOS and HELCOM websites.

2. Indicators relevant for HELCOM assessments

2.1. HELCOM indicators and environmental fact sheets

Indicators are used for many purposes, including the assessment of the environmental or ecological status of the marine environment, e.g., required by the EU Marine Strategy Framework Directive (MSFD) and Water Framework Directive (WFD). Relevant ocean observations are essential to develop suitable data products (e.g., indicator assessments) for science-based decisions and management actions. Indicator-based assessments can have legal implications if applied, for instance, in the process of the implementation of EU directives.

The MSFD requires that Member States define indicators and associated thresholds to indicate whether a good environmental status (GES) in a marine area is achieved or not. Such GES indicators must be scientifically sound and based on freely available data collected according to agreed monitoring strategies and guidelines. Agreed protocols must be followed on how the indicator values are calculated (including spatial and temporal integration, i.e., assessment units and seasons), with an agreed set GES threshold. HELCOM applies a eutrophication status assessment with a set of core indicators characterising nutrient levels (dissolved inorganic nitrogen – DIN, dissolved inorganic phosphorus – DIP, total nitrogen – TN, and total phosphorus – TP), direct effects (chlorophyll-a – Chl-a) and indirect effects (Secchi depth and Oxygen debt) of eutrophication. In addition, in some sea basins, cyanobacterial blooms and the status of soft-bottom macrofaunal community indicators are used (Table 1 for details). Furthermore, a shallow water oxygen indicator is under development.

Most of the HELCOM core eutrophication indicators only use laboratory analysis results of collected water samples as the sole data source. Exceptions to this include the oxygen debt indicator that in addition to laboratory results, uses information from CTD profiles and a Chl-*a* indicator which integrates water sample analyses in the laboratory with underway water sampling using a ferrybox and satellite derived earth observational data (note: this is not always the case for all sub-basins). Traditional methods, such as water sampling from research vessels, require relatively high efforts regarding cost and time, and therefore, cannot be conducted as often as is necessary to meet the data requirements regarding spatio-temporal resolution and coverage (Mack *et al.*, 2020).

As a result, the confidence of the indicator assessments for DIN and DIP in open sea areas of the Baltic Sea is ranked as moderate or low due to the lack of monitoring data (HELCOM, 2018a[1]; HELCOM, 2018b[2]). In principle, the number of stations and monitoring frequency for both DIN and DIP in HELCOM countries is quite high. However, since the indicator assessments need DIN and DIP data in winter (December – February), the total number of data points used is relatively low (Lips *et al.*, 2018). Thus, the HELCOM community want to improve the confidence of the environmental assessments by applying new technologies to increase the amount of data used for the assessments. Until now, numerical models are not used as an additional data source.

[1] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-nitrogen-DIN-HELCOM-core-indicator-2018.pdf
[2] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-phosphorus-DIP-HELCOM-core-indicator-2018.pdf

Table 1. HELCOM core indicators for eutrophication status assessment

Indicator	Depth range	Season	Calculation	Data used	Link
DIN (dissolved inorganic nitrogen)	0-10 m	Winter (Dec-Feb)	Arithmetic mean	Water sample analyses	HELCOM, 2018a[3]
DIP (dissolved inorganic phosphorus)	0-10 m	Winter (Dec-Feb)	Arithmetic mean	Water sample analyses	HELCOM, 2018b[4]
TN (total nitrogen)	0-10 m	Whole year (Jan-Dec)	Arithmetic mean	Water sample analyses	HELCOM, 2018c[5]
TP (total phosphorus)	0-10 m	Whole year (Jan-Dec)	Arithmetic mean	Water sample analyses	HELCOM; 2018d[6]
Chl-a	0-10 m	Summer (Jun-Sep)	Arithmetic mean[7]	Water sample analyses, ferrybox[8] and EO[9]	HELCOM, 2018e[10]
Cyanobacterial Bloom Index (CyaBI)	Sea surface	Summer (20 June – 31 August)	Normalized mean value	Earth observations and water sample analyses	HELCOM, 2018f[11]
Water clarity (Secchi depth)	-	Summer (Jun-Sep)	Arithmetic mean	Visual observations, daytime only	HELCOM, 2018g[12]
Oxygen debt	Sub-halocline layer	Whole year (Jan-Dec)	Arithmetic mean	Water sample analyses and CTD profiles	HELCOM, 2018h[13]
State of the soft-bottom macrofauna community	Bottom	Late spring -early summer	20th percentile of BQI[14]	Grab sample analyses	HELCOM, 2018i[15]

The environmental status of a sea area depends on both natural forcing and human-induced pressures. Among natural forcing, hydrographic conditions, long-term changes (natural climate variability) and extremes are of a major interest. HELCOM has a tradition of producing Baltic Sea Environmental Fact Sheets. These reports are available on the HELCOM web site[16]; however, they are infrequently published (Table 2).

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[3] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-nitrogen-DIN-HELCOM-core-indicator-2018.pdf
[4] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-phosphorus-DIP-HELCOM-core-indicator-2018.pdf
[5] https://helcom.fi/wp-content/uploads/2019/08/Total-nitrogen-HELCOM-core-indicator-2018.pdf
[6] https://helcom.fi/wp-content/uploads/2019/08/Total-phosphorous-HELCOM-core-indicator-2018.pdf
[7] Arithmetic mean is calculated separately for each data source and after that the results are integrated using specified weights
[8] Only in the Northern Baltic Proper and Western Gulf of Finland
[9] Earth observations, data used not in all basins
[10] https://helcom.fi/wp-content/uploads/2019/08/Chlorophyll-a-HELCOM-core-indicator-2018.pdf
[11] https://helcom.fi/wp-content/uploads/2019/08/Cyanobacterial-bloom-index-HELCOM-pre-core-indicator-2018.pdf
[12] https://helcom.fi/wp-content/uploads/2019/08/Water-clarity-HELCOM-core-indicator-2018.pdf
[13] https://helcom.fi/wp-content/uploads/2019/08/Oxygen-debt-HELCOM-core-indicator-2018.pdf
[14] BQI – biological quality index calculated based on the share of sensitive species in the community
[15] https://helcom.fi/wp-content/uploads/2019/08/State-of-the-soft-bottom-macrofauna-community-HELCOM-core-indicator-2018.pdf
[16] https://helcom.fi/baltic-sea-trends/environment-fact-sheets/

Table 2. HELCOM Baltic Sea Environment Fact Sheets (BSEFS) on hydrography

No.	Title	Latest year available
1	Hydrography and oxygen in the deep basins	2017
2	Development of sea surface temperature in the Baltic Sea	2019
3	The ice season	2012
4	Total and regional runoff to the Baltic Sea	2016
5	Water exchange between the Baltic Sea and the North Sea, and conditions in the deep basins	2017
6	Wave climate in the Baltic Sea in 2020	2021

The HELCOM Recommendation 10/1 on abnormal situations in the marine environment[17] recommends that the contracting parties to the Helsinki Convention should use early warning systems for alerts and for reporting abnormal environmental situations. Events that can be considered include river flooding, extreme storms, sea level change, ice conditions, sea surface temperature change, salt water inflows, etc. Since CMEMS data allow the characterisation of such conditions and events, it was proposed that the EuroSea project develop relevant indicators. The wish from HELCOM was that the developed indicators should be useful for environmental assessments. Thus, spatial and temporal presentation of hydrography / extreme events indicators must be comparable with the HELCOM assessment units and seasons when calculating environmental indicators (e.g. eutrophication status indicators).

In addition to the data-based factsheets, HELCOM and the Baltic Earth community have developed and published climate change 2021 fact sheet (HELCOM/Baltic Earth, 2021[18]). These climate change indicator reports are based on information in the scientific literature, describing for each parameter, what has happened in the past, what the prediction of the future is, and where the knowledge gaps are. The parameters/indicators considered include water temperature, salinity and salt water inflows, water column stratification, sea level, waves, etc.

2.2. Potential indicators derived from available CMEMS products

Eutrophication indicators

All HELCOM eutrophication core indicators were considered for production in EuroSea Task 6.3. The selected indicators (Table 3) cover nutrients (DIN, DIP, TN, TP), direct effects (Chl-*a*) and indirect effects (Oxygen debt). CMEMS modelled products (based on BAL MFC PDAF-NEMO-ERGOM model complex) BALTICSEA_ANALYSISFORECAST_BGC_003_007 and BALTICSEA_REANALYSIS_BIO_003_012 were tested and the outcome of the reanalysis product was selected for initial indicator calculations. For the Chl-*a* indicator, the satellite remote sensing CMEMS product OCEANCOLOUR_BAL_CHL_L3_NRT_OBSERVATIONS_009_049 can be used. Spatial coverage considered to calculate the indicators included the entire Baltic Sea area, while the assessment results are derived for the HELCOM open-sea sub-basins. Temporal coverage examined was between 1993-2020 and the assessment results were presented yearly or for a multi-year assessment period, a similar approach to that take in previous HELCOM assessments (e.g., 2011-2016) was used. Within the current activity, DMI interim reanalysis was carried out by assimilating near real time HELCOM and

[17] https://helcom.fi/wp-content/uploads/2019/06/Rec-10-1.pdf
[18] https://helcom.fi/wp-content/uploads/2021/09/Baltic-Sea-Climate-Change-Fact-Sheet-2021.pdf

operational data to test if the increased amount of *in-situ* data assimilated will improve the confidence of indicator assessments for the selected HELCOM core indicators.

Table 3. Potential indicators derived from CMEMS products for the Baltic Sea eutrophication status assessment

Eutrophication indicators	**Extended description**
Dissolved inorganic nitrogen (DIN) and	Winter concentrations of dissolved inorganic nitrogen (DIN) in the surface layer (Dec-Feb, 0-10 m)
Total nitrogen (TN)	Yearly average concentration of total nitrogen (TN) in the surface layer (Jun-Sep, 0-10 m)
Dissolved inorganic phosphorus (DIP)	Winter concentrations of dissolved inorganic phosphorus (DIP) in the surface layer (Dec-Feb, 0-10 m)
Total phosphorus (TP)	Yearly average concentration of total phosphorus (TP) in the surface layer (Jun-Sep, 0-10 m)
Chlorophyll-*a* (Chl-*a*)	Summer concentrations of chlorophyll-a (Chl-*a*) in the surface layer (Jun-Sep, 0-10 m)
Oxygen debt	Oxygen debt in the deep layer (yearly average, sub-halocline layer)[19]

Since CMEMS products are unavailable for total nutrient concentrations (TN and TP), calculations of related indicators require making additional assumptions on the proportions of inorganic nutrients in total concentrations. Therefore, the present action is limited to winter concentrations of inorganic nitrogen and phosphorus as nutrient indicators. The Chlorophyll-*a* indicator is calculated based on both model outputs and remote sensing data. The oxygen debt indicator, based on CMEMS data, is still under development. There are problems with CMEMS output on deep water oxygen in some Baltic Sea basins (e.g. Gulf of Finland), and the applicability of CMEMS data has to be analysed in more detail. However, we are able to show that interim reanalysis, where water column data from *in-situ* measurements are incorporated, improve the existing deep-layer oxygen products (see Section 5).

Indicators describing hydrographic conditions and/or abnormal events

Four groups of indicators on hydrographic conditions and extremes were considered for the EuroSea Task 6.3 – Baltic Sea extremes include indicators derived from sea surface temperature (SST), indicators describing the strength of water column stratification, and indicators on the extent of near-bottom hypoxia and anoxia (Table 4). Ocean state reports, regularly prepared and published by the CMEMS consortium[20,21,22], include trends on sea surface temperature, sea level, ice conditions, chlorophyll etc. and comparison of the year under consideration with the long-term averages and statistics. CMEMS also provides ocean monitoring indicators based on *in-situ* observations, remote sensing and reanalysis products[23]. However, these indicators are mostly integrated over the entire Baltic Sea or represent individual stations. Such indicators give valuable information on long-term changes, but do not focus on certain seasons or basin/assessment units. In our task, we decided to concentrate on indicators that could be relevant for the Baltic Sea

[19] The volume-based average oxygen debt is defined as the “missing” oxygen relative to a fully saturated water column; another term often used is the apparent oxygen utilization (AOU).
[20] https://marine.copernicus.eu/access-data/ocean-state-report/ocean-state-report-4th-issue
[21] https://marine.copernicus.eu/access-data/ocean-state-report/ocean-state-report-5
[22] https://marine.copernicus.eu/news/copernicus-ocean-state-report-6-release
[23] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators

environmental status assessments. We developed and presented the indicators derived from the SST distributions, such as marine heatwaves and upwelling intensity, stratification, such as the upper mixed layer (UML) depth, temperature and salinity, and near-bottom salinity and oxygen.

Table 4. Potential indicators derived from CMEMS products for the Baltic Sea eutrophication status assessment

Indicators on hydrography/extremes	**Extended description**
Baltic Sea extremes	Extremes in sea level, surface waves, ice, etc.
Sea surface temperature (SST)	SST yearly, seasonal and monthly averages and variability, including marine heatwaves, upwelling intensity, etc.
Stratification	Upper mixed layer (UML) characteristics (depth), deep layer salinity (salt water inflows) and vertical stratification
Near-bottom hypoxia and anoxia	The area and volume of hypoxic and anoxic waters in the Baltic Sea

The selection of heatwaves and upwelling index as indicators was justified by their relevance for eutrophication-related assessments. Cyanobacteria is the main phytoplankton group responsible for higher chlorophyll-*a* concentrations in the Baltic Sea basins in summer. Water temperature is considered one of the main factors determining cyanobacteria bloom intensity. For instance, a positive relationship between SST and a cyanobacteria bloom strength in the Baltic Sea was found using remote sensing data (Siegel & Gerth, 2008). Currently, with sufficiently high SSTs, about 20-40 days of high temperatures promote cyanobacteria bloom development. By the end of this century, the number of days is likely to extend (e.g. 50–70 days), with the first cyanobacteria blooms occurring 10-20 days earlier then that observed today (Neumann *et al.*, 2012). Along with the higher SST, coastal upwelling events transporting nutrients to the sea surface are considered a factor that triggers blooms (Lips & Lips, 2008).

Data used in this task was acquired from CMEMS. Reanalysis and remote sensing SST data are from the CMEMS products BALTICSEA_REANALYSIS_PHY_003_011 and SST_BAL_SST_L4_REP_OBSERVATIONS_010_016, respectively. In addition, for near-bottom oxygen, CMEMS product BALTICSEA_REANALYSIS_BIO_003_012 was used.

2.3. Consultations with the HELCOM working group STATE & CONSERVATION

Consultations with the HELCOM relevant working structures started in the planning phase of the EuroSea project, specifically Task 6.3. HELCOM WG State & Conservation was informed about the activities at the WG meeting on 21-25 October 2019, i.e., before the EuroSea kick-off. The positive feedback on the project funding decision was reflected in the meeting memo:

"*5J.2 The Meeting welcomed the information that, regarding the abnormal events Recommendation, the EuroSea application to Horizon 2020 was successful and that the kick-off meeting will be held late November 2019 and State and Conservation 12-2020 will be invited to provide input to the discussion on project end product and service, with the intention to replace Recommendation 10/1 with a service.*"

At the HELCOM State & Conservation working group meeting in May 2020, the EuroSea Task 6.3 team asked for feedback on potential indicators to be developed and introduced the plan to speed up the data delivery in order to produce interim reanalyses and improve the products. Relevant future actions were highlighted in the meeting memo:

“*3MA.1 The Meeting took note of the EuroSea project activities (document 3MA-1 and Presentation 15), as presented by Estonia.*

3MA.2 The Meeting invited the Contracting Parties to reflect on their expectations regarding regular assessment reports on marine extreme events (e.g. what are the events to be included in the service?, how often the reports should be made available?, who should be informed?, should it be available as an HELCOM factsheet?) and inform Estonia (oliver.samlas@taltech.ee) by 4 June 2020 on their conclusions.

3MA.3 The Meeting invited the EuroSea project to share the status of its activities to STATE & CONSERVATION 14-2021.”

According to the request from HELCOM State & Conservation, the first product results were presented in the 2021 spring meeting of the working group. The wish of the WG for more elaborated products and dynamic presentation was reflected in the meeting memo:

“*3MA.1 The Meeting took note of the status of activities within the EuroSea project as presented by Urmas Lips, Estonia (Presentation 17).*

3MA.2 The Meeting considered the expectations regarding regular assessment reports on marine extreme events and discussed what parameters and themes would be useful to include in the HELCOM report to guide project development.

3MA.3 The Meeting supported that it would be interesting to more broadly consider extreme events as factors contributing to changes in the state of the marine environment (e.g. predictive formation of algal blooms) and to further evaluate underlying drivers of extreme events, as ecologically the extreme events are often more relevant than gradual change in mean conditions.

3MA.4 The Meeting noted that the project outcomes regarding extreme events could be incorporated into the driver indicator work within HOLAS III and made more accessible by using a more dynamic approach to presenting the material and the results, compared to that used for current Baltic environmental fact sheets, acknowledging that decisions on the use of the project outcomes should be considered in more detail when preliminary results are available.”

After the product development, the updated indicators and their potential use were presented at the 2022 spring meeting of the working group. The proposed products were well received, and the expectation was that they would be made operational in autumn 2022, and the final discussion on the products and the service will be in spring 2023 at the relevant WG meeting. The feedback was reflected in the memo as:

“*3MA.1 The Session recalled that STATE & CONSERVATION 12-2022 discussed end products and services prepared under the Horizon 2020 funded project EuroSea, with the long term intention to replace the HELCOM Recommendation 10/2 with a service. The Session took note of the information presented by Estonia on the status of activities under the task 6.3 within the EuroSea project (presentation 9).*

3MA.2 The Session noted the relevance of the questions from the task 6.3 of EuroSea project on marine heat waves as well as on upwelling index:

- *Marine heat waves:*
    - *Is such presentation of the thermal regime useful?*
    - *Should we include coastal areas?*
    - *Which indicators could be the most influenced (Chl-a, cyanobacterial bloom index, etc.)?*

- *Upwelling index:*
  - *Is such presentation of upwelling activity useful?*
  - *Should we divide the basins into northern and southern coastal areas?*
  - *Which indicators could be the most influenced (Chl-a, cyanobacterial bloom index, nutrients, etc.)?*

3MA.3 The Session invited the CPs to provide input on the questions mentioned above to Urmas Lips (urmas.lips@taltech.ee) by 06 June 2022 to guide further project activities.

3MA.4 The Session discussed the aggregation of data and took note of the information from Estonia that the current modelling tool can provide results on a yearly basis provided that the necessary data is made available. The Meeting noted that for the foreseeable future the data is secured through the Copernicus Marine services.

3MA.5 The Session highlighted the relevance of this work and invited EG EUTRO to consider the project outputs and their possible used.

3MA.6 The Session recommended the projects outputs be considered for inclusion in relevant sections of the HOLAS 3 reports."

2.4. Indicator results based on CMEMS products

Eutrophication indicators

DIN, DIP and Chl-*a* indicators are calculated based on CMEMS reanalysis products following the HELCOM core indicator methodologies[24,25,26]. Results can be presented for the Baltic Sea off-shore basins and compared with the set indicator threshold values. Achievement of good environmental status is determined by the ratio between the calculated indicator value and threshold value for each open-sea sub-basin set by HELCOM (Eutrophication Ratio – ER). If the calculated indicator value is below the threshold value, i.e. the eutrophication ratio is <1, then the marine status corresponds to a good environmental status. Below some selected examples of indicator presentation are given.

DIN

Average winter concentrations of dissolved inorganic nitrogen (DIN) in the upper 10 m layer are calculated for each model grid point of the CMEMS reanalysis product for every year from 1993-2020. DIN distributions are presented in HELCOM assessment units as shown for selected basins and years in Figure 1 and Figure 2. A user of the EuroSea Task 6.3 service can browse the maps for every basin and year. They demonstrate the variability within the basins and between the years. As the HELCOM routine foresees calculating indicator values over the entire basin and the fixed assessment period, a corresponding average distribution for basins or the entire Baltic Sea can be presented. Example output in Figure 3 shows the distribution of average DIN concentrations in the off-shore areas of the Baltic Sea in 2011-2016. This period corresponds to the last HELCOM assessment period.

DIN indicator values for the basins in 2011-2016 were calculated and compared with the set threshold and HELCOM indicator results from the same period. The results are presented in Figure 4 as eutrophication ratios

[24] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-nitrogen-DIN-HELCOM-core-indicator-2018.pdf
[25] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-phosphorus-DIP-HELCOM-core-indicator-2018.pdf
[26] https://helcom.fi/wp-content/uploads/2019/08/Chlorophyll-a-HELCOM-core-indicator-2018.pdf

(ER), calculated as average DIN concentrations divided by the threshold for the relevant basin. If the ER value was above 1, the basin did not reach good environmental status (GES). As seen from the figure, CMEMS-based assessment results differ from HELCOM assessment results for the same period (based on HELCOM monitoring data). In most of the central, deep Baltic basins, CMEMS data reveal a good status, while the HELCOM assessment showed non-GES for all basins. The largest difference, however, appeared in the Gulf of Riga, where CMEMS reanalysis results showed approximately five times larger ER value (calculated by dividing the average winter concentration of DIN by threshold) than the HELCOM assessment.

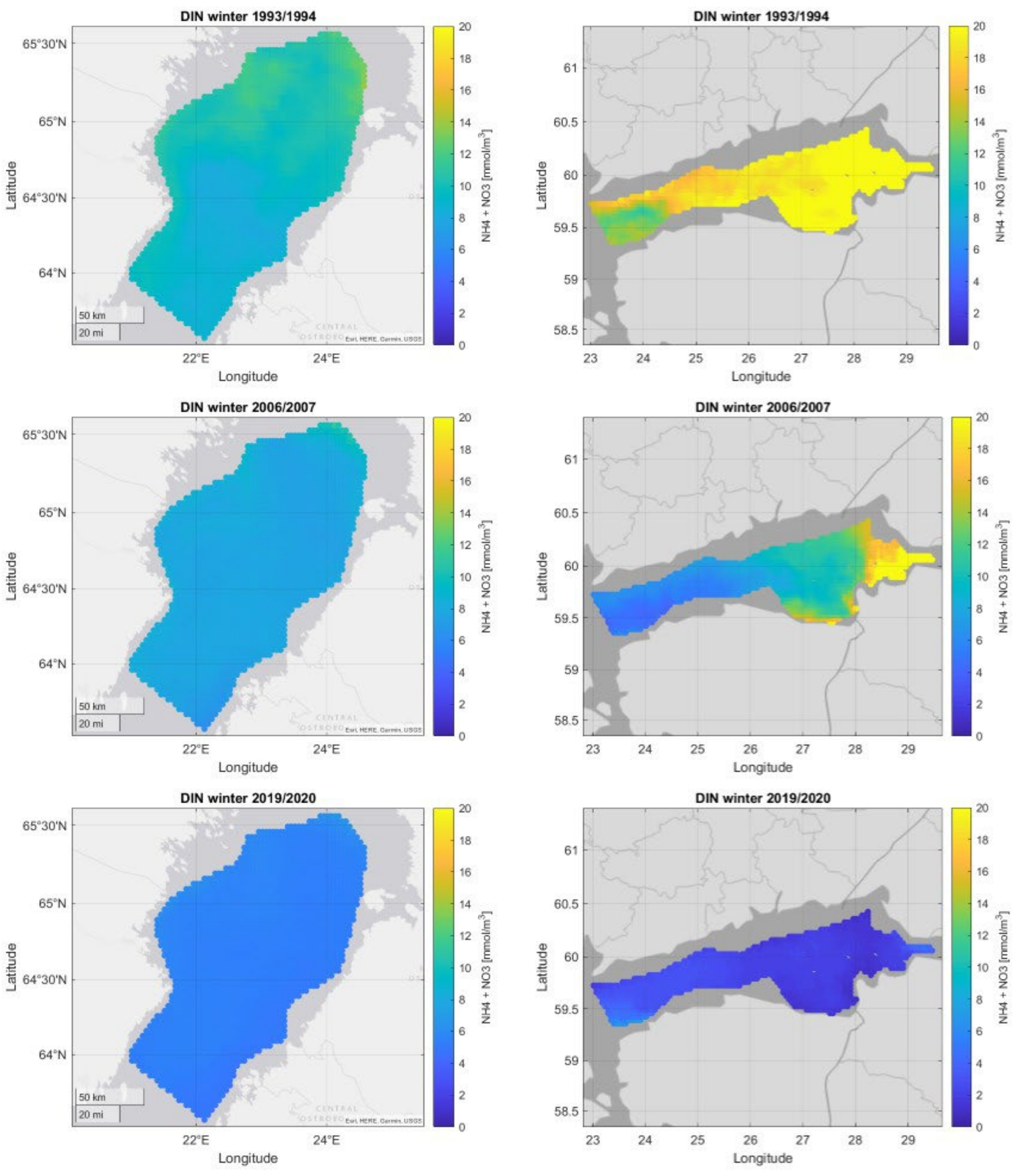

Figure 1. Distribution of dissolved inorganic nitrogen concentrations in the surface layer (0-10 m) of the Bothnian Bay (left column) and the Gulf of Finland (right column) in winters 1993/1994, 2006/2007 and 2019/2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

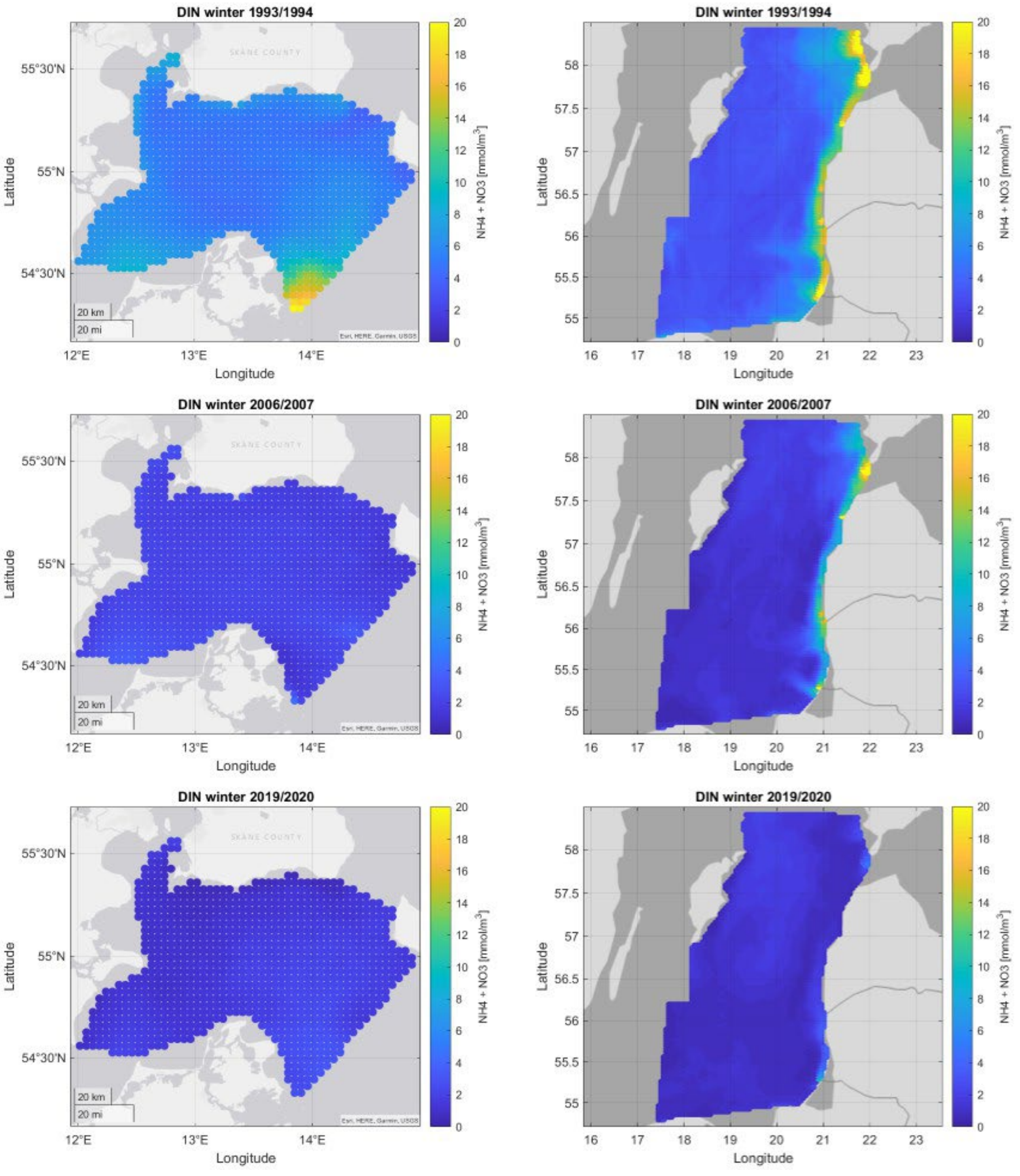

Figure 2. Distribution of dissolved inorganic nitrogen concentrations in the surface layer (0-10 m) of the Arkona Basin (left column) and the Eastern Gotland Basin (right column) in winters 1993/1994, 2006/2007 and 2019/2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

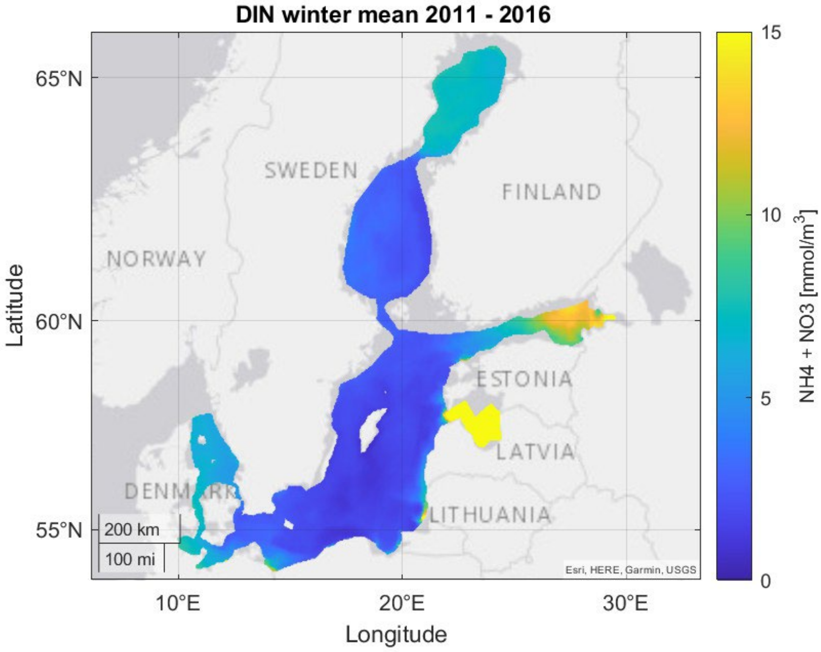

Figure 3. Distribution of dissolved inorganic nitrogen concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in winters 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

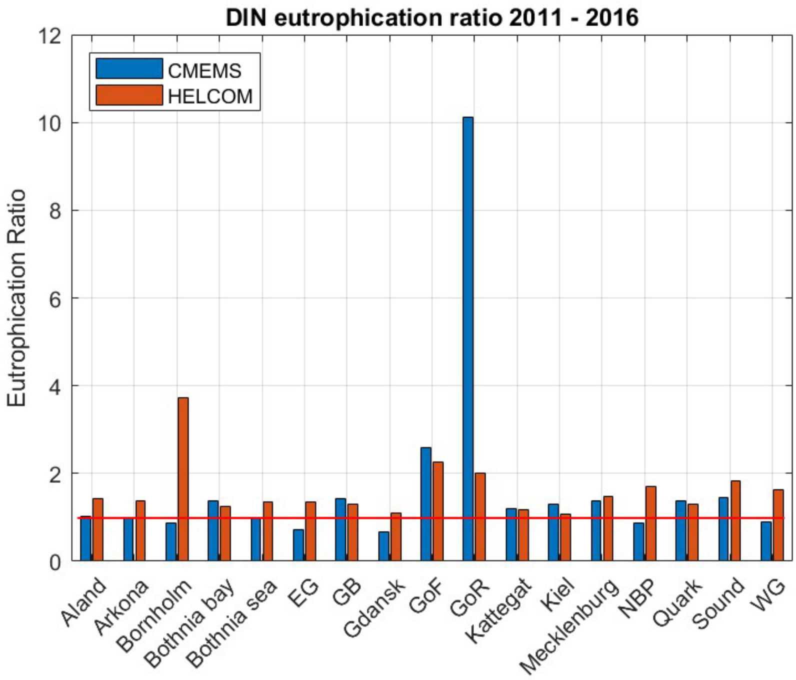

Figure 4. Assessment of eutrophication status (presented as eutrophication ratio – ER) based on average inorganic nitrogen concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in winters 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (blue bars) and HELCOM monitoring data (red bars). The Red line marks ER value one corresponding to the threshold of good environmental status.

DIP

Average winter concentrations of dissolved inorganic phosphorus (DIP) in the upper 10 m layer are calculated for each model grid point of the CMEMS reanalysis product for every year from 1993-2020. DIP distributions are presented in HELCOM assessment units as shown for selected basins and years in Figure 5 and Figure 6. The variability within the basins and between the years are seen in the presented example figures. The average distribution of winter concentrations of DIP during the assessment period 2011-2016 for all off-shore areas of the Baltic Sea in is presented in Figure 7.

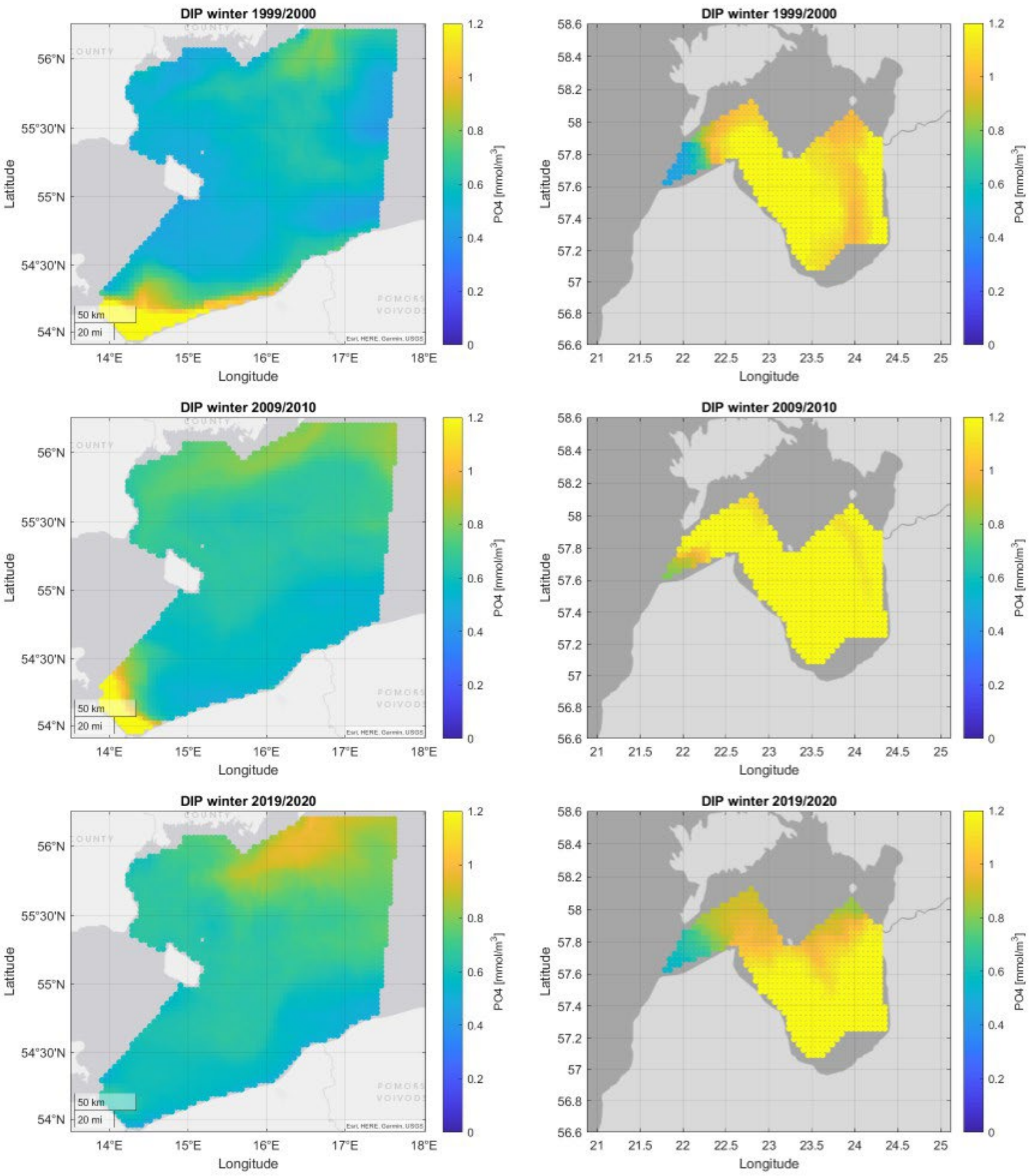

Figure 5. Distribution of dissolved inorganic phosphorus concentrations in the surface layer (0-10 m) of the Bornholm Basin (left column) and the Gulf of Riga (right column) in winters 1999/2000, 2009/2010 and 2019/2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

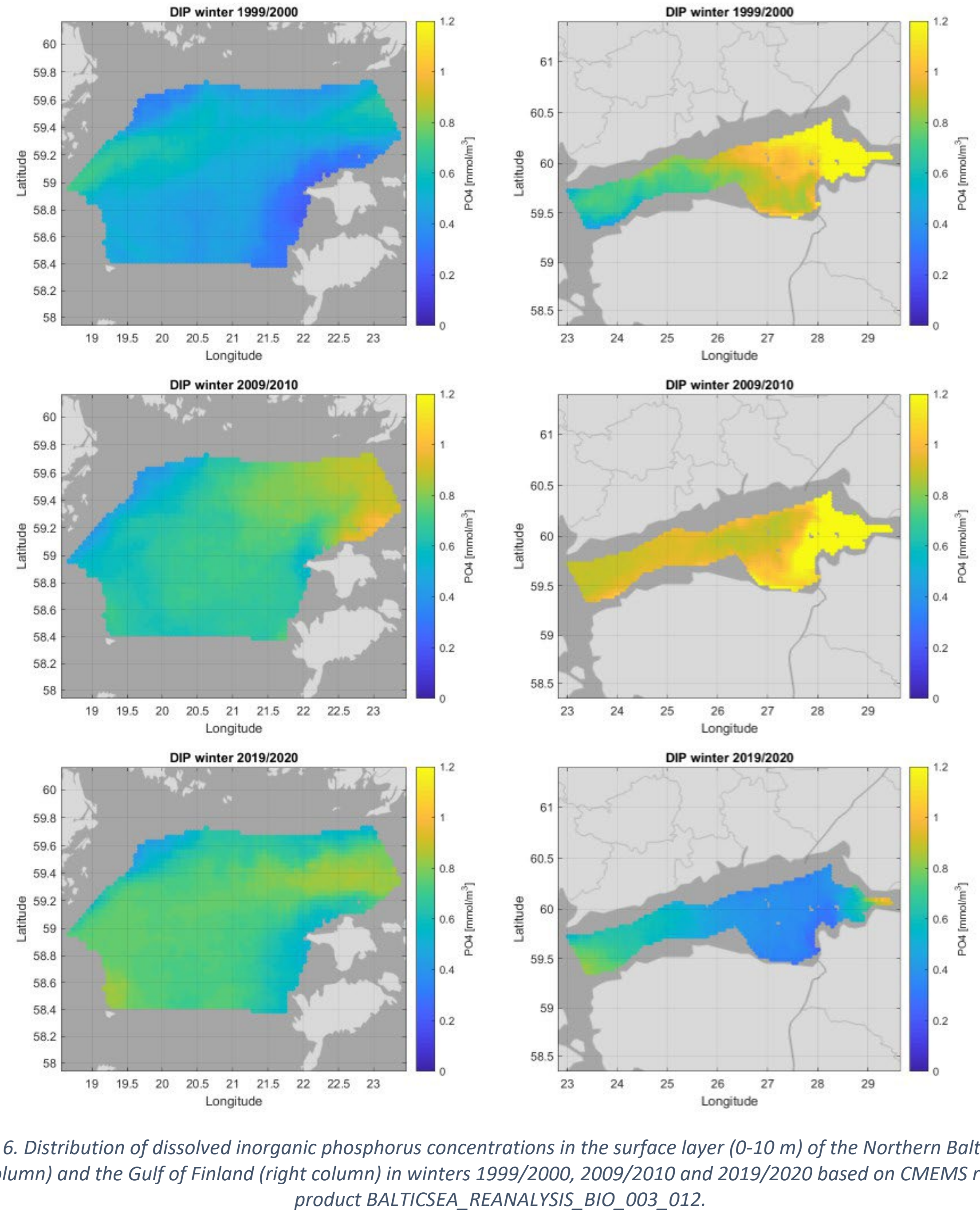

Figure 6. Distribution of dissolved inorganic phosphorus concentrations in the surface layer (0-10 m) of the Northern Baltic Proper (left column) and the Gulf of Finland (right column) in winters 1999/2000, 2009/2010 and 2019/2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

Comparing indicator values for the basins in 2011-2016 with the set threshold and HELCOM indicator results from the same period indicate that CMEMS-based assessment results differ from the HELCOM results but in opposite directions in different basins (Figure 8). In general, the CMEMS results overestimate DIP concentrations in most of the basins except the northernmost basins – the Bothnian Bay, Quark and Bothnian Sea. As a result, GES has been achieved in Bothnian Bay and Quark based on CMEMS data, while it is not based on HELCOM assessment results (Figure 8). At the same time, DIP concentrations have been decreasing during recent years in some basins, e.g. the Gulf of Finland (Figure 6), which could be connected to the decrease in nutrient loads. However, HELCOM monitoring has not yet identified such a decrease in winter concentrations of DIP in the Gulf of Finland.

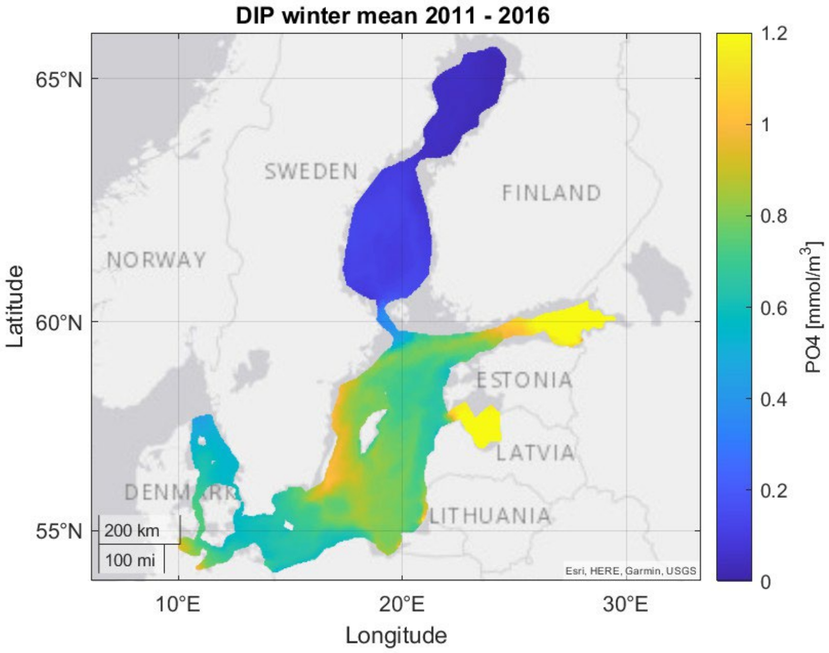

Figure 7. Distribution of dissolved inorganic phosphorus concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in winters 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

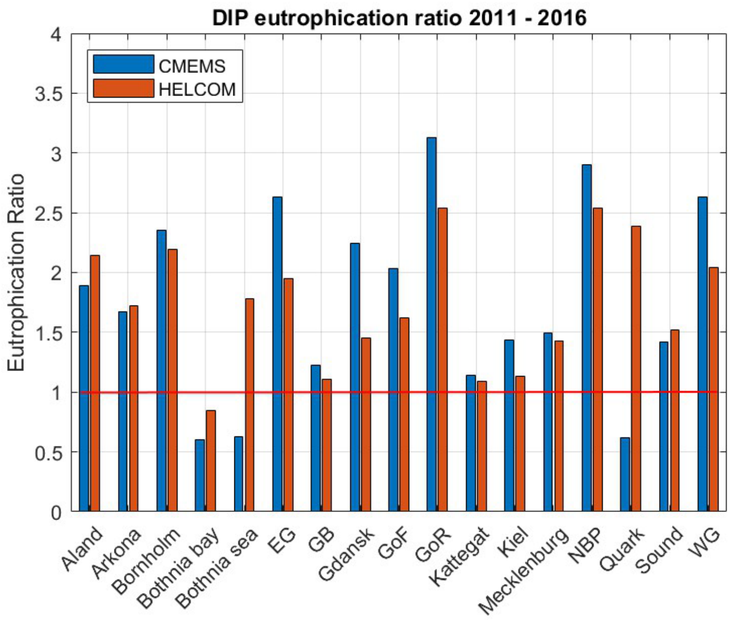

Figure 8. Assessment of eutrophication status (presented as eutrophication ratio – ER) based on average inorganic phosphorus concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in winters 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (blue bars) and HELCOM monitoring data (red bars). The Red line marks ER value one corresponding to the threshold of good environmental status.

Chlorophyll-a

Chlorophyll-*a* indicator calculations are based on the HELCOM core indicator report. The values of the indicator were calculated using BALTICSEA_REANALYSIS_BIO_003_012 from 1993 to 2020. Each year, the average chlorophyll-*a* concentration in the surface layer (0-10 m) for June-September was calculated. The surface layer was taken to include four depth layers for the reanalysis product.

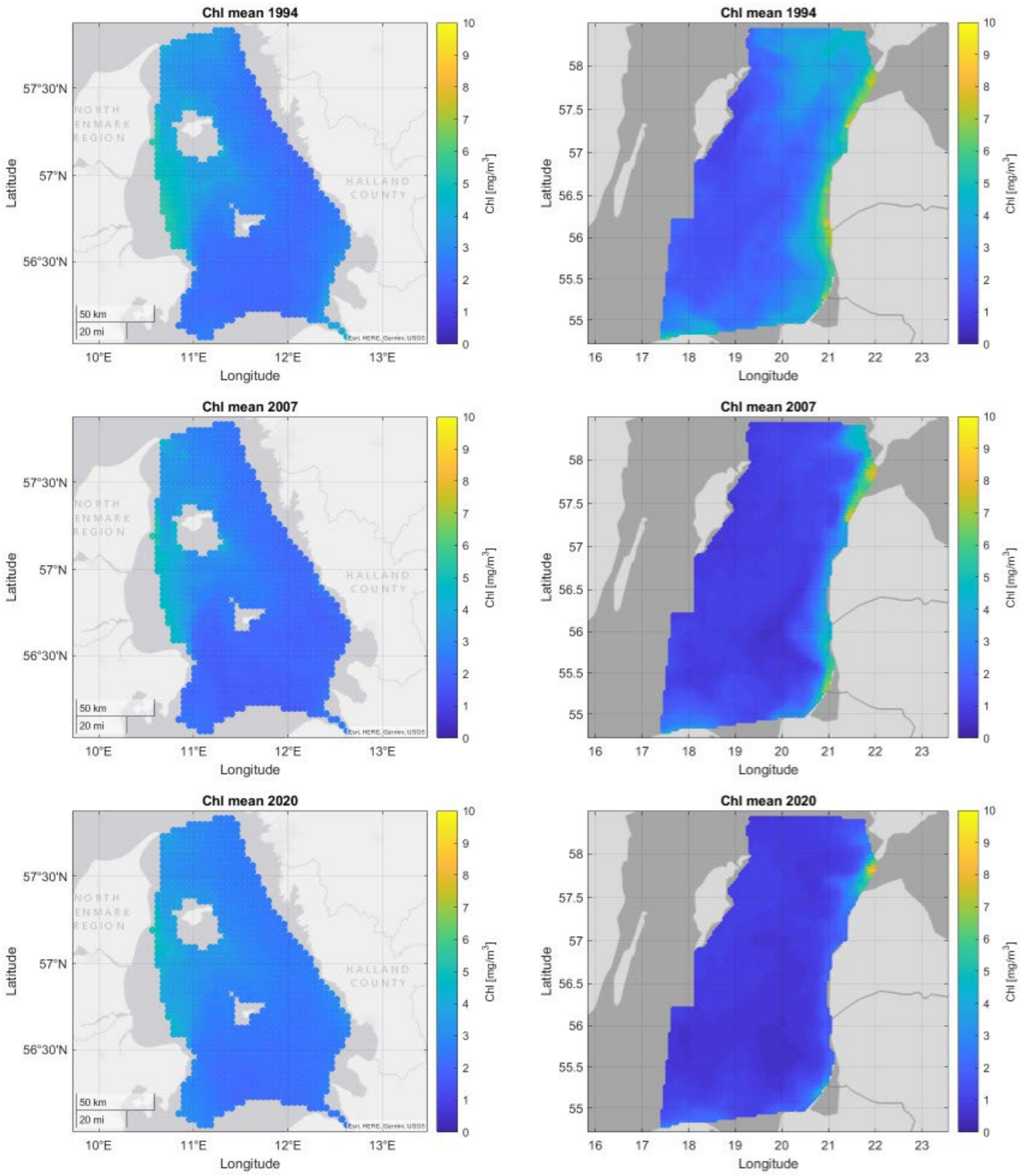

Figure 9. Distribution of chlorophyll-a concentrations in the surface layer (0-10 m) of the Kattegat (left column) and the Eastern Gotland Basin (right column) in summers 1994, 2007 and 2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

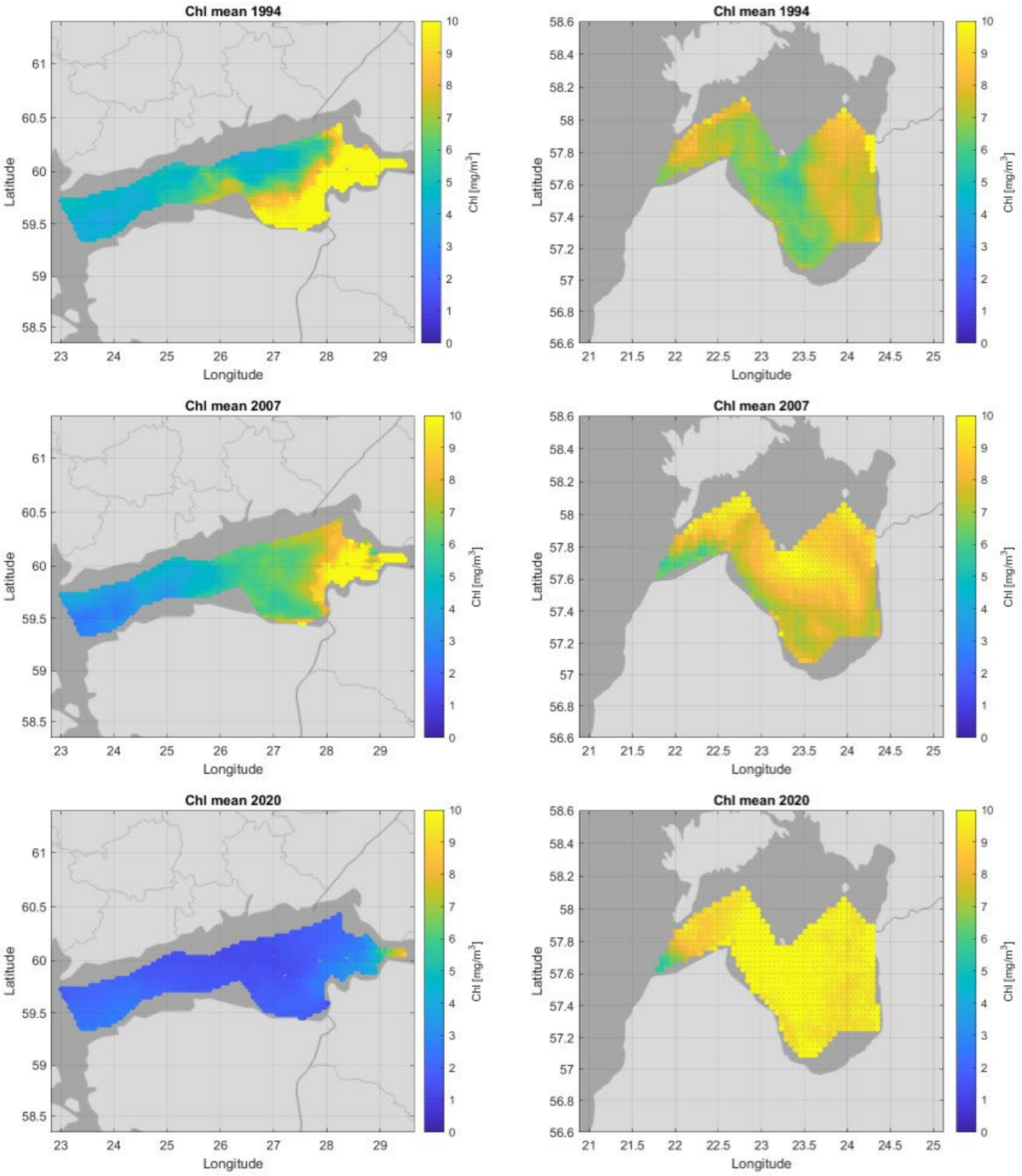

Figure 10. Distribution of chlorophyll-a concentrations in the surface layer (0-10 m) of the Gulf of Finland (left column) and the Gulf of Riga (right column) in summers 1994, 2007 and 2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

Chlorophyll-*a* distributions are presented in HELCOM assessment units as shown for selected basins and years in Figure 9 and Figure 10. The variability within the basins and between the years is seen in the presented example figures – low average chlorophyll-*a* levels are detected for the western and central basins, while much higher levels are characteristic for the eastern basins. Similar to the changes in DIP concentrations, chlorophyll-*a* concentrations have decreased in the Gulf of Finland in recent years if distributions are based on the CMEMS products (Figure 10 and Figure 11). However, HELCOM *in-situ* monitoring efforts has not observed such a decline in chlorophyll-a concentrations in this basin.

Chlorophyll-*a* indicator values in the northeastern basins for each year calculated from reanalysis model data are shown in Figure 11. In both central, deep basins – the Eastern Gotland Basin (EG) and Northern Baltic Proper (NBP), chlorophyll-*a* concentrations show low inter-annual variability, a relatively steady decline in the 1990s and achieving an almost constant average concentration of < 2 mg/m^3 in the 2000s. The inter-annual variability is relatively high in the Gulf of Finland (GoF) and Gulf of Riga (GoR). The latter basin is the only one where the chlorophyll-*a* concentrations have not decreased. The highest maximum concentration of 10.5 mg/m^3 was observed in the GoR in 2012, with concentrations almost at the same level since then. The GoF exhibits the largest fluctuations in chlorophyll-*a* concentrations, with the average concentration rising to 8.7 mg/m^3 in 2012. However, a drastic decline was evident after that, with a minimum of 1.1 mg/m^3 in the summer of 2019.

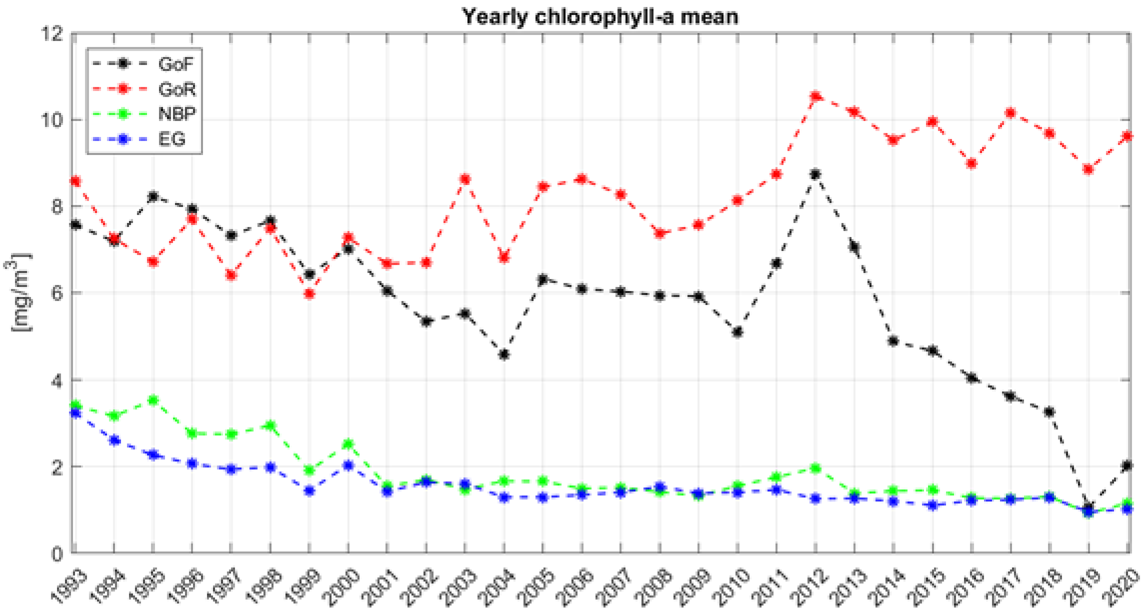

Figure 11. Long-term changes in chlorophyll-a for selected four sub-basins of the Baltic Sea in 1993-2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012. Averages for June-September in the surface layer 1-10 m are presented.

The average distribution of summer concentrations of chlorophyll-a during the assessment period 2011-2016 for all off-shore areas of the Baltic Sea is presented in Figure 12. High chlorophyll-*a* levels were detected in the Gulf of Riga and the Gulf of Finland. In all other basins, the summer chlorophyll-*a* concentrations are much lower. If the CMEMS-based assessment results are compared with the threshold values in basins and the HELCOM assessment results, some peculiarities can be noticed (Figure 13). Reanalysis data revealed that GES should have been achieved in the southern and central basins of the Baltic Sea. The HELCOM assessment indicated the achievement of GES only in the Kattegat. At the same time, the CMEMS-based assessment results in the eastern basins are worse than the HELCOM assessment has indicated.

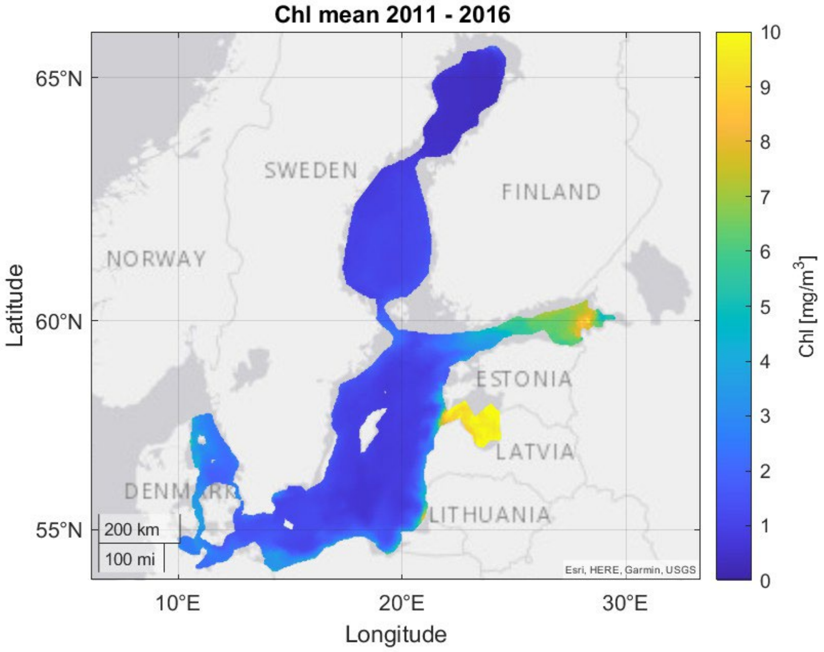

Figure 12. Distribution of chlorophyll-a concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in summers 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012.

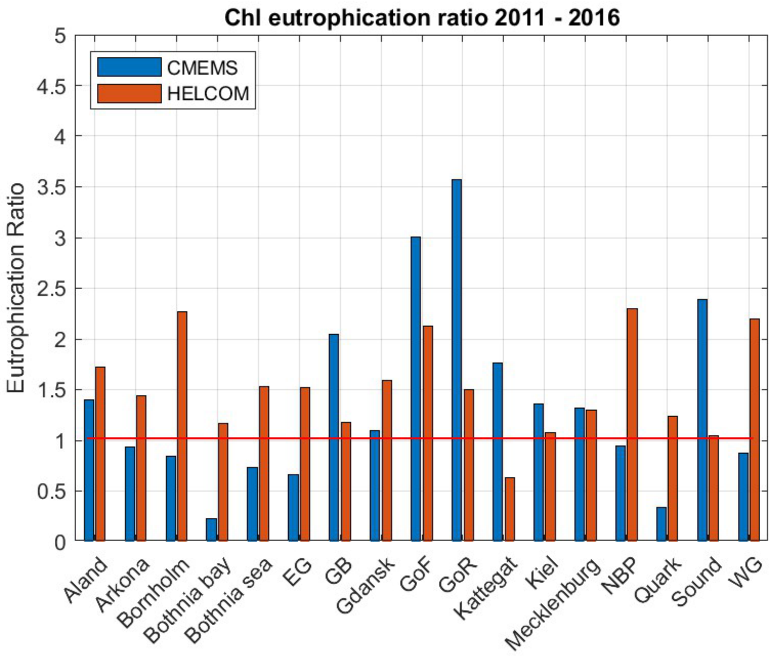

Figure 13. Assessment of eutrophication status (presented as eutrophication ratio – ER) based on average chlorophyll-a concentrations in the surface layer (0-10 m) of the off-shore areas of the Baltic Sea in summers 2011-2016 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (blue bars) and HELCOM monitoring data (red bars). The Red line marks ER value one corresponding to the threshold of good environmental status.

Indicators on hydrographic conditions

Available CMEMS indicators

Copernicus Marine Service offers a number of ocean monitoring indicators based on *in-situ* observations, remote sensing and reanalysis products. For the Baltic Sea, the following indicators are published in CMEMS:

- Ocean Health: Baltic Sea chlorophyll-*a* time series and trend, Baltic Sea cod reproductive volume, Baltic Sea chlorophyll-*a* trend map;
- Temperature and Salinity: Baltic SST cumulative trend map, Baltic SST extreme, Baltic SST anomaly time series and trend, Baltic Sea subsurface salinity trend, Baltic Sea subsurface temperature trend;
- Water Mass and Heat Exchange: Major Baltic Inflow: bottom salinity, Major Baltic Inflow: time/depth evolution S, T, O2;
- Sea Ice: Baltic Sea ice extent, Baltic Sea ice volume;
- Sea Level: Baltic Sea mean sea level time series and trend, Baltic Sea level extreme;
- Sea State: Baltic Sea significant wave height extreme.

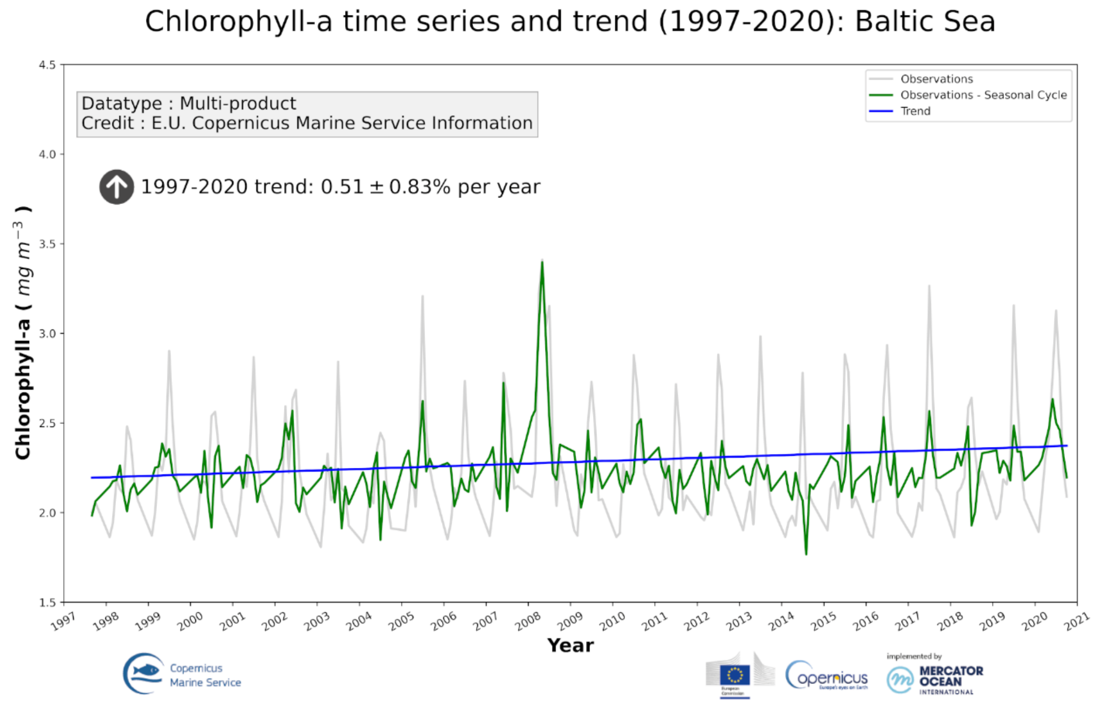

Figure 14. Baltic Sea time series and trend (1997-2020) of satellite chlorophyll, based on CMEMS product OCEANCOLOUR_BAL_CHL_L3_REP_OBSERVATIONS_009_080. The monthly regional average (weighted by pixel area) time series is shown in grey, with the deseasonalized time series in green and the trend in blue[27].

[27] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/baltic-sea-chlorophyll-time-series-and-trend-observations

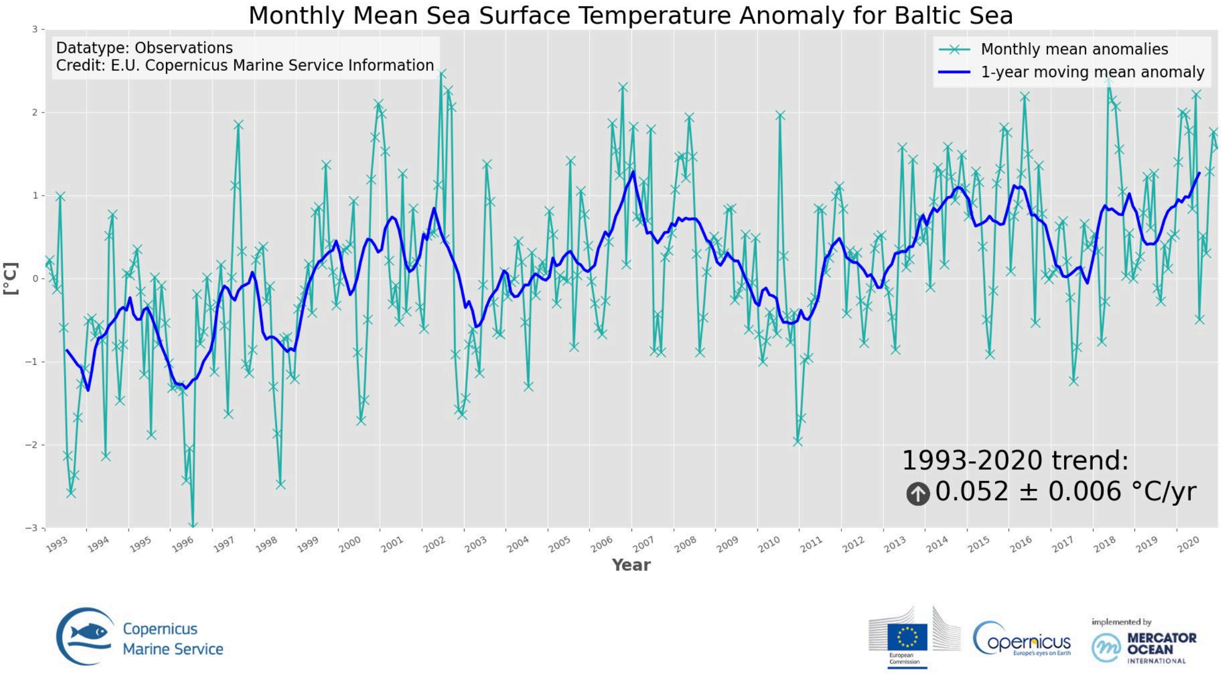

Figure 15. Time series of monthly mean (turquoise line) and annual mean (blue line) of sea surface temperature anomalies for January 1993 to December 2020, relative to the 1993-2014 mean, for the Baltic Sea SST product (BALTIC_OMI_TEMPSAL_sst_area_averaged_anomalies). The data are based on the multi-year Baltic Sea L4 satellite SST reprocessed product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016[28].

All listed CMEMS indicators are of great value for describing hydrographic and environmental conditions in the Baltic Sea. They pick up the long-term trends and interannual variability in essential ocean variables, such as chlorophyll-*a* (Figure 14), SST (Figure 15), and sea level (Figure 16). At the same time, more focused indicators are needed for the regional assessments of the environmental status. For instance, if the environmental status indicators are calculated for a specific ecosystem component, the influencing hydrographic conditions could be presented with a similar integration scale in time and space. In EuroSea Task 6.3, after consultation with the HELCOM community, the decision was made to concentrate on heatwaves and upwelling indicators. The spatial integration of indicators has to be the same as the environmental indicators to assign the changes in hydrographic conditions to the variability and trends in environmental indicators. Integration in time should be chosen based on the assumed impact of hydrographic conditions on the status assessment indicator values. It would help to explain the observed changes and differentiate between human-induced changes and natural variability.

[28] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/baltic-sea-surface-temperature-anomaly-time-series-and

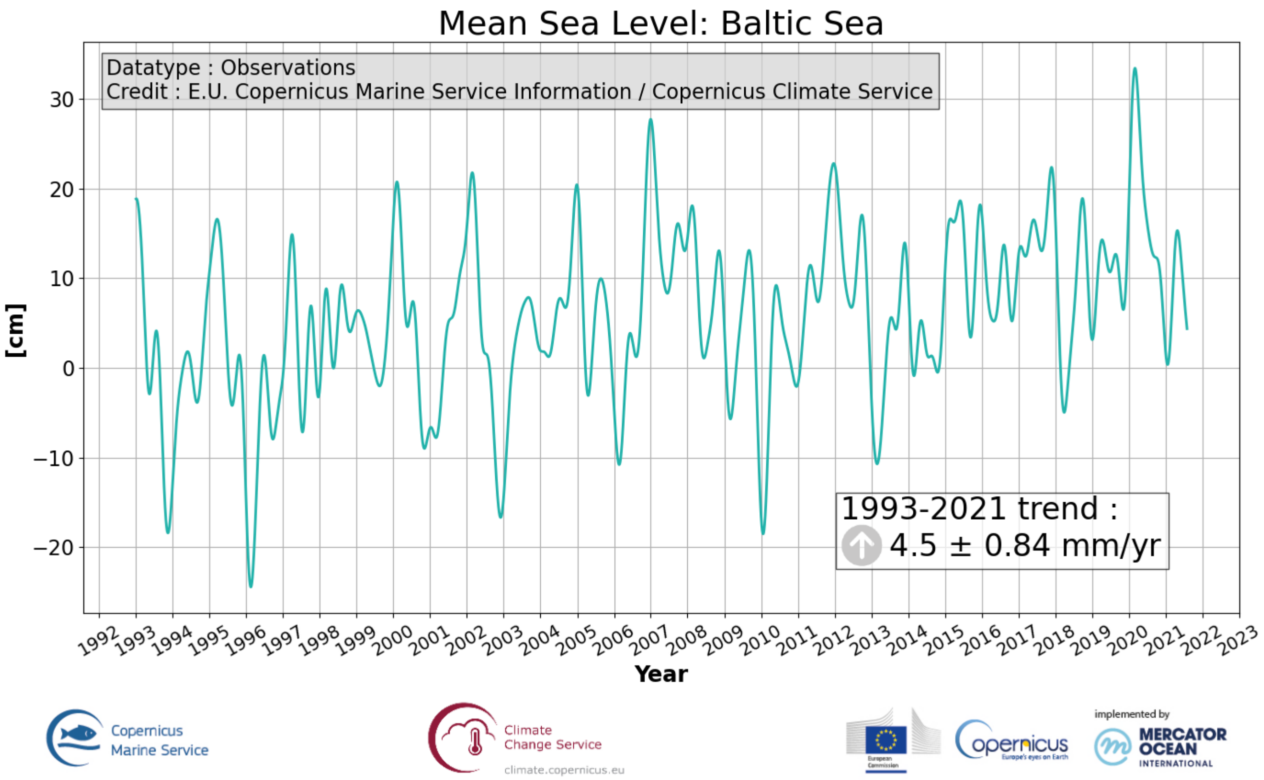

Figure 16. Mean sea level daily evolution since January 1993 (in cm) from the satellite altimeter observations estimated in the Baltic Sea, derived from the average of the gridded sea level maps weighted by the cosine of the latitude. The original product is the DUACS delayed-time (reprocessed version DT-2021) altimeter sea level gridded products distributed by the Copernicus Climate Change Service (C3S), also available in the CMEMS catalogue (SEALEVEL_GLO_PHY_CLIMATE_L4_MY_008_057). The timeseries is low-pass filtered, the annual and semi-annual periodic signals are adjusted, and the curve is corrected for the GIA using the ICE5G-VM2 GIA model (Peltier, 2004).[29]*.*

Heatwaves

For the occurrence and intensity of marine heatwaves, CMEMS reanalysis model product BALTICSEA_REANALYSIS_PHY_003_011 (called below as "reanalysis product") and remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016 (called below as "reprocessed product") were used. Since the remote sensing product provides longer time series, it was used to calculate the climatology and the 90th percentile of the sea surface temperature for each date in each grid cell from the period 1986-2020. The daily average and 90th percentile values were smoothed with a 30-day moving window.

Daily SST data representing all grid points were used from the reanalysis product. The remote sensing product has higher spatial resolution and was reassembled into a new grid coinciding with the reanalysis grid taking only the closest points to the reanalysis product grid points. Each year, a heatwave was identified when SST exceeded the calculated 90th percentile value in a grid point at that date within a period from 1 April to 31 October. This period was chosen because there is a higher possibility of encountering heatwaves, and it roughly corresponds to the vegetation period in the northeastern Baltic Sea. Examples of heatwave definitions/occurrences for two grid points in the Gulf of Finland are shown in Figure 17.

[29] https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/baltic-sea-mean-sea-level-time-series-and-trend

Additionally, separate calculations were made for the period from 1 June to 30 September, coinciding with the chlorophyll-*a* indicator period. The occurrence of a heatwave was estimated as the number of days with heatwaves, and the intensity of heatwaves was calculated as the sum of daily temperature deviations above the 90th percentile – an integrated measure of the duration and intensity.

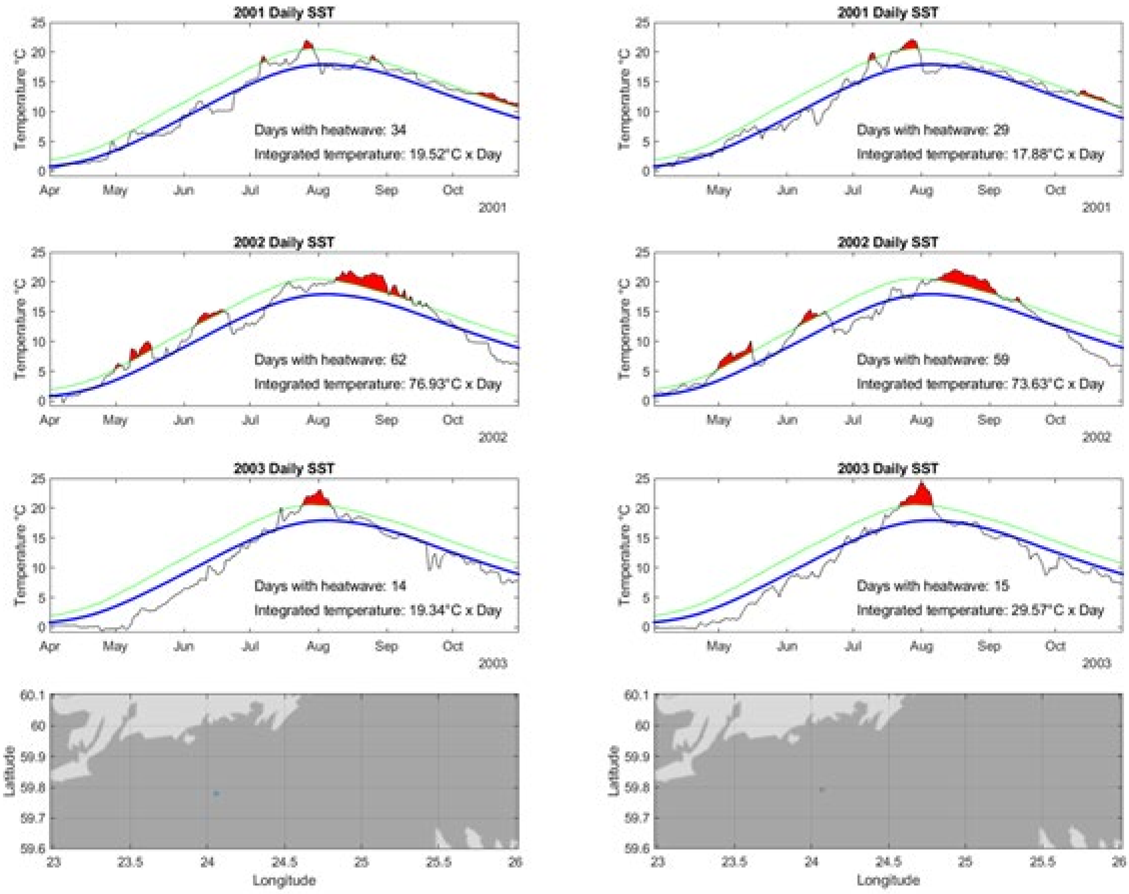

Figure 17. Time series of daily SST (grey line), climatological mean (blue line) and 90th percentile (green line) at two selected grid points in the Gulf of Finland based on the CMEMS remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016 in April-October 2001-2003. Climatology is calculated for 1986-2020. Heatwaves are indicated with the red areas above the 90th percentile line.

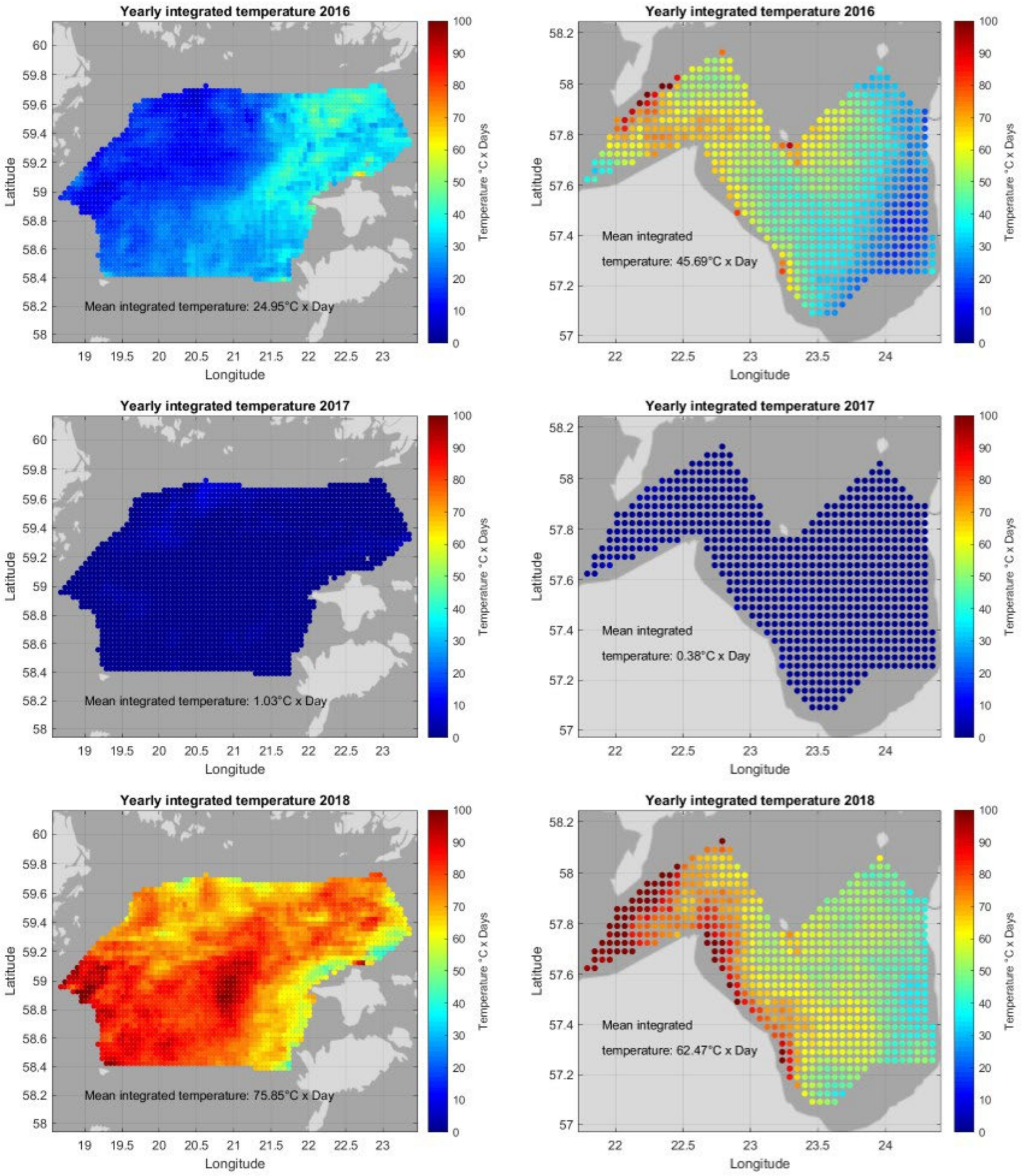

*Figure 18. Intensity of marine heatwaves (in units °C*day) in the Northern Baltic Proper (left column) and the Gulf of Riga (right column) based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011 in April-October 2016-2018. Climatology is calculated for 1986-2020 using the CMEMS remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016.*

Marine heatwaves in all sub-basins of the Baltic Sea are calculated based on reanalysis and remote sensing products, while in Figure 18 and Figure 19, the reanalysis-based estimates are given. As seen for the selected years, the inter-annual variability is very high. The largest number and intensity of marine heatwaves were detected in 2018 in all basins and the lowest in 2017. However, the spatial distribution of marine heatwaves intensities within a basin (in the years with relatively high intensities) vary greatly. Marine heatwaves had the highest intensity in the eastern part of the Northern Baltic Proper in 2016 and on the western part of this basin in 2018 (Figure 18). Marine heatwaves were almost absent near the eastern coast of the Gulf of Riga in 2016, while high intensities were found in the north-western part of the Gulf. In 2018, when the highest heatwave intensity was registered for almost all sub-basins, marine heatwaves were most pronounced in the western parts of the basins (Figure 18 and Figure 19).

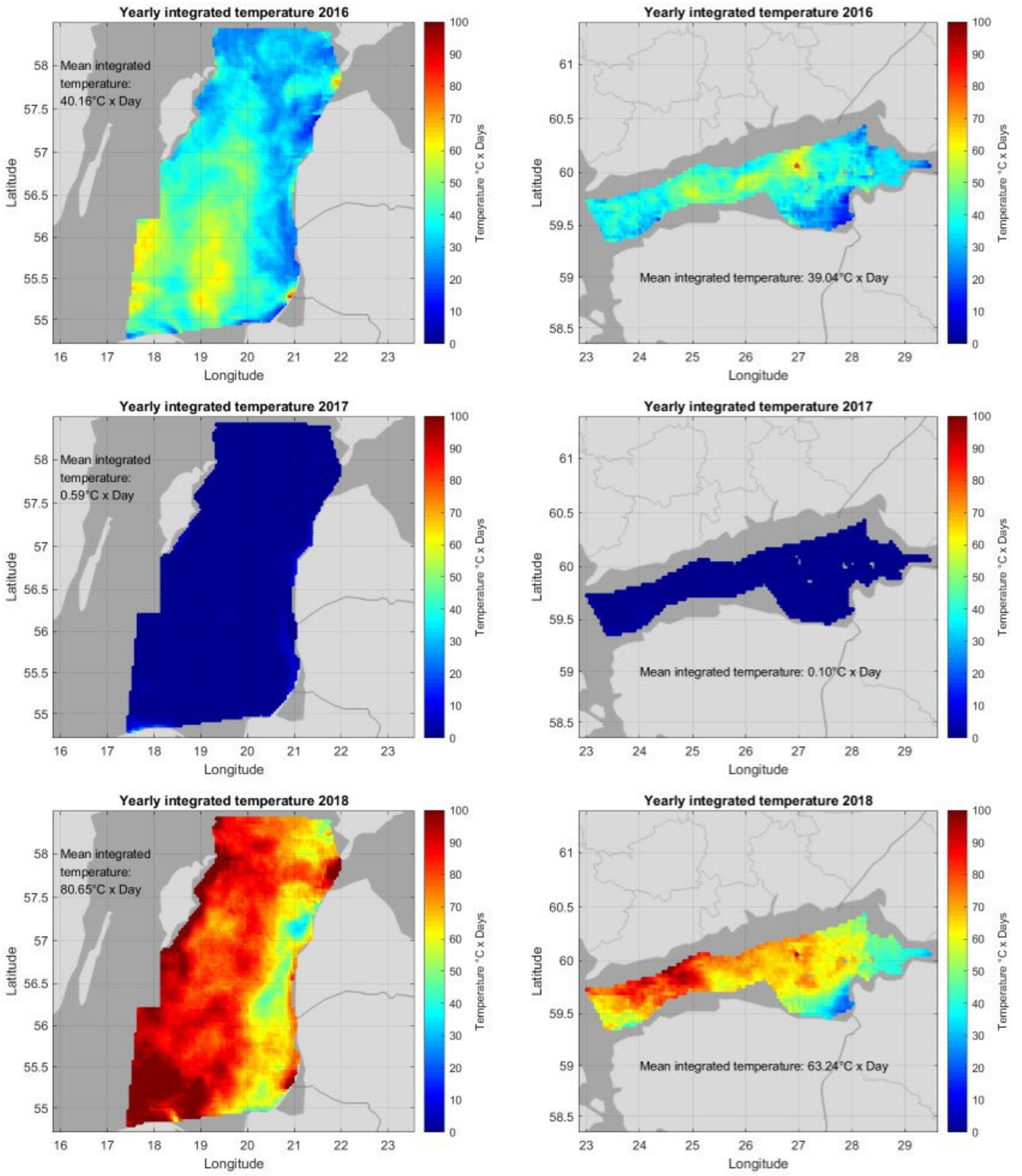

*Figure 19. Intensity of marine heatwaves (in units °C*day) in the Eastern Gotland Basin (left column) and the Gulf of Finland (right column) based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011 in April-October 2016-2018. Climatology is calculated for 1986-2020 using the CMEMS remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016.*

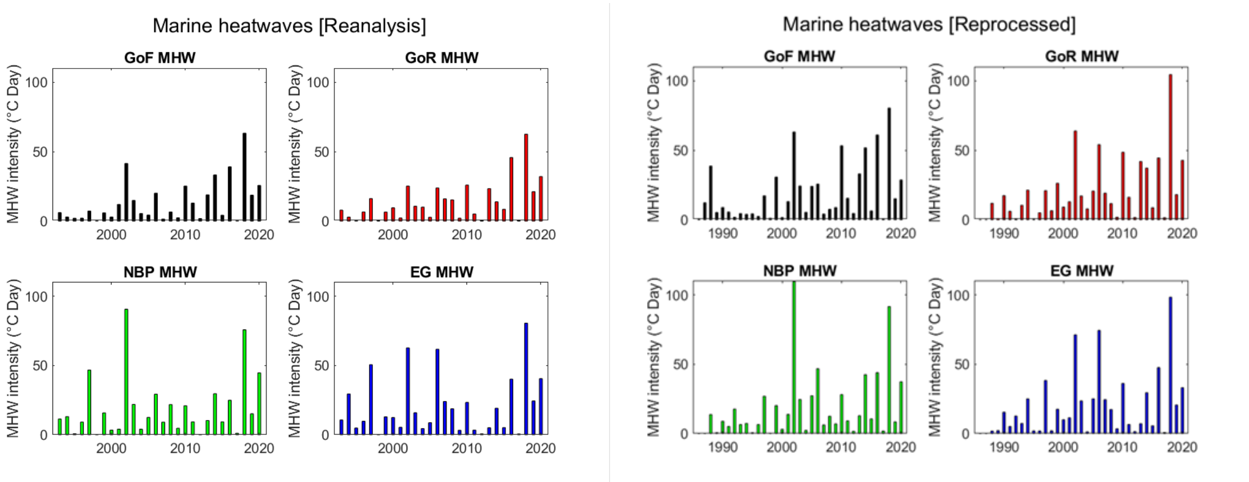

*Figure 20. Interannual variability of marine heatwave intensities (in units °C*day) in four Baltic Sea basins – Gulf of Finland, Gulf of Riga, Northern Baltic Proper, and Eastern Gotland Basin in 1993-2020 based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011 (left panels) and in 1986-2020 based on the CMEMS remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016. Climatology is calculated for 1986-2020 using the latter product. Yearly values are calculated for April-October.*

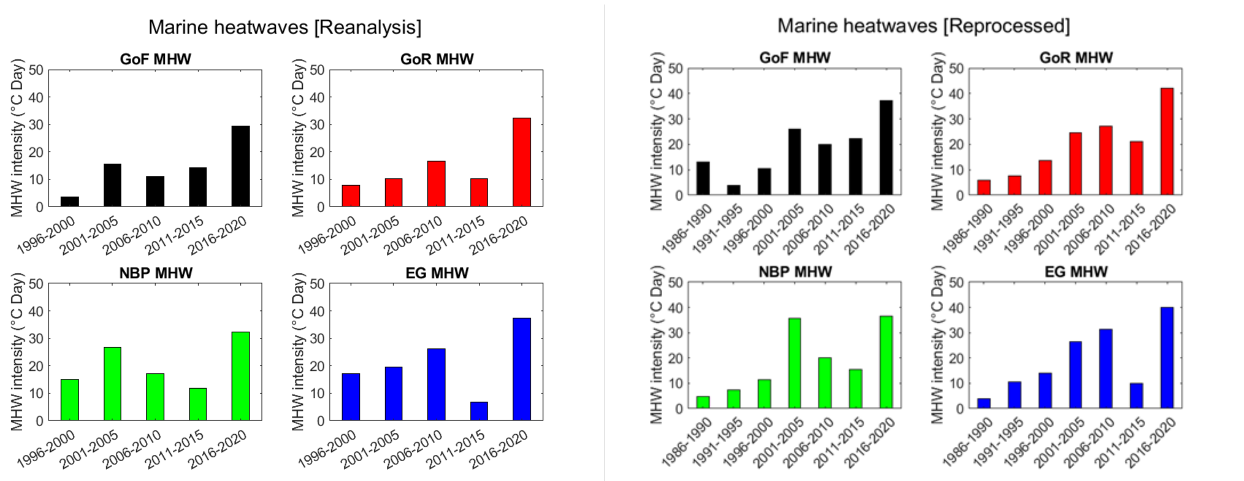

*Figure 21. Interannual variability of marine heatwave intensities (in units °C*day) in four Baltic Sea basins – Gulf of Finland, Gulf of Riga, Northern Baltic Proper, and Eastern Gotland Basin in 1993-2020 based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011 (left panels) and in 1986-2020 based on the CMEMS remote sensing product SST_BAL_SST_L4_REP_OBSERVATIONS_010_016. Climatology is calculated for 1986-2020 using the latter product. Yearly values are calculated for April-October.*

Interannual variability of marine heatwaves in four sub-basins are presented in Figure 20 and as five-year averages in Figure 21. Reanalysis and remote sensing data were used in the calculations for the years 1993-2020 and 1986-2020, respectively. While in almost all basins, 2018 was the year with the highest intensity, in the case of the Northern Baltic Proper it was in 2002. This result is the same for reanalysis and reprocessed remote sensing data. The two products generally give a similar variability in marine heatwaves, with slightly higher intensities found based on remote sensing data. It is expected since remote sensing data represent SST in the very surface layer, while in the model, the first layer is 3 m thick. The difference between the reanalysis and remote sensing results is lower in the open sea areas (EG and NBP) and higher in the shallower basins (GoF and GoR). The long-term trend in marine heatwaves intensity in the analysed periods since 1986 is positive and significant for all basins.

Upwelling index

Upwelling frequencies and intensities were calculated based on CMEMS reanalysis and remote sensing products BALTICSEA_REANALYSIS_PHY_003_011 and SST_BAL_SST_L4_REP_OBSERVATIONS_010_016.

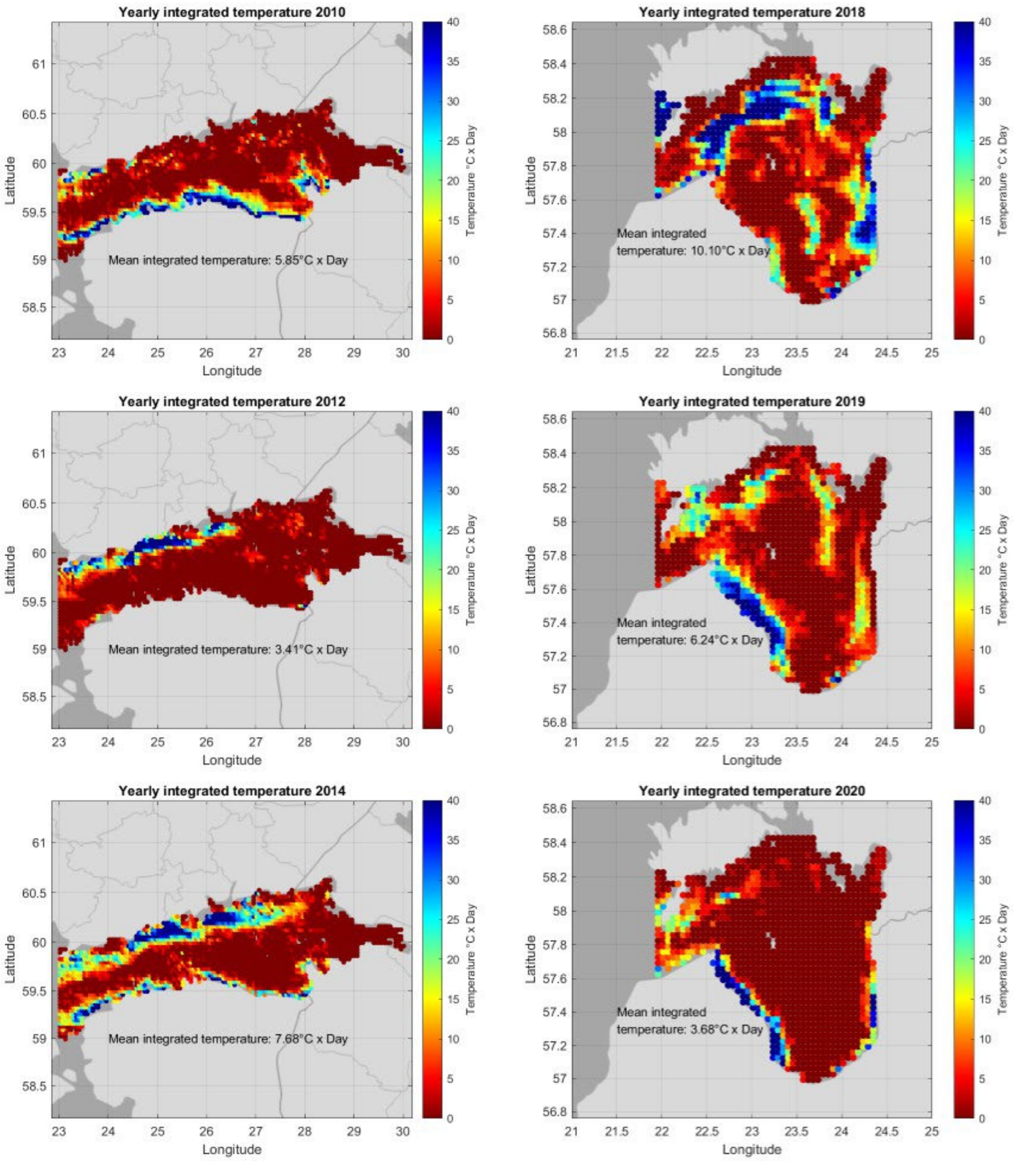

*Figure 22. Spatial distribution of upwellings (in units °C*day) in the Gulf of Finland in 2010, 2012 and 2014 and in the Gulf of Riga in 2018-2020 based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011. Upwelling index is calculated for May-September.*

SST is used to define when and where an upwelling event develops, similarly as applied by Lehmann *et al.* (2012) and by Kikas and Lips (2016). From daily SST fields, an average temperature value along a north-south or east-west line was calculated. As a next step, temperature in each individual grid point was compared with the average on the line passing this point. If temperature was lower by 2 °C or more, this point was assigned to an upwelling area. Two indices were calculated – (1) the number of days with upwelling events identified and (2) the upwelling intensity. Upwelling intensity is the sum of all negative temperature deviations from the daily averages from May to September. These months were selected since in the Gulf of Finland, the occurrence and intensity of cyanobacterial blooms (associated with high chlorophyll-*a* levels in summer) are influenced by pre-bloom upwelling events, which transport nutrients into the photic layer (Vahtera *et al*., 2005; Lips & Lips, 2008).

The method is best applicable in basins with the shoreline oriented approximately south-north or east-west direction. Such a basin is, for instance, the Gulf of Finland. It is possible to define the years (from spring to autumn) with upwelling events mostly along the northern coast, or southern coast, or their occurrences along both coasts of the Gulf of Finland. Such examples are shown in Figure 22 (left column). In the Gulf of Riga, we applied both options (south-north and east-west) to detect upwelling events. Examples in Figure 22 (right column) are obtained using east-west lines, and the upwellings are well detected when occurring mostly along the western or eastern coast, as in 2019 and 2020.

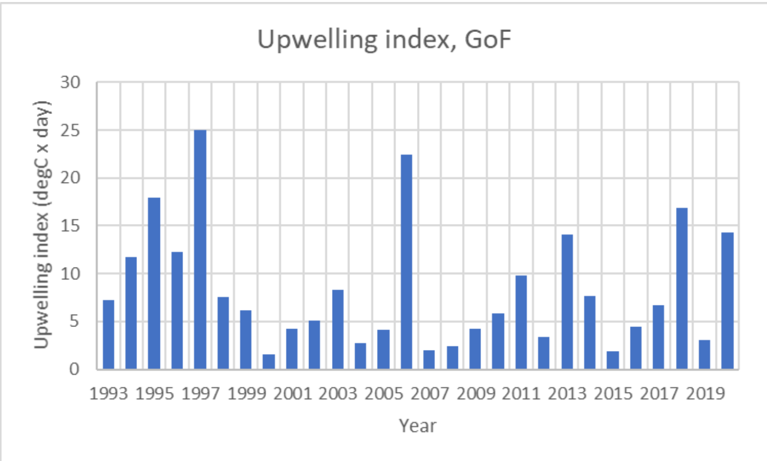

*Figure 23. Interannual variability in upwelling intensities (in units °C*day) in the Gulf of Finland in 1993-2020 based on the CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011. Upwelling index is calculated for May-September.*

The time series of upwelling intensities in the Gulf of Finland in 1993-2020 reveals high variability between the years, with a slightly higher upwelling activity in the mid-1990s than after. Relatively high intensities were detected in 1995, 1997, 2006, 2013, 2018 and 2020 (Figure 23). In some of these years, SST was, on average, higher and marine heatwaves occurred with high intensity (as in 1997, 2016 and 2018). When such hydrographic factors coincide, an impact on productivity and phytoplankton blooms is expected. Thus, the developed upwelling index is useful for use in environmental assessments. It is also required by Marine Strategy Framework Directive to characterise upwelling activity in the sea area, where the assessments of the environmental status are made.

2.5. Potential of using CMEMS-based indicators for HELCOM assessments

The potential of developed indicators and the benefits of incorporating them into HELCOM assessments will be analysed in a later outcome of Task 6.3. However, some preliminary options can be derived from the products presented here. We compared eutrophication status assessments derived by using CMEMS products with the HELCOM assessment results. For chlorophyll-*a*, the results differ considerably (Figure 24 and Table 5). The CMEMS-based assessments indicate that GES is achieved in the deep open sea basins with failures in the shallower basins. If the results coincide, as in the Gulf of Finland and the Gulf of Riga, the indicator values for the assessment period differ substantially (up to two times or more). Since HELCOM has evaluated their assessment confidence as high, we suggest further developing the reanalysis. One way could be to employ more monitoring data in the reanalysis.

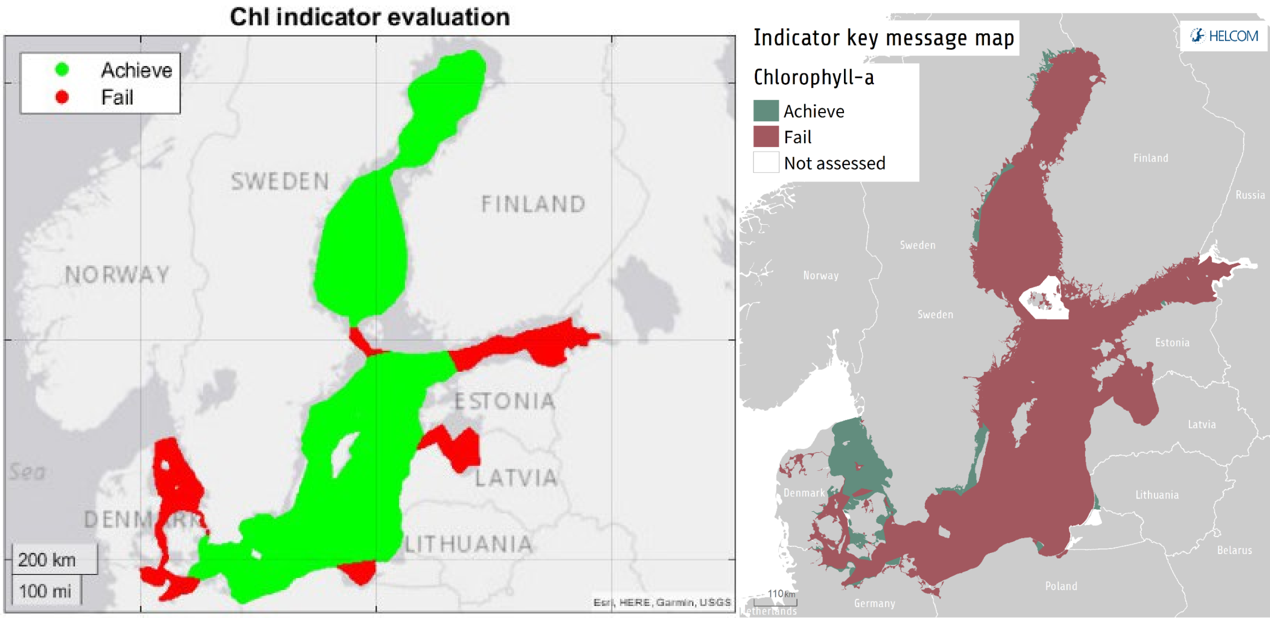

Figure 24. A comparison of eutrophication status assessments (GES achieved or not) using HELCOM chlorophyll-a indicator based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and HELCOM monitoring data[30] (right panel) in 2011-2016.

Table 5. Chl-a indicator values for the assessment period of 2011-2016 and set thresholds to define whether GES is achieved or not

Basin	CMEMS mg/m3	HELCOM mg/m3	GES threshold mg/m3
GoF	6.01	4.27	2.00
GoR	9.65	4.04	2.70
NBP	1.55	3.79	1.65
EG	1.26	2.90	1.90

[30] https://helcom.fi/wp-content/uploads/2019/08/Chlorophyll-a-HELCOM-core-indicator-2018.pdf

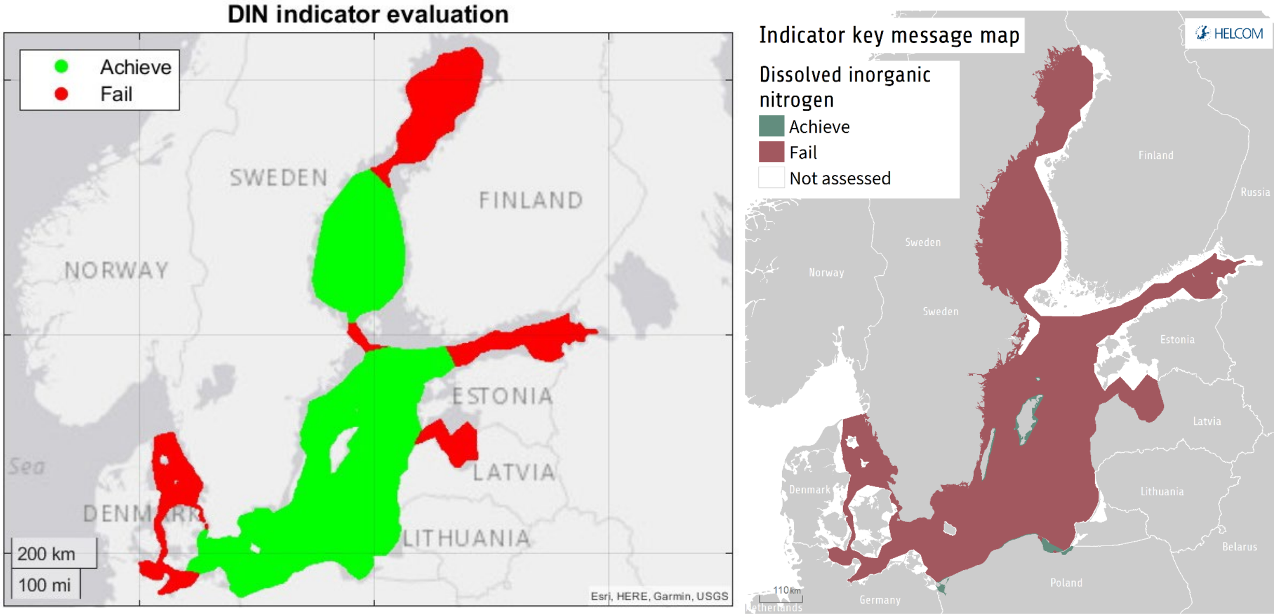

Figure 25. A comparison of eutrophication status assessments (GES achieved or not) using HELCOM DIN indicator based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and HELCOM monitoring data[31] (right panel) in 2011-2016.

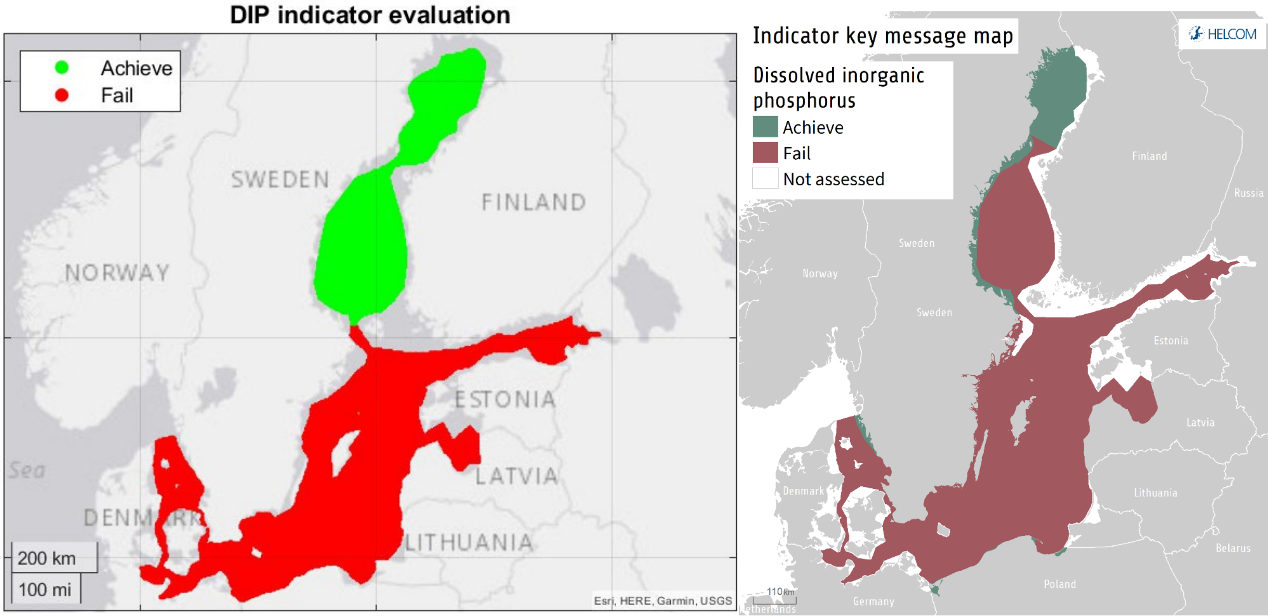

Figure 26. A comparison of eutrophication status assessments (GES achieved or not) using HELCOM DIP indicator based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and HELCOM monitoring data[32] (right panel) in 2011-2016.

The differences in the eutrophication status assessment results between the CMEMS-based and HELCOM assessment results when using the DIN indicator are similar to those revealed regarding the chlorophyll-*a* indicator (Figure 25). Most open sea basins indicate GES, which is not the case in the latest HELCOM

[31] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-nitrogen-DIN-HELCOM-core-indicator-2018.pdf
[32] https://helcom.fi/wp-content/uploads/2019/08/Dissolved-inorganic-phosphorus-DIP-HELCOM-core-indicator-2018.pdf

assessment for 2011-2016. Although the CMEMS-based and HELCOM assessments showed that GES had not been achieved, the indicator values are much larger in the shallower bays (especially in the Gulf of Riga) for CMEMS. Thus, the DIN indicator derived from the CMEMS data is not in good accordance with the HELCOM assessment using the same indicator. A slightly better agreement between the two assessment results was revealed for the DIP indicator (Figure 26). The status assessment differed only in the Bothnian Sea. Still, the gradients from the open sea basins towards the shallower basins are stronger in the CMEMS-based indicator results than in the HELCOM assessments. Although HELCOM has evaluated the confidence of both their indicator results in some basins as moderate, the observed pattern in disagreement between the results indicates that CMEMS reanalysis does not simulate the spatial distribution in the nutrient concentrations well enough.

3. Data collection and aggregation for generating interim reanalysis

3.1. Introduction

In order to make more frequent, interim and accurate eutrophication assessments, timely delivery of ship data is essential. Currently, the ship data related to environmental monitoring are delivered with a 1-2 or more years delay after measurements are collected at sea. At the start of the EuroSea project, only SMHI delivered near real time CTD data from the Baltic Sea to the CMEMS INS TAC (In Situ Thematic Centre). One subtask in WP6.3 is to vastly improve the delivery of Baltic Sea ship CTD observations at an interim time interval, i.e., within a few months. This will facilitate the assimilation of measurements into ocean models to produce a so-called interim reanalysis product that can be further used for eutrophication assessments.

3.2. Data collection

Observations collected for this study include CTD data from environmental monitoring cruises, operational T/S profile data from moorings, Argo floats, gliders in CMEMS INSTAC (In Situ Thematic Assembly Center), glider data from VOTO and offline research cruise data from ICES.

Regular monitoring cruises are carried out by Baltic Sea environmental institutes, which include both HELCOM and BOOS (Baltic Operational Oceanographic System) members (Table 6). It is found that most of the BOOS members also deliver ship data to HELCOM. However, for many BOOS members, the operational oceanographers do not work in the environmental monitoring space. HELCOM also did not use model products for the assessment. In previous years, data assimilation was not used in national and Baltic Sea model forecasts; hence the use of NRT observations was not even considered. Today, with the development and availability of the Baltic Sea model reanalysis in CMEMS, it is possible to develop an improved, more timely HELCOM eutrophication assessment by combining *in-situ* observations and modelled data. In EuroSea, we focused on the user's needs for updating ship observation delivery more frequently.

Since it is a major challenge to get NRT ship observation data than it is to get this data at an interim scale, and the actual eutrophication assessments only need interim data delivery, we decided to start with the interim data delivery. This means the ship data should be available within 3 months after the *in-situ* measurements. DMI and Taltech are working on this activity, since DMI chairs BOOS and TalTech is heavily involved in the HELCOM eutrophication assessment process. For this milestone, DMI focused on getting interim ship data delivered via BOOS cooperation and TalTech focused on the same goal via HELCOM channels.

Table 6. BOOS members who deliver regular cruise monitoring data

Institute	**Country**	**BOOS member**	**HELCOM data contributor**
AU	Denmark	X	X
TalTech	Estonia	X	X
SYKE, FMI	Finland	X	X
IOW, BSH	Germany	X	X
LVGMC	Latvia	X	X
KU	Lithuania	X	X
IOPAN, IMGW	Poland	X	X
RSHU	Russia	X	
SMHI	Sweden	X	X

3.3. Speed up ship data delivery via BOOS cooperation

DMI closely works with the BOOS Working Group on “near real time ship data delivery” and the BOOS Steering Group. At the start of the EuroSea project, only SMHI was delivering NRT CTD data. Our 2020 efforts ensured that Estonian data was delivered in NRT. The data was first delivered by TalTech to SMHI, where it was further processed and disseminated to CMEMS and EMODnet.

Later in the project, some of the BOOS partners agreed to deliver more *in-situ* data at the requested interim scale. The current status of this initiative is documented in the “Minutes of the BOOS Steering Group meeting, 3 September 2021”, as written in Table 7.

Table 7. Action list for NRT ship data delivery (BOOS Steering Group meeting, 3 September 2021)

NRT delivery and access to ship data		**Ship data WG**		
Action	Responsible	Expected contributors	Status	Note
Set up ftp at SMHI	SMHI		Done	Host: ftp.smhi.se User: ObsoceanografiFtp Password:
Upload recent sample data to SMHI ftp	DMI, FMI, IOPAN, TalTech	IOW, BSH	Done	In csv, cnv format
Set an operational data flow to upload data to SMHI ftp	DMI, FMI, IOPAN, IOW, BSH		On-going	
Process all the BOOS data (i.e. SMHI, TalTech, DK_ODA, BSH, IOW, FMI and IOPAN) and store it in SMHI ftp site for BOOS access	SMHI		On-going	
Upload these data to BOOS website	SMHI, EuroGOOS	BOOS WebWG	To be started	

In parallel with the BOOS efforts, DMI has established an automatic download protocol to download the interim CTD data from Denmark, Germany, Estonia, Sweden and EMODnet. Figure 27 shows the data downloaded and processed in May 2021. Finnish and Polish data will be made available via the BOOS ftp site, as shown in Table 7.

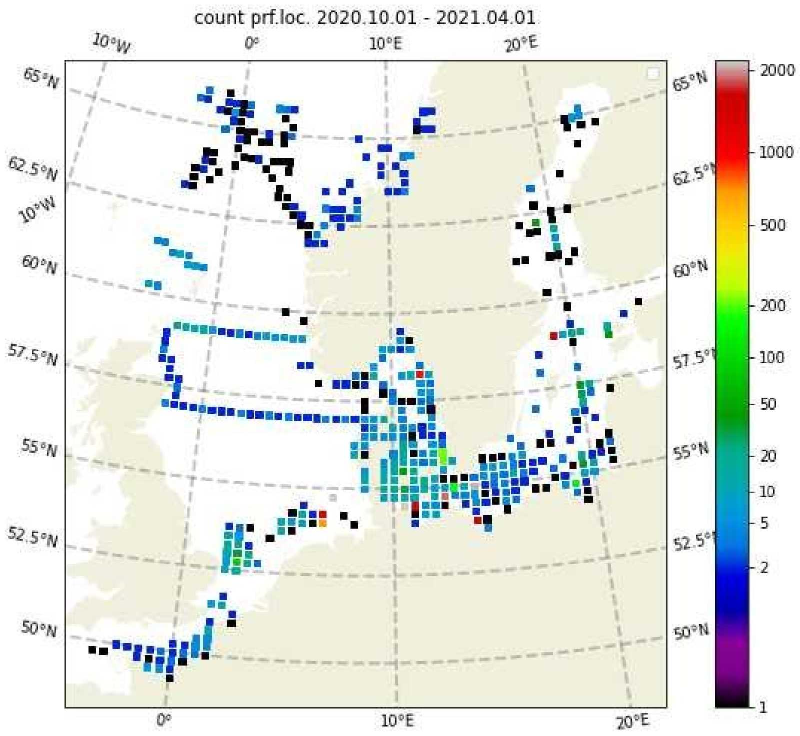

Figure 27. Frequency of T/S observations with less than a 6-month delay time in May 2021, the results are aggregated in 0.5 (longitude) x 0.25 (latitude) bins for observation profiles.

3.4. Speed up data delivery via HELCOM cooperation despite of COVID-19

COVID-19 related restrictions had an impact on the observation system, with some monitoring cruises postponed. However, autonomous *in-situ* observation collection continued during this disruption except for ferryboxes, which had a sampling gap of two months when all ferries were stopped.

To get more monitoring agencies to join the data delivery system, we will stress that the quality of the products will also depend on the data flow. In the HELCOM IN-Eutrophication group (HELCOM STATE sub-group) meeting held on 1-2 September 2021, partners agreed to deliver all CTD profiles from all countries to ICES from the last assessment period, 2016-2021. This could be agreed upon as a regular update procedure without waiting for the yearly data delivery deadline. Up to now, all the HELCOM members have delivered CTD data in 2021.

3.5. A review on data availability in 2021

Data from CMEMS INSTAC

As of 30 April 2022, the availability of T/S profile data in 2021 is shown in Figure 28. It shows that there are large data gaps in the CMEMS database in the mid-south North Sea, Kattegat, and western and northern Baltic Sea. The CMEMS data consist of operational observations provided by ROOS (Regional Operational Oceanographic System) members (moorings, Argo profilers and cruise data from Estonia, Sweden and Norway).

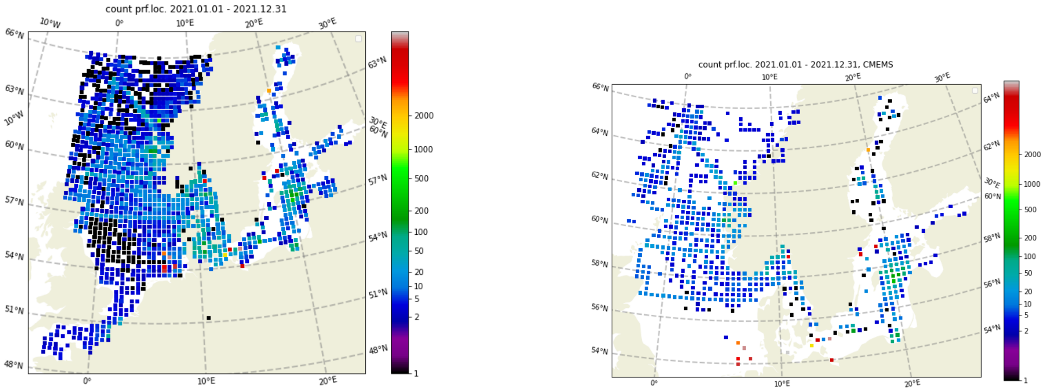

Figure 28. Number of observed T/S profiles in 2021. Left panel: all data collected in EuroSea; right panel: data from CMEMS INS TAC. (as of status of 30 April 2022).

Observations from national environmental monitoring cruises

This part of the data is made available by BOOS and HELCOM partners. The station distribution observed by IOW (Germany), AU (Denmark), LIAE (Latvia) and SMHI (Sweden) are displayed in Figure 29. Most of these stations were sampled at least 4 times in 2021.

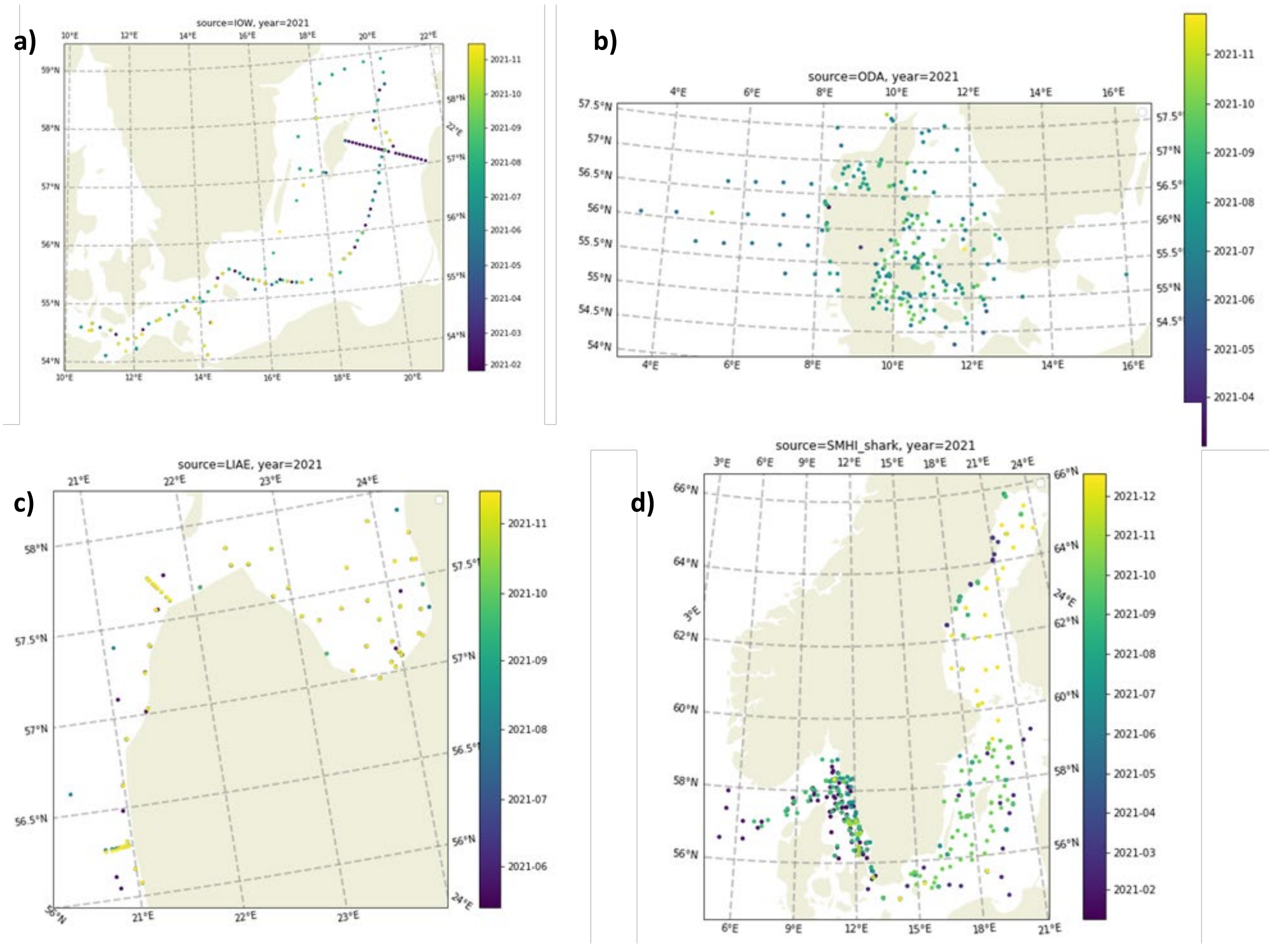

Figure 29. Sampling stations observed by a) IOW (Germany), b) AU (Denmark), c) LIAE (Latvia) and d) SMHI (Sweden) in 2021, as of status of 30 April 2022. The colour represents time of the last profile observations in 2021.

ICES database

This dataset includes research cruises from all countries worldwide. Figure 30 displays the ICES station distribution in 2021.

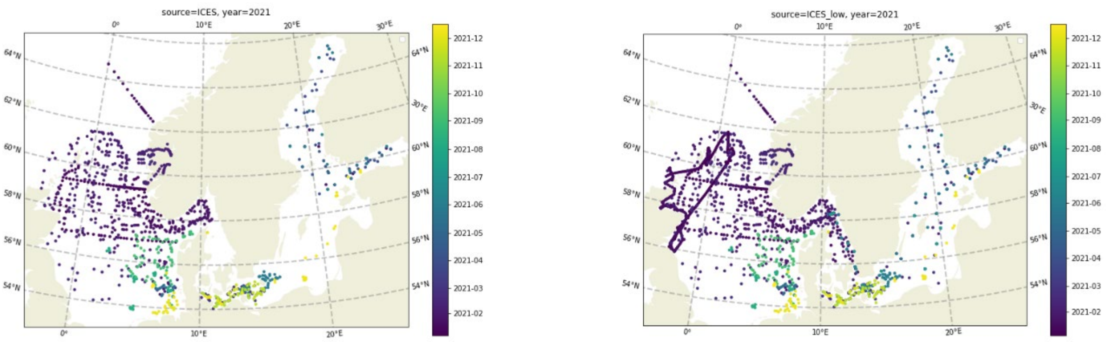

Figure 30. T/S profile stations in ICES database in 2021 as of status of 30 April 2022. Left panel: CTD stations; Right panel: low vertical resolution stations. The colour represents time of the last profile observations in 2021.

Private data sources

This includes glider data from VOTO (Voice of Ocean…), as shown in Figure 31. There are 3-4 gliders, maintaining a continuous operation in eastern Skagerrak, Bornholm Basin and Gotland Deep. VOTO is involved in BOOS public-private partnership and working with BOOS partners, e.g. TalTech and DMI, in EU projects GROOM II and OLAMUR.

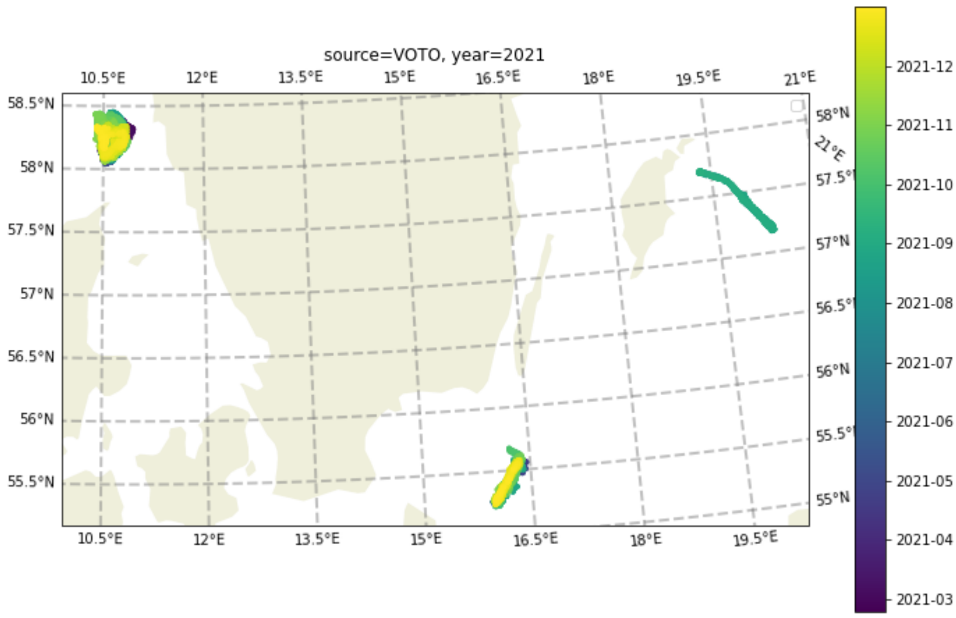

Figure 31. Glider transections made by VOTO in 2021. The colour represents time of the last profile observations in 2021.

3.6. Data quality control

Interim observations, due to their fast delivery, may have more quality problems than the reprocessed *in-situ* data. Thus, use of the interim observations should apply some quality control measures. This can be illustrated by data on 1 September 2021. In this single day, the platform 58JH, an undulated profiler, provided large amount of data (Figure 32). However, the platform data in the North Sea (between 56-60N) gives too low water temperature, some of them even below zero in depths of 40-100 m. The observations shown by other platforms are all above 7.5 °C in all depths.

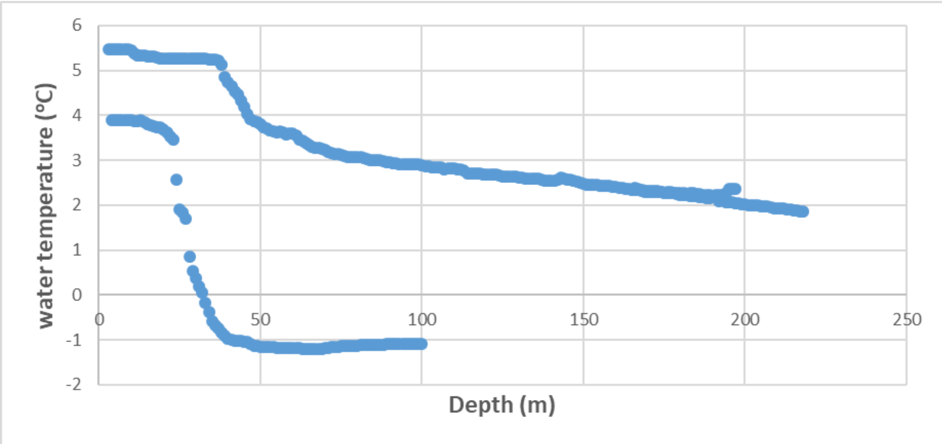

Figure 32. Water temperature (2W – 12E, 56 – 60 N) on 1 September 2022, measured by platform 58JH. The data are identified as erroneous.

3.7. Data aggregations

The multi-source observations obtained are aggregated into daily mean data with 0.01 degree horizontal resolution. The data are then used for data assimilation and generating interim reanalysis during 1 October 2019 – 31 December 2021.

4. Generation of interim reanalysis

4.1. Introduction

The task in EuroSea WP6.3 is to generate eutrophication indicators using improved reanalysis in the interim time scale, which is less than one year. Hence, these eutrophication indicators can be used by HELCOM or national environmental agencies for more rapid environmental assessment. The best physical-biogeochemical reanalysis products currently available are from CMEMS BAL MFC (Liu et al., 2017), which is based on a NEMO-SCOBI model system where NEMO is a coupled ocean-ice model in version 3.6 (v3.6), SCOBI is a biogeochemical model used at SMHI. The data assimilation uses a "singular evolutive interpolated Kalman" (LSEIK) filter assimilation scheme (Nerger, 2007), which is embedded in a Parallel Data Assimilation Framework (PDAF, Nerger et al., 2005), with a horizontal resolution of 2 nautical miles (nmi). The reanalysis production system assimilates satellite SST, profiles of T/S, dissolved oxygen, nutrients and ammonia. Up to now, the reanalysis has been updated up to December 2020. In the interim period, the available data from CMEMS INSTAC are much less than in the historical period. Thus, one may expect a less frequent update of the interim reanalysis with a quality lower than the historic period.

In EuroSea WP6.3, by speeding up ship CTD data delivery, we have obtained much more data than that is available in the INS TAC, as shown in Figure 28. By assimilating these data, we generated an interim reanalysis for the period October 2019 – December 2021. One may expect that, by assimilating more T/S profile data, this interim reanalysis will have better quality and more frequent updates than the current CMEMS reanalysis. In this chapter, we describe the model and data assimilation system used in producing the interim reanalysis and a preliminary validation of the interim reanalysis.

4.2. Method and input data

Description of reanalysis production system

Models: The modeling system used for the INTERIM-RAN is the newly developed BAL MFC reanalysis production system PDAF-NEMO-ERGOM for the Baltic-North Sea region. The system consists of the general ocean circulation model NEMO 4.0 (Kårnå et al., 2021), one-way coupled to the bio-geochemical model ERGOM, and the data assimilation package PDAF v.1.16. The horizontal resolution is 1 nmi with 75 vertical layers. This version has been tuned and tested to fit the needs of the Baltic Sea region; more details of the model setup and tuning can be found in Kårnå et al. (2021).

Surface forcing: For the assimilation period, the model system was forced using meteorological data from the DMI-HIRLAM SKA system with a horizontal resolution of 3 km.

Boundary forcing: The ocean model domain has two open boundaries (Orkney Island, UK -Norway & English Channel). The model was forced with data derived from the CMEMS Atlantic North West Shelf forecast system (NORTHWESTSHELF_ANALYSIS_FORECAST_PHY_004_013). Two-dimensional temperature and salinity, as well as sea level (including tides), were derived from the daily mean outputs.

River run-off and nutrient loads: For the river run-off and nutrient loads, data from the operational hydrological model Ehype of SMHI (Seibert and Bergström, 2021) were used.

Initial conditions: Both NEMO and ERGOM were started using the restart files from the BAL MFC NRT (near real time) system on 01.10.2019.

Data assimilation

The PDAF v.1.16 assimilation package is configured as LESTKF (Local Error Subspace Transformation Kalman Filter) filter and runs in the offline mode. This means that every time the analysis is performed, the model is stopped, and after the assimilation is completed, the model is re-started again from the restart files. A 3-day cycle between different observation types (SST, T-profiles and S-profiles) was chosen, with each observation type assimilated at midnight. Assimilation was performed in a semi-univariate mode for SST (meaning that SST observations were used to update temperature in the water column upper 25-meters) and pure univariate mode for *in-situ* (T/S) observations (meaning that the 3-d temperature or salinity profile is used to update the full water column for only corresponding variable).

Error covariance was extracted from the long historical run without data assimilation covering the years 2011-2016. The state vector consisted of one two-dimensional variable (sea level) and two three-dimensional variables (temperature and salinity). The ensemble anomalies were calculated by subtracting the running mean, calculated using a sliding time window of 15 days before and after the analysis date, resulting in the ensemble with a number of ensemble members equal to 70. The error covariance is therefore varying with time and is anisotropic and three-dimensional.

The localization of the error covariances in the LESTKF filter is achieved by treating each horizontal model grid point as a separate local analysis domain. Only the observations within a specified influence radius around the analysis domain are selected in the analysis, which effectively removes the spurious long-range correlations resulting from the limited ensemble size. In our implementation, the influence radius is spatially variable, with smaller values near the coast (minimum of 25 km) and larger values in the open areas (maximum of 100 km). The horizontal map defining the influence radius shown in Figure 33 was derived from the Naval Oceanographic Office (NAVOCEANO) distance to the coast map.

Assimilated datasets

SST and T/S profile data are assimilated. The SST dataset is the level 3 gridded L3S CMEMS product, covering the Baltic Sea – North Sea (CMEMS product ID: SST_BAL_SST_L3S_NRT_OBSERVATIONS_010_032).

The T/S profile data assimilated are multisource, collected from INS TAC, ICES, BOOS and HELCOM partners and NGO VOTO, which have been described in section 3.5. Figure 34 shows the distribution of the *in-situ* observations during one month of 2020-09 (a), while the panel (b) shows the number of *in-situ* and satellite observations during the entire period 2019-2021.

The satellite observations were interpolated to the model grid prior to assimilation using the linear interpolation method. Since the number of satellite observations is very large for a data assimilation system, SST observations were re-processed into super-observations leaving roughly every 10th observation from the original data set. *In-situ* profiles were brought to the model grid both horizontally and vertically using the simple nearest neighbour method. This simplifies the observation search in PDAF and greatly speeds up calculations. Since the assimilation window was 3 days in our simulations, the daily *in-situ* observations were re-processed as a 3-day accumulated file, containing one day before the analysis date and one day after the analysis date. This increases the number of assimilated *in-situ* observations and allows us to retain the observations between the cycles.

As a CMEMS product, the SST observations were quality controlled before the data assimilation using corresponding error estimates. For the T/S profiles, data from ICES, BOOS/HELCOM partners and VOTO were quality controlled, while INS TAC data only had a preliminary quality check. An additional quality control measure was applied during data assimilation. The absolute value of the innovation vector, defined as the difference between the background field and the corresponding observation, was limited to 3.0 °C for temperature or 3.0 psu for salinity. This means that if the magnitude of the absolute value of the innovation is larger than these limits, the observation is discarded from the assimilation.

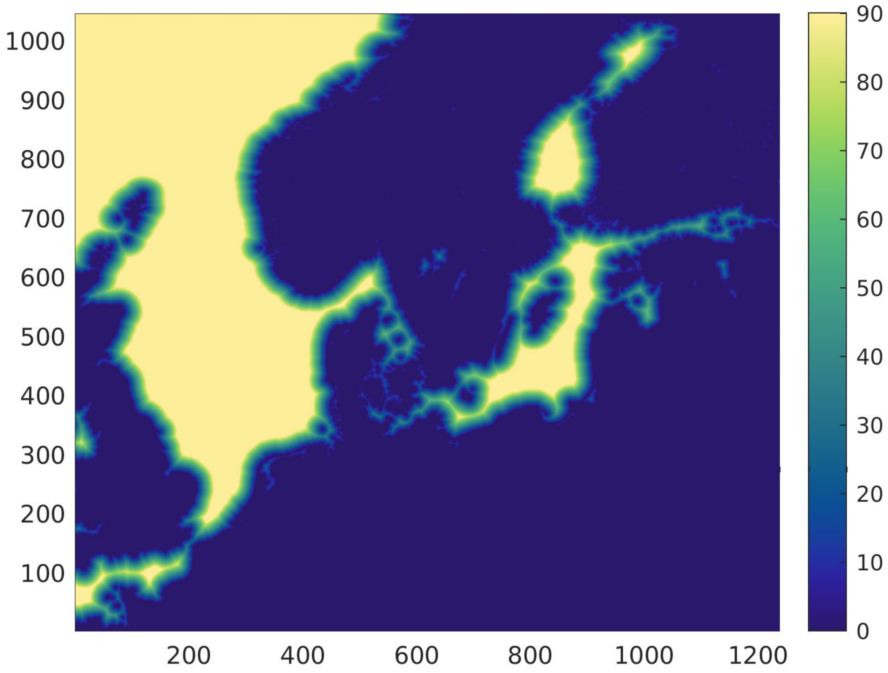

Figure 33. Map of the horizontally varying influence radius (in km).

Interim reanalysis production: the reanalysis production system PDAF-NEMO-ERGOM was running for the period of 1 October 2019 – 31 December 2021. The model system and assimilation run stably for the entire period.

4.3. Validation of interim reanalysis and intercomparison with CMEMS reanalysis

Before the assimilation, the satellite SST was validated against the *in-situ* observations during year 2020. First, all *in-situ* observations in the upper 5 meters were collected. Then the satellite observations were averaged within the 11 km radius around each *in-situ* surface observation and the difference was calculated. The daily mean difference between satellite SST and *in-situ* surface temperature is shown in Figure 35. Overall, the comparison shows the small positive bias of only 0.12 °C and the standard deviation of 0.46 °C.

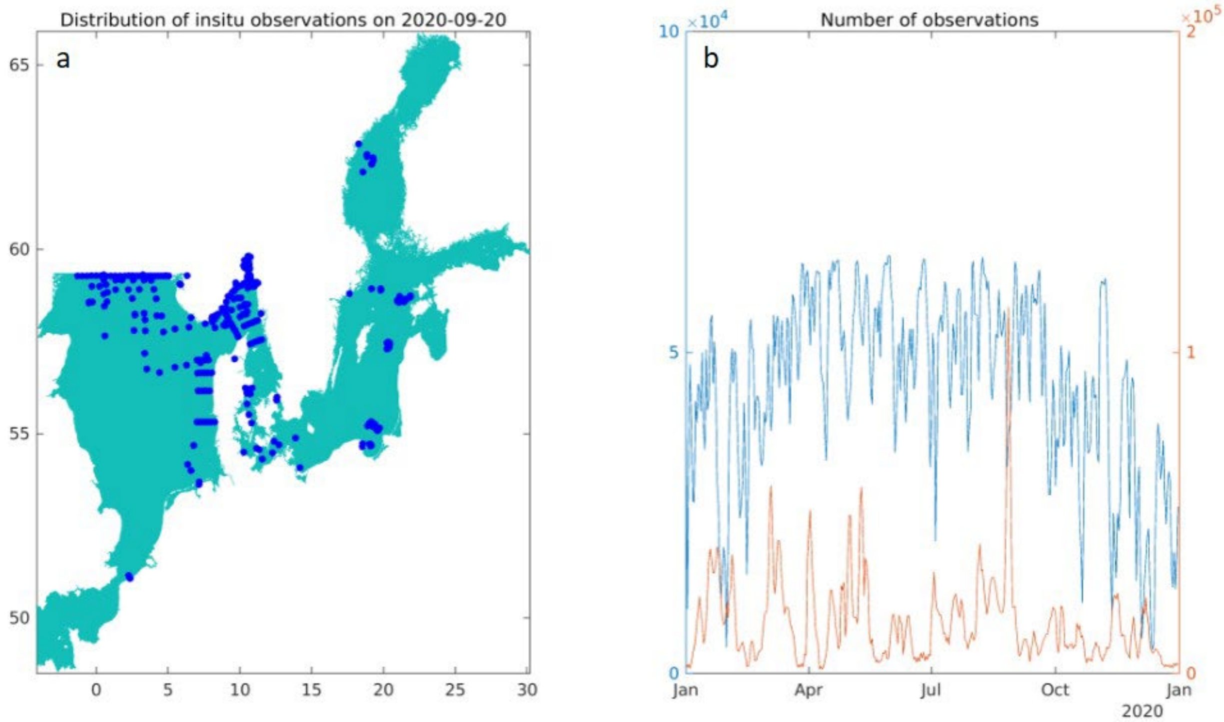

Figure 34. (a) Distribution of in-situ profiles, accumulated during a 3-day window centered on 2020-09-20 (b) Number of satellite SST observations before super-observations are processed (blue curve) and number of in-situ observations (red curve) during year 2020.

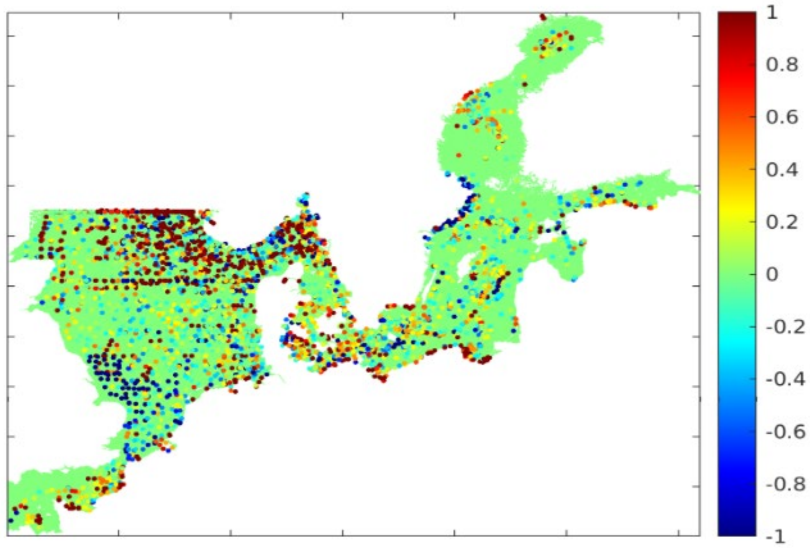

Figure 35. Satellite minus in-situ SST difference. Satellite SST was averaged in the radius of 11 kms around each near-the-surface in-situ observation. The validation period covers the whole year 2020.

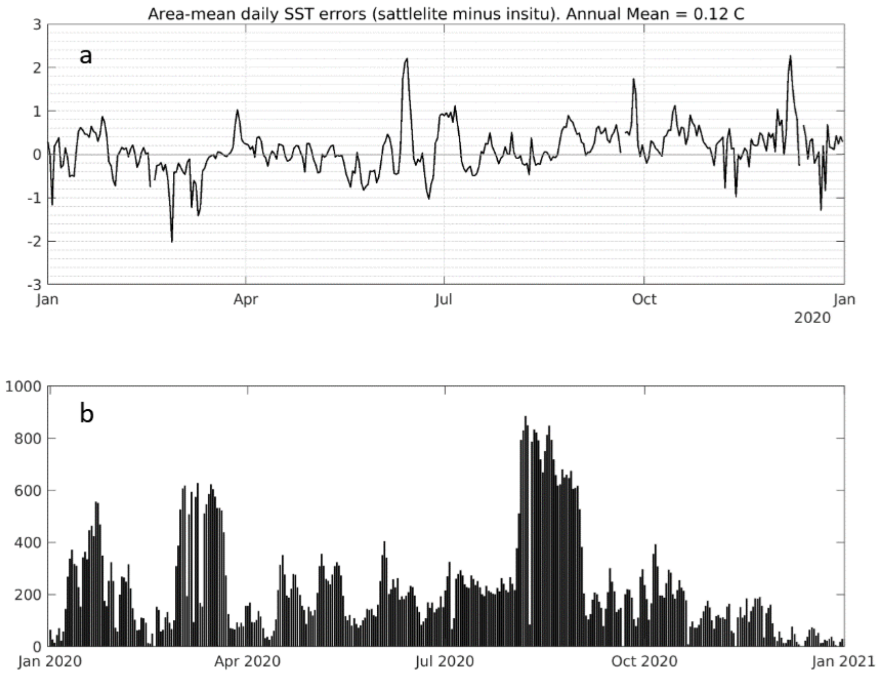

Figure 36. (a) Mean difference between satellite SST and in-situ surface temperature during 2020. (b) Number of daily in-situ near-the-surface observations used for comparison.

The improvements in the SST fields can be assessed by comparing the SST from the interim reanalysis with the old CMEMS 2-nmi reanalysis. Figure 36 shows the monthly mean error maps (bias and centred root mean square errors - cRMSE) for April 2020. It is important to note that both reanalyses assimilated the same SST product, and therefore the differences are explained only by the increased model resolution, differences in the assimilation scheme, different model errors, and different in-situ data. The daily spatially averaged bias and cRMSE over the Baltic Sea area in April 2020, as an example, are shown in Figure 37. Comparing with CMEMS level 4 SST, the EuroSea interim reanalysis has a smaller bias (0.046 °C) and cRMSE (0.28 °C) than the existing CMEMS reanalysis (0.21 °C for bias and 0.37 °C for cRMSE, respectively).

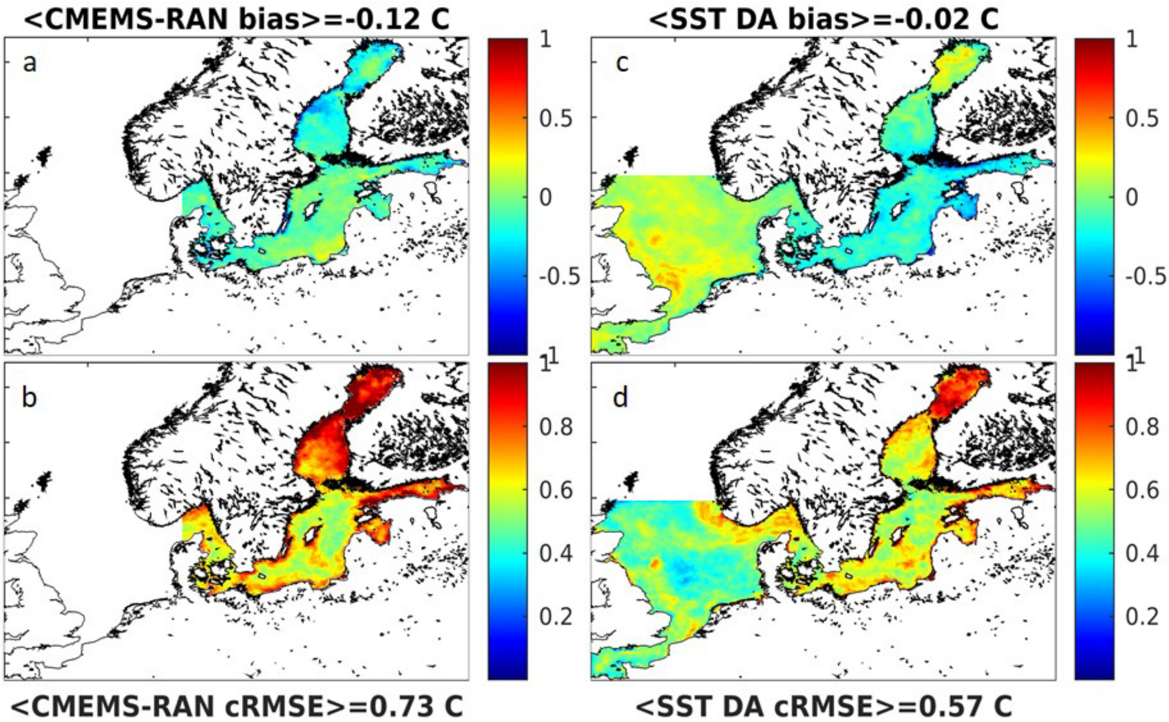

Figure 37. Map of the yearly mean SST bias (a,c) and centered RMS error (b,d) for 2020 for the interim RAN (a,b) and 2-nmi CMEMS RAN (c,d). The SST is validated against the level4 CMEMS dataset.

It seems that the new interim reanalysis is constantly superior to the existing CMEMS reanalysis, both in bias and cRMSE, as shown by daily error statistics in Figure 38.

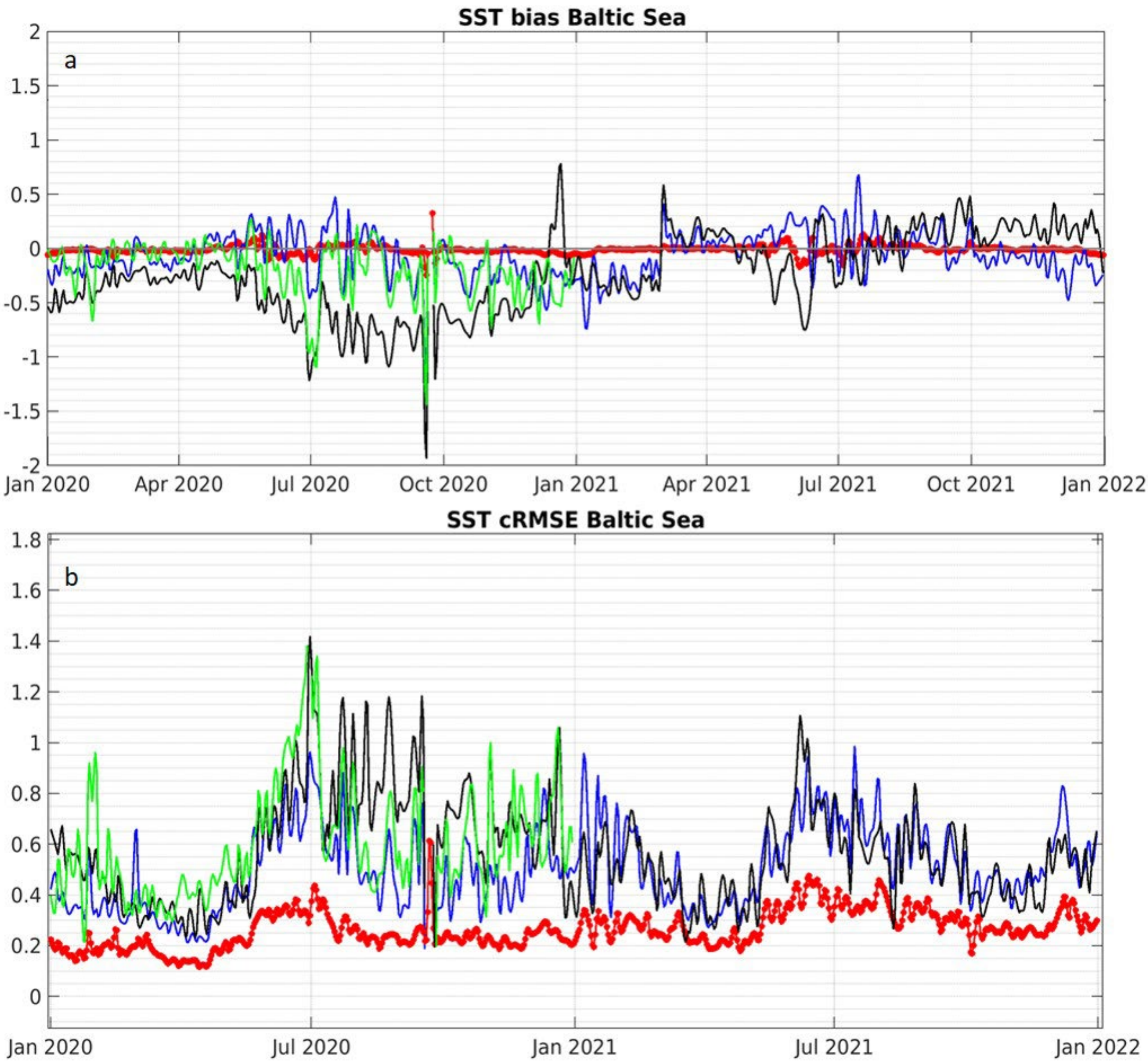

Figure 38. Daily spatially averaged over the Baltic Sea area bias (a) and centered rms errors (b) for Interim RAN (red) and 2-nmi CMEMS RAN (green) during 2020-2021. The blue line represents Interim RAN 24-hour forecast and the black line corresponds to the CMEMS NRT system SST errors (BALTICSEA_ANALYSISFORECAST_PHY_003_006).

There are, unfortunately, few independent *in-situ* observations for proper data assimilation assessment. Here the temperature and salinity reanalysis products are validated against the existing ICES database. Examples of T/S profiles from the Interim RAN (red) and from the CMEMS RAN (green) are shown in Figure 39 for a selected day on 26 March 2020. The Interim RAN seems to correct deeper salinity errors and also correct the position of the thermocline.

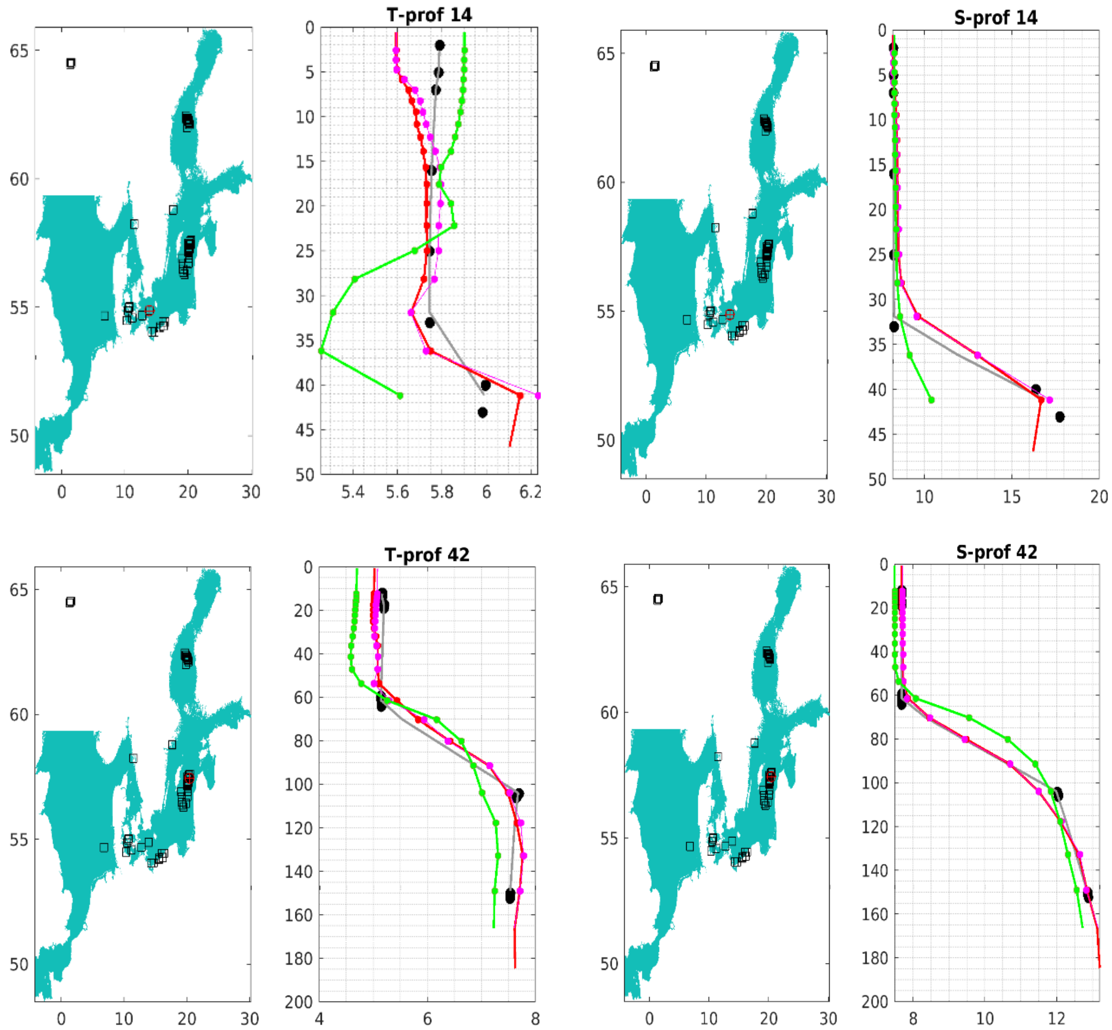

Figure 39. Examples of Temperature and Salinity profiles from Interim RAN (red) and 2-nmi CMEMS RAN (green) on 26th March 2020. In-situ observations are shown with grey line with black circles.

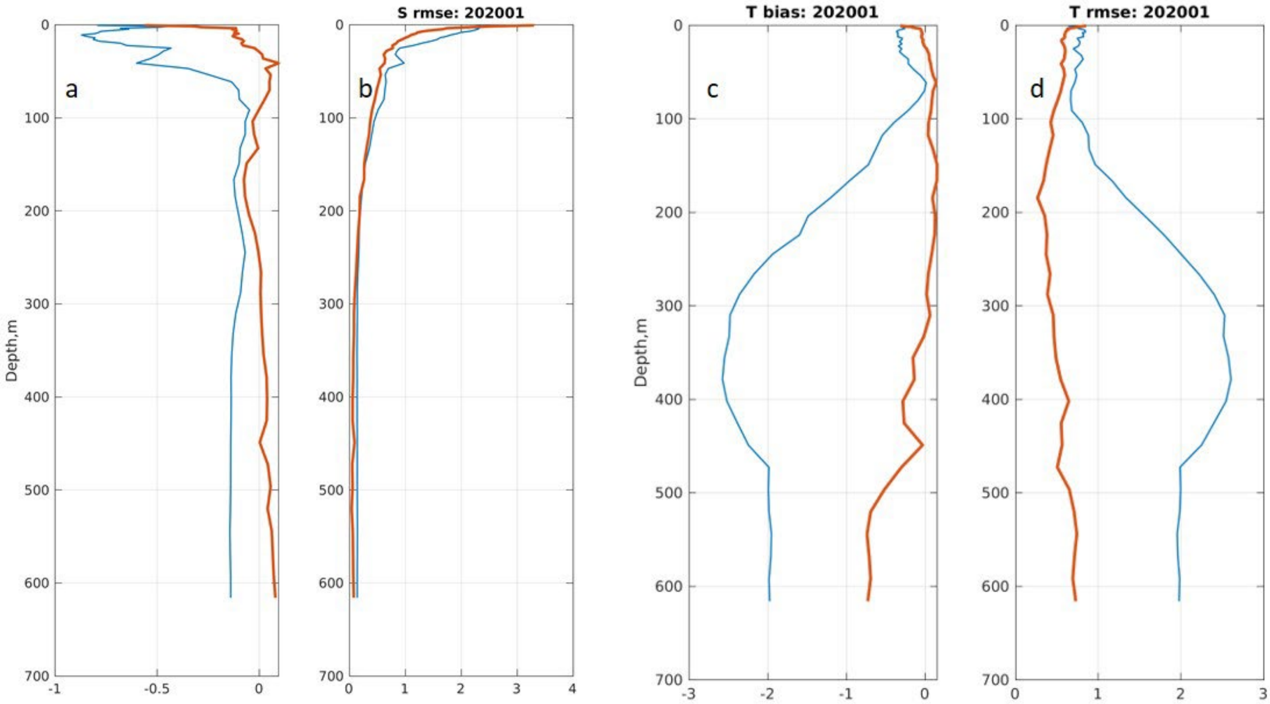

Figure 40. Monthly mean bias (a,c) and cRMSE errors (b,d) of Salinity and Temperature profiles with respect to ICES in-situ observations averaged during the period 2020.01.01-2020.01.31. Interim RAN is shown in red, and 2-nmi CMEMS RAN is shown by blue curve.

Figure 40 shows the monthly mean bias and cRMSE error of the averaged over all Salinity and Temperature profiles during January 2020. Both old and Interim reanalysis errors are calculated with respect to the ICES *in-situ* observations. The results show that Interim reanalysis has much smaller errors than the old reanalysis, especially in the deeper layers.

Finally, we compare the performance of the reanalysis by plotting temperature and salinity time series at a mooring station, Arkona (Figure 41). Both variables are improved in the Interim RAN, showing a better fit to observations. This is especially true for the bottom temperature and salinity.

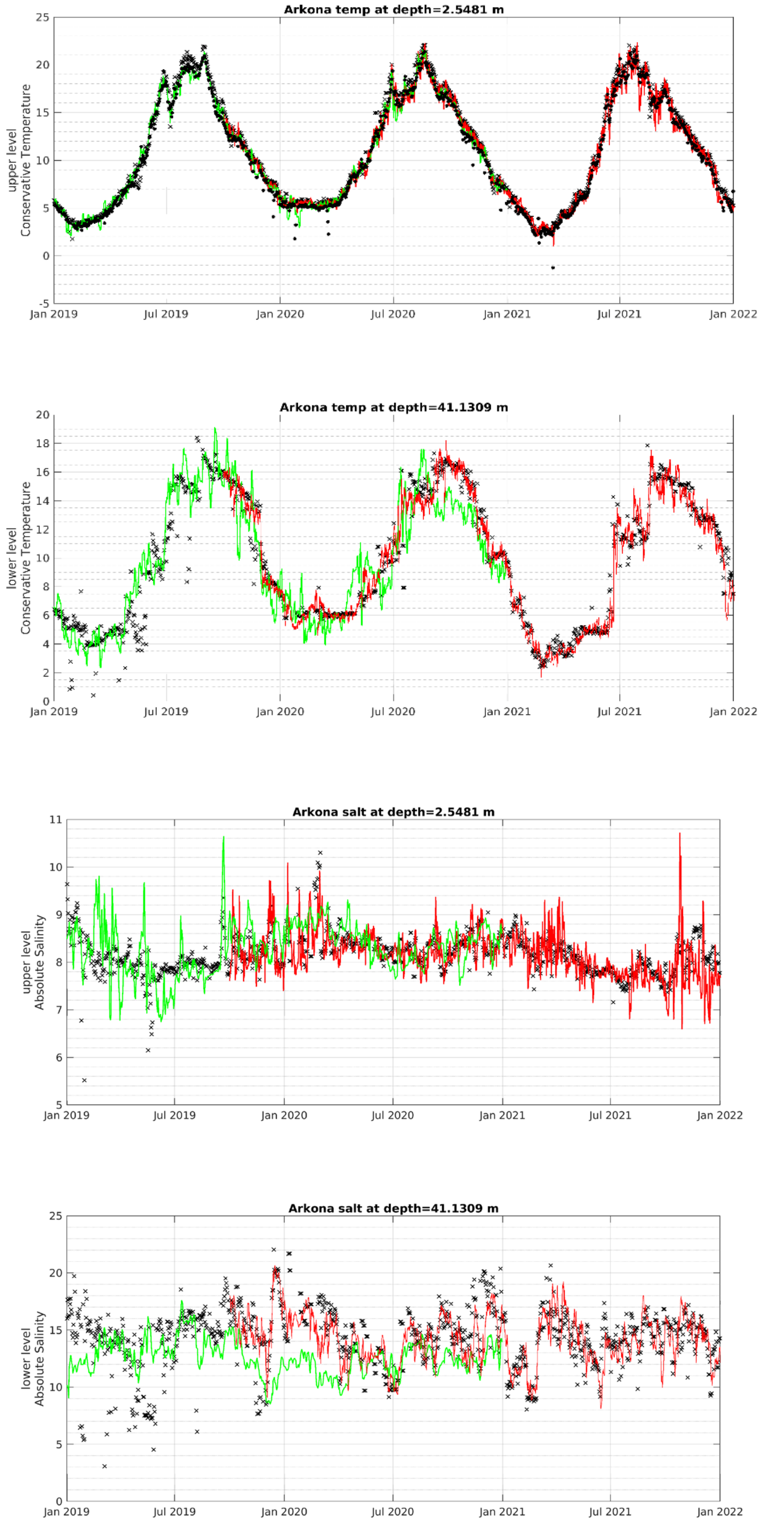

Figure 41. Surface and Bottom Temperature and Salinity at Arkona station during the whole period 2019.10-2021.12. Observations are shown with black dots (satellite) or crosses (ICES), Interim RAN is shown in red, and 2-nmi CMEMS RAN is shown by green curve.

5. Indicator reports based on interim reanalysis

5.1. Near-bottom salinity and oxygen

The impact of additionally collected profile data (CTD casts) on the reanalysis results is demonstrated by comparing near-bottom salinity and oxygen distributions from DMI Interim reanalysis product and CMEMS products (BALTICSEA_REANALYSIS_PHY_003_011 for salinity and BALTICSEA_REANALYSIS_BIO_003_012 for oxygen). The monthly average maps are created, and examples of salinity and oxygen distributions for June 2020 are presented in Figure 42 and Figure 43, respectively.

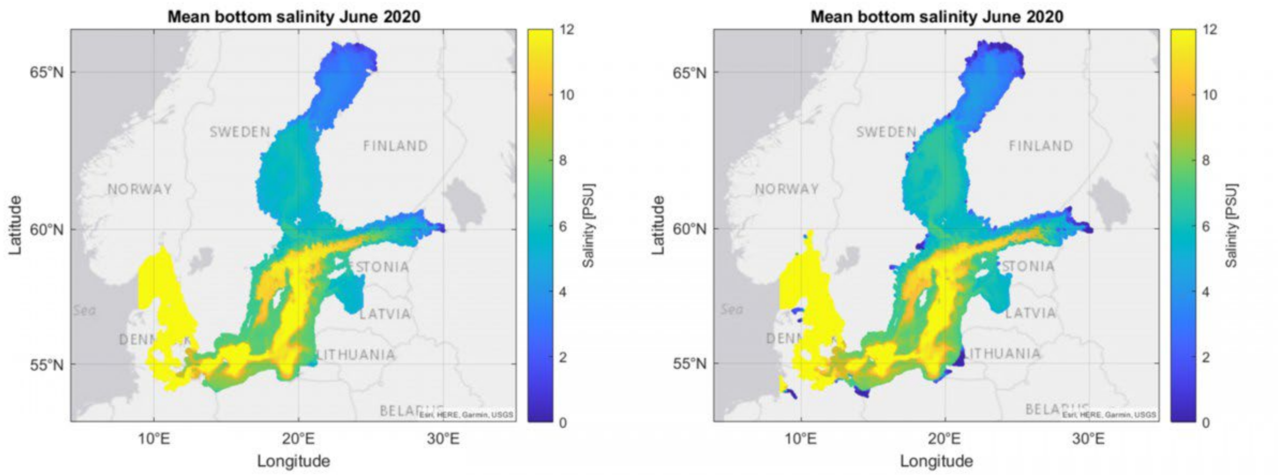

Figure 42. A comparison of the distributions of monthly average near-bottom salinity based on CMEMS reanalysis product BALTICSEA_REANALYSIS_PHY_003_011 (left panel) and DMI interim reanalysis (right panel).

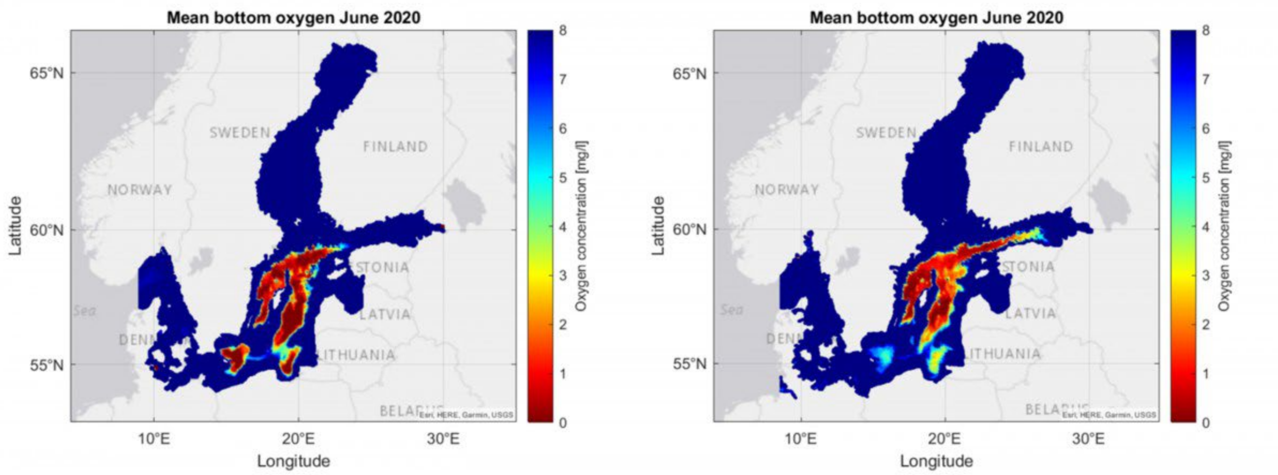

Figure 43. A comparison of the distributions of monthly average near-bottom oxygen content based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and DMI interim reanalysis (right panel).

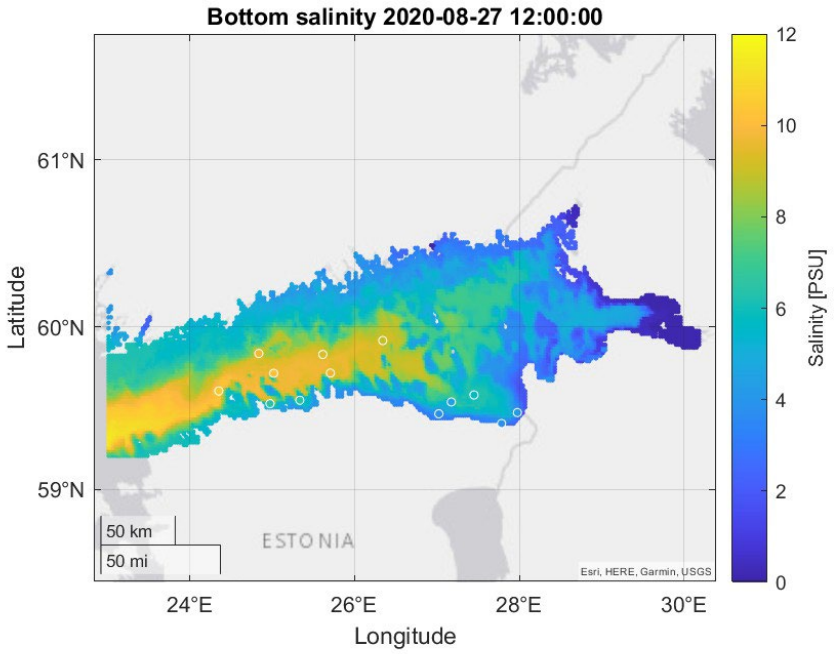

Figure 44. A comparison of the near-bottom salinity distribution based on DMI interim reanalysis and Estonian monitoring data on 27 August 2020.

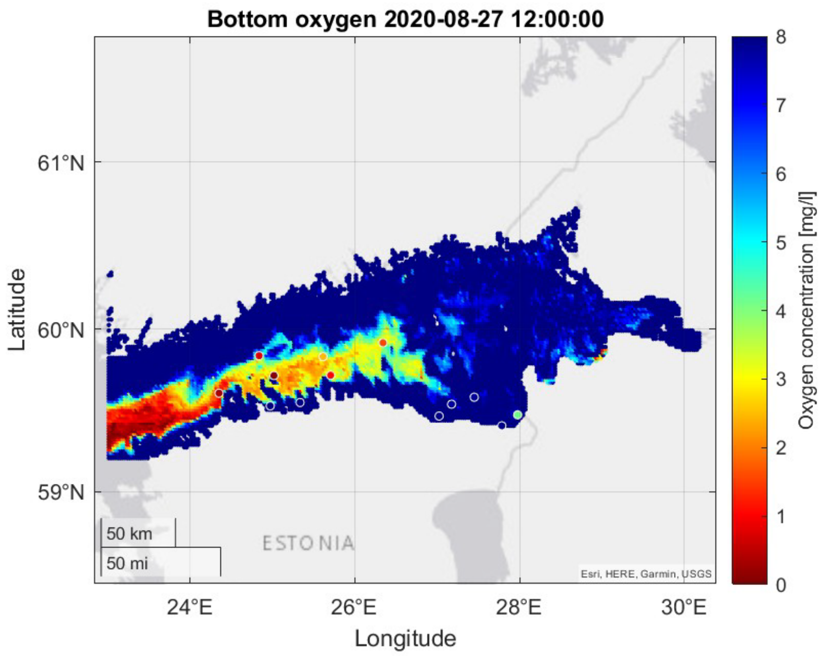

Figure 45. A comparison of the near-bottom oxygen concentration distribution based on DMI interim reanalysis and Estonian monitoring data on 27 August 2020.

Noticeable differences in near-bottom salinity distributions are seen as slightly higher salinities in the eastern Gulf of Finland, while the differences are not large in the rest of the basins. However, the near-bottom oxygen distributions differ significantly. DMI Interim reanalysis product has higher concentrations of oxygen in the near-bottom layer of the southern Baltic Sea basins and lower in the Gulf of Finland. To demonstrate that the DMI reanalysis results are more in line with the observations, the modelled salinity and oxygen distributions in the Gulf of Finland are compared with the monitoring data from the same day (see Figure 44 and Figure 45). The validation dataset was not used in the reanalysis process. As seen in the figures, the observations and model data agree very well for salinity and reasonably for oxygen. It shows that additional data for reanalysis improves the result significantly since, based on the CMEMS product, such low oxygen values were not simulated in the near-bottom layer of the central and eastern Gulf of Finland.

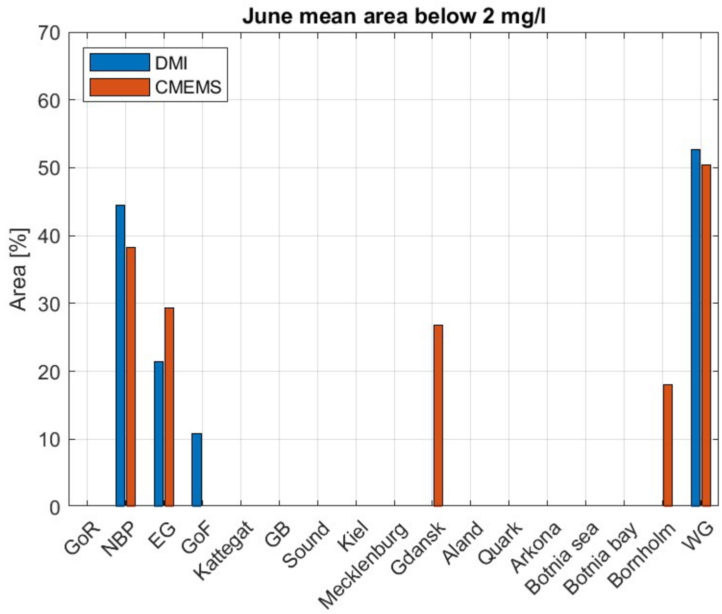

Figure 46. A comparison of the monthly mean extents of hypoxic bottoms in the Baltic Sea sub-basins based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (red bars) and DMI interim reanalysis (blue bars) in June 2020.

The highlighted change in near-bottom oxygen distributions between the two products – higher values in the southern Baltic Sea basins and lower values in the Gulf of Finland in the DMI reanalysis results – also impacts potential indicator assessment. For instance, the status evaluation using Oxygen debt or the extent of hypoxia as an indicator could be more reliable based on the Interim reanalysis. The hypoxic area was present in the CMEMS product in the Gdansk Bay and the Bornholm Basin while not in the Gulf of Finland in June 2020 (Figure 46). DMI Interim reanalysis results indicate the opposite situation – no hypoxia in the Gdansk Bay and the Bornholm Basin, but more than 10% of the bottom areas were hypoxic in the Gulf of Finland in June 2020.

5.2. Nutrients in the surface layer

Comparing monthly average nutrient concentrations in the surface layer (0-10 m) between CMEMS-based and DMI Interim reanalysis estimates also revealed some differences (see Figure 47 and Figure 48). Although the distribution pattern was the same in both products in February 2020, the spatial gradients between the semi-enclosed basins as the Gulf of Riga and the more open basins were reduced in the DMI reanalysis product compared to the CMEMS product. It also could reduce the difference between the HELCOM assessment and CMEMS-based assessment of the eutrophication status presented in sub-section 2.4 (e.g. see a comparison using the DIN indicator in Figure 4).

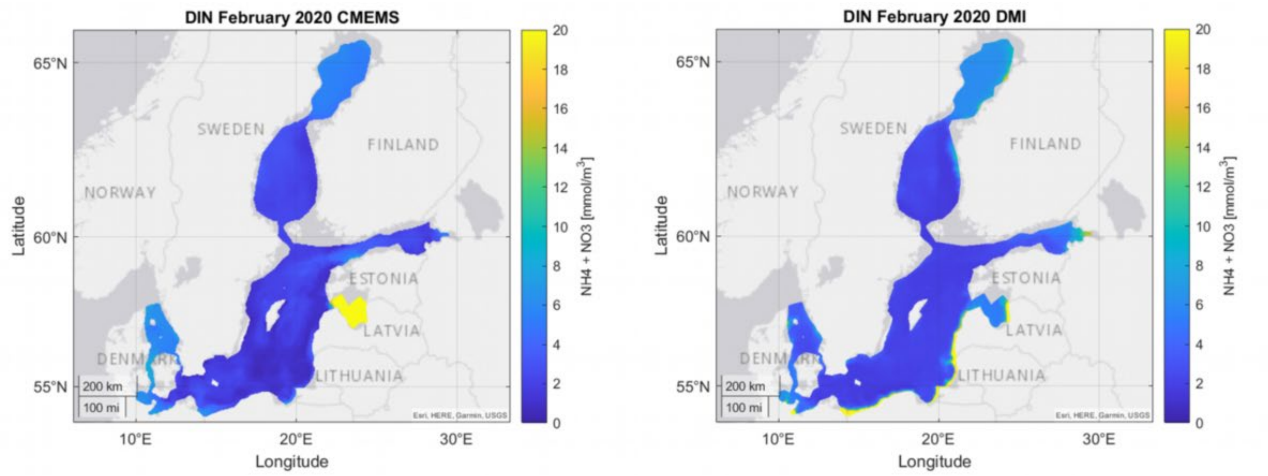

Figure 47. A comparison of the monthly average distributions of DIN in the surface layer (0-10 m) of the Baltic Sea in February 2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and DMI interim reanalysis (right panel).

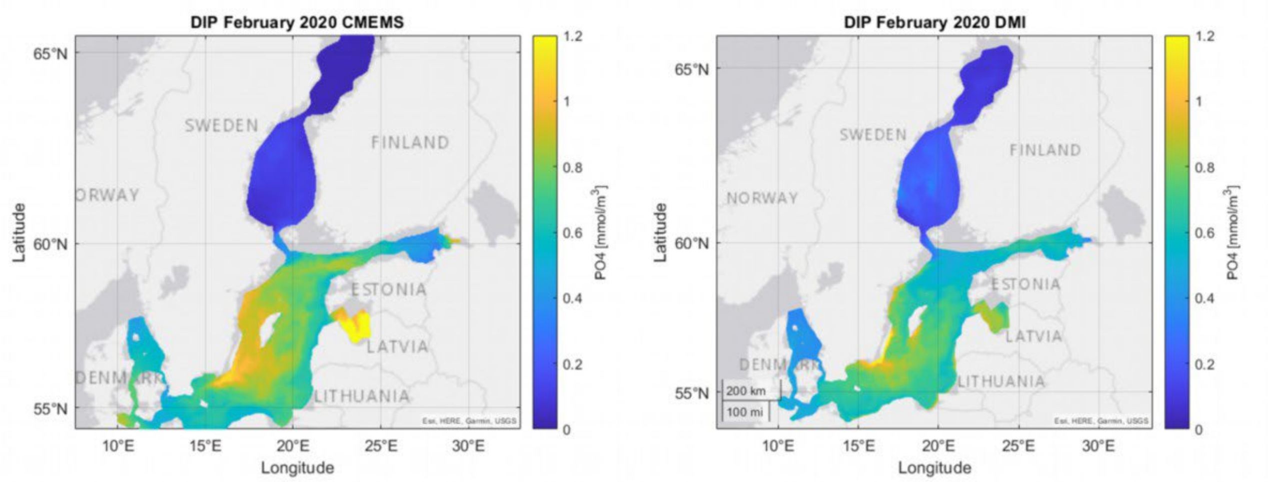

Figure 48. A comparison of the monthly average distributions of DIP in the surface layer (0-10 m) of the Baltic Sea in February 2020 based on CMEMS reanalysis product BALTICSEA_REANALYSIS_BIO_003_012 (left panel) and DMI interim reanalysis (right panel).

Using more observational data would be expected to improve the agreement between the model-based and measurement-based results. However, models show that DIN, DIP and Chl-a concentrations vary within the assessment units. If the spatial coverage with measurements is not good enough, the assessments based on conventional monitoring analyses could also be biased. The data availability (temporal and spatial coverage) was the main reason for evaluating the confidence of the HELCOM DIN and DIP indicator assessments moderate or low. Thus, combining HELCOM monitoring data with the reanalysis products, where all available measurements are employed, would improve the confidence of eutrophication status assessments.

6. Conclusions

Selected HELCOM eutrophication indicators were calculated following HELCOM methodology as average concentrations in the surface layer (0 – 10 m) for winter (DIN and DIP) and summer (Chl-*a*). Indicator calculations show a steady decline in concentrations of all nutrient compounds in recent years for all basins in the north-eastern Baltic Sea that is not confirmed by the measurements. We suggest a way forward for harvesting monitoring data before their official submission deadline and producing interim reanalysis products to improve the confidence of assessments based on CMEMS products.

For the occurrence and intensity of heatwaves, a climatological distribution of sea surface temperatures was calculated for each grid cell in the Baltic Sea using data from 1986-2020. The marine heatwave was identified when SST exceeded the 90th percentile value for a site and date. For upwellings, the SST data were analysed along transects from coast to coast in either North-South or East-West direction. Every grid point with a local SST value >2 °C colder than the transect average was assigned to a coastal upwelling event. The results based on two selected products (reanalysis and remote sensing) agree well except in years/seasons when the seasonal thermocline was very shallow (e.g. 2018).

We demonstrate that CMEMS products covering the surface layer dynamics in the Baltic Sea (e.g. SST) can describe long-term trends and inter-annual variability in hydrographic conditions (also extreme events) and serve as background information for indicator-based eutrophication assessments.

Faster delivery of CTD and monitoring data has been encouraged within the BOOS and HELCOM communities. More T/S observations have been collected from BOOS partners and other data sources than what are currently available in CMEMS INSTAC. These data have been aggregated and made available for data assimilation in generating the interim reanalysis. DMI developed the interim reanalysis for year 2020-2021 by assimilating satellite SST and T/S observations from ICES database, mooring buoys, Argo floats, gliders and ship CTD data delivered by BOOS partners. The validation results showed that the interim reanalysis has better quality than the existing CMEMS reanalysis products. It has been shown that the quality of the eutrophication status assessment improves as well when interim reanalysis data are used.

Acknowledgement

Authors acknowledge supports from Vilnis Frishfelds at DMI (currently in University of Latvia) for pre-processing the T/S observations.

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