1 Project data

BONUS INTEGRAL

Integrated carbo**N** and **T**rac**E** **G**as monito**R**ing for the b**AL**tic sea

Third Annual Report

Reporting Period: July 1st 2019 to Sept 30th 2020

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Leibniz Institute for Baltic Sea Research Warnemünde (IOW),
University of Uppsala (UU),
Finnish Meteorological Institute (FMI),
Institute of Oceanology of the Polish Academy of Sciences (IOPAN),
Tallinn University of Technology (TTU),
GEOMAR Helmholtz Centre for Ocean Research Kiel (GEOMAR),
Swedish Meteorological and Hydrological Institute (SMHI),
University of Exeter (UNEXE)

2 Scientific and technological results achieved during the reporting period

A.) INTRODUCTION

Several European nations are investing in the Integrated Carbon Observation System (ICOS). Finland, Sweden, and Germany are already partner of the ICOS ERIC with established infrastructure, while other countries like Poland and Estonia are currently in the process of developing their strategy. Although the overall aim of ICOS is to provide European-wide carbon dioxide and other greenhouse gas (GHG) concentration and flux data, an integration for the Baltic Sea region has not been pursued, and the added value of ICOS and related infrastructure for the Baltic Sea ecosystem assessment has not been exploited at all.

Within BONUS INTEGRAL, we aimed to

- Integrate the different data streams of ICOS and related infrastructure in the pan-Baltic area,
- Provide better charts of seasonal carbon dioxide and GHG flux over the Baltic Sea, including advanced remote sensing approaches,
- Integrate the carbon system into a high-resolution 3D-model, which will contribute to a better description of the biogeochemical coupling of eutrophication and deoxygenation,
- Demonstrate the added value for a better biogeochemical ecosystem status description of the Baltic Sea,
- Advise the implementation of ICOS in the south-eastern countries of the Baltic, and actively promote components strengthening the value for Baltic Sea ecosystem status assessment,
- Develop, in close interaction with stakeholders, strategies for a better, cost efficient monitoring approach for the Baltic Sea by integration of ICOS and related data.

The work plan is subdivided into 7 work packages. WP's 2-6 are related to the R&D program, WP1 to management of the project, and WP 7 to dissemination and outreach: WP1 Coordination and Management; WP2 Data mining, assimilation, integration; WP3 Infrastructure and observation amendments; WP4 Greenhouse Gas data integration, WP5 Flux parameterization and estimates; WP6 Carbon-based ecosystem assessment; WP7 Dissemination and outreach.

B.) WORK PACKAGE 1 - ORGANIZATION AND MANAGEMENT (Lead: IOW)

The major task of the management was to assure that the project goals could be met, by assuring communication between the groups and inquiry about the progress. After the busy 2nd year of the project with the summer school and two dedicated BONUS INTEGRAL cruises, the 2nd periodic report was submitted in time. The 2nd annual meeting in Krusenberg Herregard near Uppsala was hosted by partner UU from August 6th to 8th 2019, but was reported already in the 2nd annual report. Because of delay in several parts of the project mainly due to some delayed implementation of infrastructure amendments or technical problems, late finalization of the aftermath of the two cruises, and some required personnel changes (parental leaves, changes of position), it was decided to request a three months prolongation of the project. This required formal application at BONUS as well as all national funding agencies, and was granted in spring 2020. At the same time, it was communicated to BONUS EEIG and the German National funding agency that the stakeholder meeting (WP7), which was foreseen as a side event of the HELCOM S&C meeting in May in cooperation with BONUS SEAM and FUMARI, could not take place due to the COVID 19 pandemic.

The final meeting of the project was held online on September 28th to 29th 2020. During the meeting, the status of pending deliverables was briefly discussed and the time line for the 3rd periodic and final reporting agreed upon. Most of the time, however, was dedicated to presentation of science, to a large fraction by the young PhDs and PostDocs involved in the project. It has to be emphasized that the project already produced a huge number of scientific publications, with several additional being submitted, and more than ten further publications envisaged to be finalized in the near future (see also Chapter 7 – Publications).

Another task of the management was to oversee the payments of the EU contribution based on the claims of the project partners. Here, the collaboration with the subcontracted company turned out to be very efficient.

Some new staff members entered the BONUS INTEGRAL team over the course of the 3rd period. At IOW, Dr. Matthias Kreuzburg joined the team, in particular to oversee the preparation and delivery of all project-related data to secured international established data bases. At IOPAN, associate professor Monika Kędra has been temporarily hired (0.3 PM) to interpret marine CO_2 system data against the productivity patterns in the Gulf of Gdansk. At TTU, PhD Student Kai Salm, entered the BONUS INTEGRAL team for the analysis of meteorological and hydrographic data related to the BONUS INTEGRAL cruises on RV Salme in 2018. GEOMAR hired Dr. Tobias Steinhoff for BONUS INTEGRAL from August 15th 2019 until September 30th 2020. He was in charge for sensor maintenance and data management of the trace gas data from the Tavastland SOOP line.

Despite the delays, which resulted from the wish of the group to meet or exceed all goals of the project, we can state that all deliverables have been submitted prior to the submission of the 3rd annual report.

Deliverable 1.4: Delivery of all quality assured data to secure data bases (IOW, with all partners)

The obtained quality-controlled environmental data by the partners within BONUS-INTEGRAL are an important contribution to the state-of-the-art HELCOM monitoring program and provide high-resolution data on greenhouse gas fluxes and budgets of the Baltic Sea. Data include the quality assured data collected by the two cruised dedicated to the project (RV Elisabeth Mann Borgese, RV Aranda), data from monitoring cruises amended by BONUS INTEGRAL campaigns (e.g. RV Salme), data from ships of opportunity (SOOPS Finnmaid, Silja Serenade and Agat), as well as from the continuous measuring station of Östergarnsholm. In accordance to EU principles, BONUS INTEGRAL aimed to secure these data in long-term maintained data bases following the FAIR principles for archiving and easy conduit to the data. Due to the nature of the data, it was not reasonable to post the data/metadata on a single platform, as part of the data are submitted to specially dedicated data bases following clearly defined schedules (e.g. annual delivery of surface pCO_2 data to SOCAT).

Data of these cruises and platforms was submitted to the data bases SOCAT, PANGAEA, EMODNET, and depending on the extent and complexity of the data submission the editorial process and minting of DOI names can take up to 8 weeks. In general, all data and metadata are quality checked, harmonized, and processed for machine readability, which allows efficient and reliable re-usage of the data. Surface pCO_2 data for the year 2020 from several *platforms will be submitted in January 2021 to be included in the next version of the SOCAT Alas, feeding into important international products such as the Global Carbon Project.*

BONUS INTEGRAL Delivery Report D1.4 references the public databases where project data is stored. It briefly describes the data submission and how the quality assurance of the data will be guaranteed and where and when references to the database can be found. An overview of the data and main contact persons is given in Table 1. More information can be found in Deliverable Report 1.4.

Data source	***Contact Person***	***Mail of contact person***	***Del. date***	***Data storage***
EMB Cruise	*Stefan Otto (IOW),* *Erik Jakobs (IOW)*	*Stefan@otto@io-warnemuende.de* *Erik.Jakobs@io-warnemuende.de*		*PANGAEA*
Aranda Cruise	*Heidi Pettersson (FMI)*	*Heidi.Pettersson@fmi.fi*		*PANGAEA*
Finnmaid Cruise	*Gregor Rehder (IOW)*	*Gregor.Rehder@io-warnemuende.de*		*SOCAT*
Tavastland data	*Anna Willstrand Wranne (SMHI)* *Tobias Steinhoff (GEOMAR)*	*anna.wranne@smhi.se* *tsteinhoff@geomar.de*		*SOCAT*
Östergarnsholm	*Anna Rutgersson*	*Anna.Rutgersson@met.uu.se*		*ICOS / SOCAT*
Silja Serenade data	*Lauri Laakso (FMI)* *Martti Honkanen (FMI)*	*Lauri.Laakso@fmi.fi* *Martti.Honkanen@fmi.fi*		*PANGAEA*
Agat data	*Karol Kulinski*	*kroll@iopan.gda.pl*		-
Salme Data	*Urmas Lips*	*urmas.lips@taltech.ee*		SeaDataNet

Table 1: *Overview of the cruises conducted and platforms used during the project BONUS INTEGRAL, contact persons, details for the individual datasets, and indication of the database the data was submitted to.*

C.) WORK PACKAGE 2 (Lead IO PAN)

All objectives of WP 2 were fulfilled within the first two years of the project.

D.) WORK PACKAGE 3 (Lead: IOW)

In order to get vital additional information on surface greenhouse gas concentrations and fluxes as well as carbon system data to support WPs 4-6, INTEGRAL provided several amendments to existing infrastructure, used its close relation/involvement in the HELCOM monitoring to effectively gain carbon system and trace gas data from selected monitoring stations, performed two field campaigns on research vessels, and installed a basic underway pCO_2 system on a coastal-near ferry line traversing the plume of the river Vistula. For individual platforms and locations, please refer to Figure 1 and Deliverable Report 3.1. We update the information based on achievements of the 3rd year of the project.

Update on Work related to Deliverable 3.1: Installation / operation of infrastructure amendments

The main steps to amend / extend the infrastructure within the BONUS INTEGRAL project were reported in the 2nd annual report, as well as a brief description of the platforms. However, due to the continuous nature of the actions taken, we provide a short update on the status of the infrastructure and steps taken during the last year of the project.

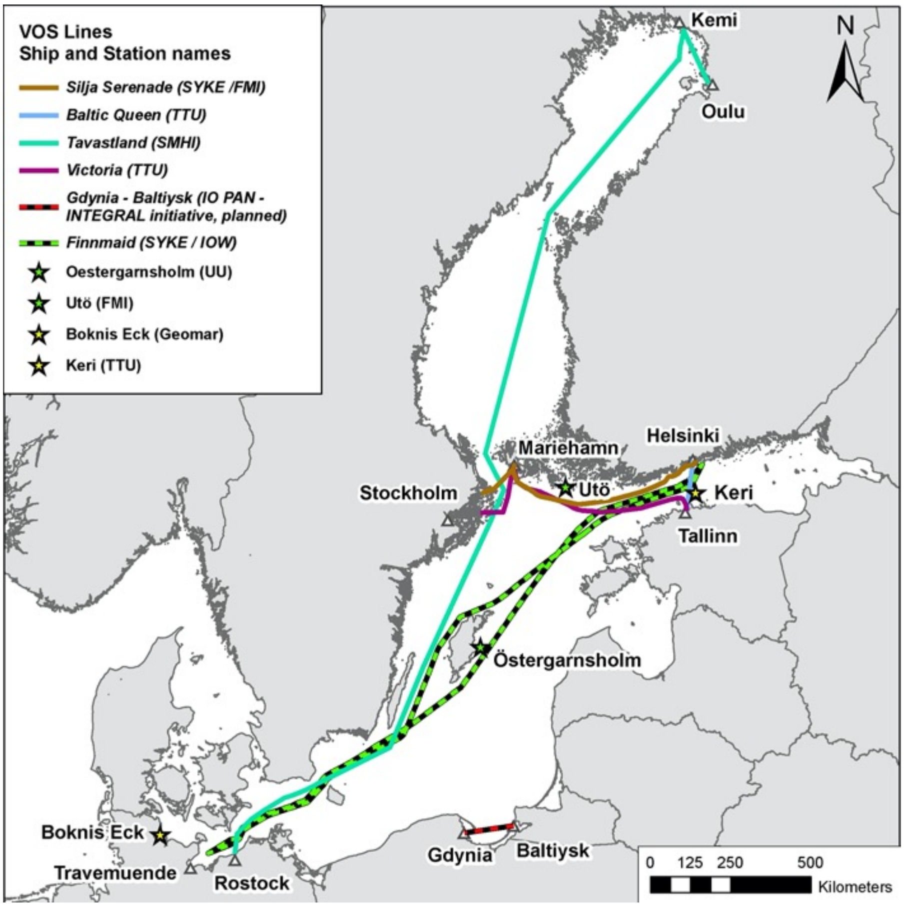

Figure 1: *Map of locations of infrastructure used within BONUS INTEGRAL. The stations Östergarnsholm, Utö, and SOOP Finnmaid are part of ICOS. The line Gdynia Baltiysk (SOOP Agat) is projected within BONUS INTEGRAL. All other infrastructure is established by other initiatives, but was partially amended.*

- **SOOP Finnmaid**: The system was operational over most of the reporting period and after several years of preparation by IOW, the new instrumentation (generation 3) was installed on board and delivered high quality data right after installation in November 2019. Since that date, the worldwide unique system records data of pCO_2, pCH_4, O_2, pH, N_2O and CO from the surface waters with a time resolution of 1 min. Like in the original system, two independent water air equilibration chambers measure, amongst the other parameters, the pCO_2 of seawater independently, and the consistency of both measurements within $<2\mu$atm is an important QC-criterion for both subsystems. The installation of the HydroFia pH system developed within BONUS PINBAL is the first long-term test on a SOOP line and provides an unprecedented data set of surface pH measurements across the Baltic Sea. An overview of the data from a single transect, which is produced usually within one day after finalization as basis for QC and trouble detection, is displayed in Figure 2.The system is controlled by a custom made software developed at the Department for Automatization at the University of Rostock, allowing remote control and realizing a huge amount of internal safety switches and controls, water guards etc. to maximize data recovery and minimize any remaining hazard to the ship (mainly leakage, venting calibration gas, or electricity circuit problems).

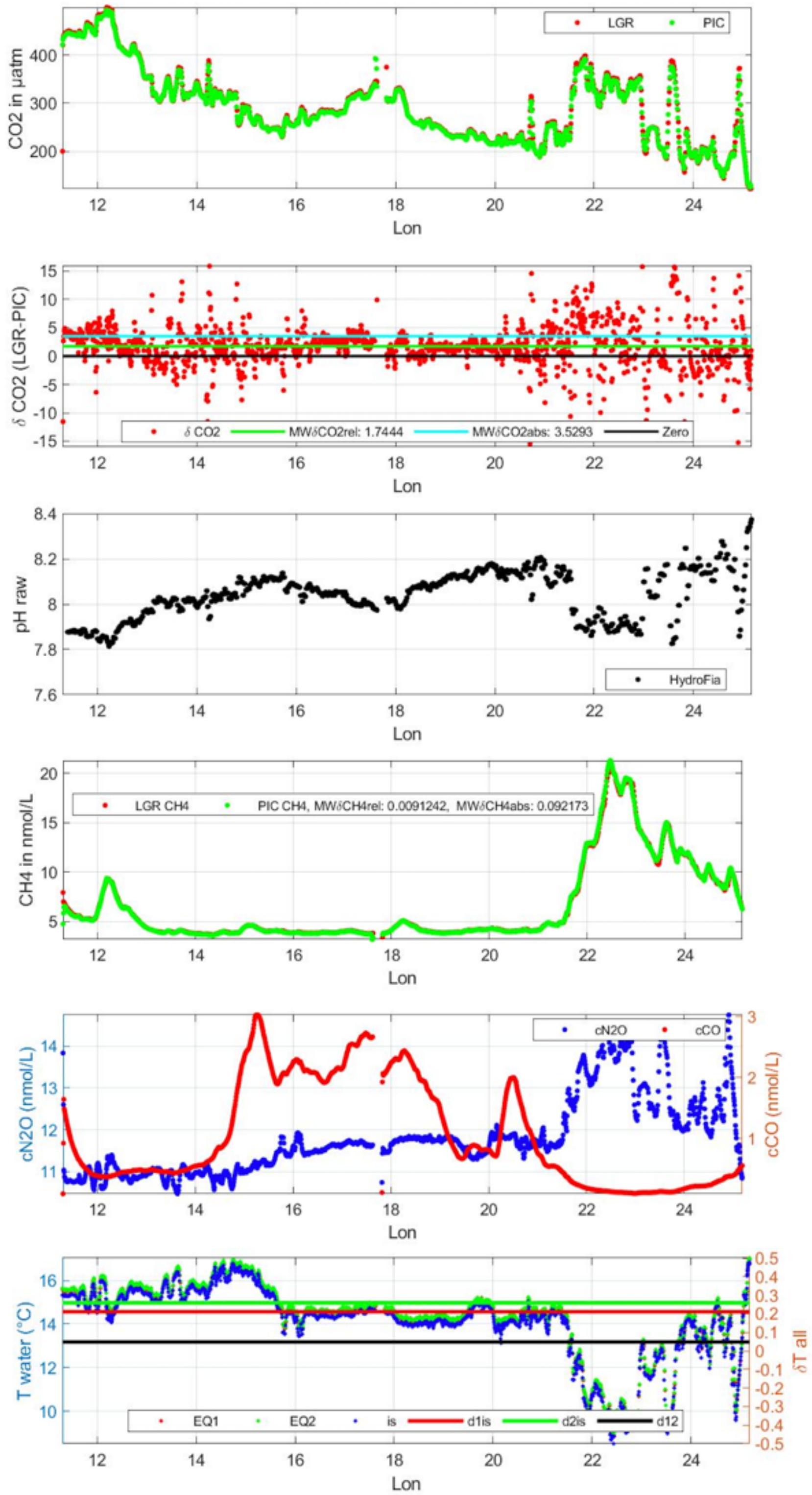

Figure 2: *Extract of the automated measurements of the new surface monitoring system on SOOP Finnmaid from June 21st to June 22nd between Lübeck (left) and Helsinki (right), for ship track see Figure 1. Panels from top to bottom:* pCO_2 *(from two sensors), difference in* pCO_2 *measurements with mean deviation, pH (uncalibrated),* C_{CH4} *(from two sensors),* c_{N2O} *and* C_{CO}*, water temperature from the equilibration systems and at the inlet (in situ), with indication of mean differences.*

- **SOOP Tavastland** is operated by SMHI and started as a joined effort with SYKE in 2009. The ferrybox measures salinity, temperature, oxygen, turbidity, chlorophyll fluorescence, phycocyanin fluorescence, and CDOM-fluorescence. A pCO_2 system from General Oceanics was installed next to the ferrybox one year later. After years of problems with the system and sporadic data collection, it was finally fully operational in the fall of 2019 due to supportive efforts by the BONUS INTEGRAL-partner GEOMAR, and has been measuring continuously since. With support of BONUS INTEGRAL, the station is now an official marine station within the Integrated Carbon Observation System (ICOS). Figure 3 shows the seawater pCO_2 data from October 2019 onwards. The data gaps are mainly caused by problems with the seawater supply. The seawater supply will be completely renewed in fall 2020.

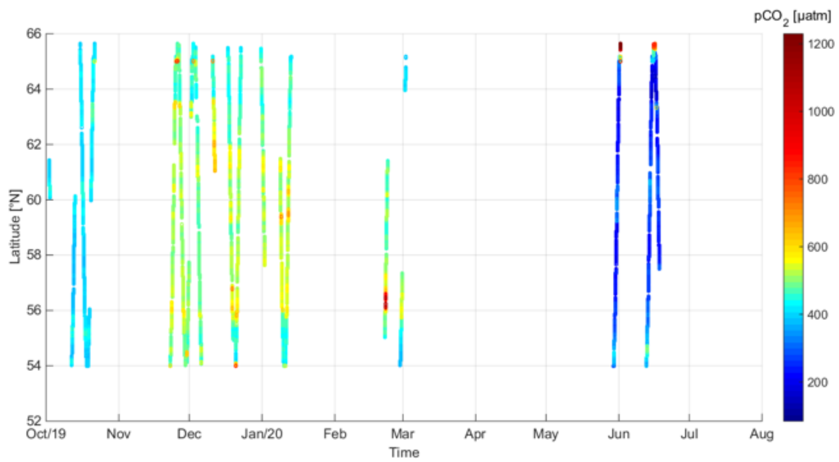

Figure3: *Data of seawater pCO_2 from October 2019 until July 2020 recorded by the SOOP Tavastland. Data gaps are mainly due to pump problems. The huge gap in spring 2020 was caused by the Covid-19 pandemic as maintenance on board was not allowed. Data given against latitude. For cruise track information, see Fig. 1.*

IOW and GEOMAR provided two off-axis ICOS CH_4/CO_2 and N_2O/CO sensors (Los Gatos Research, San Jose, CA) for the installation onboard SOOP Tavastland to expand the existing measurement setup by continuous high-frequency measurements of methane and nitrous oxide. For those parameters, the database in the northern basins is particularly scarce. IOW also provided fine calibration of the needed reference gases.

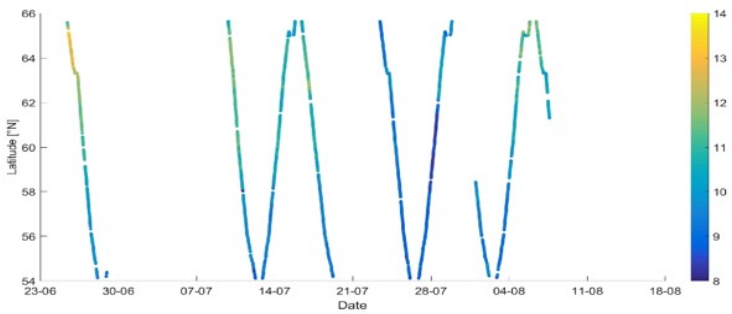

Figure 4: *Data of seawater CH_4 and N_2O [nmol L^{-1}] from July 2019, when the N_2O/CH_4 sensor array was measuring continuously for several weeks. Data given against latitude. For cruise track information, see Fig. 1.*

The Los Gatos Research N_2O /CO and CH_4/ CO_2 sensors have been running since April 2019 and data has been evaluated continuously, although it was frequently interrupted by phases of seawater supply problems and sensor malfunctioning. Figure 4 shows CH_4 and N_2O concentrations from July 2019

- **SOOP Silja Serenade** had a very versatile year due to the COVID-19 epidemic. Before March 19th 2020, Serenade was operating on its regular route, Helsinki-Stockholm. As a result of COVID-19 restrictions, Silja Serenade was not operating from March 19th to June 26th 2020. Since then, the ship route was changed to Helsinki-Riga. On this new route, the ship operated June 26th to September 13th 2020, after which the ship has stayed in harbor because Latvia classified Finland as a country with medium risk to health. According to the shipping line Tallink, the ship will start to operate again on the Helsinki-Riga route in May 2021. The measurements have been running successfully all the time when the ship has been operating on any of these two routes, except during the period from October 3rd to November 19th 2019, when the measurements were biased due to a malfunction in the system.
- **SOOP Silja Europa** (Line Tallinn-Helsinki) & **Baltic Queen** (Line Tallinn-Stockholm) are operated by TTU. A new ferrybox system was purchased and installed onboard Silja Europa (Tallinn-Helsinki), which would enable to add more sensors, including those measuring carbon system parameters. The ferry stopped operation in spring 2020 until June 12th 2020 due to travel restrictions. Installations of additional sensors cannot be realized before 2021, as operation was stopped again in September 2020 at least until March 31st 2021.
- **SOOP Agat**. The status and progress is updated in the section addressing Deliverable 3.4.
- **Fixed Station Östergarnsholm**, operated by partner UU, is a marine micrometeorological field station with continuous direct air-sea flux measurements of CO_2 exchange accompanied by other atmospheric parameters (heat flux, turbulence, radiation, precipitation). In the water, the station features continuous measurements of pCO_2, O_2, temperature profile, and salinity. The station is funded by the Swedish Research Council (VR) and Uppsala University. For the BONUS INTEGRAL project, direct flux measurements of methane (CH_4) were added in September 2017 and have been running continuously since then. The first year of CH_4 flux results has been published in a special issue (The Baltic Sea in transition) of Frontiers in Earth Science (Gutierrez-Loza et al., 2019). During the BONUS INTEGRAL sub-project BloomSail, pCO_2, CH_4 and N_2O sampling/measurements were performed around Östergarnsholm from June to August 2018 by IOW. Parts of the data are being submitted to SOCAT.
- At the **fixed Station Utö**, run by FMI, the main seawater measurements, including all carbon measurements, continued as usual with only one interruption: the submerged pump had a failure on May 15th 2020, and the flow-through measurements were offline until the replacement of the pump on July 28th 2020. The vertical profiler, however, provided data for only a month during the reporting period due to a series of technical and software problems. Tests for the quality validation of the long sample tube of the flow-through system were carried out. For this purpose, two SAMI-CO_2 instruments (Sunburst Sensors) and one CTD were used in two different setups. In the first setup, the sensors were deployed in the sea next to the inlet of the flow-through system. For the second setup, these sensors were lifted from the sea and placed to the chamber (ca. 1 m^3) which was

connected to the flow-through at the station in aim to get a reference measurement that is not affected by the pipeline. On May 15th 2019, a stand-alone thermistor was installed directly on the inlet.

- At the **Boknis Eck Time Series Station**, run by Partner GEOMAR, discrete water column sampling (at six standard sampling depths from 1 to 25 m) for N_2O, CH_4 and DIC/alkalinity is conducted on a monthly basis. Two manuscripts about the monthly N_2O/CH_4 data from BE have published in Biogeosciences by Xiao Ma (PhD Student, GEOMAR) partly supported by the project. The monthly N_2O/CH_4 and DIC/alkalinity measurements have been continued until now. The underwater observatory at Boknis Eck (with continuous measurements of dissolved pCO_2 and CH_4) has been destroyed in August 2019, unfortunately. We are currently reconstructing the observatory and hope that measurements can be resumed in spring/summer 2021.

Deliverable 3.2: Report on carbon system data gathered during regular monitoring cruises

The deliverable 3.2 is the result of task 3.2 in WP 3 and involves the major part of the partners in BONUS INTEGRAL, since they are involved directly or through cooperation in the HELCOM biogeochemical monitoring of the Baltic Sea.

During the regular monitoring program additional samples of several carbon system parameters have been taken. This will enhance the data with a more complete carbon system description in combination to the HELCOM standard variables. The sampling strategy is guided by identified gaps in process understanding and need for extrapolation verification according to work within WPs 4 and WP 6.

SMHI Monitoring program

SMHI has performed monitoring cruises in its current form since the early 1990-ies. Since 2014, SMHI has used the Finnish research vessel Aranda for this work. The monitoring cruises visit the same fixed positions every month with some extended cruises during the winter, for mapping nutrient loads and oxygen concentration.

During regular SMHI monitoring cruises, pH is analysed using a pH electrode calibrated with NBS buffers. This setup has been used since the early 1990-ies. A Contros HydroFIA pH system was tested during a cruise in March 2019. The pH-system was borrowed from University of Gothenburg and is a result of the BONUS PINBAL project (Development of a spectrophotometric pH-measurement system from monitoring in the Baltic Sea). The aim of BONUS PINBAL was to develop a pH system that would meet the requirements for measuring in the brackish waters of the Baltic Sea with its large salinity and temperature gradients.

Discrete samples from 11 different stations in the Swedish national monitoring program were analysed on both systems. The aim of this comparison is to change the monitoring set up for pH to a spectrophotometric method in order to improve the precision and long-term intercomparibility of measurements, and thereby the understanding of the carbonate system in the Baltic Sea.

Additional sampling within the Estonian monitoring program

All six Estonian marine monitoring cruises on *RV Salme* in 2018 were joined by IOW in order to perform continuous surface water CO_2 and CH_4 measurements as well as discrete sampling for carbon system parameters (pH, C_T, A_T) and the trace gases CH_4 and N_2O.

Discrete CO_2 and trace gas samples were taken at seven stations on a transect from the Northern Baltic Proper deep into the Gulf of Finland and on seven stations in the Gulf of Riga (five in January and April). The map (Fig. 5) shows the cruise track of the May/June cruise in 2018 with all stations where additional samples have been taken. Furthermore, the continuously-measured partial pressure of CO_2 is displayed, indicating a strong spring bloom in both gulfs with $p$$CO_2$ values as low as 16 µatm in the central to south-eastern Gulf of Finland.

Cruises RV Salme 2018	No of samples A_T/C_T/pH/CH_4/N_2O	No of samples DOC/Metals
January	62	
April	65	
May/June	80	
July	79	
August	83	27
October	77	27

Table 2: Samples collected for the BONUS INTEGRAL project with RV Salme during 2018.

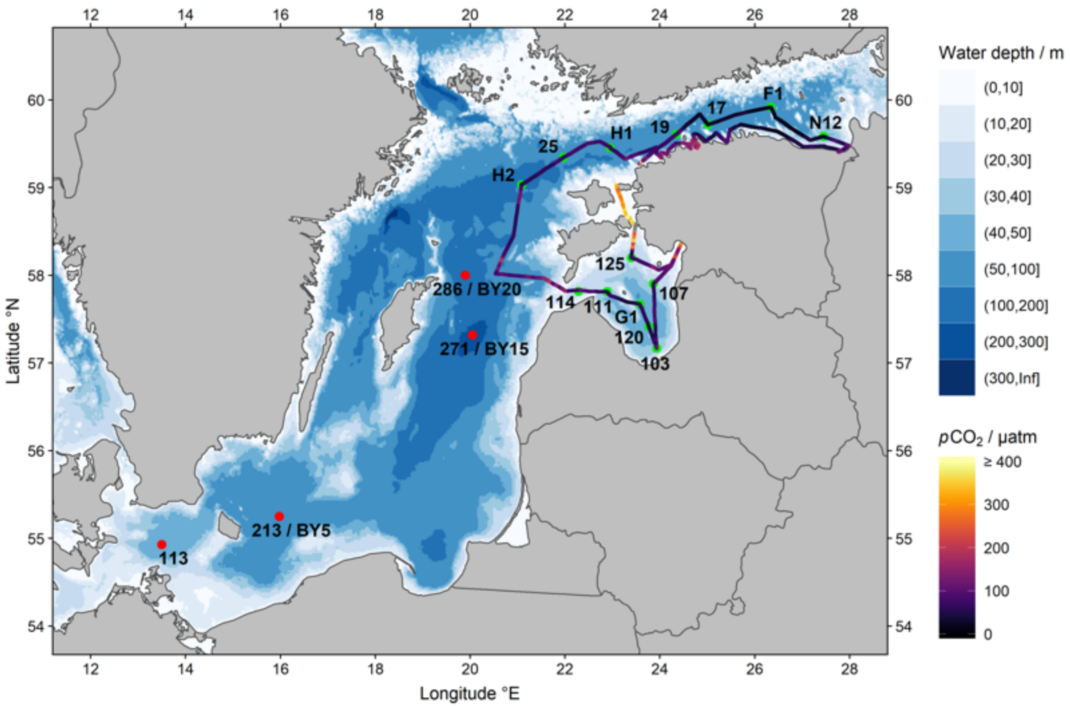

Figure 5: Stations with additional CO_2 system and trace gas sampling performed on monitoring cruises aboard *RV Elisabeth Mann Borgese* (red) and *RV Salme* (green). Additionally, the cruise track of *RV Salme* from May 28th to June 2nd 2018 is shown with colors representing the partial pressure of CO_2 in the surface water as measured continuously with IOW's flow-through equilibrator system. Low $p$$CO_2$ values down to 15.5 µatm indicate a strong spring bloom.

There are multiple reasons for this extended joint effort: Firstly, it is to our knowledge the first seasonal trace gas study in the Gulf of Riga and the measured parameters will allow a first assessment of the trace gas and carbon system dynamics in this region. Therefore, additional nutrient samples have been collected for a better biogeochemical assessment by partner TUHH, as well as samples for DOC and metal concentrations within cooperation with IO PAN (August and October cruise only, see Table 2). Secondly, the Gulf of Finland is a highly dynamic part of the Baltic Sea, which is also true with respect to the concentrations of dissolved gases as observed on the SOOP *Finnmaid* traversing the Baltic Sea between Lübeck-Travemünde (Germany) and Helsinki (Finland) (see also Fig. 2). In order to understand the underlying processes of those trace gas distributions, the analyses aboard Salme will certainly prove valuable since they add not only vertical profiles of trace gases, CO_2 system and other parameters, but also surface data that are both parallel and perpendicular to the Finnmaid track. Therefore, the cruises provide detailed profiling with a wider parameter range to the superior spatial-temporal coverage of the SOOP line.

Comparison with the model-derived CO_2 distribution will provide valuable insight into the performance of the model for which hitherto the data for model validation were completely lacking. Lastly, this one-year long endeavour demonstrates a seamless integration of standard HELCOM monitoring and the amendments pursued within BONUS INTEGRAL, and fostered the collaboration between the institutions executing the biogeochemical monitoring in Estonia and Germany considerably.

Additional sampling within IOW: The CO_2 system in the major basins of the central Baltic Sea

The accumulation of total CO_2 in the deep water of the Gotland Basin (Fig. 5, Station 271/BY15) has been measured since 2003 in conjunction with the IOW long-term observation program. The data provided insight into the dynamics of the organic matter mineralization including the release and transformation of nitrogen and phosphorus compounds (Schneider and Otto, 2019). In the frame of BONUS INTEGRAL the measurements were considerably extended. Three additional stations (Fig. 5) which represent the deep water in the Arkona Basin (Station 113), the Bornholm Basin (Station 213/BY5) and the Farö Deep (Station 286/BY20) were included in the measurement programme. At these stations the vertical profiles between the surface and the bottom water of total CO_2, alkalinity and pH are determined with a seasonal resolution of 2 – 3 months. The vertical resolution amounts to 5 m – 10 m in the surface layer and 25 m in deeper water layers.

The total CO_2 and pH profiles in the surface water are used to integrate vertically the net community production and thus to complement the pCO_2 measurements on SOOP Finnmaid which provide productivity data for the upper surface layer with a high temporal resolution (2 – 3 days). The deep water measurements of total CO_2, pH and alkalinity are used to derive mineralization rates and modifications of the acid-base system (alkalinity) in the course of H_2S formation and denitrification. Through this the work provides validation data for biogeochemical models and their modifications/amendments pursued within BONUS INTEGRAL and contributes to improved parameterizations of the key biogeochemical processes: production and mineralization of organic matter (biomass).

Additional sampling within GEOMAR:

Discrete samples for N_2O and CH_4 in the water column were also collected during two cruises to the southwestern Baltic Sea: (i) R/V Littorina cruise Lit-1914 (PI Jan Scholten, Univ. of Kiel, Germany) from October 21st to October 25th 2019 and (ii) R/V Alkor cruise Alk-543 (PI Florian Scholz, GEOMAR) from August 21st to August 28th 2020. The data from both cruises will significantly extend the data coverage of N_2O and CH_4 water column measurements in the southwestern Baltic Sea.

Deliverable 3.3: Report on outcome of expeditions on research vessels dedicated to BONUS INTEGRAL

The two expeditions BONUS INTEGRAL field expeditions on RV Aranda and RV Elisabeth Mann Borgese took place almost as planned from February 28th 2019 to March 11th 2019 (RV Aranda Cruise 04/19) and May 20th 2019 to June 5th 2019 (RV Elisabeth Mann Borgese Cruise 214). The scientific program of both cruises served almost exclusively the purposes of BONUS INTEGRAL. Several goals were pursued during both cruises:

- Extending the data set of surface data for the creation of maps of surface concentrations of CO_2, N_2O, and CH_4, and pH;
- Information on gradients of these parameters from the basins to the coastal-near regions;
- Simultaneous recording of data potentially useful for the interpretation of parameters retrievable through remote sensing, e.g. CDOM and Chl a;
- Insight into the vertical distribution of CH_4, N_2O, and inorganic carbon system parameters;
- Fostering the understanding of the poorly constrained biogeochemistry of the Gulf of Bothnia by recording a comparable data set in the pre-bloom and post-bloom period, to describe the nitrogen, phosphorus and carbon dynamics.

Both cruises really constituted highlights of cooperation within the project. Cruise Aranda 04/2019 hosted 13 scientists from 5 institutes, while Cruise EMB 214 was fully booked with its 12 places occupied, again representing 5 institutes. IOW; FMI, IO PAN, UU, TalTech, SYKE, and UU were all involved in the campaigns, including almost all of the PhD students involved in the project. While the hosting institutes took care of the standard instrumentation and analysis (CTD, hydrographic data, nutrients (subcontracted to SYKE in the case of RV Aranda), various groups joined lab-forces to retrieve the most complete data sets.

- IOW and GEOMAR were responsible for underway trace gas measurements;
- IOW, with a lot of support from the other labs, was in charge of the carbon system parameters (C_T, pH, pCO_2)
- IO PAN sampled for the home-based analysis of POC and PON, including isotopic information;
- IOW and SYKE took samples for TN and in some cases TP;
- FMI took care of optical measurements (Chl a and CDOM), including some discrete sampling.

A total of 32 stations was sampled during Aranda 04/2019, while 33 stations were sampled during EMB 214, including 7 hydrographic transects using ScanFish.

The cruise tracks of both expeditions are shown in Figures. 6ab. As an example of the data gathered the on-board results for Station 24 of EMB 214 (TF 286 Faro Deep) is displayed in Figure 7.

The data have been used to fill gaps and extend the data base for surface trace gas measurements, and as a control data for an EOF-based generation of pCO_2 maps (see Deliverable Report 6.2). In particular, they substantially enhanced the data density for carbon parameters and other greenhouse gases in the Northern Basins. This is very obvious in the compilation of available data for the generation of surface concentration maps, e.g. D. 4.3. All data of the cruises have been transferred to the Pangea data base, which will facilitate the interpretation of the data, also in a concerted view to assess the processes between late winter and late spring in e.g. terms of productivity.

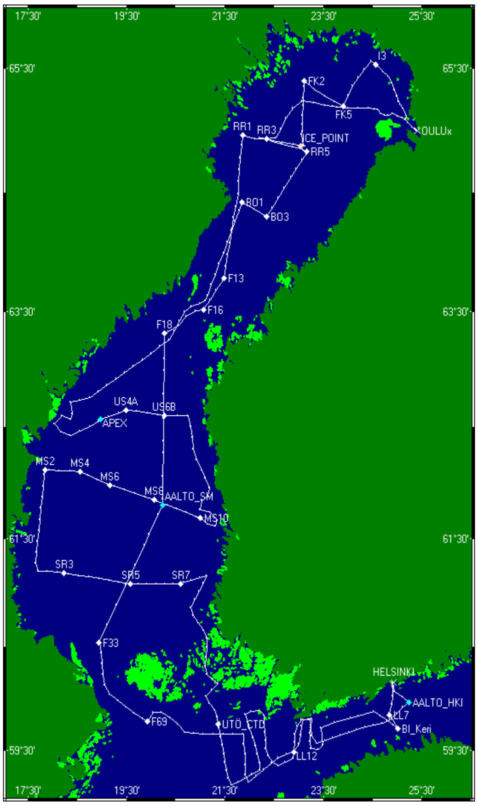

__Figure 6a:__ Track and stations of the BONUS INTEGRAL WINTER cruise February 28th to March 11th 2019.

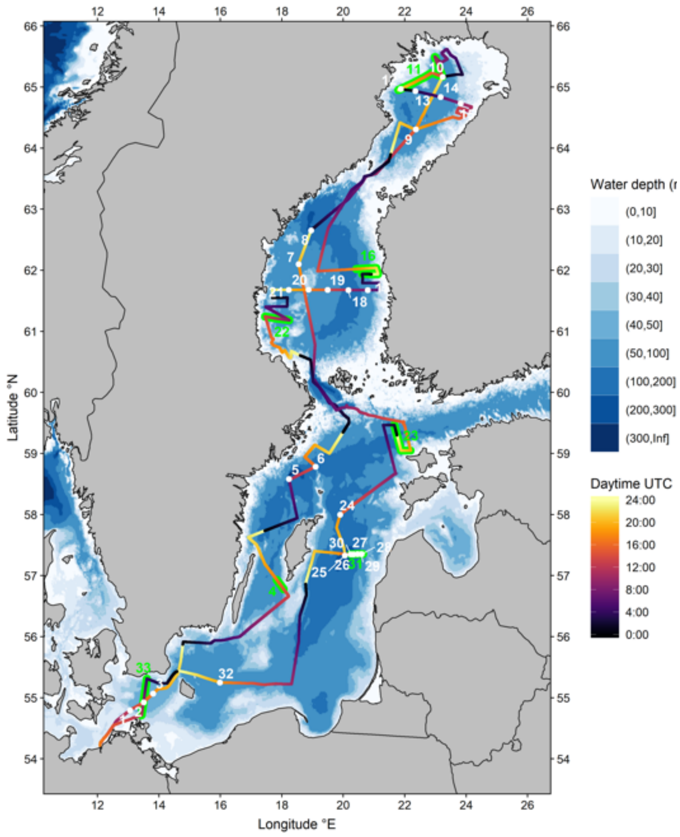

__Figure 6b:__ Cruise Track for the BONUS INTEGRAL summer cruise, May 21st to June 5th 2019 with underlaying bathymetry. The colour code of the track indicates the time of day (UTC). CTD sampling stations are indicated as white dots, ScanFish Transects as green lines.

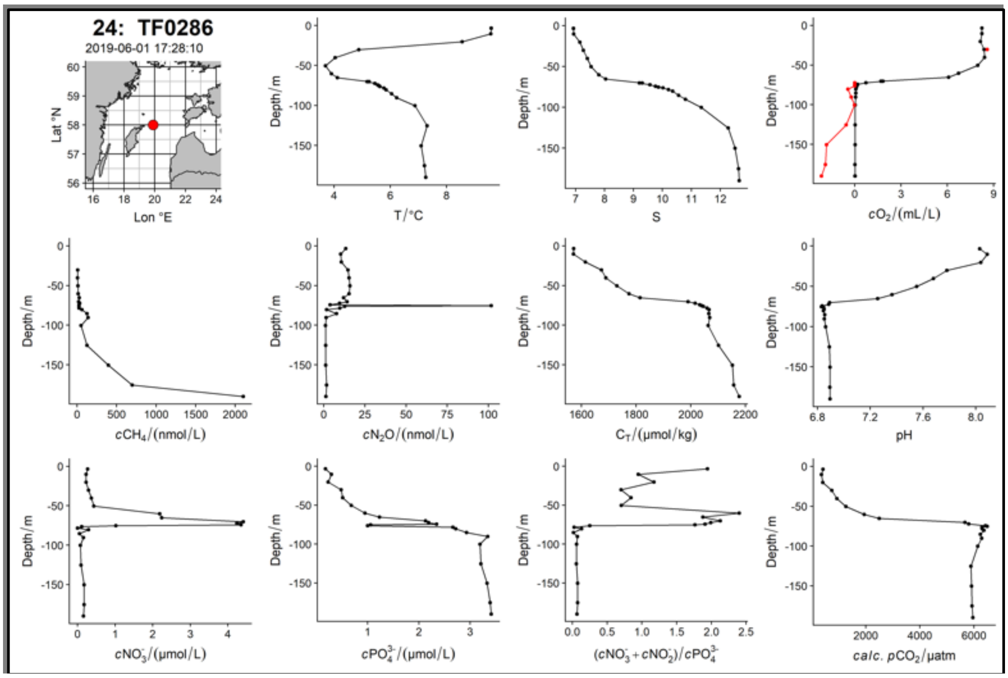

Figure 7: *Preliminary results from Station 24 of EMB 214 (TF 286), including Temperature, Salinity, Oxygen (and H_2S), dissolved CH_4 and N_2O, CT, pH, dissolved nitrate and phosphate, and derived C/P ratio and calculated pCO_2.*

In particular, the data allow - for the first time - for a carbon-based budget of net carbon production in the Bothnian Sea over the spring bloom. The biological carbon uptake in the Gulf of Bothnia between late winter and late spring/early summer 2019 was assessed by using the data gathered from the two BONUS INTEGRAL cruises. The uptake estimate is based on the differences in the dissolved inorganic carbon (DIC) between summer (R/V Elisabeth Mann Borgese) and winter (R/V Aranda) in the upper water column.

Because the dissolved inorganic carbon was analysed from water samples, its horizontal representativeness was not sufficient in order to make directly basin-wide conclusions on the biological uptake by spatial interpolation. To solve this problem, we constructed linear functions between DIC and salinity (S) for different depths by using the method of least squares. This way, we could interpolate DIC over the Gulf of Bothnia using the strong linear correlations between these parameters for both cruises. For the fitting, data from the northernmost station (I3 on the winter cruise, Fig. 6a) were omitted, as this station was affected by the discharge of the River Kemijoki, and thus did not represent the conservative mixing of water masses within the whole basin. The least squares fit for the DIC-S relationships were generally good, as the lowest R^2 value of the fits was 0.997 and the mean squares errors were less than 9 µmol kg^{-1}, while the range of DIC covered almost 600 µmol kg^{-1}. In Fig. 8a, the dissolved inorganic carbon is shown as a function of salinity for the surface (sampling depth of less than or equal to 10 m). In this surface layer, the DIC in summer was lower than it was in winter for the same salinity, i.e. the summer slope of the best fit is lower than the winter slope. For all depths, the slope of the winter DIC was closely the same, but the slope of summer DIC increased as depth increases, and at the depth of approximately 40 m, the slopes of winter and summer DIC were equivalent. Thus, the removal of DIC due to primary production in the Gulf of Bothnia was limited to the surface waters, down to a maximum depth of 40 m. With our approach, we can estimate the net carbon uptake due to biological production. As the summer cruise took place shortly after the spring bloom, the counteracting invasion of atmospheric CO_2 should be almost negligible. Still, we can consider our approach as a conservative estimate.

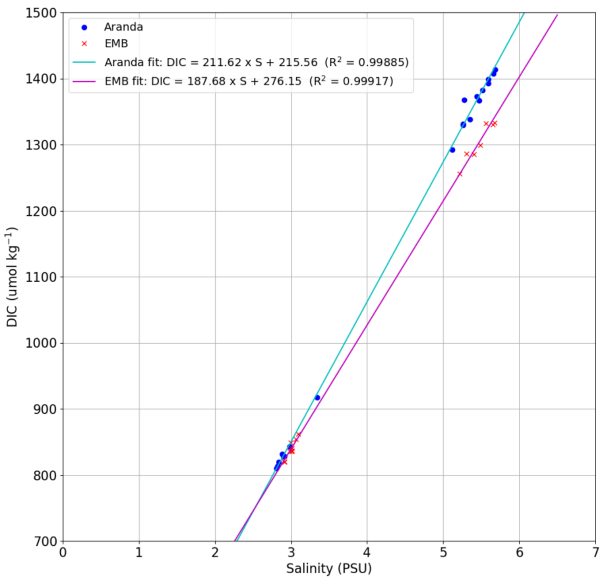

Figure 8a: The dissolved inorganic carbon concentration (DIC) as a function of salinity: winter measurements as blue dots and summer measurements as red crosses.

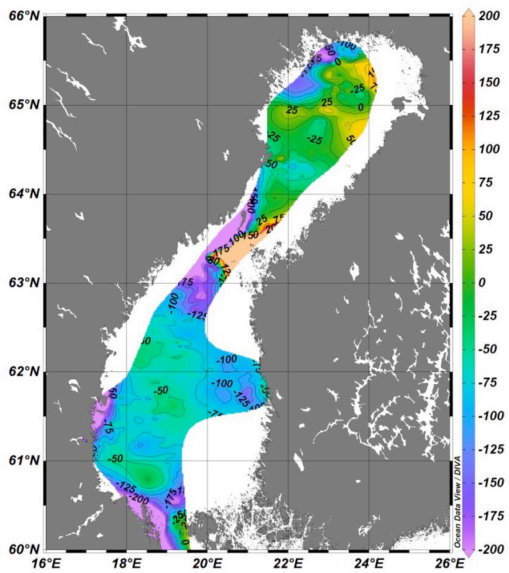

Figure 8b: The change in dissolved inorganic carbon (µmol kg^{-1}) between June and February 2019.

By using the sea surface salinity measured with the flow-through system and the derived DIC-S relationships, we interpolated the dissolved inorganic carbon in the Gulf of Bothnia, for both in summer and winter. The DIC change between winter and summer in the first 10 m is shown in Fig. 8b. In the centre of the Bothnian Sea, the biological carbon uptake in the first 10 m was approximately 50 µmol kg^{-1}, whereas in the Bothnian Bay, the carbon uptake was barely evident, confirming that the summer bloom had not yet effectively started in this Northern basin. This work emphasises the applicability of smart interpolation methods when dealing with limited number of sampling stations.

In summary, the BONUS INTEGRAL expeditions in winter and early summer 2019 considerably extended the project-relevant data base, which was important towards the goals of WPS 4, 5, and 6. Moreover, it allows for detailed studies related studies in the scope of the project, such as the assessment of the integrated net carbon uptake in the Northern Basins during spring. Lastly, and not completely planned beforehand, it turned out to be a hands on training for carbon and greenhouse data retrieval at sea for the young scientists involved in the project, and fostered the networking and knowledge transfer between the different groups very effectively.

Additional activity related to Deliverables 3.2 and 3.3: The BloomSail project

The Bloom Sail expedition took place as announced in the first periodic report, with the "hot phase" between June and August 2018. An overview of the project, embedded in the BONUS INTEGRAL research strategy, can be found at: https://www.io-warnemuende.de/Tina-V-home-en.html. It was lucky coincidence that the experiment took place within the summer 2018, which ended with the warmest surface temperatures ever recorded in some areas of the Central Baltic Sea. The samples and data are compiled and interpreted.

The central scientific finding of the expedition is a tight coupling between the vertical distribution of net community production of organic matter and warming of surface waters over the course of a cyanobacteria bloom. Lacking depth-resolved observations with high spatio-temporal resolution and coverage, this coupling was not known before. The value of this finding lies in its application to combined SOOP and hydrographical model data: With the newly gained understanding it is possible to calculate the depth-integrated net community production based on surface CO_2 observations (SOOP) and changes in the vertical distribution of seawater temperature over time (model). Taking SOOP FINNMAID and GETM model data as an example, both required data sets are available for almost two decades and – taking into account the new findings – will allow to estimate net community production and therefore the potentially available organic matter for export with enhanced confidence.

A manuscript summarizing the findings is almost finalized for submission to the open access journal *Biogeosciences*.

Deliverable 3.4: Installation/Operation/Results of small SOOP line package in the Gulf of Gdansk

Background

The Gulf of Gdansk basin is highly influenced by the Vistula River, which is the second largest river entering the Baltic Sea. The rivers draining the continental part of the Baltic Sea catchment, including the Vistula River, are known from very high total alkalinity (TA), nutrient and organic matter loads. This drives high organic matter production and remineralization and may lead to high spatial and temporal variability of the marine CO_2 system including changes in pH, CO_2 partial pressure (pCO_2) and levels of CO_2 exchange through the air-sea interface. Nevertheless, coastal regions of the southern Baltic Sea are still highly undersampled in terms of the CO_2 system, and pose a large question on the transformation and transport processes towards the open basins. This was the motivation for initiating surface observations of the CO_2 system across the Gulf of Gdansk within the BONUS INTEGRAL project to allow for improving the biogeochemical monitoring in one of the most dynamic land sea exchange areas, the drainage of the Vistula River. The ferrybox system, exclusively funded by the BONUS INTEGRAL project, was installed in December 2017 on MS Agat – a small passenger ferry operating regularly in the Gulf of Gdansk on the routes: Gdynia-Hel and Gdynia-Baltijsk. In the open tender the instrumentation offered by 4H Jena Engineering GmbH has been selected and purchased. The system comprises a thermosalinograph (Seabird) and a pCO_2 detector Hydro-C (Kongsberg Maritime Contros GmbH, now 4H Jena Engineering). Additionally, the system has been adjusted to be compatible with a spectrophotometric system for pH measurements, HydroFIA pH, developed within the BONUS PINBAL project.

Activity in the third year

After successful installation and first deployments of the ferrybox system, the extensive tests for long-term stability performed in the third year of the project revealed a series of technical problems (they are described in details in deliverable report D3.4), which made the acquisition of high quality environmental data impossible. The GPS receiver, acid pump and water supply pump have been replaced in the ferrybox by the manufacturer. After solving all technical problems, further quality and long-term stability tests of the system were planned for spring 2020. However, this was impeded by the COVID-19 pandemic. As a consequence of the mobility restrictions and the lock-down in Poland, the regular cruising to Baltiysk has been suspended and until now have not been revived.

The other route operated by MS Agat, between Gdynia and Hel (Polish inland waters) has been restored in late May 2020. Despite the lower interest of tourists in cruising, we were able to collect quite a number of pCO_2 measurements in the region. Fig. 9 shows the mean daily values of salinity, temperature, pCO_2 and water flow in the system for the summer period 2020. First of all, the data indicates that the problem with unstable water flow has been resolved. The water flow stays at a relatively constant level, which guarantees stable response time of the system and allows resolving CO_2 system variability in that dynamic ecosystem. In the period covered by the data, the surface water temperature was continuously increasing starting from late May until the end of June. In July it was oscillating between 18 and 20 °C, reaching its maximum (23 °C) in the mid-August. Salinity was relatively variable in that period showing often signs of the freshwater inflows from Vistula. It was especially well seen in August, when it drops below 6.

During the entire investigated period seawater was undersaturated with CO_2 in the turn of May and June, pCO_2 was steadily decreasing as a consequence of continuing spring production. After reaching first local minimum (about 195 µatm) in mid-June, it increased slightly and remained at relatively constant level (220-300 µatm) until mid-August, when a second minimum (about 280 µatm) was reached. The latter was likely related to the cyanobacteria bloom enhanced by the highest temperatures and input of the Vistula water rich in nutrients. In late August the relaxation period has started in which both sea surface temperature decreased and pCO_2 increased.

This valuable data, although still sparse, demonstrates the potential in improving our understanding of the CO_2 system variability in the coastal zone of the southern Baltic Sea. Identification of the direct influence of the Vistula River in the region covered by the measurements suggests also that data generated from this newly established monitoring platform can help in the future to assess the CO_2 system transformations and ecosystem productivity in that highly dynamic region of freshwater and open Baltic Sea water mixing. The data therefore strongly support the case for including this part of the infrastructure developed within the BONUS INTEGRAL project into ICOS Poland.

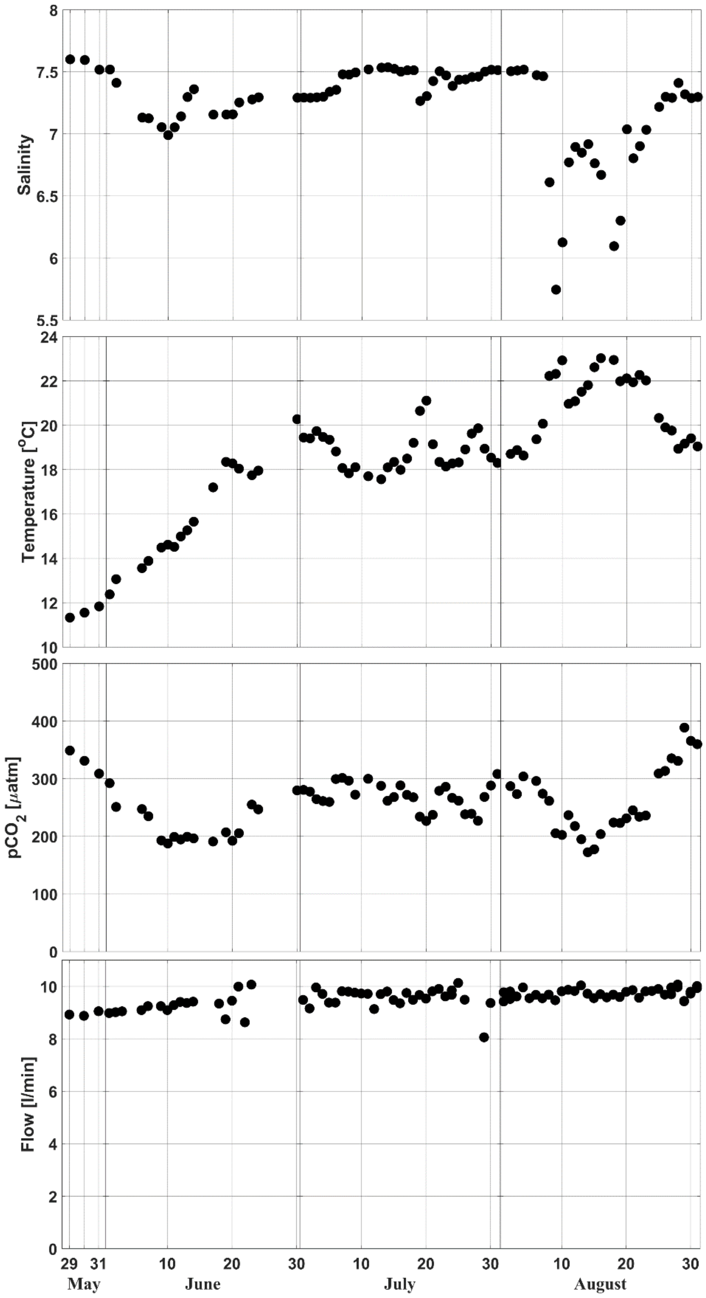

Figure 9: *Mean daily values of salinity, temperature, pCO_2 and water flow in the system collected around the mid-point of the transit between Gdynia and Hel for the summer period 2020.*

E.) WORK PACKAGE 4 (Lead: GEOMAR)

The overall objective of WP4 is to provide GHG (CO_2, N_2O and CH_4) concentration fields for the Baltic Sea and make them available to WP5, other scientists, and the public/stakeholders.

Specific objectives are: i) to merge historical data provided by WP2 as well as actual data from the Baltic Sea GHG monitoring network under BONUS INTEGRAL; ii) to perform quality check and harmonize the data; iii) to compute GHG concentrations fields; and iv) to publish the Baltic Sea GHG concentration fields.

Deliverables 4.2 and 4.3: Report on computation of GHG concentration fields and publication of GHG concentration fields

pCO_2 fields

Earth observation satellites have revolutionized the study of the ocean. They now provide detailed repetitive measurements over remote areas of the globe which were previously monitored by instruments mounting on ships and buoys and with a limited number of (isolated) observations. To date, however, no generally valid remote sensing algorithm available for deriving the surface partial pressure of carbon dioxide (pCO_2) in all ocean basins exists. It is generally agreed that the sea surface pCO_2 is determined by biological processes, physical mixing in vertical and horizontal directions, and the bacterial respiration, which converts organic carbon into CO_2. We use remotely sensed SST, chlorophyll-a, CDOM (from MODIS and MERIS) together with modelled sea surface salinity and mixed layer depth.

We produced the improved pCO_2 fields from high quality oceanic variables with algorithms of improved performance compared to earlier studies. The monthly maps of sea surface pCO_2 were derived for the period of 2002 to 2011, from February to October (see Figure 10 below, also Zhang et al., submitted).

As the Baltic Seas is situated at high latitudes frequent cloud coverage and poor illumination during the winter hamper the availability of the satellite images and sea surface variables of adequate quality during these months. As a result, the pCO_2 maps based on remote sensing data were generated for the months from February to October. For the months from November to January, we adopted an interpolation method to derive the pCO_2 field based on only in-situ data.

A completely different approach to derive monthly pCO_2 fields was pursued with WP6, using observational data in combination to model-derived patterns for spatial interpolation. While direct observations of pCO_2 provide accurate samples of the spatio-temporal distribution, sampling by necessity is limited in space and time. Biogeochemical models, in contrast, provide filled spatio-temporal fields of the distribution without gaps. However, they only approximate reality and their accuracy and representation of processes may be questionable. Using either observations or models alone to reconstruct the “true” pCO_2 field falls short of both approaches' combined potential.

With our method, data errors and temporal spread in the data can be accounted for to yield synoptic mapped fields without gaps or discontinuities. It has been used to establish a monthly surface pCO_2 climatology for the Central Baltic Sea based on SOOP Finnmaid pCO_2 data from 2003 to 2019, as an alternative approach to the Earth Observation based Random Forrest approach. More detailed information is given in D4.3 and 6.4.

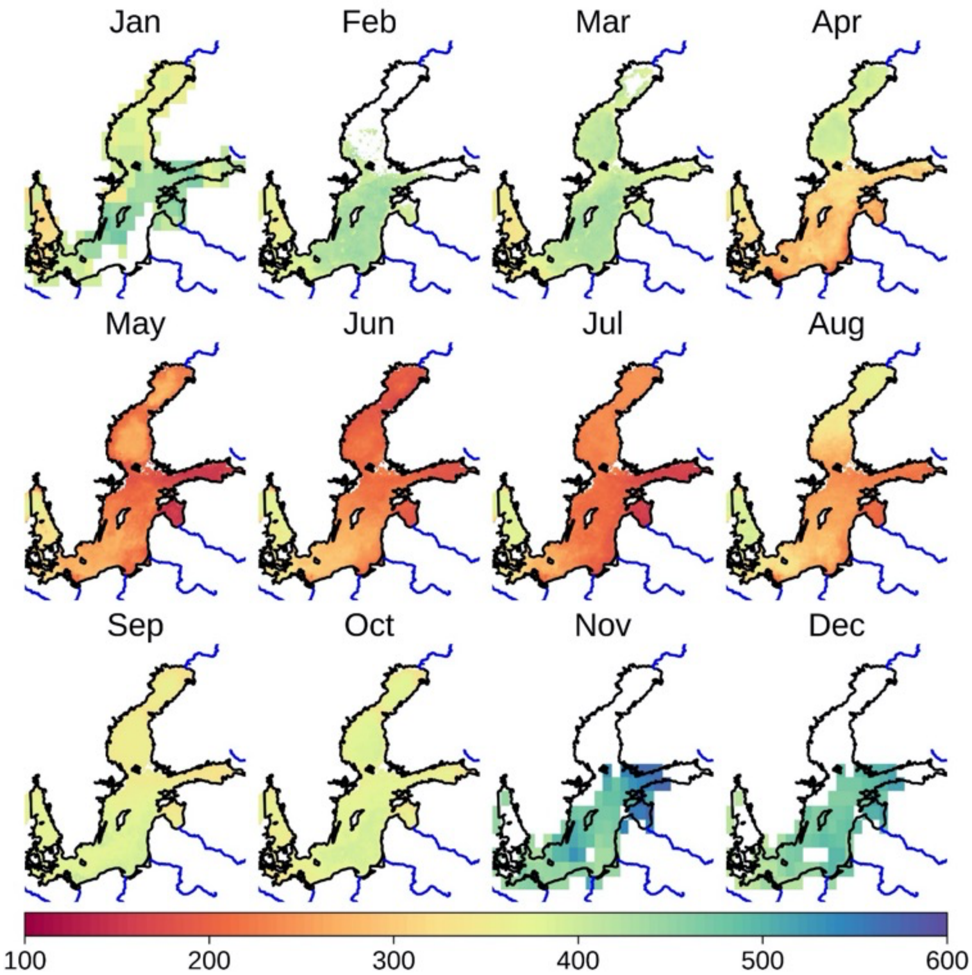

***Figure 10**: Monthly average pCO_2 concentrations for the period 2002 to 2011; for the months February to October Random Forest with remote sensing products are used and for November to January interpolation of in-situ data are used.*

Methane and nitrous oxide fields

Since N_2O and CH_4 emissions from the ocean could offset the CO_2 sink, we aim at the quantification of the N_2O and CH_4 emissions from the Baltic Sea to estimate the potential offset of these gases on the Baltic Sea carbon sink with the BONUS INTEGRAL project.

BONUS INTEGRAL greatly enhanced the data coverage for surface N_2O and CH_4 measurements from the Baltic Sea (Figure 11). The collection of historic data from the Baltic Sea revealed a very limited data coverage for N_2O, while the availability of surface CH_4 data was strongly dominated by data from the ship of opportunity SOOP Finnmaid, which mainly covered the central part of the Baltic Sea. Hardly any data were available from the Gulf of Bothnia, Gdansk Bay and the Gulf of Riga. During BONUS INTEGRAL, additional surface CH_4 and N_2O data were collected from the BONUS INTEGRAL cruises (R/V Aranda cruise 04/2019, February/March 2019, R/V Elisabeth Mann Borghese cruise EMB 214, May/June 2019), from the SOOP Finnmaid (2011-2017, CH_4 data only), from the Boknis Eck Time Series Station and from the SOOP Tavastland (start of CH_4 and N_2O measurements in March 2019).

The data compilation shows that N_2O in the Baltic Sea is comparably uniform, as large gradients between the coastal and the open waters could not be identified. N_2O saturation ranged between ~90 and 120%. The annual distribution seemed to show noticeable seasonality with N_2O supersaturation in late spring/early summer and undersaturation in autumn/winter.

The CH_4 distribution showed strongly enhanced concentrations in the marginal seas, particularly in regions with large riverine inputs, such as the Oder river, the Neva river and the Bay of Bothnia. In these regions, the CH_4 measurements also showed the highest variability between different sampling campaigns.

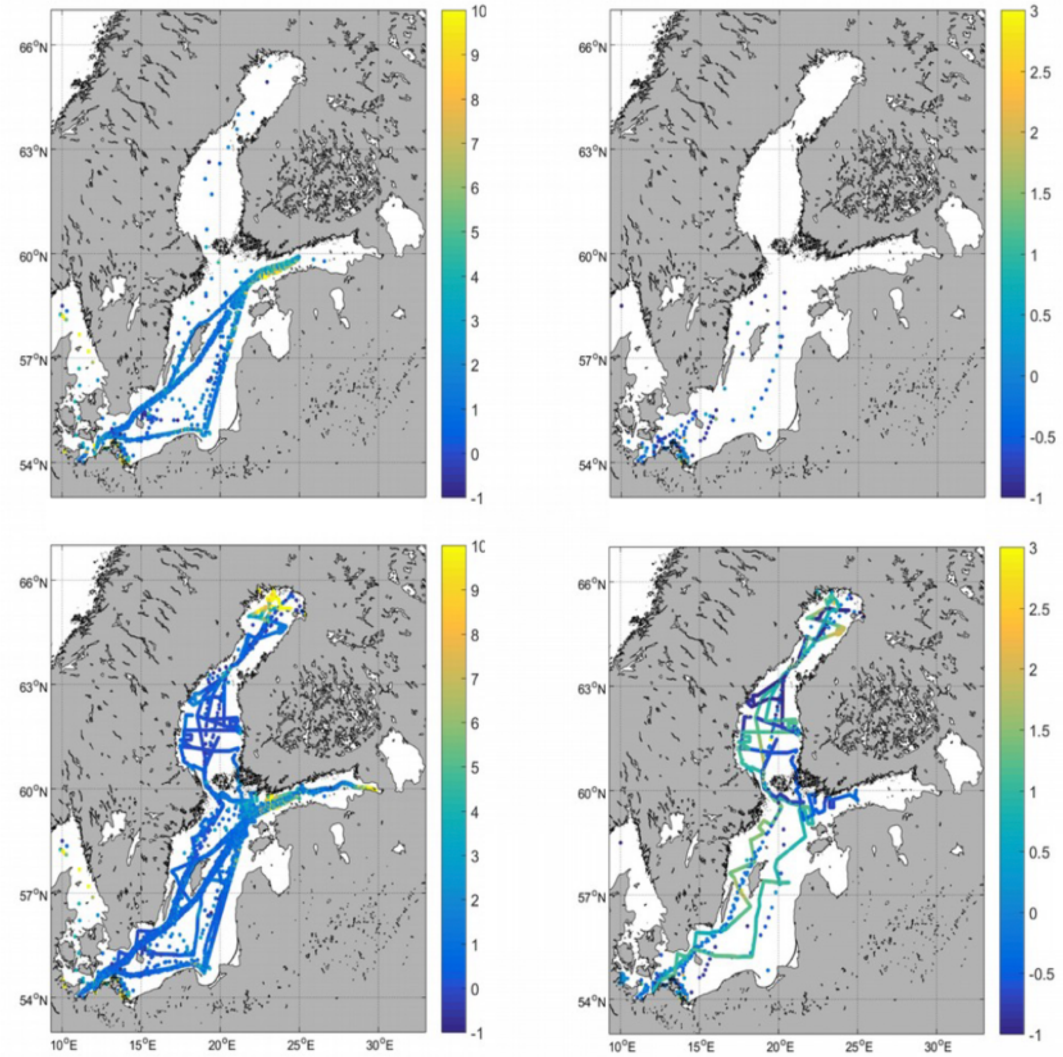

Figure 11: *ΔCH₄ [nmol L⁻¹] (left) and ΔN₂O [nmol L⁻¹] (right) from surface measurements before (top) and after the BONUS INTEGRAL project.*

The temporal data coverage currently does not allow for the calculation of monthly maps of CH_4 and N_2O based on spatial interpolation Annual and seasonal distribution maps of ΔCH_4 could reproduce the original fields to a high level of convergence (Fig. 12). However, since the data coverage particularly in the south eastern part of the Baltic Sea and across gradients between the near-coastal area and the „open" Baltic Sea is comparably sparse, the distribution field may underestimate CH_4 gradients in the near-coastal range. Due to the data sparsity in large parts of the Baltic, the derived ΔN_2O and ΔCH_4 fields furthermore have a high risk of bias towards selected sampling periods on one hand, and towards measurement bias between the different campaigns on the other hand.

This is particularly evident for the N_2O distribution fields: since the N_2O seasonality revealed phases of N_2O oversaturation as well as N_2O undersaturation without any obvious spatial pattern, the role of the entire Baltic as an overall source or sink of N_2O remains unclear.

Overall, we therefore found that the N_2O and CH_4 data basis is not yet sufficient for the publication of basin-wide N_2O and CH_4 distribution fields.

F.) WORK PACKAGE 5 (FMI)

Within WP5, Baltic Sea sea-atmosphere gas fluxes were calculated using new, state-of-the art methods and the concentration fields provided by WP4. The work comprised a new Baltic-specific, air-sea parameterization based on turbulence, wave, and air-sea flux data. The parameterization was introduced into a third-generation numerical wave model and implemented in the FluxEngine toolbox to allow for a comparison of different air-sea exchange models for the Baltic Sea flux estimates.

Deliverables 5.2 and 5.3: Flux calculations with the new wave model-based parameterization (D5.1) and other parameterizations using the FluxEngine Toolbox

Air–sea gas fluxes are commonly estimated using wind-based parameterizations. At regional scales, neglecting other gas exchange forcing mechanisms may lead to large uncertainties in the flux estimates and the carbon budgets, in particular in heterogeneous environments such as marginal seas and coastal areas.

The methodology of D5.2 and D5.3 was two-fold. On one hand, D5.2 used a numerical wave model to calculate Baltic Sea wide estimates of the transfer velocity from the wave-based parameterizations of D5.1 (Figure 12). On the other hand, D5.3 used an existing wind speed-based parameterization, but accounted for a range of other factors, namely convection, precipitation, and surfactants. The FluxEngine Toolbox was used to calculate CO_2 fluxes using different parameterizations for the transfer velocity, resulting in estimates for the mean annual flux in the Baltic Sea.

The results of the wave-dependent parameterizations that were implemented in D5.2 captured more variability than traditional wind-speed based models in sheltered and near shore areas. For this reason, including wave effects explicitly (as opposed to using the wind speed as a proxy) seems like a promising approach for smaller semi-enclosed basins, as well as for coastal applications globally. The amount of wave breaking is calculated in all third-generation numerical wave models, but in the case of WAM, the model code was modified to offer this variable as an output to the user; this model set-up is now ready to be used in upcoming studies for the Baltic Sea. Implementing the results in a different wave model is certainly possible, but might require a re-parameterization of the transfer velocity, since different models use different solutions to estimate the wave breaking dissipation.

In addition to the actual amount of wave breaking, one key assumption is the profile of the sub-surface turbulence. For the purpose of modelling the transfer velocities, the results that did not assume a constant turbulence layer near the surface – combined with a varying exponent for the Schmidt number – were found to be most applicable. With a fixed exponent for the Schmidt number the parameterization was consistent with published results that describe the transfer velocity based on general measurements of the sub-surface turbulence. However, additional well-designed experimental studies are clearly needed to further our understanding of the connection between wave breaking, the sub-surface turbulence it creates, and the role that turbulence has in increasing gas-fluxes.

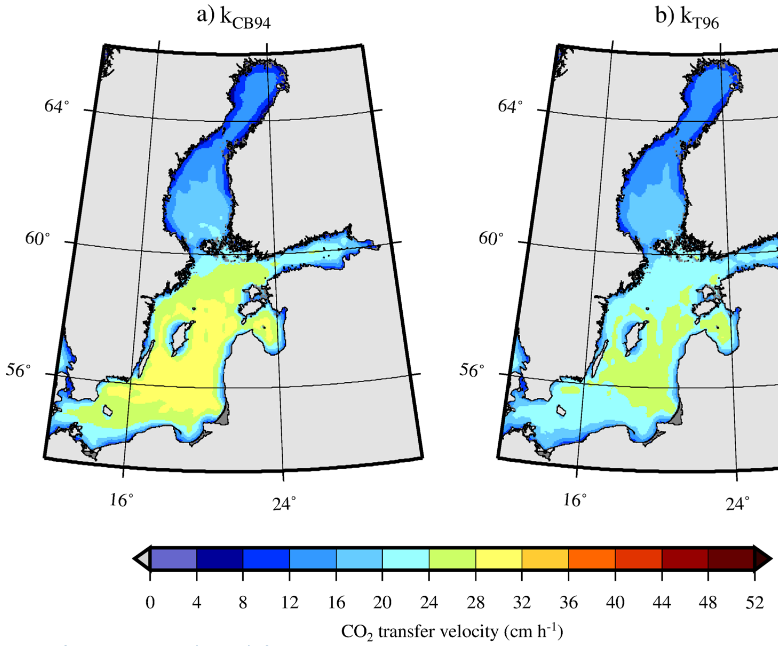

Figure 12: *Mean transfer velocities (k660) for October 2016 using the wave breaking based parameterizations from D5.1. Here, k_{T96} (panel b) assumes a constant turbulence layer below the surface that depends on the significant wave height, while k_{CB94} (panel a) does not.*

In D5.3 we investigated the impact of relevant parameters—other than wind speed—on air–sea CO_2 exchange in the Baltic Sea. We use six parameterizations of the gas transfer velocity to evaluate the effect of precipitation, oceanic convection, and surfactants on the net CO_2 flux at regional and sub-basin scales.

The difference in the CO_2 mean flux is small with values ranging between 0.0 and −0.02 g C $m^{-2}d^{-1}$ among the different cases. However, the implications on the seasonal variability are shown to be significant. The inter-annual and spatial variability are also found to be associated with the forcing mechanisms evaluated in the study. Oceanic convection is the most relevant parameter modulating the air–sea gas exchange by enhancing upward fluxes in our study. Convective processes have a major effect in the Gulf of Bothnia and Central Basin due to the strong cooling of the surface during the winter months. During summer, surfactants and convection act as competing mechanisms. Convective processes slightly enhance the downward fluxes, while surfactants tend to suppress it. Precipitation is the only parameter that results in an overall increase of the downward net flux.

In addition, a new parameterization based on wave information from the WAM-model and the friction velocity are introduced following the methodology presented for FluxEngine and WAM. The transfer velocity is clearly higher throughout the year (in particular during fall). This also influences the seasonal cycle of the flux. The impact of using the wave-based parameterization is less for the annual flux, as the enhanced downward flux during summer is partly compensated with an enhanced upward flux during winter (Figure 13).

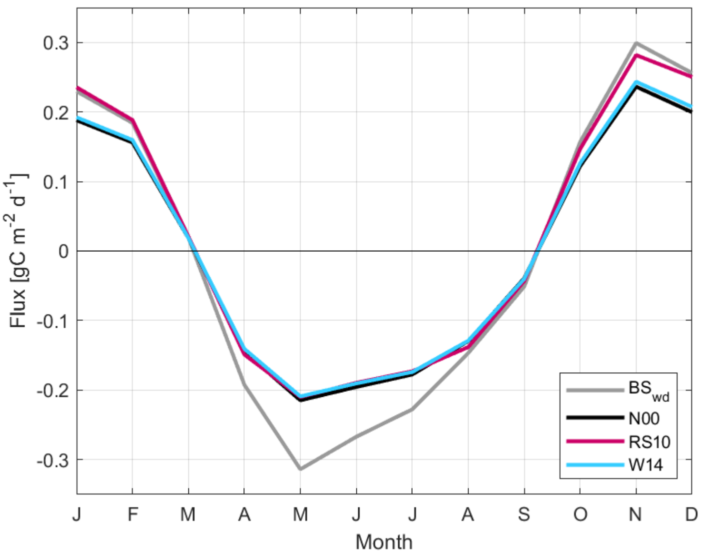

***Figure 13**: Monthly means of the air–sea CO_2 flux in the Baltic Sea using different parameterizations as specified in D5.2-5.3, in addition to the wave-based parameterization (BS_{wd}).*

G.) WORK PACKAGE 6 (Lead: IOW)

WP 6 aims to improve carbon cycle models by using the improved process understanding from measurements compiled in WP 2 and 3, and implement carbon as central variable for the assessment of the Baltic Sea eutrophication. We aimed for a calculation the carbon budget and its changes in time for the entire Baltic Sea, for the coastal zone, and the Baltic Sea sub-basins separately, using a high-resolution carbon system model and BONUS INTEGRAL observations. The model was also used to develop strategies for optimized carbon monitoring with as little as possible sampling effort into account, taking temporal and spatial variability of the system

Deliverable 6.3: Report on optimized monitoring strategies for the carbonate system

A combined approach between model and observations was described in Delivery Report D6.2, merging model patterns with scattered observations to produce data-supported, realistic surface pCO_2 distribution maps. These maps come with uncertainties of their pCO_2 estimates, which were used to evaluate the impact of individual or a network of observations to reduce the uncertainties. This way, different observation network designs or monitoring strategies were compared in Delivery Report D6.3 with a quantifiable metric.

Key for any spatial or temporal design of a monitoring strategy is a suitable choice of parameters and sampling methods to ensure accuracy of the data. For full inorganic carbon system determination, at least 2 out of the 4 observable carbonate system parameters (C_T, A_T, pCO_2, and pH) should be observed. Given the special conditions of the Baltic Sea, measurement of more than 2 parameters is desirable to have an overdetermined system. In any case, high accuracy data are key, which implies that pH sampling needs to transition to spectrophotometric pH rather than the classical electrochemical pH measurement.

To observe surface CO_2 variations, spatial coverage of continuous surface observations on Ships of Opportunity (SOOPs) is unmatched (Figure 14). This is particular true when considering a network of sustained (e.g., Finnmaid) and reinforced or newly established SOOPs (e.g., Tavastland, Agat) as part of BONUS INTEGRAL (Figure 14f). Typically, limitation to specific shipping routes is a drawback of SOOP lines, however, due to the extent of the Baltic Sea, this is less of an issue. Nonetheless, highly dynamic and more secluded areas such as the Gulf of Finland East of Helsinki, the Gulf of Riga, or the wider Gdansk basin would benefit from additional SOOP surface observations with their characteristic high temporal repeat as additional asset.

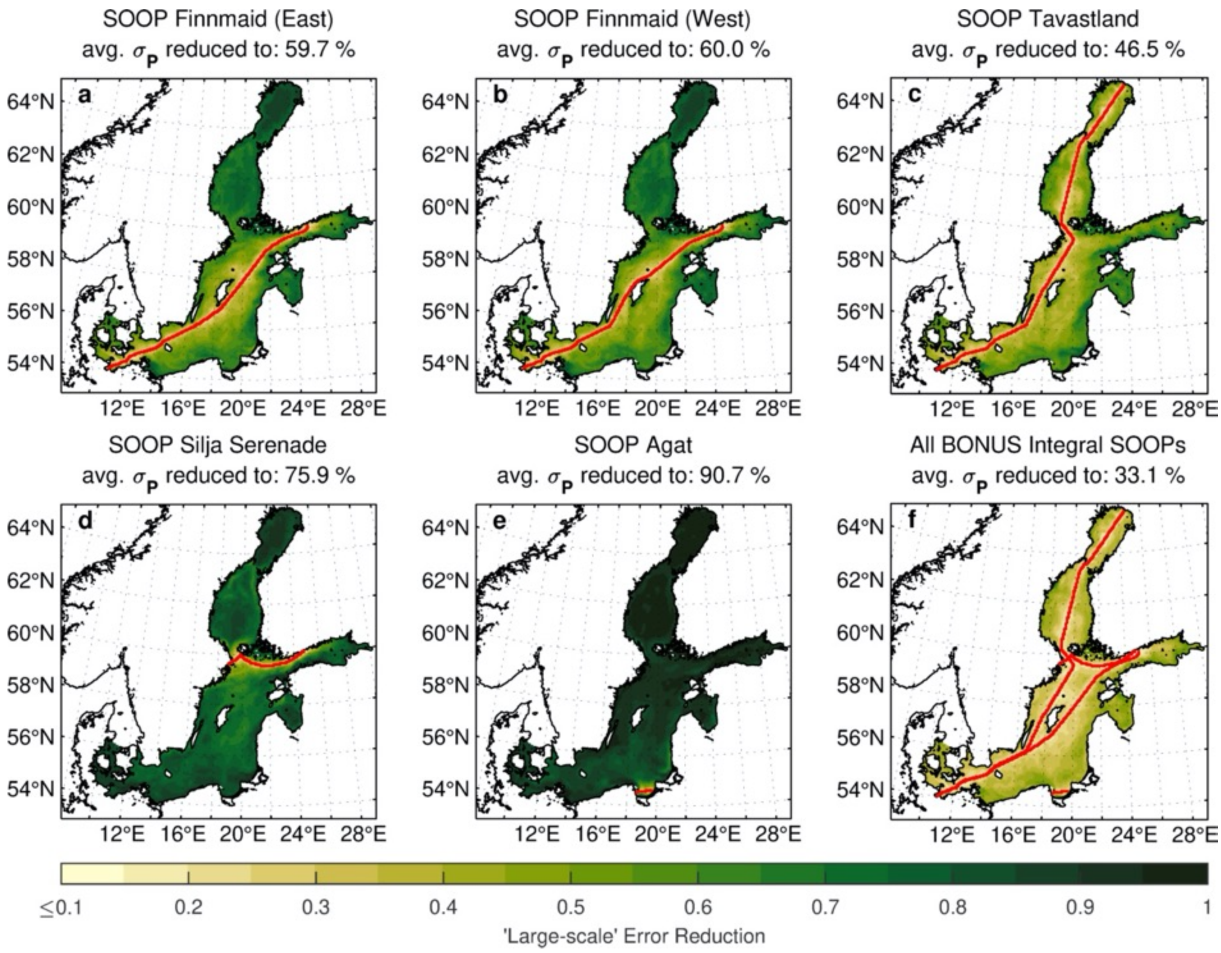

Figure 14: *Reduction in large-scale error by SOOP line surface pCO_2 sampling for (a) Finnmaid on Eastern route, (b) Finnmaid on Western route, (c) Tavastland, (d) Silja Serenade, (e) Agat, and (f) all SOOP lines of BONUS INTEGRAL combined (with an assumed common 5 µatm observation error).*

When considering ship-based station sampling as is typical for HELCOM monitoring, the dynamics of the Baltic Sea require a critical threshold of observations to allow a reasonable assessment of the carbonate system; e.g., sampling with just one station per sub-basin is probably too sparse a sampling to cover underlying variability, while an approach with half a dozen stations per larger sub-basin appears more suitable.

Deliverable 6.4: Budget, Fluxes, Trend Analysis, and Monitoring Strategies

Delivery Report D6.4 provides a concise summary of the results obtained in WP6, with up to date numbers and figures of the state of knowledge at the end of BONUS INTEGRAL. It addresses a model and observation-based description of the seasonal carbon cycle both at the surface (surface pCO_2) and in the upper water column (total inorganic carbon, C_T), as well as surface, profile, and boundary fluxes. The last ones are assessed with respect to their impact on the overall budget as well as potential temporal trends. Finally, the report expands Delivery Report D6.3 by addressing monitoring strategies both for surface and profile carbon monitoring.

The analysis of the mean seasonal cycle of air-sea CO_2 fluxes reveals the Baltic Sea to be a net sink of atmospheric CO_2 on the order of 1.2 mol C m^{-2} yr^{-1}. While the surface water layer exhibits a similar biologically-driven seasonal amplitude, the profile fluxes, however, indicate that this net carbon uptake does not persist in the upper water column. Instead, it is buried in the sediments eventually (60–70 %) or exported through the open boundary to the North Sea together with the freshwater excess of the Baltic Sea.

To complement Delivery Report D6.3, regional temporal decorrelation scales were derived from the model (Figure 15). They show a small temporal decorrelation scale of within 1–2 weeks in near-coastal waters, which are expected because of high dynamics nearshore. In the open Central Baltic, this scale is more on the order of 6–7 weeks, indicating that a monthly monitoring would cover most of the variability. Decorrelation time scales are somewhat smaller in the Bothnian Bay (4–5 weeks) and even smaller in the Bothnian Sea (2–3 weeks) based on this analysis, which is likely linked to intense surface pCO_2 variations over a rather short productive spring and summer season, which reduces overall temporal coherence.

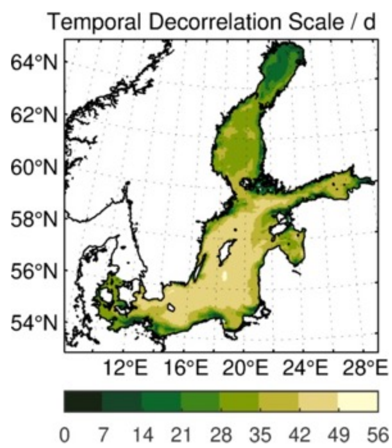

Figure 15: Decorrelation time scale of model-based surface pCO_2 data. The decorrelation time scale is given by the lag (in days) at which the autocorrelation R (t,t+lag) of the time series at a given location first drops below 0.63.

This decorrelation time scale can be used as indication of which frequency is required for monitoring efforts to capture an important part of the variability.

In addition, Delivery Report D6.4 established that the surface observation-based assessments of Delivery Report D6.3 on spatial footprints of samples and monitoring network designs retain their validity also for carbon sampling inside the water column, with a similar impact per station or profile.

G.) WORK PACKAGE 7 (Lead: UU)

Dissemination of knowledge from BONUS INTEGRAL at various levels was an essential part of the project's concept. This includes knowledge transfer within the group and among countries, training about modern carbon and greenhouse gas analytics, flux assessment and modelling for the next generation of enthusiastic scientists in the framework of a summer school and training workshops, the promotion of the use of SOOP lines and carbon data for a cost effective monitoring of the Baltic Sea via workshops and a stakeholder conference, and a brochure demonstrating and road-mapping a better integration of SOOP-based sampling strategies and ICOS-related infrastructure for the ecosystem monitoring of the Baltic Sea.

Deliverable 7.4 or more specifically, Task 7.3: Stakeholder dialogue and information

While in the first two reporting periods of the project, the dissemination of knowledge amongst scientists (cooperation and knowledge transfer, D7.1), including a dedicated technological workshop (D7.2), as well as the training of the new generation of scientists (summer school, D7.3) could be executed according to the originally planned work or even exceeding original expectations (e.g. the joined IOCCP – BONUS INTEGRAL training activity, D7.3), the plans towards stakeholder dissemination for the third year had to be largely adjusted due to two changed important boundary conditions:

1) The stakeholder conference, which was planned as a side meeting to the HELCOM S&C meeting in agreement with BONUS and the projects BONUS SEAM and FUMARI (discussed with A. Andrusaitis and the two respective BONUS project coordinators at the BSSC in Stockholm) had to be cancelled due to the COVID 19 pandemic. This event was a main component of the strategic dissemination plan of BONUS INTEGRAL.

2) The granting of two synthesis projects targeting improved monitoring strategies (BONUS FUMARI and SEAM) produced large synergy potential, but also some competition for e.g. stakeholders attendance, written products etc.. Despite the very different nature of BONUS INTEGRAL in comparison to BONUS SEAM and FUMARI, with the former having a strong focus on network design, construction and operation as well as knowledge transfer, while the latter two focus on assessment and recommendations, the stakeholder messages to be transported by BONUS INTEGRAL could be seen as a subpart of these synthesis efforts, though being more detailed.

With these boundary conditions, which were not foreseeable when drafting the original dissemination plan, BONUS INTEGRAL did its best to make best use of resources with respect to stakeholder communication, lobbying for high resolution carbon system measurements, and changing the political landscape. In several aspects, the situation at the end of the project is far beyond our original expectations. HELCOM, identified early as our primary stakeholder entity and hub towards decision makers, was addressed in several ways, in some cases by interaction with other initiatives. Using the visibility of the project and some of the project partners in the European Integrated Carbon Observation System Research Infrastructure (ICOS RI) was also pivotal for some of the achievements towards the main overarching goal of BONUS INTEGRAL, i.e. development and improvement of the scientific-technological basis for monitoring programs.

In the following, major achievements and products of BONUS INTEGRAL in connection to the tasks 7.3 and 7.4 of the BONUS INTEGRAL workplan, addressing dissemination and stakeholder dialogue, are summarized.

Lobbying for a strong component of the ocean (marine) theme of ICOS in the pan-Baltic area

Over the course of the project, BONUS INTEGRAL played a pivotal role in strengthening the pan-Baltic ocean component of ICOS, emphasizing the co-benefit for the assessment of the ecological status in the Baltic Sea, addressing in particular eutrophication and acidification. The individual measures are reported in Deliverable Report 7.4. Continuous effort let to – or at least played an important role - in the following achievements:

- IO PAN as only marine partner in the ICOS-PL consortium, with a long-term plan to include the installation running on MS Agat established within BONUS INTEGRAL, is foreseen as part of ICOS-PL;
- TTU as partner for the ocean component of ICOS in Estonia, though the joining of ICOS has been recently postponed;
- The pCO_2 instrumentation on SOOP Tavastland is now official component of ICOS Sweden, with BONUS INTEGRAL partner Anna Willstrand Wranne as PI. The line, once fully operational, will have a tremendous importance for the ecological assessment of the northern basins.

Implementation of inorganic carbon monitoring in the Baltic Sea

Apart from the additional surface pCO_2 measurements mentioned above, considerable progress has been made towards the implementation of carbon system parameters for a better monitoring of eutrophication and acidification in the Baltic Sea

- The development of the monitoring program for carbon system parameters in the Estonian marine areas was suggested, based on the data and knowledge gained during the BONUS INTEGRAL project. The proposal was accepted by the Estonian Ministry of the Environment and the program is under development
- SMHI, executing the biogeochemical open water monitoring in the Baltic Sea for Sweden, performed an intercomparison between formerly used measurement methods for pH and the newly developed method now commercially available through BONUS PINBAL and further scrutinized within BONUS INTEGRAL. This is the first step towards a long-term traceable monitoring of pH in the Baltic Sea
- In Germany, based on BONUS INTEGRAL results, the national authority responsible for the HELCOM monitoring in the Baltic Sea (Bundesamt für Seeschifffahrt und Hydrographie, BSH) granted a project to establish monitoring of pH by spectrophotometry in the Baltic Sea. This might result in the resumption of the monitoring of carbon parameters which was discontinued decades ago. The recognition of this need is strongly related to the stakeholder work of BONUS INTEGRAL at the German national authorities.
- The interplay of the different components run by Finland, Estonia and Germany are supposed to be integrated further in the Gulf of Finland pilot supersite in the framework of the Horizon 2020 project JerichoS3. BONUS INTEGRAL played a pivotal role in establishing the network and harmonization of the infrastructure.

Supporting monitoring development through HELCOM-related work

Based on presentations given at the 7th and 8th meeting of HELCOM State & Conservation (the latter given by the coordinator of BONUS INTEGRAL, Sweden and Germany offered to co-lead work on an acidification indicator, which is under the auspice of IN Eutrophication. In the following, Gregor Rehder as Coordinator of BONUS INTEGRAL participated free of charge in the project OMAI (Operational Marine Acidification Indicator) funded by the Nordic Research Council, with partners from Sweden, Germany, Denmark and Finland, including current IN Eutrophication chair Vivi Flehming-Lehtinen.

Several members of BONUS INTEGRAL were involved in producing the HELCOM Climate fact sheets, partly in leading positions. In particular, Karol Kuliński, Gregor Rehder, and Anna Rutgersson, all PIs within BONUS INTEGRAL (and involved in Baltic Earth) drafted the part on "Changes in carbonate chemistry (including air-sea exchange of CO_2 and acidification). In addition Anna Rutgersson was leading the section on Energy Cycles.

Direct stakeholder dialogue

BONUS SEAM, FUMARI and INTEGRAL organized a stakeholder event on "Revising monitoring in the Baltic Sea: a workshop on recommendations to and from three BONUS-projects" held at the Swedish Agency for Marine and Water management, Gothenburg, with various stakeholder from foremost Swedish environmental agencies.

Due to the COVID-19-caused cancellation of a stakeholder conference as a side event to the 12th Meeting of HELCOM State & Conservation, BONUS INTEGRAL (as BONUS SEAM and FUMARI) got time to present their key messages and recommendations at the HELCOM meeting itself in form of online presentations. This event was scheduled on May 14th.

Print dissemination products

In the BONUS INTEGRAL DoW, it was envisaged to provide a brochure and whitepaper reporting the "added value of carbon dioxide and greenhouse gas measurements on SOOP lines and the use of SOOP lines within the HELCOM Monitoring strategy.." The brochure was created in the last month of the project with assistance of a graphic design bureau, published as a BONUS Policy Brief (https://www.bonusportal.org/files/6964/BONUS_INTEGRAL_Policy_Brief.pdf), and posted on the BONUS webpage. The printed version will be distributed at larger conferences and workshops once these will take place again.

For the white paper, it was decided to merge the work with a very related effort by the project BONUS SEAM (BONUS SEAM Deliverable 3.2 on "High-frequency automated observing systems to meet the monitoring and assessment needs in the Baltic Sea"). This appears appropriate, as one of the added values in the technological approach promoted within BONUS INTEGRAL is in fact the high-resolution data acquisition ability that has been optimized and demonstrated in the project. This paper is slightly delayed and will be submitted in the first quarter of 2021.

In connection to the cooperation between BONUS INTEGRAL and OMAI, we envision another paper reviewing the current knowledge on acidification and a potential indicator, which will likely be submitted in the first half of 2021.

3 Promoting an effective science-policy interface to ensure optimal take up of research results (corresponding with the reported performance statistics 1-4)

The Members of BONUS INTEGRAL are actively promoting the overarching goals of BONUS INTEGRAL to stakeholders and related science organizations. This is facilitated by the active role several PIs play in the key organizations (HELCOM, IPCC, SOLAS, ICOS, National Authorities, Baltic Earth). The activities according to the Performance Statistics (PS) 1-4 are listed below.

IOW

PS2: November 26th 2019 - Gregor Rehder: INTEGRAL Presentation on options for a better biogeochemical monitoring by carbon observations at the Stakeholder Workshop on "Revising monitoring in the Baltic Sea: a workshop on recommendations to and from three BONUS-projects" held at the Swedish Agency for Marine and Water management, Gothenburg Sweden.

PS2: May 14th 2020 - Gregor Rehder presented the INTEGRAL recommendations for an enhanced biogeochemical monitoring of the Baltic Sea 12Meeting of HELCOM State and Conservation (virtual meeting), May 11th to May 15th 2020.

PS3: Gregor Rehder served on the Science Committee of the 2019 Baltic Sea Science Congress.

PS3: Gregor Rehder participated in the 3rd HELCOM EN Clime Meeting, Stockholm; Development of Climate Fact Sheets, August 19th, 2019.

PS3: 26. May 2020 - Gregor Rehder participated in the planning meeting of the 2021 BSSC Science Conference as member of the Scientific Committee, online meeting.

PS3: February 12th 2020 - Markus Meier at SMHI Norrköping, Sweden: 14th Baltic Earth Science Steering Group (BESSG) Meeting and tribute to Anders Omstedt .

PS3: April 15th to April 16th 2020 - Markus Meier: BEAR Author Meeting, online.

PS3: April 16th to April 17th 2020 - Markus Meier: 5th EN Clime Meeting, online.

PS3: May 5th to May 8th 2020 - Markus Meier at EGU General Assembly 2020: Baltic Earth Session "Climate change and other drivers of environmental change: Developments, interlinkages and impacts in regional seas and coastal regions", online.

UU

PS2: Contribution (A. Rutgersson) to producing the Climate Fact Sheet on demand of HELCOM as part of the EN Clime Work.

PS3 ESA-Baltic Earth Workshop, September 2020, online, Anna Rutgersson co-organiser.

PS3 Anna Rutgersson participated in the SOLAS work (being a member of the SSC).

PS3 Anna Rutgersson participated in Baltic Earth work, being in the SSG.

PS3 Anna Rutgersson participated in the SMHI Insynsråd.

FMI

PS3 Lauri Laakso, SOLAS (The International Surface Ocean - Lower Atmosphere Study SOLAS), National reporting for Finland, 2019-20.

PS3 Lauri Laakso, Finnish Marine Research Infrastructure FINMARI management board 2019-20.

PS3 Lauri Laakso, Finnish National Scientific Committee on Oceanic Research 2019-20.

PS3 Heidi Pettersson, Scientific Committee on Oceanic Research (SCOR), vice chairman of the Finnish National Committee. Meeting March 13th 2020.

PS3 Heidi Pettersson Scientific Committee on Oceanic Research (SCOR), vice chairman of the Finnish National Committee. evaluation of Working Group proposals July 31st 2020.

PS3 Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. IUGG General Assembly, Montreal, Canada July 8th to July 18th 2019.

PS3 Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. Meeting November 8th 2019.

PS3 Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. Meeting March 9th 2020.

PS4 Finnish Marine Research Infrastructure FINMARI reasearch days, Jan-Victor Björkqvist presented a new approach to describe the wave spectrum. Åbo Akademi, Turku March 10th 2020. Stakeholders and Academia, 70 people.

IOPAN

PS3: Karol Kuliński acts as a member of the Scientific Committee of Baltic Sea Science Congress 2021 that will be held on June 14th to June 18th 2021 in Aarhus.

PS3: Karol Kuliński was a member of the scientific and organisation committees of the 3rd Baltic Earth Conference "Earth System Changes and Baltic Sea coasts", online conference.

PS3: Karol Kuliński acts as a vice-chair of the Baltic Earth Science Steering Group

TTU

PS3: Urmas Lips, HELCOM SOM platform meeting, chair; Helsinki, Finland, September 16th to September 17th 2019.

PS3: Urmas Lips, HELCOM State&Conservation WG meeting, member; Riga, Latvia, October 21st to October 22nd 2019.

PS3: Urmas Lips, HELCOM GEAR WG meeting, invited participant; Helsinki, Finland, November 6th to November 7th 2019.

PS3: Urmas Lips, FINMARI advisory board meeting, member of the board; Helsinki, Finland, March 9th to March 11th 2020.

PS3: Urmas Lips, HELCOM SOM platform meeting, chair; on-line, March 24th to March 26th 2020.

PS3: Urmas Lips, HELCOM EN-CLIME meeting, member; on-line, April 16th 2020.

PS3: Urmas Lips, HELCOM State&Conservation WG meeting, member; on-line, May 11th to May 14th 2020.

PS3: Urmas Lips, HELCOM SOM platform meeting, chair; on-line, September 15th 2020.

PS3: Urmas Lips, EOOS Advisory Board meeting, member; on-line, September 18th 2020.

PS3: Urmas Lips, HELCOM EN-CLIME meeting, member; on-line, September 22nd to 23rd 2020.

UNEXE

PS3: Jamie Shutler was invited to contribute (1 of 30 international scientists) and co-author the UNESCO lead International Oceanographic Commission (IOC) decadal plan for ocean carbon research.

4 Collaboration with relevant research programs and the science communities in the other European sea basins and on international level (corresponding with the reported performance statistic 5)

The activities listed below fall into both categories 5 or 13 under performance statistics; we feel that category 13, is strongly related to category, and also list some of the more important contributions of PS 13.

IOW

PS 5: October 14th to October 15th 2019: Henry Bittig, 8th BGC-Argo Data Management Meeting in Villefranche-sur-Mer, France.

PS5: October 16th to October 18th 2019: Henry Bittig, 20th Argo Data Management Team Meeting (ADMT-20) in Villefranche-sur-Mer, France.

PS5: November 11th to 12th 2019: Henry Bittig, Global Oceanic Oxygen Data Product Scoping Workshop in Sopot, Poland.

PS5: January 28th to 30th 2020: Henry Bittig, ARVOR-PROVOR technical Workshop, Ifremer, Brest, France

PS5: March 31st to April 3rd 2020, April 29th 2020: Henry Bittig, GLODAP Reference Group meetings, held online.

PS5: April 14th to April 17th 2020: Henry Bittig, 21st Argo Steering Team Meeting (AST-20), held online

August 20th 2019: Henry Bittig: Seasonal evolution of the spring bloom in the Gotland Deep in the years 2013-2019; poster presentation at the Baltic Sea Science Congress 2019, Stockholm Sweden, August 19th to August 23rd 2019.

August 21st 2019: Erik Jacobs: Enhanced surface concentrations and air-sea fluxes of methane and carbon dioxide in the Baltic Sea caused by coastal upwelling; talk at the Baltic Sea Science Congress 2019, Stockholm Sweden, August 19th to August 23rd 2019.

August 22nd 2019: Gregor Rehder: Unusual observations of productivity patterns during the spring bloom 2018 in the Central Baltic Sea suggest vertical nutrient shuttling and the potential for climate-induced changes; plenary talk at the Baltic Sea Science Congress 2019, Stockholm Sweden, August 19th to 23rd 2019.

February 21st 2020: Henry Bittig: Assessing Bloom Timing and Carbon, Nutrient and Oxygen Budgets from VOS Surface, BGC-Argo profiling Float, and Monitoring Data in the Baltic Sea; talk at the Ocean Science Meeting 2020, San Diego, USA, February 17th to February 21st 2020.

March 2020: Gregor Rehder gave a report on the 2019 IOCCP – BONUS INTEGRAL summer school at the 4th annual meeting of the EU project Ringo, Posnan, Poland, March 2nd to March 4th 2020 (on invitation).

September 17th 2020: Gregor Rehder gave the talk "Extreme productivity patterns during the spring bloom 2018 in the central Baltic Sea suggest vertical nutrient shuttling: Unforeseen surprises for the fight against eutrophication in a warming world?" at the 2020 ICOS Science Conference, online, September 15th to September 17th 2020.

UU

2nd Nordic ICOS Symposium, Shuping Zhang introduced estimated pCO_2 concentration fields based on remote sensing data, October 2019, Gothenburg, Sweden.

2nd Nordic ICOS Symposium, Lucia Gutierres Loca introduced Flux Engine results, October 2019, Gothenburg, Sweden.

AGU fall meeting 2019, Shuping Zhang introduced estimated pCO_2 concentration fields based on remote sensing data , December 2019, San Francisco, USA.

ESA-Baltic Earth Workshop, Shuping Zhang introduced estimated pCO_2 concentration fields based on remote sensing data, September 2020, online.

ICOS 2020, Shuping Zhang introduced estimated pCO_2 concentration fields based on remote sensing data, September 2020, online.

FMI

August 19th to August 23rd 2019: Martti Honkanen gave an oral presentation on the diurnal cycle of the carbon dioxide in the Baltic Sea in the 12th Baltic Sea Science Congress (BSSC), Stockholm, Sweden (PS13).

November 15th to November 17th 2019: Jan-Victor Björkqvist presented a poster "Vindvågorna beskrivna med ett nytt fashastighetspektrum" (in Swedish) in a conference arranged by Finlandssvenska Fysik- och Kemidagarna on board the Helsinki-Stockholm ferry (PS13).

August 19th 2020: Jan-Victor Björkqvist gave an oral presentation " A new inverse phase-speed analysis of surface waves" in a teleconference arranged by the Surge Structure Atmosphere Interaction Facility -laboratory (SUSTAIN) in the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami (PS13).

September 24th to September 25th 2019: Marcin Stokowski and Karol Kuliński gave oral presentation on Characteristics of marine CO_2 system at the conference "Chemistry, Geochemistry and Protection of the Baltic Sea Environment", Gdynia, Poland

October 9th to October 10th 2019: Karol Kuliński was invited by BALSAM project led by AirClim to give an oral presentation on "Peculiarities of the acid-base system in the Baltic Sea", Kristineberg, Sweden

October 19th to October 20th 2019: Karol Kuliński gave an oral presentation on “Structure and variability of the CO2 system in the Baltic Sea – facts and challenges” at the Baltic Earth Workshop on “Climate projections and uncertainties in the northern Baltic Sea region”, Helsinki.

June 25th 2020: Karol Kuliński gave presentation “Towards establishing ICOS in Poland…” during Ocean MSA meeting.

GEOMAR

September 27th 2019: Oral presentation ‘The changing Baltic Sea: 60 years of measurements at the Boknis Eck Time-Series Station’ by Hermann Bange at the European Researchers’ Night in Eckernförde, Germany.

UNEXE

PS5: Jamie Shutler and Tom holding, exchange of updated software toolbox and methods with the EU Ringo project and two co-authored publications (co-authored by Integral and Ringo partners and international collaborators).

PS5: Jamie Shutler was invited to contribute (1 of 30 international scientists) and co-author the UNESCO lead International Oceanographic Commission (IOC) decadal plan for ocean carbon research.

PS5: Jamie Shutler gave an invited keynote talk on atmosphere-ocean carbon exchange and the oceanic sink of carbon at the ICOS France annual science meeting.

PS5: Jamie Shutler gave an invited talk at the ICOS annual science meeting.

5 Progress in comparison with the original research and financial plan, and the schedule of deliverables

Progress in comparison with the original research plan

Some of the work planned in the project was fulfilled slightly delayed for various reasons. This included delayed installation of some of the instrumentation due to technical difficulties, rescheduling due to changes in personnel, and in the last period, also some restrictions caused by the Covid 19 pandemic (like maintenance or technological changes on the measurement platforms, in person travel etc. Therefore, an extension of the project for 3 months was requested and granted and a new schedule of deliverables was agreed upon (see also Chapter 6). Still, the project could meet all deliverables.

Progress in comparison with the original financial plan

According to the BONUS rules, for the last period, budget change requests should be submitted through EPSS only if those are requested by the national funding organisation; in all other cases differences between budget and actual use of funds should be explained in the last periodic report.

INTEGRAL budget deviations RP3 (not including budget changes less than 5.000 € or minor than 10 % of the periodic value of the respective item)		
Partner	**Budget Deviation**	**Reasons**
IOW	– Underspending Other Activities (Other Direct Costs)	32.513 € underspending, mainly resulting from the cancellation of the stakeholder event, as well as reduced travel expenses due to the COVOID 19 pandemic
UU		
FMI	– Overspending RTD (Personnel) – Overspending Management (Personnel)	(1) Overspending Research personal: modelling of wave fields, handling the pCO_2 field data as well as combining all the data needed in the tasks in WP5 caused more work than anticipated. (2) Overspending Management Personnel: the final year of the project with extensions and rescheduling caused more administrative tasks to be completed.
IO PAN	– Minor costs reported in budget lines that were not planned (Management / Personnel)	“management staff costs” needed for communication and collaboration with NCBR with regard to reporting and national payments
TTU	- Slight underspending	Reduced calibration and maintenance for the ferry box system and pCO_2 sensor and reduced travel due to the COVOD 19 pandemic
GEOMAR	– Overspending RTD (Personnel)	- Absence of A. Kock in RP1, additional staff needed in RP3 to compensate this absence; - Extension of the project by three months led to increased staff costs
SMHI		
UoE		While there are no cost deviations, more person months than detailed in the DoW were reported: Jamie Shutler worked more hours in the last claim period than originally planned on the project due to the Covid-19 lockdown which slowed down communication and collaboration between partners and external dissemination activities. As a result, the number of required person months increased.

***Table 3** Budget deviations and rationale*

Against this background, the Table 3 explains all overspendings above 5.000€ or 10% of the period value of the respective item. As to underspendings, only major deviations or those affecting the planned activities were included. In total, roughly 64.000 € of the funding were not used and will be returned back to the funding sources. The main reason for this cancelled stakeholder conference and reduced travel costs in the last year due to the Covid 19 pandemic.

6 Amendments to the description of work and schedule of deliverables

As already mentioned above, slight delays on several aspects of the project were the motivation to request a three months extension of the project, which was granted in May. A new schedule of deliverables was proposed with this extension and granted. In this connection, the stakeholder conference was cancelled due to the Covid 19 pandemic, and the related report as a Deliverable was reduced. In some cases, it was appropriate to merge Deliverables due to their strong interrelation, and in some cases related submitted publications which addressed more than one Deliverable (e.g. D5.2-5.3). Delays occurred even compared to the updated Schedule of Deliverables, which has to be seen in the light of data retrieval and workup until the very last day of the project – and beyond.

7 Other information

Publications arising from the project

A: currently submitted or under review:

Friedlingstein, P., et al. (2020), Global Carbon Budget 2020, Earth System Science Data, in press.

Gutierrez-Loza, L., Wallin, M.B., Sahlée, E., Holding, T., Shutler, J., Rehder, G., Rutgersson, A. "Air-sea CO_2 exchange in the Baltic Sea—a sensitivity analysis of the gas transfer velocity" (submitted to J. Mar Sys).

Jacobs, E., Bittig, H. C., Gräwe, U., Graves, C. A., Glockzin, M., Müller, J. D., Schneider, B., and Rehder, G.: Upwelling-induced trace gas dynamics in the Baltic Sea inferred from 8 years of autonomous measurements on a ship of opportunity, Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-365, under review, 2020.

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Zhang S., et al. Remote sensing supported sea surface pCO_2 estimation and variable analysis in the Baltic Sea (submitted).

Martti Honkanen, M. , Müller J.D., Jukka Seppälä, J., Rehder, G., Kielosto S., Ylöstalo, P., Mäkelä. T., Hatakka, J., and Laakso, L.: Diurnal cycle of the CO_2 system in the coastal region of the BalticSea (submitted to Ocean Sciences).

B: published

Bange, H. W., Arévalo-Martínez, D. L., de la Paz, M., Farías, L., Kaiser, J., Kock, A., Law, C. S., Rees, A. P., Rehder, G., Tortell, P. D., Upstill-Goddard, R. C. and Wilson, S. T., (2019). A harmonized nitrous oxide (N_2O) ocean observation network for the 21st century. Frontiers in Marine Science, 6; doi: 10.3389/fmars.2019.00157.

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Gutiérrez-Loza, L., Wallin, M. B., Sahlée, E., Nilsson, E., Bange, H. W., Kock, A. and Rutgersson, A., (2019). Measurement of air-sea methane fluxes in the Baltic Sea using the Eddy covariance method. Frontiers Earth Sci, 7.

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8 Acknowledgement

THE BONUS INTEGRAL project receives funding from BONUS (Art 185), funded jointly by the EU, the German Federal Ministry of Education and Research, the Swedish Research Council Formas, the Academy of Finland, the Polish National Centre for Research and Development, and the Estonian Research Council. Additional funding to UNEXE (as the UK is a non-BONUS partner) is provided by the University of Exeter.