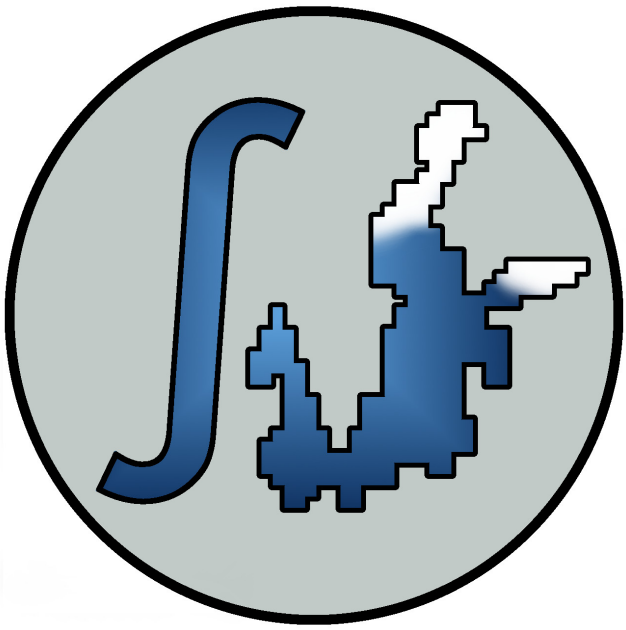
1 Project data

BONUS INTEGRAL

Integrated carboN and TracE Gas monitoRing for the bALtic sea



Second Annual Report

Reporting Period: July 1st, 2018 to June 30th, 2019

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Partners: 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 partners 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 will

- 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 southeastern 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)

Management of the project in the 2nd year turned out to run smoothly, though time consuming. Major work included the coordination of the planning for the two expeditions (see WP3), as it was the aim to have as many partners involved as possible. Another major effort was the preparation of the summer school, where in particular the coordinator and Henry Bittig from IOW had various tasks in the different planning and preparation bodies. Due dates of deliverables was reminded to the responsible WP leaders, and despite of some smaller delays, the project is well on track.

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.

Sole deliverable within the reporting period of Work Package 1 **(Deliverable 1.2)** was the organization, compilation and finalization of the first periodic report. This was achieved in

time, and iteration with the BONUS Secretariat during the following months only addressed minor points.

Due to the tight schedule of events in May and June 2018 (BONUS INTEGRAL summer cruise, directly followed by the IOCCP / BONUS INTEGRAL summer school, it was decided to distribute a strict timetable for the 2nd periodic report early in June 2019, and to have a draft version already at hand during the 2nd annual meeting (see below).

Some new staff members entered the BONUS INTEGRAL team over the course of the 2nd period. At IOW, Post Doc Anja Eggert (WP6) left in August 2018 for a permanent position at another institute. In September 2017, Post Doc Henry Bittig was hired to fill this gap. At UU, PhD student Lucia Guiterrez Loza and post-docs Gaelle Parard, and Shuping Zhang continued in the project (funded by BONUS INTEGRAL and complementary projects). Professor Anna Rutgersson (PI) and research engineer Marcus Wallin are involved in the project, but paid by other funding sources (in kind). In addition, post-doc Leonie Esters also contributes to the project (as in-kind contribution). At IOPAN, few persons have been temporarily hired in the 2nd year of the project: IT specialist Krzysztof Rutkowski who developed telemetry for the ferrybox system on MS AGAT; one PostDoc (Aleksandra Winogradow) and technicians: Anna Malenga and Jolanta Walkusz-Miotk, who were responsible for sampling and chemical analyses of AT, CT, pH. At TTU, Silvie Lainela (PhD student and engineer) joined the BONUS INTEGRAL team in TTU since April 2019. At SMHI, Madeleine Nilsson, PhD, and Magnus Wenzer started working within the project.

The 2nd annual meeting took place at Krusenberg Herregard, near Uppsala, hosted and kindly arranged by partner UU, from August 6th to 8th, 2019. Though formally within the 3rd period, we report it here because from the project management strategy, it served for everybody to get an overview of the activities within the 2nd year of the project, as well as to finetune the contributions to the 2nd annual report. The project showed the great advancement made within the project, and the wealth of data generated during the project. It also served to get an overview of planned publications and exploit the potential for contribution/cooperation. The major decision made at the meeting is that the coordinator was assigned to assess the possibility for a cost-neutral extension of the project by 3 month, which would help with the compilation and further use of the data in WPs 4 and 5. Another major decision was to urgently address BONUS, HELCOM and BONUS project coordinators with stakeholder information tasks in order to channel these efforts.

C.) WORK PACKAGE 2 (Lead IO PAN)

The overall objective of WP2 is to identify and evaluate the quality of existing data on greenhouse gases (CO_2, CH_4 and N_2O) as well as on the carbonate system (AT, CT, pH) in the Baltic Sea. All the identified and quality-controlled data are to be published in the form of meta-data on the BOOS data platform, with easy-access links to the repositories of the real data.

Update on Deliverable 2.2: Data identified and verified in the project published as meta-data on the BOOS- platform

Patrick Gorringe represented SMHI during the BOOS Annual meeting in Rostock, June 12th - 13th, 2019, and has discussed the question about the possibility to add a meta data map on the BOOS web page. Unfortunately, this question is not yet solved and the meta data map is still to be found at smhi.se.

Deliverable 2.3: Report on the historical data quality

The assessment of the data quality identified three key characteristics of good quality data, namely: consistency and completeness of the data, and the analytical quality control. The

valuation process followed the SOCAT Quality Control Cookbook and incorporated the data quality control flags system. Each Flag (from A to J) corresponds to several criteria. The description of each criteria is provided in Table 2 of deliverable report D2.3. Criteria 1 is devoted to timeliness, Criteria 2-4 provide information upon completeness of the data, while Criteria 5 delivers information about the accuracy and precision of CO_2, CH_4, N_2O, AT, CT, pH. Based on the type of the flag and accompanying criteria the division of data was made. As a consequence, flags from A to D represent the good quality data, flags from E to H define poor data while Flag I and J characterize bad data. In Table 3 of the Deliverable report, a quality control flag is assigned to each meta data file and provides information on the expected quality of each dataset. All data characterized in meta data files are defined as good data, however only 10 out of 33 relates to continuous systems while only two single activities enable cross check with carbonate system parameters.

During the 2nd annual meeting, it was decided to develop a strategy to convince data holders from data not publicly available yet to deposit the data, so that the meta data compiled within the project would be of use after the project comes to an end. This was initiated by the recognition that some earlier data mining efforts, also within former BONUS projects, are not accessible any more.

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 will: provide several amendments to existing infrastructure, use its close relation/involvement in the HELCOM monitoring to effectively gain carbon system and trace gas data from selected monitoring stations, seek to execute two field campaigns on research vessels, and install a basic underway pCO_2 system on a coastal-near ferry line traversing the plume of the river Vistula. The “base case” year for this additional efforts will be the 2nd year of the project, though installations for continuous measurements on the VOS-lines and permanent stations are foreseen to be operational until the end of the project and in most cases beyond. For individual platforms and locations, please refer to Figure 1.

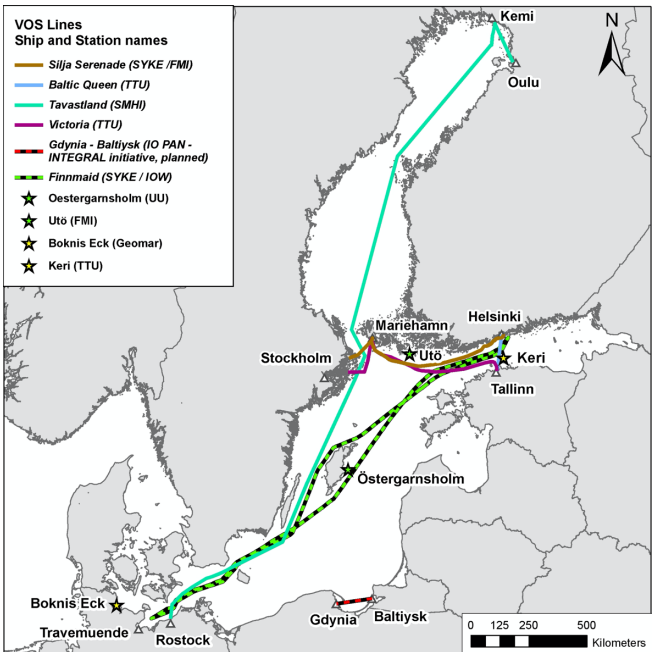

Figure 1: *Map of locations of infrastructure used within BONUS INTEGRAL. The stations Östergarnsholm, Utö, and VOS Finnmaid are part of ICOS. The line Gdynia Baltiysk (VOS Agat) is projected within BONUS INTEGRAL. All other infrastructure is established by other initiatives, but will be partially amended.*

Deliverable 3.1: Installation / operation of infrastructure amendments

This deliverable, originally due on month 14 of the project, was finally filed in month 23. The decision to postpone the report until close to end of the reporting period was motivated by the continuous nature of the actions taken. So the later delivery appeared justified by the higher level of completeness.

Rationale: 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 aims at providing several amendments to existing infrastructure.

The "base case" year for these additional efforts was intended to be the 2nd year of the project, though installations for continuous measurements on the VOS-lines and permanent stations are foreseen to be operational until the end of the project and in most cases beyond. Individual platforms and locations within the BONUS INTEGRAL observation network are displayed in Figure 1 and the amendment status for individual platforms was detailed in **Deliverable Report 3.1**. Here, we just briefly highlight the actions taken and current status.

- **VOS Finnmaid** was operational and recording surface values of pCO_2, CH_4 and O_2. The scientific effort is a joined effort between the Finnish Environmental Institute (SYKE) and IOW. A current complete rebuild of the instrumentation with amendments to the measurement of pN_2O and $\delta^{13}C\text{-}CO_2$ is finalized. Installation of the new instrumentation was scheduled for the 1st quarter of 2019, but needed to be postponed to fall due to sickness of involved key personnel. Still, the data set acquired by VOS Finnmaid is the backbone of several efforts within WPs 4 and 6.
- **VOS 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. There are two automated water samplers that can be used to collect reference samples. In 2010, a pCO_2 system from General Oceanic based on IR-absorption spectroscopy was purchased and installed next to the ferrybox. After years of problems with the system and sporadic data collection, it was finally fully operational in the fall of 2017 due to supportive efforts by the BONUS INTEGRAL project, and has been measuring continuously since. 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 VOS Tavastland to expand the existing measurement setup by continuous high-frequency measurements of methane and nitrous oxide. IOW also provided fine calibration of the needed reference gases. For those parameters, the database in the Northern Basins is particularly scarce. The Los Gatos Research N_2O/CO and CH_4/CO_2 sensors have been running since April 2019. The data processing and quality control is in progress. With support of BONUS INTEGRAL, the station is now in the strategic plan for the Swedish contribution to ICOS:
- **VOS Silja Serenade** was equipped with pCO_2 observations in November 2017, but has to be stopped during the ice seasons. Data recording was up and running again in March 2018, but was stopped in October 2018, for testing the setup in an intercomparison exercise (H2020-project Jerico-Next, INTERCARBO TNA) in Oslo in November 2018. After the winter ice season, the observations were restarted in March 2019. In addition to standard ferrybox-system and pCO_2-observations, Finnish environment Institute operates also a pH-sensor in the flow-through system.
- **VOS Silja Europa** (Line Tallinn-Helsinki) & **Baltic Queen** (Line Tallinn-Stockholm) are operated by TTU. The Tallinn-Helsinki ferrybox records horizontal profiles of temperature,

salinity and chlorophyll a fluorescence twice a day. Bi-weekly sampling for chlorophyll a, phytoplankton, and nutrient analyses are conducted. A public procurement process was launched to purchase a new ferrybox system for the Tallinn-Helsinki ferry line. It will also include pH sensor and ability to attach pCO_2 sensor meeting the ICOS quality standards. Discussion how to equip the line for test/demonstration purposes with instrumentation of the network is ongoing. MS Baltic Queen is equipped with a ferrybox measuring temperature, salinity, turbidity, and pCO_2 daily between Tallinn and Stockholm (pCO_2 measurements running since spring 2017). Altogether, 195 successful pCO_2 transects are available for 2017 and 126 were recorded in 2018.

- Partner IO PAN got funding within BONUS INTEGRAL to install a new line which operates within the Gulf of Gdansk, the **VOS AGAT**. The 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 Swedish Research Council (VR) and Uppsala University and was so far the only Swedish marine contribution to ICOS. For the BONUS INTEGRAL project, direct flux measurements of methane were added in September 2017 and have been running continuously since then. The first year of CH_4 flux results has recently been evaluated and has been published in a special issue (The Baltic Sea in transition) of Frontiers in Earth Science (Gutierrez-Loza et al., 2019). During the INTEGRAL sub-project BloomSail, pCO_2, CH_4 and N_20 sampling/measurements were performed around Östergarnsholm from June-August 2018 by IOW. Data were provided to UU and are available to compare direct flux estimates from the tower measurements to flux estimates calculated from in-situ measurements and gas exchange parameterizations.
- At **fixed Station Utö**, run by FMI, observations continued during the entire funding period until 21st May 2018, when they were stopped due to several instrument failures. All observations started again 3 July 2018 after a scheduled maintenance visit. Since that, they have functioned continuously. The main amendment during the first year of BONUS INTEGRAL was the installation of a cabled profiling observatory at Utö in April 2018. The new system provides vertical information on biological and physical variables relevant to the biological carbon sink (Laakso et al., 2018). However, due to several technical issues, the profiler had been non-operational from August 2018 to April 2019. However, the carbonate system observations at Utö worked continuously with only minor downtime.
- **Fixed Station Keri** run by TTU, provides vertical profiles of temperature, salinity, dissolved oxygen, chlorophyll a, and turbidity from 3 to 100 m eight times per day. No additional sensors for carbon system observations have been installed yet, but the location has been sampled for additional parameters during the 6 Estonian Monitoring cruises in 2018 in a joined effort of TTU and IOW (see work towards **Deliverable 3.2**). The station is part of the Estonian Environmental Observatory (a Research Infrastructure facility) which contains atmospheric, terrestrial and marine stations and has applied for funding to join the ICOS network.
- At the **Boknis Eck Time Series Station**, run by Partner GEOMAR, discrete water column sampling (6 depths, 1 - 25m) for N_2O, CH_4 and DIC/Alkalinity is conducted on a monthly basis. A manuscript about the monthly N_2O data from BE in the period from June

2005 to Dec 2017 was submitted to Biogeosciences by Xiao Ma (PhD Student, GEOMAR), and synthesis of the monthly CH_4 measurements from July 2006 to Dec 2017 is currently ongoing. The monthly N_2O/CH_4 and DIC/Alkalinity measurements have been continued until now within BONUS INTEGRAL. The underwater node at Boknis Eck has been operative from July to October 2017 and from April 2018 to Dec 2018, conducting continuous CH_4 and pCO_2 measurements at 14m. It was taken out of the water for maintenance and repair in December 2018. Due to some unforeseen technical problems, re-deployment was delayed to April 2019 and all instruments are by now up and running.

- For the implementation of **spectrophotometric pH measurements**, IOW procured 3 spectrophotometric HydroFIA pH instruments from Kongsberg Maritime Contros GmbH. The system was developed within the project BONUS PINBAL, coordinated by IOW (PI Rehder). During this project, also some fundamental gaps in the description of the method for brackish water conditions were filled (Müller et al., 2018, Müller and Rehder 2018), and the application of those findings was tested within the first months of BONUS INTEGRAL. A benchmark test was performed during a joined effort for testing several carbon system sensors in the framework of a Transnational Access (TNA) activity within the European Jericho Next project (see also D 7.1.) Another earlier prototype of the system is already in use by IO PAN . IO PAN has been another partner in BONUS PINBAL. The HxdroFIA pH has been successfully implemented to the ferrybox system on VOS AGAT. The remaining prototype of the BONUS PINBAL project was used by SMHI in cooperation with the University of Gothenburg. Two of the other instruments will be used on VOS Finnmaid after the installation of the new ferry box unit in fall 2019 and VOS Tavastland (see above). They have also been used on the two RV vessel based BONUS INTEGRAL expeditions on RV Aranda (February 2019) and Elisabeth Mann Borgese (May-June 2019). This work within BONUS INTEGRAL is an essential step towards an acidification monitoring for the Baltic Sea.

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

Swedish monitoring and additional sampling

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. The spectrophotometric Contros HydroFIA pH system, one of the prototypes developed during BONUS PINBAL, was tested during a cruise in March 2019. The system was borrowed from former BONUS PINBAL Partner University of Gothenburg. Discrete samples from 11 different stations in the Swedish national monitoring program were analysed on both systems, and transferred to a common pH scale (total scale). The aim of this comparison is to change the monitoring set up for pH to a spectrophotometric method in order to improve the precision, accuracy and traceability in measurement and thereby the understanding of the carbonate system in the Baltic Sea. The comparison to the electrode based measurement is an important component of the implementation of the new method, as SMHI is the only institute involved in the monitoring of the Baltic Sea which has not discontinued these measurments in the past.

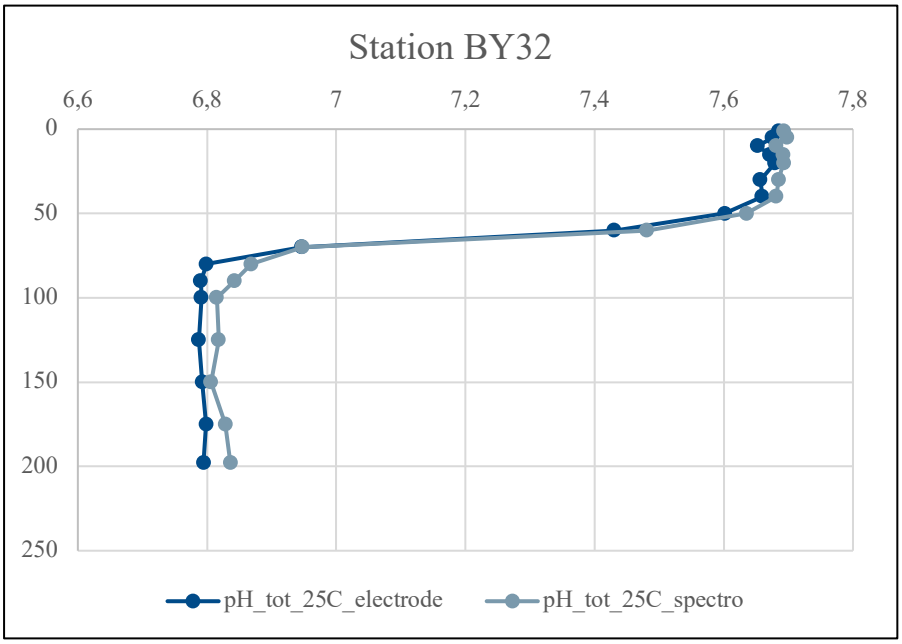

Figure 2. *pH analysed with NBS-electrode and Contros HydroFIA at BY32 during SMHI monitoring cruise in March 2019.*

Estonian monitoring program and additional sampling

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. Cruises were from January 8th – 12th, April 16th – 20th, May 28th – June 2nd, July 9th – 13th, August 22nd – 27th, and October 22nd – 28th. During the first cruise in January, only CO_2 concentrations were measured in the surface water using a LI-COR instrument; during the five following cruises, both CO_2 and CH_4 concentrations were analyzed using an LGR spectrometer. Both systems rely on gas phase measurements in the headspace of an equilibrator continuously supplied with water by the flow-through system of the vessel.

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), two of them in the Latvian waters in the southern gulf The map (Fig. 3) 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 pCO_2 values as low as 16 µatm in the central to south-eastern Gulf of Finland.

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 TTU, as well as samples for DOC and metal concentrations within a cooperation with IO PAN (August and October cruise only).

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 *VOS Finnmaid* traversing the Baltic Sea between Lübeck-Travemünde (Germany) and Helsinki (Finland) (e.g. Gülzow et al., 2013). 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 VOS 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 endeavor demonstrates a seamless integration of standard HELCOM monitoring and the amendments pursued within BONUS INTEGRAL.

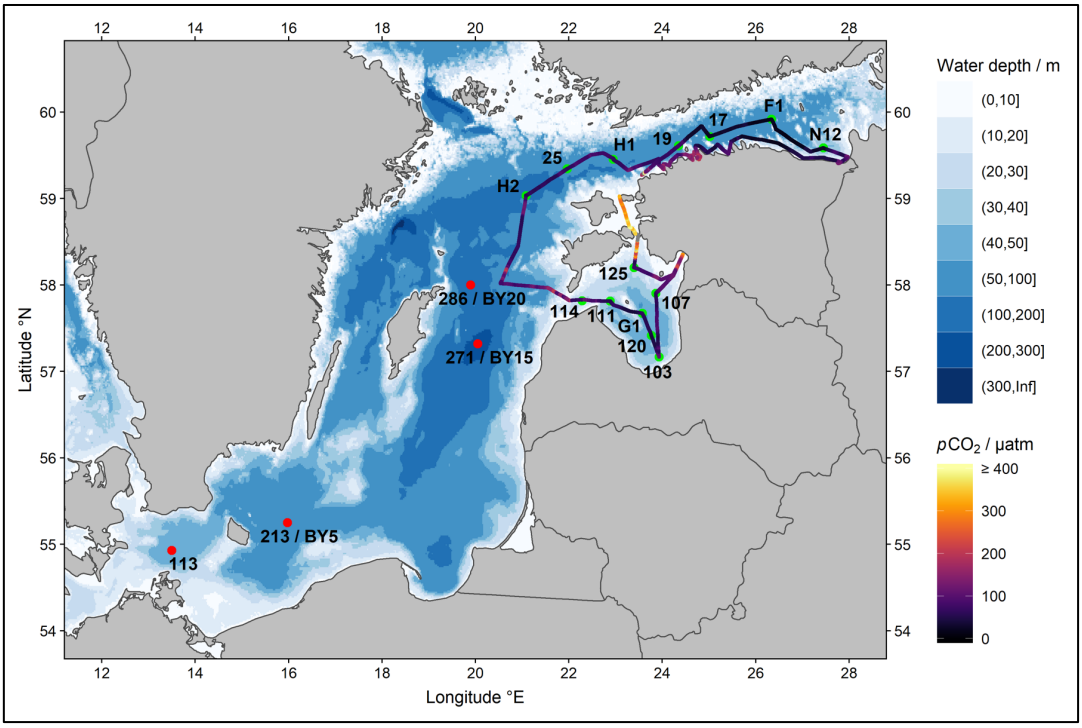

Figure 3: *Stations with additional CO_2 system and trace gas sampling performed on monitoring cruises aboard RV Elisabeth Mann Borgese (red) and RV Salme (green). Additionally, the cruise track of RV Salme from May 28th to June 2nd 2018 is shown with colors representing the partial pressure of CO_2 in the surface water as measured continuously with IOW's flow-through equilibrator system (1 min average). Low pCO_2 values down to <20 µatm indicate a strong spring bloom.*

German monitoring additional sampling: 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. 3, 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. 3) 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 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 VOS FINNMAID

which provide production 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 we provide validation data for biogeochemical models and their modifications/amendments pursued within BONUS INTEGRAL.

Work towards Deliverable 3.3: Expeditions on RVs dedicated to BONUS INTEGRAL (Month 30)

The two expeditions BONUS INTEGRAL field expeditions on RV Aranda and RV Elisabeth Mann Borgese took place almost as planned from February28th, 2019 to March 11th, 2019 (RV Aranda Cruise 04/19) and May 20th 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 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 (CT, 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 Figs. 4ab As an example of the data gathered, The on-board results for Station 24 of EMB 214 (TF 286 Faro Deep) is displayed in Fig. 5. Note that the data are preliminary.

For further workup and best accessibility of data within the project, OwnCloud-Folder are used for data storage and update.

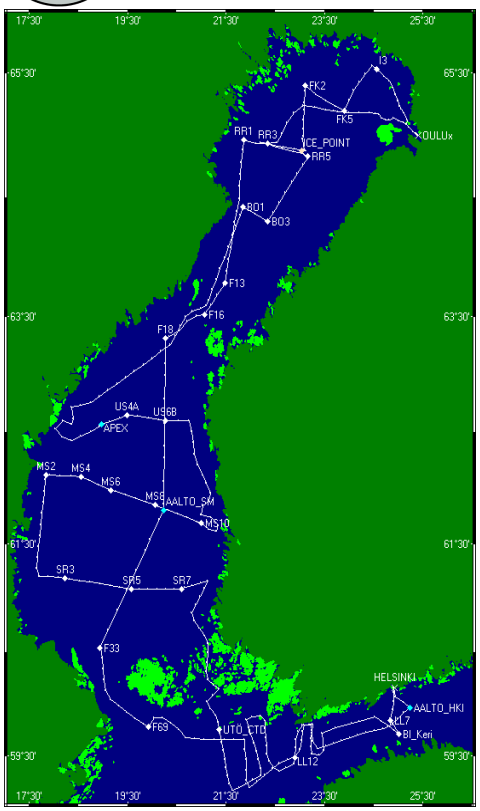

Figure 4a: *Track and stations of the BONUS INTEGRAL WINTER cruise 28 February - 11 March 2019.*

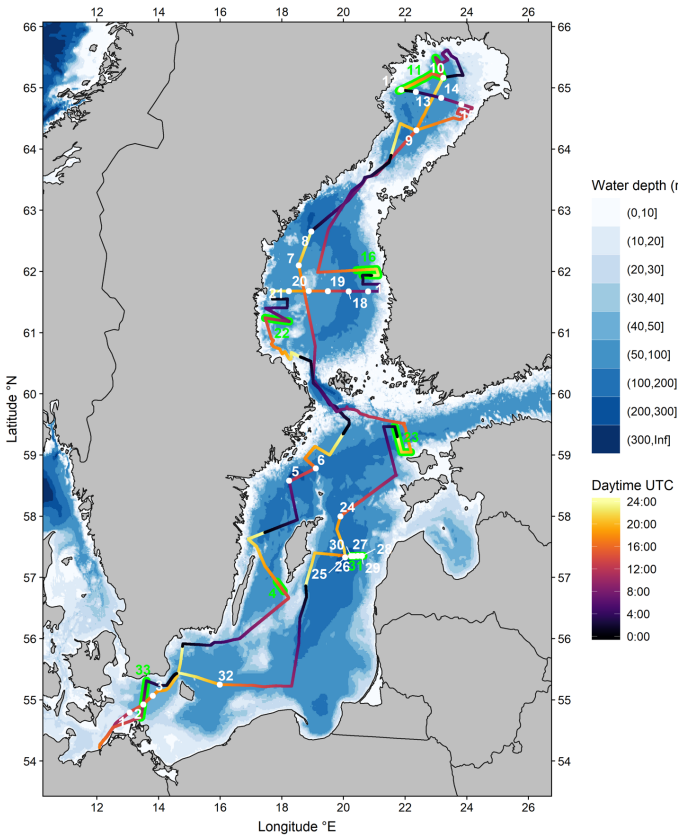

Figure 4b: *Cruise Track for the BONUS INTEGRAL summer cruise, May 21st to June 5th, 2019 with underlaying bathymetry. The colour code of the track indicates the time of day (UTC). CTD sampling stations are indicated as white dots, ScanFish Transects as green lines.*

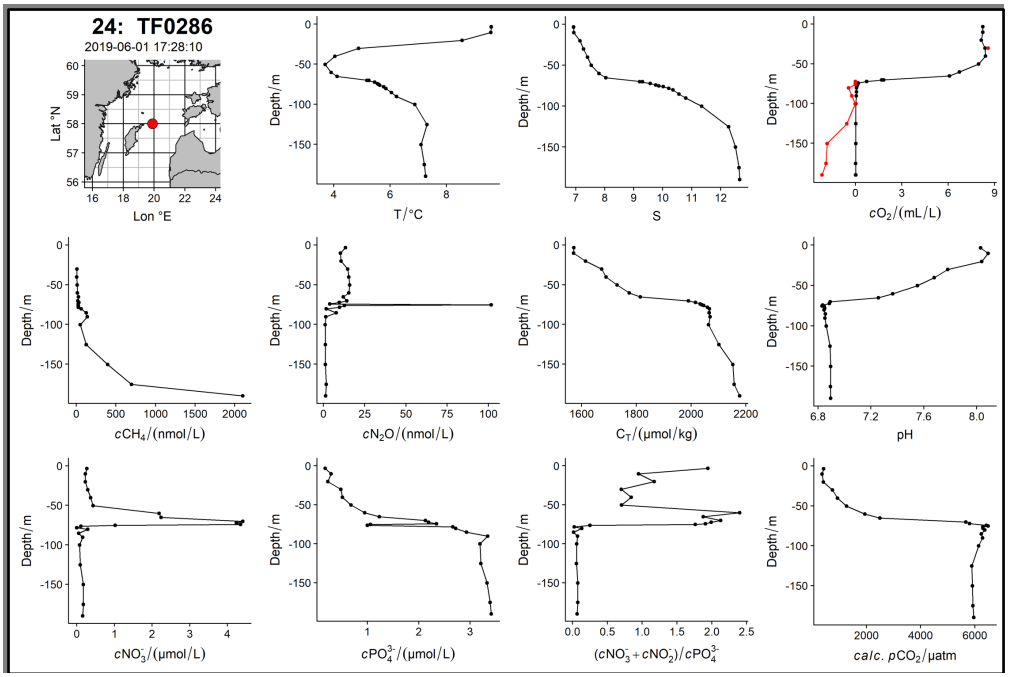

Figure 5: *Preliminary results from Station 24 of EMB 214 (TF 286), including Temperature, Salinity, Oxygen (and H_2S), dissolved CH_4 and N_2O, CT, pH, dissolved nitrate and phosphate, and derived C/P ratio and calculated pCO_2.*

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

The endeavor, apart from its merits to bring young people to science, and creating a lot of media attention (see Chapter 4 of this report), was also scientifically successful and created new knowledge with respect to the development of the summer cyanobacterial bloom. 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. As the samples are still compiled and interpreted, more detail on the results will be given in the 3rd annual report.

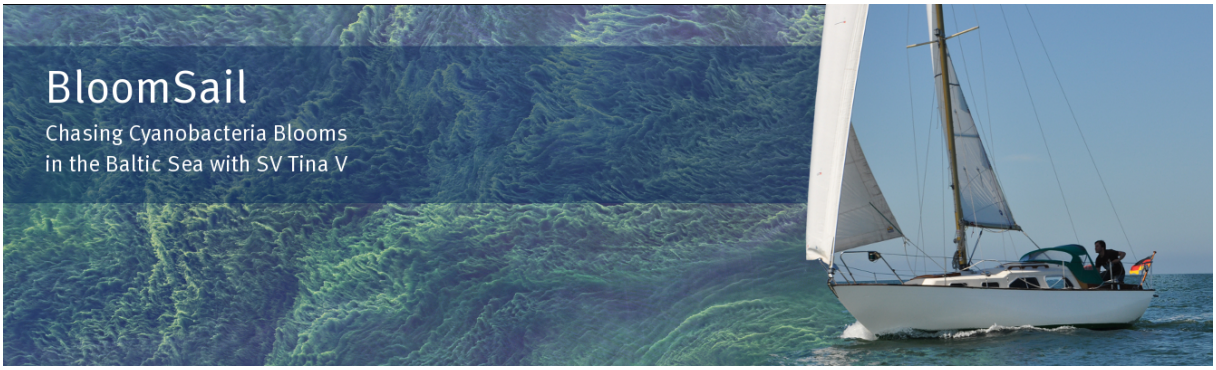

Figure 6: *Dissemination example in connection to the BloomSail expedition.*

Work towards Deliverable 3.4: Installation/Operation/Results of small VOS line package in the Gulf of Gdansk

The ferrybox system, exclusively funded by the BONUS INTEGRAL project, was installed in December 2017 on VOS *AGAT* – a small passenger ferry operating regularly in the Gulf of Gdansk on the routes Gdynia-Hel and Gdynia-Baltijsk (Fig. 7). In an open tender the instrumentation offered by 4H Jena Engineering GmbH has been selected and purchased. The system contains a thermosalinograph (Seabird) and pCO_2 detector Hydro-C (Kongsberg Maritime Contros GmbH). Additionally, the system has been equipped with a spectrophotometric system for pH measurements, HydroFIA pH (Kongsberg Maritime Contros GmbH), developed within the BONUS PINBAL project.

In 2018, the ferrybox system was extensively tested for both its long-term mechanical stability as well as data quality. Based on the results some necessary amendments in the system were established in winter 2019 in parallel to the ship's renovation and its service in the shipyard. The cleaning procedure has been changed and adopted to frequent, short-distance cruises (up to 6 cruises per day). Before the system was automatically rinsed with acid after entering the harbour. This is the method commonly used in this kind of measurements. However, after acidification the pCO_2 sensor required relatively long time to stabilize. As a result most of the pCO_2 results were of poor quality as the sensor did not have enough time to rinse with the seawater, especially on the route Gdynia-Hel.

The pCO_2 measurements have been verified by cross-comparison of measured pCO_2 values with those calculated from DIC and pH. Along with continuous measurements by the ferrybox system, discrete samples for DIC and pH were collected and measured later in the IO PAN laboratories. Then DIC and pH results have been used to calculate pCO_2. The performed comparison of pCO_2 showed in most cases a consistency within 10 µatm.

In the coming months further quality assessments are planned including cross-check experiments and inter-calibration with the system available on RV Oceania.

Figure 7. *Ferrybox system (right) installed on VOS Agat (left).*

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.

Deliverable 4.1: Interim Report on GHG data integration (GEOMAR)

The aim of WP4 is to integrate, quality-control and to harmonize GHG data collected in the framework of BONUS INTEGRAL and to merge it with existing datasets to create a consistent data set as a basis for the calculation of a best-estimate for seasonal GHG distributions in the Baltic Sea.

Deliverable 4.1, the interim report on GHG data integration, was filed in month 26. The status of the data integration for the different greenhouse gases is described below. We aim to include data from all contributors so far collected during BONUS INTEGRAL by the end of November 2019, thus giving the data originators sufficient time for post-processing. The deadline for submission of BONUS INTEGRAL GHG data sets is end of October.

The modular structure of data processing routines allows for the creation of intermediate data products that will be made available for the creation of routines for GHG and flux map calculations (WP4 and 5).

CO_2

pCO_2 data from the VOS line Silja Serenade, the Utö Atmospheric Station and the Aranda winter cruise have been processed and merged with the SOCAT V2019 data from the Baltic Sea to create a harmonized fCO_2 dataset. Data from VOS lines Finnmaid (IOW) and Östergarnsholm (UU) station are already largely included in the SOCAT data collection. Additional data from the BONUS INTEGRAL summer cruise and other project partners will be integrated into the data collection once their data processing is finalized.

CH_4 and N_2O

CH_4 and N_2O data from the Baltic Sea have been extracted from the MEMENTO database. Three additional datasets from the WP2 metadata search have been integrated into the data collection. We furthermore included following datasets from BONUS INTEGRAL partners: VOS Finnmaid CH_4 data from 2010-2017, Boknis Eck Time Series data (2006/2007 – 2014). Additional CH_4 and N_2O data from the BONUS INTEGRAL winter and summer cruises and four cruises from the Kiel Bight and from the VOS line Tavastland will be integrated into the data collection as soon as their data processing is finished.

Data integration routines allow the calculation of spatially and temporally averaged fCO_2, ΔN_2O and ΔCH_4 fields with variable spatial and temporal resolution.

Work towards Deliverable 4.2: Report on computation of GHG concentration fields (UU) M27

Computation of GHG concentration fields will (at least for carbon dioxide) be done using remote sensing data. This work is jointly funded by BONUS INTEGRAL and the Swedish national Space Agency. By training statistical algorithms using unique in-situ data from Deliverable 4.1 as well as other data together with satellite data (from MODIS, MERIS and Sentinel platforms) improved GHG concentration fields are being calculated. The methodology uses an extrapolation of the in-situ data using the additional information on horizontal variability of relevant parameters (for example ocean colour and water temperature) from the satellite sensors. Initial tests shows the improvement by an improved statistical methodology and the importance of data from the Bothnian Sea and Bothnian Bay for accurate estimates.

For CH_4 and N_2O, GEOMAR developed routines to spatially interpolate CH_4 and N_2O concentration fields based on the Barnes (1973) interpolation scheme (Koch et al. 1983) and on Data-Interpolating Variational Analysis (DIVA, (Troupin et al., 2012). These data can be used to calculate basin-wide GHG emission estimates, since data coverage is too sparse for alternative mapping techniques. It is planned to provide annual and, if data coverage is sufficient, seasonal climatological N_2O and CH_4 distribution fields.

References in Section E:

Koch, S. E., desJardins, M., & Kocin, P. J. (1983). An Interactive Barnes Objective Map Analysis Scheme for Use with Satellite and Conventional Data. *Journal of Climate and Applied Meteorology*, *22*(9), 1487–1503.

Tomczak, M. (1998). Spatial Interpolation and its Uncertainty Using Automated Anisotropic Inverse Distance Weighting (IDW) - Cross-Validation/Jackknife Approach. *Journal of Geographic Information and Decision Analysis*, *2*(2), 18–33.

Troupin, C., Barth, A., Sirjacobs, D., Ouberdous, M., Brankart, J.-M., Brasseur, P., … Beckers, J.-M. (2012). Generation of analysis and consistent error fields using the Data Interpolating Variational Analysis (DIVA). *Ocean Modelling*, *52–53*, 90–101.

F.) WORK PACKAGE 5 (FMI)

Within WP5, Baltic Sea sea-atmosphere gas fluxes will be calculated using new, state-of-the art methods and the concentration fields provided by WP4. The work comprises a new Baltic-specific, air-sea parameterization based on turbulence, wave, and air-sea flux data. The parameterization will be introduced into an operational wave model, and implemented in the

Flux Engine toolbox to allow a comparison of different air-sea exchange models for the Baltic Sea flux estimates.

Deliverable 5.1: Report presenting the new turbulence-based gas exchange coefficients

The subsurface turbulence is regarded as a dominant factor in air-sea gas exchange (Garbe et al. 2014), but the relative importance of different sources of turbulence is still not known. In order to model the gas transfer accurately, at least the most important sources should be solved. Since wind-generated waves are an important, if not dominant, source of subsurface turbulence via breaking, both microscale and whitecapping, kinetic energy dissipation (TKE) due to wave breaking is a good candidate for the parameterisation of the transfer velocity.

Fluxes of CO_2, humidity, temperature, momentum and high-frequency wave measurements from several cruises on RV Aranda were used to study the role of turbulence caused by wave breaking in the gas exchange. The experimental set-up for measuring the wind and wave data on board RV *Aranda* has been verified and documented in a peer-reviewed paper published on-line in August 23rd (Björkqvist et al., 2019). The high-frequency wave data, important for the air-sea interaction processes, was used to quantify the dissipated wave energy (Fig. 8).

It was found that the dissipation of TKE was a better predictor of the observed CO_2 fluxes than the parameterisation based solely on shear-induced turbulence (water side friction velocity) or mean wind speed. The scatter in the observations was quite large, suggesting that there are other factors involved in certain environmental conditions. The dissipation of TKE was calculated using the same formulation than in the wave model WAM, and the new developed parametrisation of transfer velocity based on TKE dissipation can be directly used with the wave model WAM. The manuscript about the new parameterisation was provided as interim report, and will be updated upon final submission.

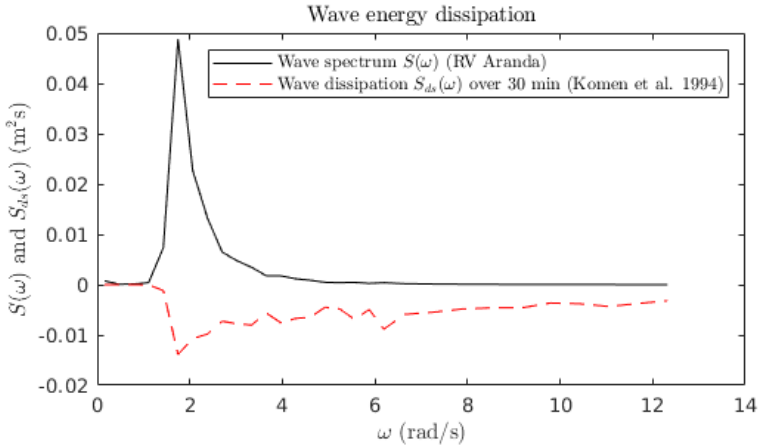

Figure 8: *The wave energy dissipation calculated from the RV Aranda wave data using the Komen et al. (1994) wave energy dissipation formulation in the wave model WAM Cycle 4. The dissipation is largest at the dominant wave frequencies, and remains prominent also in the high frequency range (short waves) important for the air-sea interaction.*

Work towards Deliverable 5.2: Calculation of spatially and temporally compartmentalized fluxes for the Baltic Sea based on the new parameterization implemented in WAM model

The wave model WAM has been modified to output the wave energy dissipation needed for the new transfer velocity parameterisation developed in Task 5.1. The wave energy dissipation can be saved for each time and grid point during the model runs. Examples of the dissipation rates are given in Fig. 9. These data can be applied to calculate the gas flux either inside the WAM model, or after the wave model runs using pCO_2 data and the saved dissipation values. The typical output of the WAM model is 30 minutes, and the fluxes can therefore be estimated for short time scales. Average maps can be used to evaluate long term fluxes. Resolution and input of concentration fields is discussed with WP4.

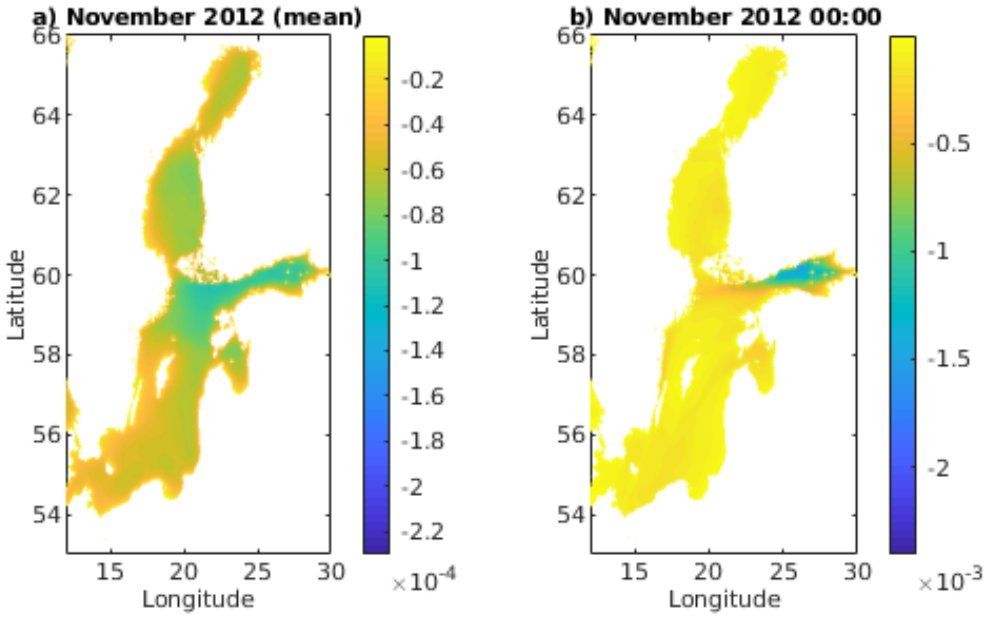

Figure 9: *Examples of the wave energy dissipation (m^2/s) in WAM that has been retrieved using the modified model code. Panel a) shows the mean wave energy dissipation over November 2012. Panel b) shows the momentary dissipation during the storm Antti.*

Work towards Deliverable 5.3: FluxEngine runs with different ASE parameterizations

UNEXE completed the BONUS INTEGRAL specific extensions to the FluxEngine (open source atmosphere-ocean gas flux toolbox) and preliminary analyses (integral specific test cases), and this work is described within Holding et al., (in-review), in which several BONUS INTEGRAL members were involved. The toolbox has now been considerably updated to allow its use as a Python library, to enable simplified installation, verification of its installation, to enable the handling of multiple sparingly soluble gases (e.g. N_2O and CH_4) and greatly expanded functionality for supporting *in situ* dataset analyses. This new functionality for supporting *in situ* analyses includes user defined grids, time periods and projections, the ability to re-analyse *in situ* CO_2 data to a common temperature dataset and the ability to easily calculate gas fluxes using *in situ* data from drifting buoys, fixed moorings and research cruises. The Integral-specific test cases are i) identifying the impact of surfactants on suppressing N_2O ocean to atmosphere gas fluxes and how this can be parameterised, ii) the impact of ignoring vertical temperature gradients within atmosphere-ocean CO2 gas fluxes and how this can be avoided, iii) how to use the FluxEngine to calculate atmosphere-ocean gas fluxes for a fixed monitoring station and iv) a method to easily implement a turbulence-based gas transfer velocity parameterisation within the FluxEngine toolbox (i.e. using the results described in Deliverables 5.1 and 5.2. All of these test cases are described in full within Holding et al. (in-review) and the configuration files are contained in the main software installation and the test cases i to iii form the content of the interactive Jupyter (iPython) notebooks that were developed for the IOCCP / BONUS INTEGRAL summer school.

AT UU, the FluxEngine toolbox is being used to generate regional maps of air-sea fluxes in the Baltic Sea. Monthly surface concentration maps of carbon dioxide from satellite images, in situ data, and model outputs, are used to obtain monthly 4-by-4 km resolution maps of derived carbon dioxide fluxes. The estimated fluxes will be compared with eddy covariance measurements from two ICOS stations in the Baltic Sea and with flux estimations from in situ observations. Flux calculations using commonly-used transfer velocity parameterizations will be tested with a sensitivity analysis to assess the suitability of such build-in parameterizations for the estimations in the Baltic Sea. Additionally, the flexibility of the

toolbox will allow us to evaluate the impact of relevant processes in high-latitude semi-enclosed basins (i.e. water-side convection) which are not included in the transfer velocity parameterizations. Input from all partners and using the available data from the project will generate improved products from the FluxEngine and evaluating the use for limited-size basins and marginal seas.

As a result of this work, a better understanding of the air-sea flux parameterizations in the Baltic Sea will lead to the best possible flux estimates, and provide regional maps with enough resolution to evaluate the seasonal behaviour of the fluxes over the Baltic Sea.

References in Section F:

Garbe C.S., Rutgersson A., Boutin J., Delille B., Fairall C.W., Gruber N., Hare J., Ho D., Johnson M., de Leeuw G., Nightingale P., Pettersson H., Piskozub J., Sahlee E., Tsai W.-T., Ward B., Woolf D.K., Zappa C., 2014: Transfer across the air-sea interface, in: P. Liss and M. Johnson (eds.), Ocean-Atmosphere Interactions of Gases and Particles, pp. 55 - 112, Springer-Verlag Berlin and Heidelberg GmbH & Co.

Komen, G. J., Cavaleri, L., Donelan, M. A., K.Hasselmann, Hasselmann, S., and Janssen, P.: Dynamics and Modelling of Ocean Waves, Cambridge University Press, Cambridge, 1994.

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 will calculate 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 will also be 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

Update on Deliverable 6.1: Report on model performance with focus on the carbonate system

The ERGOM model has been modified to include non-Redfield stoichiometry in an (extracellular) DOM / POM pool as outlined in Delivery Report D6.1. In effect, two modified versions of ERGOM were produced, one with only one additional DOM / POM component that modifies only the C-content ("TEP"-version) and one with three additional DOM / POM components that modify the C-, N- and P-content ("pocNP"-version; for details see Delivery Report D6.2). These modifications improve the reproduction of the surface pCO_2's seasonal amplitude, however, at the expense of an overestimation of this amplitude in the Western basins and a strongly diminished summer CO_2 drawdown by N-fixing cyanobacteria.

Deliverable 6.2: Model-derived carbon budget

Delivery Report D6.2 was submitted in month 25. The assessment is based on high resolution runs of the modified ERGOM models on the entire Baltic Sea. However, the report focuses on the 7 HELCOM subbasins that are regularly passed by VOS Finnmaid (Bay of Mecklenburg, Arkona Basin, Bornholm Basin, Eastern Gotland Basin, Western Gotland Basin, Northern Baltic Proper, and Gulf of Finland West of 26° E), i.e., where adequate carbon validation data are available. In the overlapping period between model and VOS Finnmaid observations (2003 – 2018), the annual cycle of surface pCO_2 is adequately reproduced by the model. Still, observations show a stronger year to year variability in the seasonal pCO_2 amplitude than the model, and also a trend to larger amplitudes in recent years, indicating that some of the drivers remain to be identified. This led us to not derive absolute carbon budget numbers from the model, which may not reflect reality. We still believe, however, that the patterns of the modified ERGOM model give a good, high resolution picture of the basin-wide CO_2 distribution.

The processes determining the seasonal cycle of surface pCO_2 (biologically-driven pCO_2 drawdown during the productive spring and summer period and entrainment of pCO_2-enriched sub-mixed layer waters during the autumn and winter period) are discernible both in the model and observations. Some discrepancies exist in the magnitude of these processes. Winter (Jan/Feb) surface pCO_2 agree well between model and observations. However, spring and summer surface pCO_2 diverge: In particular, the spring bloom surface pCO_2 drawdown is more intense in the model than supported by observations (by –50 µatm on average). The spring excess pCO_2 decline in the model is especially pronounced in the Western basins, with a magnitude of up to –100 µatm (Fig. 10). The onset of the spring bloom is coherent between model and observations, except for the Western basins, where the model leads the observed pCO_2 decline, and for the Gulf of Finland, where the model trails the observations. The summer observations show a steady surface pCO_2 or a second local surface pCO_2 minimum in July, corresponding to carbon uptake by nitrogen-fixing plankton, predominantly in the open Baltic Proper (Fig. 10). This second bloom is not as much mirrored in the model data. In autumn and towards winter, surface pCO_2 values increase towards and above atmospheric levels through entrainment of CO_2-rich sub-surface waters. Due to the second pCO_2 minimum / summer bloom, this increase starts later in the observations than in the model, and tends to be steeper. In the shallower basins except for the Bay of Mecklenburg, the observations also show higher pCO_2 levels than the model, i.e., a larger remineralized carbon pool exposed back to the surface.

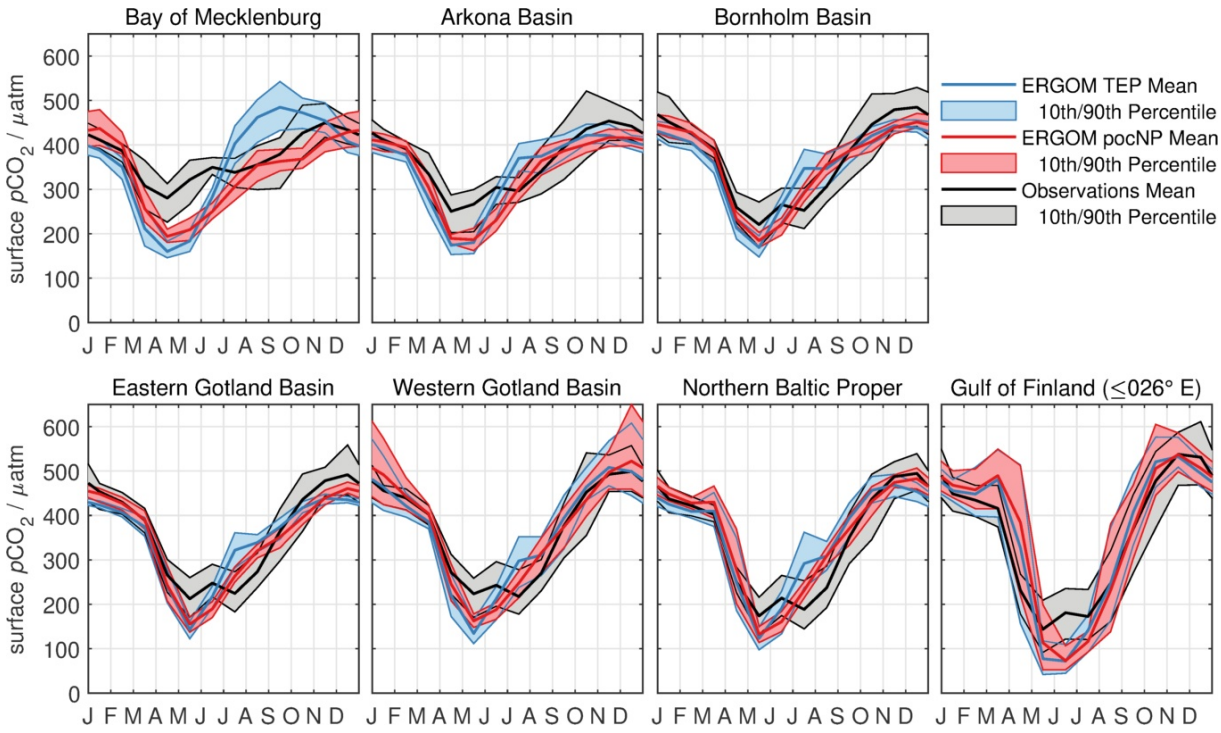

Figure 10: *Seasonal, monthly time series of surface pCO_2 for each of the HELCOM subbasins, averaged for the period 2003 to 2014. ERGOM model data are shown in blue and red (TEP and pocNP version, respectively) and data from the Finnmaid observations in black. Monthly means are denoted by a bold line and the 10th/90th percentile range by the shading / thin line.*

As for the water column structure and inorganic carbon (C_T) inventory, the surface to depth gradient for C_T and total alkalinity (A_T), as well as the level of variability at surface and depth, are comparable between ERGOM pocNP and observations. However, model C_T are consistently offset by about –150 to –100 µmol kg^{-1} as a consequence of model A_T being

lower by about –200 to –150 µmol kg^{-1} than observations. The reason for this reduced A_T is not fully clear, but a relation to the balance of riverine input loads is likely.

The air-sea CO_2 flux follows the surface CO_2 disequilibrium (Fig. 11). However, due to changes in wind intensity between winter and summer, with a smaller asymmetry than the surface pCO_2 disequilibrium. In consequence, the model data suggest only a small, insignificant CO_2 sink for the area considered, while combination with observations indicate a small, insignificant CO_2 source. Despite a typically smaller surface pCO_2, i.e., larger undersaturation, in the coastal zone (within 12 nm from the coast) compared to offshore (beyond 12 nm), both coastal and offshore areas show a comparable flux magnitude in the model. Their difference is mainly in the timing, where the coastal areas lead offshore areas.

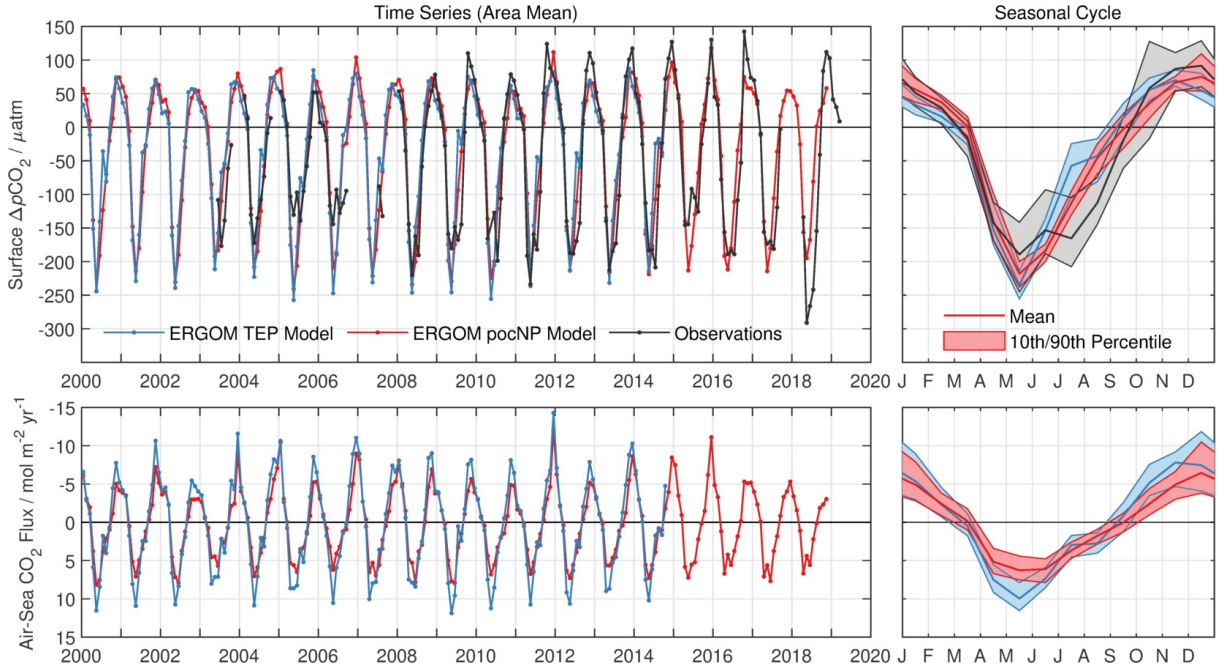

Figure 11: *Surface air-sea pCO_2 difference (top; positive being supersaturated) and air-sea CO_2 flux (bottom; positive being ingassing) for the two ERGOM versions (blue and red, TEP and pocNP, respectively) and from observations (black; pCO_2 difference only). Left panels give the entire available time series and right panels the monthly mean seasonal cycle (bold line) with 10th/90th percentiles (shading / thin lines).*

Work towards Deliverable 6.3: Model-derived carbon budget and trends, and optimized monitoring strategies (M30)

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 can subsequently be used to define focus areas, where added future observations have most impact on surface pCO_2 estimation and accuracy. It can already be seen that additional high resolution data of pCO_2 and the CO_2 system, as initiated by BONUS INTEGRAL in the Northern Basins (VOS *Tavastland*), near the Odra Bight (VOS *Agat*), or in the Gulf of Riga (amendment to the Estonian Monitoring program) are urgently needed for a better biogeochemical, carbon-based understanding of the Baltic Sea.

G.) WORK PACKAGE 7 (Lead: UU)

Dissemination of knowledge from BONUS INTEGRAL at various levels is 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 VOS lines and carbon data for a cost effective monitoring of the Baltic Sea via workshops and a stakeholder conference, and a Report/White Paper and brochure demonstrating and road-mapping a better integration of VOS-based sampling strategies and ICOS-related infrastructure for the ecosystem monitoring of the Baltic Sea.

Deliverable 7.1: Knowledge transfer measures during installation / operation of infrastructure amendments

Knowledge transfer activities include a variety of events in the different countries by different partners. Examples are the Jericho NEXT intercomparison experiment in Oslo organised by FMI where a variety of pCO_2, pH and alkalinity instruments were tested in different temperatures, salinities and pCO_2-concentrations. Exchange of experience and discussion of postprocessing lead to transfer of expertise. The participants from BONUS INTEGRAL included IOW, FMI and SMHI (as an observer). In Sweden, the development of ICOS Sweden is ongoing and for the new funding period the VOS Tavastland and SMHI are being brought in as members of the ICOS Sweden consortium (participants UU and SMHI from BONUS INTEGRAL). On 1-3 April 2019 the workshop on "Underway CO_2 data and metadata quality control procedures" was held at the IOPAN. It was co-organized jointly by Karol Kuliński representing BONUS INTEGRAL and Maciej Telszewski representing IOCCP and the AtlantOS project (see Deliverable Report 7.2). Six combined cruises of Estonian marine monitoring and BONUS INTEGRAL were completed in 2018 – from January 8th – 12th, April 16th – 20th, May 28th – June 2nd, July 9th – 13th, August 22nd – 28th, and October 22nd – 28th. In all cruises two participants from IOW and 2-4 participants from TTU were on board the vessel. The joined activity was also used for mutual knowledge transfer regarding measurements of carbon system parameters that is planned to be introduced into the marine monitoring programme in Estonia, as well as regarding the hydrographical setting of the Gulf of Riga and Gulf of Finland, for which decades-long experience exist at TTU. The installation of the instrumentation on VOS *Agat* has been supported by consultation of partners, in particular Bernd Schneider from IOW. Exchange of students amongst partner institutes for joined workup of data, in particular related to the two field campaigns, has been agreed upon, and will strengthen the education of the students involved. More detailed information on knowledge transfer is summarized in Deliverable Report 7.1.

Deliverable 7.2: Workshop on ICOS implementation in Poland and Estonia

Throughout the project, BONUS INTEGRAL seeks for knowledge transfer from institutions with already established ICOS (Integrated Carbon Observation System) infrastructure towards institutions currently preparing or extending their efforts within ICOS. This knowledge transfer was expected along several lines: strengthening the "oceanic" branch of ICOS by highlighting the importance of measurements in the Baltic Sea, hands on training and scientific exchange amongst partners with different nature and depth of expertise, and measures to advance education with respect to the methodology. Part of these efforts have been described under deliverable 7.1, relating to Task 7.1 of the BONUS INTEGRAL DoW. As one of the components of this strategy, we had identified a special need for a workshop on technology and quality control, with special (but not exclusive) focus on Estonia and Poland.

For the realization, BONUS INTEGRAL joined forces with the IOCCP and the EU project Atlantos to host this workshop due to the common interest within these projects, at the same time allowing closer networking with the "open ocean" community addressing similar tasks.

On April 1st to 3rd, 2019, the workshop on "Underway CO_2 data and metadata quality control procedures" was held at the IOPAN. It was co-organized jointly by Karol Kuliński representing BONUS INTEGRAL and Maciej Telszewski representing IOCCP and the AtlantOS project (H2020). The goal of this workshop was to update the participants, especially those who are in the process of establishing ICOS-related activities, on those protocols through a series of lectures and practicals given in the context of the most comprehensive surface ocean CO_2 data set, the Surface Ocean CO_2 Atlas (SOCAT). The lectures as well as practical training were provided by:

- Siv Lauvset from UiB (Norway), a SOCAT Expert for data synthesis and national coordinator for ICOS Norway
- Maciej Telszewski from IO PAN (Poland), Director of IOCCP, member of AtlantOS project
- Bernd Schneider from IOW (Germany), BONUS INTEGRAL Expert on pCO_2 measurements

The workshop gathered altogether 13 students from all over Europe, including considerable representation from the Baltic Sea region. More information, including list of participants and agenda, is presented in **Deliverable Report 7.2**.

Deliverable 7.3: BONUS INTEGRAL summer school

The basic concept of the BONUS INTEGRAL summer school was developed during the first months of the project. After discussions with international contacts like the ones in ICOS OTC meetings, the annual meetings, and internal communication of the EU project RINGO, it was revealed that related activities were already in preparation by ICOS/RINGO and by the IOCCP. During the AGU/ASLO Ocean Science meeting in February 2018 in Portland, USA, the potential of merging the BONUS INTEGRAL effort with the planned 2nd IOCCP summer school on ocean sensors was discussed. After several planning rounds of M. Telszewski, Director of IOCCP, and Gregor Rehder, coordinator of BONUS INTEGRAL, we came to the conclusion that a joined IOCCP / BONUS INTEGRAL summer school would be an ideal solution and a true win-win situation for both sides. It would lead to an outstanding summer school, increase the international visibility of BONUS INTEGRAL and BONUS as a whole, and would ideally be suited to train the next generation of bright students in the use of technology and data handling for autonomous high resolution environmental observation, which is exactly the strategy pursued by BONUS INTEGRAL. At a later stage, the ICOS OTC was encouraged and also committed to the training workshop.

To help train the new generation of marine biogeochemists in the proper use of a suite of biogeochemical sensors and to assure the best possible quality of the data produced, the International Ocean Carbon Coordination Project (IOCCP; www.ioccp.org) and the EU BONUS INTEGRAL Project (www.io-warnemuende.de/integral-home.html) held a 10-day training workshop on "Instrumenting our ocean for better observation: a training course on a suite of biogeochemical sensors". The course, held at the Sven Lovén Center for Marine Sciences, was attended by 27 outstanding early career scientists, including 18 females, invited from over 135 applicants worldwide. Two PhD students from BONUS INTEGRAL were accepted as participants based on their qualifications. A group of dedicated instructors volunteered to share their time and expertise to provide basic training for those just embarking on their adventure with the biogeochemical sensors that the course focused on:

- Oxygen - with optodes from three manufacturers
- Bio-optics - with chlorophyll fluorescence and backscatter/turbidity sensors
- pH - with both ISFET- and spectrophotometry-based sensors
- pCO_2 - with both membrane based sensors and an underway General Oceanics system.

Table 1**: List of Instructors and affiliations, BONUS INTEGRAL members in **bold.

Last name	First name	Affiliation	Country
Ashton	**Ian**	University of Exeter	UK
Atamanchuk	Dariia	Ocean Frontier Institute, Dalhousie University	Canada
Becker	Meike	University of Bergen	Norway
Bittig	**Henry**	Leibniz Institut für Ostseeforschung Warnemünde (IOW)	Germany
Bresnahan	Phil	Scripps Institution of Oceanography at University of California, San Diego (UCSD)	USA
Briggs	Nathan	National Oceanography Centre	UK
Connelly	Douglas	National Oceanography Centre	UK
Dall'Olmo	Giorgio	Plymouth Marine Laboratory	UK
Dickson	Andrew	Scripps Institution of Oceanography	USA
Garçon	Véronique	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS)	France
Holding	**Tom**	University of Exeter	UK
Landschützer	Peter	Max Planck Institute for Meteorology	Germany
Neill	Craig	CSIRO Oceans and Atmosphere	Australia
Palacz	Artur	IOCCP, IO PAN	Poland
Rehder	**Gregor**	Leibniz Institut für Ostseeforschung Warnemünde (IOW)	Germany
Shutler	**Jamie**	University of Exeter	UK
Skjelvan	Ingunn	NORCE Norwegian Research Centre AS	Norway
Telszewski	Maciej	IOCCP, IO PAN	Poland
Ulfsbo	Adam	Gothenburg University	Sweden

This intensive workshop provided trainees with lectures and hands-on experience with sensors across the whole spectrum of operations from deployment and interfacing, through troubleshooting and calibration, to data reduction, quality control and data management. In addition, participants were given an overview of the use of remote sensing, modelling and smart data extrapolation techniques to broaden their perspectives and effectively open new avenues for exciting research ideas and collaborations. The training course was thus ideally suited for the next generation of users of large scale biogeochemical ocean observation networks such as Biogeochemical Argo, ICOS, or SOCONET (and of course the BONUS INTEGRAL network.

As stated consistently by the participants in their evaluations, the course succeeded in teaching best practices for selected biogeochemical sensors and autonomous measurement systems. Moreover, it provided guidelines and practical tips for data reduction and data quality control practices for sensor data, including specific reporting requirements (e.g. meta-data, calibration, validation, error estimates, formats, etc.).

Perhaps most importantly, this workshop succeeded in forming a tight network of almost 50 biogeochemical sensor users, combining experts with beginners, coming from 19 countries, 6 continents, and representing a total of 26 nationalities. The importance of networking

enabled by this workshop will be revealed in the years to come, but its fruits can already be seen through the maintained active communication among the participants who organize themselves through professional collaborative workspaces such as Slack, or more causally via Twitter and a dedicated group on WhatsApp.

Recognizing the need to broaden the impact and leave a legacy of this course, IOCCP and BONUS INTEGRAL plan to share the training materials, including video recorded lectures, with the broad ocean community via the course website: www.ioccp.org/2019-training-course. On this website, additional information is also available, including the program and session description, and short vitas of the instructors. More detailed information is also given in **Deliverable Report 7.3**. Between the organizers, it was discussed that we shall continue to meet the community demands for such comprehensive training events, by offering them on a bi-annual basis and further improving their effectiveness.

Work towards Deliverable 7.5 and 7.4, or more specifically, Task 7.3: Stakeholder dialogue and information

The major aim of BONUS INTEGRAL is to prove that the use of VOS lines and integration of carbon system data provide a cost-effective tool to improve the biogeochemical monitoring of the Baltic Sea, and to communicate and lobby for an observational network. In this regard, tremendous progress was achieved over the last year, in which BONUS INTEGRAL played at least a supporting role.

VOS *Tavastland,* run by SMHI, is now accepted by ICOS Sweden as the second marine pCO_2 station in Sweden. ICOS Sweden is right now applying for infrastructure funding from the Swedish Research Council for another 6 years and the response to the call is due in fall 2019. A letter of recommendation had been filed in the first reporting period from the project's coordinator to the head of the board of ICOS Sweden.

The *KERI* station in the Gulf of Finland is part of the Estonian Environmental Observatory (a Research Infrastructure facility) which contains atmospheric, terrestrial and marine stations and has applied for funding to join the ICOS network. In October 2018, the consortium got a positive decision that it is developed enough, and should arrange negotiations with the relevant Ministries in Estonia to join ICOS (to fund the process). Preliminary consultations are conducted with the Ministry of the Environment. An international seminar was arranged in Tartu on 10th January 2019 (Seminar day on research of ecosystem-atmosphere relations in Estonia), where also ICOS-related activities in Estonia were presented. Marine component was represented by TTU. Director General of ICOS Werner Kutsch participated in the Seminar, where he also described what steps should be taken to join ICOS.

IO PAN, with Karol Kuliński as a PI, is a partner in the consortium that submitted in June 2018 a letter of intent towards establishing ICOS in Poland (ICOS-PL). Positive feedback received from the Polish Ministry of Science and Higher Education and Ministry of Development (potential founders of the program in Poland) resulted in submitting in June 2019 a full application to place ICOS-PL on the Polish Road Map of the Research Infrastructure. At the moment the application is under review and results are expected in autumn 2019. It is planned that on the later stage the installation running on M/S AGAT will be part of ICOS-PL.

Markus Meier, Gregor Rehder (IOW), Anna Rutgersson (UU) and Karol Kuliński (IO PAN) act as experts in the newly founded EN CLIME working group established at HELCOM within the State and Conservation Group. The role of EN CLIME is to function as a coordinating framework and a platform to harness the expertise of leading scientists on both direct and indirect effects of climate change on the Baltic Sea environment, and to make this expertise available to, and open up for closer dialogue with, policy makers. Through this, ensure that

new scientific findings on climate change and its impacts on oceans and seas should be visible in HELCOM, as well as find their way into HELCOM decision-making and the day to day work. The overall scope of the group is to facilitate the regional cooperation in relation to climate change and its impacts, including transferring quality assured science to end users, and to provide clear guidance on the level of confidence in information which is presented. The work can also vicariously support the identification of knowledge gaps and identification of possible future research priorities. The main goal is to condense the large body of scientific research into a form that is directly utilizable in developing HELCOM core indicators, updating and implementing BSAP, and in preparation of future HELCOM Assessments on climate change.

The EN CLIME group is handling the operational production and delivery of the scientific products of the dedicated work on climate change in the form of fact sheet, The fact sheets are prepared separately for individual parameters that either are dependent on the ongoing climate changes or have potential to influence the climate. Within this there are two parameters specifically linked with the scope of BONUS INTEGRAL project, namely: “ocean acidification” and “ changes in the carbonate chemistry (incl. air-sea exchange of CO_2)”. The involvement of the BONUS INTEGRAL project partners as experts in this process allows for immediate transfer of the gathered knowledge to stakeholders and policy makers.

BONUS INTEGRAL is in close contact with the BONUS synthesis projects FUMARI and SEAM. As the main task of these projects is to give a holistic overview and recommendations towards improved monitoring strategies, we believe that providing in depth information on the strategy of BONUS INTEGRAL is a very effective way of communication towards stakeholders. In that regard, it was also decided to contact several BONUS projects, the BONUS EEIG and the HELCOM Secretariat again to synchronize stakeholder activities. The wish for a joined large stakeholder meeting had already been suggested at the BONUS Triple meeting in Kopenhagen, but so far not been pursued further.

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). The activities according to the Performance Statistics (PS) 1-4 are listed below.

IOW

PS1: Partners from University Stockholm, SYKE, University of Aarhus and IOW (Gregor Rehder) successfully applied for a small grant from the Nordic Research Council to take steps towards developing an acidification indicator, as reaction to the adoption of the candidate indicator acidification.

PS2: Jens Müller presented: “New pH method to determine acidification in the Baltic at the 29th Meeresumweltsymposium BSH, Hamburg, 4.-5. Juli 2019

PS2: Contribution (M. Meier, G. Rehder, several other PIs of INTEGRAL) to drafting the Climate Fact Sheet on demand of HELCOM as part of the EN Clime Work (see also Work towards Deliverable 7.4 above regarding involvement in the EN Clime).

PS3: Markus Meier and Gregor Rehder First (Telcon) EN Clime meeting

PS3: Markus Meier and Gregor Rehder 2nd (Telcon) EN Clime meeting

PS3: Markus Meier co-organized the Baltic Earth Workshop on “Multiple drivers for Earth system changes in the Baltic Sea region”, held in Tallinn, Nov 26th to 28th, hosted by BONUS INTEGRAL member Urmas Lips.

PS3: Gregor Rehder acts as a member of the Scientific Committee of Baltic Sea Science Congress 2019 that will be held on 19-23 August 2019 in Stockholm.

UU

PS3: Anna Rutgersson: Co-chair of Baltic Earth; SSC International SOLAS; Insynsråd, SMHI, Participating in the EC-Clime support writing for HELCOM.

FMI

PS3: Lauri Laakso, SOLAS (The International Surface Ocean - Lower Atmosphere Study SOLAS), National reporting for Finland, 2018-19)

PS3: Lauri Laakso, Finnish Marine Research Infrastructure FINMARI management board 2018-19

PS3: Lauri Laakso, Finnish National Scientific Committee on Oceanic Research 2018-19

PS3: Lauri Laakso, vice member of SAFIR (The Finnish Research Programme on Nuclear Power Plant Safety) RG2,

PS3: Heidi Pettersson, Scientific Comittee on Oceanic Research (SCOR), vice chairman of the Finnish National Comittee. Meetings 20.3.2019

PS3: Heidi Pettersson, Scientific Comittee on Oceanic Research (SCOR), vice chairman of the Finnish National Comittee. Meetings 3.5. 2019

PS3: Heidi Pettersson, Scientific Comittee on Oceanic Research (SCOR), vice chairman of the Finnish National Comittee. Evaluation of WGs 14.6.2019

PS3: Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. Meetings 22.10.2018

PS3: Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. 5.-7.2.2019

PS3: Heidi Pettersson, International Union of Geodesy and Geophysics/ International Association for the Physical Sciences of the Oceans (IUGG/IAPSO), National Correspondent, Finland. 19.10.2018

PS4: Visit of the FMI advisory board to Utö Atmospheric and Marine Research Station, 23-24 August 2018; Stakeholders and Academia, 25 people.

PS4: Finnish Marine Research Infrastructure FINMARI research days, presentation on summer 2018 observations, Helsinki 26.2.2019; Stakeholders and Academia, 70 people.

PS4: FMI PI Lauri Laakso presented the research at Utö Atmospheric and Marine Research Station to the President of Finland, Mr. Sauli Niinistö, Helsinki, 3.5.2019; Policy makers, 1 person.

Figure 12: *Presentation of Station Utö, presented by Lauri Laakso, by the President of Finland, Sauli Niinistö, in Helsinki.*

PS4: FMI PI Lauri Laakso presented the research at Utö Atmospheric and Marine Research during the World Oceans Day, Helsinki, 8.6.2019; public, 600 people.

IOPAN

PS3: Karol Kuliński has been asked to serve as an expert in the HELCOM EN CLIME working group (since January 2019).

PS3: Karol Kuliński was involved in the Baltic Earth Workshop on Multiple drivers for Earth system changes in the Baltic Sea region, 26-27 November 2018.

PS3: Karol Kuliński acts as a member of the Scientific Committee of Baltic Sea Science Congress 2019 that will be held on 19-23 August 2019 in Stockholm.

TTU

PS3: Urmas Lips has acted as the co-chair of the HELCOM STATE&CONSERVATION Working Group where, among other topics, new methods for eutrophication- and ocean acidification-related monitoring are discussed. He co-chaired the WG meeting on October 22nd – 26th 2018, Copenhagen, Denmark. Urmas Lips was elected as chair of the HELCOM SOM Platform (analysing the sufficiency of measures for the update of the HELCOM Baltic Sea Action Plan) and he chaired the first meeting of SOM platform on February 28th – March 1st 2019 in Helsinki, Finland. He also contributes to the HELCOM IN-Eutrophication activities (Skype meeting on April 1st, 2019) where acidification indicator was discussed, in particular. Urmas Lips is also a member of the Scientific Advisory Board of FINMARI (Finnish marine research infrastructure) and he participated at the SAB meeting on February 25th to 27th, 2019 in Tvärminne, Finland. As a member of the EuroGOOS Executive Directors Board, Urmas Lips has discussed methods of automated high-frequency monitoring developments (including ferryboxes, profilers, etc.) in Europe at the board meetings on October 10th – 11th, 2018, January 29th – 30th, 2019, and May 7th – 10th, 2019 (also Annual Meeting of EuroGOOS AISBL).

Moreover, the Baltic Earth workshop on Multiple drivers for Earth system changes in the Baltic Sea Region was arranged in Tallinn, Estonia, on November 26th-27th 2018. Urmas Lips was local organizer of the workshop and the Baltic Earth SSG meeting on November 28th 2018.

SMHI

PS3: June 12-13, 2019: Patrick Gorringe participated in BOOS Annual Meeting in Rostock, Germany, and presented the work done by SMHI in BONUS INTEGRAL.

UNEXE

PS3: Jamie Shutler is an Expert Reviewer for the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), International Space Science Institute (ISSI) Working Group Leader (http://www.issibern.ch/workinggroups/atmosgasexchange) and a Member of the European Space Agency Mission Advisory Group for EE9 candidate SKIM.

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 5.

IOW

Nov. 21st to 28th, 2018: Gregor Rehder and Jens Müller participated in the carbon system measurement inter comparison workshop in Oslo, a collaboration with EU project Jericho Next, organized by BONUS INTEGRAL partner Lauri Laakso.

September 24 to 25, 2018: Henry Bittig participated in the NOAA OAP and ICOS “Workshop on Quality Control processes of key Biogeochemical Parameters”, at NOAA PMEL, Seattle, WA, USA.

December 2 to 7, 2018: Henry Bittig participated in the “19th Argo Data Management Team Meeting” (ADMT-19), at Scripps Institution of Oceanography, San Diego, CA, USA; including: the “SOCCOM data management meeting”, December 3 and the “7th BGC-Argo Data Management Meeting”, December 4 – 5.

October 22nd to 23rd, 2018: Henry Bittig participated in the “Ocean – Climate – Sustainability Research Frontiers” Science Conference by the three ocean/climate related clusters of excellence of Northern Germany “MARUM”, “CliSAP”, and “The Future Ocean”, Berlin, Germany Presentation: ”BGC-Argo: Science Plan, Examples and Perspectives”, Keynote of “Ocean Monitoring & Observing Systems” session.

Sept 11th to 13th, 2018: The 3rd ICOS Science Conference, Prague, Czech Republic. Gregor Rehder et al. :BONUS INTEGRAL: Using ICOS and related infrastructure to improve biogeochemical monitoring and ecosystem assessment for the Baltic Sea.

Oct. 10th to 12th, 2018: EMSO ERIC / JericoNext / AtlantOS / ENVRIplus joint workshop “EU Coastal and Open Sea Observatories – Workshop on Interoperability Technologies and Best Practices in Environmental Monitoring”, Brest, France. Presentation 1: Henry Bittig: O_2 optodes: Data acquisition, state of the art of sensor knowledge, implementation and recommendations; Presentation 2: Henry Bittig: O_2 optodes: Autonomous platforms (Argo and gliders): known issues, recommendations for implementation and qualification.

Oct. 28th to 31st, 2018: OCB Workshop on Oceanic Methane and Nitrous Oxide: The present situation and future scenarios, UCLA Lake Arrowhead, USA. Gregor Rehder, Jens Müller, and Bernd Schneider: Trace Gas Observations in the Baltic Sea from a Voluntary Observing Ship (VOS): pCO2, Methane, and Beyond (invited).

Nov 5th to 6th: Joint BONUS HELCOM Conference: Research and Innovation for Sustainability, Helsinki, Finnland. Gregor Rehder: Ocean acidification in the Baltic Sea through novel ecosystem monitoring approaches.

November 26th to 27th: Workshop on Multiple drivers for Earth system changes in the Baltic Sea region, Tallinn, Estonia. Gregor Rehder et al.: Dry warm and sunny: Response of net community production on the extreme meteorological conditions in spring/summer 2018.

Jens Müller gave a radio interview to Gotland P4 (PS11) 5 multimedia contributions (PS12), and contributed to seven public articles in relation to the Bloom Sail even or acidification (PS13).

UU

Anna Rutgersson participated in the SOLAS SSC meeting in Sapporo, May 2018; the Qingdao marine expert meeting, Qingdao September 2018; and the WCRP/WDAC annual meeting, Marrakech, April 2019.

June 11th to 15th, 2018: 2nd Baltic Earth Conference - The Baltic Sea in Transition. Anna Rutgersson, H. Pettersson, E. Nilsson, H. Bergström, M. B. Wallin, E. D.Nilsson, E. Sahlée, L. Wu, E. M. Mårtensson: Using land-based sites for air-sea interaction studies (oral presentation)

June 11th to 15th, 2018: 2nd Baltic Earth Conference - The Baltic Sea in Transition. Lucia Gutiérrez-Loza, A. Rutgersson, M. B. Wallin, E. Sahlée: Air-sea Methane fluxes in the Baltic Sea using eddy covariance (poster)

July 23rd to August 4th, 2018: 7th International SOLAS summer school. Lucia Gutiérrez-Loza, A. Rutgersson, M. B. Wallin, E. Sahlée: Quantifying air-sea methane fluxes in a coastal station using the eddy-covariance method (poster).

April 21st to 25th, 2019: SOLAS Open Science Conference. Lucia Gutiérrez-Loza, M. B. Wallin, E. Sahlée, E. Nilsson, H. W. Bange, A. Kock, A. Rutgersson: Air-sea methane fluxes in the Baltic Sea from eddy covariance measurements (oral presentation).

April 21st to 25th, 2019: SOLAS Open Science Conference. Leonie Esters, M.B. Wallin, E. Nilsson, E. Sahlée, L. Gutiérrez-Loza, A. Rutgersson: Evaluation of a turbulence-based description of the air-water gas transfer velocity (poster).

April 21st to 25th, 2019: SOLAS Open Science Conference. Anna Rutgersson, H. Pettersson, E. Nilsson, H. Bergström, M. B. Wallin, E. D.Nilsson, E. Sahlée, L. Wu, E. M. Mårtensson: Using land-based stations for air-sea interaction studies (poster).

FMI

PS5: Lauri Laakso / FMI coordinates a joint research activity project on carbonate systems in H2020-project Jerico-Next. The aim of the JRAP is to develop marine carbon system observations throughout European coastal sea. Part of the activity is related to developing data QC methods, in-line with ICOS-OTC and SOCAT standards.

PS5: Intercomparison of instruments for carbonate system measurements (INTERCARBO) TNA exercise organized by FMI and NIVA (Norway) in Oslo 20-29 November 2018. IOW, FMI and SMHI participated in the event.

PS5: Bonus-Integral project is partly related to European H2020-infrastructure project Jerico-Next, with FMI (Finland) and SMHI (Sweden) partners in both projects. As the border seas significantly differ from open oceans, we are currently writing the carbonate system observation specifications covering different European coastal area conditions; 2019

PS5: Martti Honkanen participated in Bonus-Integral summer school on carbonate system observations, 2019/06.

TTU

January 13th, 2019. Tallinn, Estonia. Workshop on innovative approaches to monitoring and assessing marine environment and nature values of Estonian sea area. Urmas Lips presented BONUS INTEGRAL approach and possible contribution for monitoring of carbon system and acidification.

IO PAN

November 26th to 27th, 2018: Baltic Earth Workshop on Multiple drivers for Earth system changes in the Baltic Sea region, Tallinn, Estonia. Karol Kuliński, Marcin Stokowski, Beata Szymczycha, Aleksandra Winogradow, Bernd Schneider. Multiple drivers for the acid-base system in the Baltic Sea (poster presentation).

November 26th to 27th, 2018: Baltic Earth Workshop on Multiple drivers for Earth system changes in the Baltic Sea region, Tallinn, Estonia. Marcin Stokowski, Bernd Schneider, Gregor Rehder, Karol Kuliński: Biogeochemical transformations in the river mouth as the drivers of the total alkalinity loads to the Baltic Sea (poster presentation).

February 23rd to March 2nd, 2019: ASLO 2019 Aquatic Science Meeting. Karol Kuliński, Marcin Stokowski, Beata Szymczycha, Aleksandra Winogradow, Bernd Schneider. Peculiarities of the acid-base system in the Baltic Sea (oral presentation).

April 7th to 12th, 2019: EGU 2019, Vienna, Austria. Karol Kuliński: The acid-base system of the Baltic Sea (oral presentation).

April 14th to 17th, 2019: Global Ocean Acidification Observing Network (GOA-ON) International Workshop. Marcin Stokowski, Bernd Schneider, Gregor Rehder, Karol Kuliński. Transformations of the carbonate system in the estuary of the Odra and Vistula rivers (the Baltic Sea) (poster presentation).

April 14th to 17th, 2019: Global Ocean Acidification Observing Network (GOA-ON) International Workshop. Karol Kuliński, Beata Szymczycha, Marcin Stokowski, Aleksandra Winogradow, Bernd Schenider. Anomalies of the CO_2 system in the Baltic Sea (oral presentation).

SMHI

October 9-12, 2018: Anna Willstrand Wranne participated in the Jerico Next workshop 'EU Coastal and Open Sea Observatories Workshop on Interoperability Technologies and Best Practices in Environmental Monitoring' at Ifremer in Brest. The purpose of the work shop was to discuss the interoperability technologies for sharing ocean instruments and to hormonize the practices among teams and users. The focus areas was sensor web implementation, cabled coastal observatories, methodology for pH, pCO2 and dissolved oxygen in environmental areas.

April 24-26, 2019: Anna Willstrand Wranne participated in the 9th Ferrybox Workshop, Genoa, Italy, and presented results from work carried out in the frame work of BONUS INTEGRAL The workshop was primarily focused on subjects such as: tackling the environmental challenges using Ships of Opportunity, Integration of data from SOOP in biogeochemical models, joint IOCS/Ferrybox collaboration and data management including QA/QC procedures and data flow to ocean data portals.

UNEXE

UNEXE has released version 3 of the FluxEngine, the atmosphere-ocean gas exchange software toolbox. Version 3 is now static and freely available on GitHub through this link: https://github.com/oceanflux-ghg/FluxEngine and includes installation and comprehensive usage instructions along with interactive (Jupyter/iPython notebook) tutorials.

March 21st, 2019: Jamie Shutler attended and participated in the third annual meeting of the EU Ringo (ICOS) project that was held in Southampton, UK. Jamie presented work from Integral (and Ringo) which highlighted linkages between Integral and Ringo, and identified how

well aligned these two projects were (in terms of methods and tools for calculating atmosphere-ocean gas fluxes).

May 13th to 17th, 2019: Tom Holding presented a poster at the European Space Agency Living Planet Symposium that was held in Milan, Italy. The poster described the FluxEngine toolbox and the extensions that have been developed to support Integral research.

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

Several deliverables were submitted with a slight delay for various reasons, but all deliverables due in the reporting period were met and the project is proceeding according to the DoW. Deliverable 3.1/7.1, originally due in month 14, was filed towards the end of the reporting period, as both additional installation and knowledge transfer is continuously ongoing. Deliverable 7.2, originally due in month 18, was submitted slightly delayed, as a workshop on Carbon data Quality Control and the Baltic Sea Carbon System, co-coordinated by the IOCCP, the ATLANTOS project and BONUS INTEGRAL, was hosted in April 2019 (month 22 of the project) and was in the core of what BONUS INTEGRAL wanted to achieve.

Partner IOW had to request a budget change from reporting period 2 to 3, because a.) the summer school took place in month 24, but reimbursement of expenses to the participants and payment of the bill to the summer school venue mainly took place in the first month of reporting period 3, and b.) a change in personnel (WP6) and partly, the higher expected personnel costs during the end of the project, required a shift in funds.

FMI requested a minor budget change (35k€) due to delays in completing tasks in WP5 due to unexpected governmental work in spring 2019.

IO PAN requested a budget change related to the shift of funds in other direct costs from reporting period 3 to 2. This was necessary due to the faster than expected at the beginning of the project depreciation procedure of the ferrybox system.

TTU requested to shift 7800 EUR from year 2 to year 3 due to some changes in work schedule, including later start of testing of carbon system sensors on Tallinn-Helsinki ferrybox line and contribution to WP6.

Partner GEOMAR has requested a budget change (personnel and travel) because 1) the set up of the N_2O/CO analyzer on VOS Tavastland has been delayed to spring 2019 and 2) Dr. Annette Kock, postdoc funded by BONUS INTEGRAL, was on maternity and parental leave from 10 September 2017 to 16 May 2018. Since she came back to work she works part-time with a reduced working time of 30 h/week (instead of 39.5 h/week). Xiao Ma (PhD student) was employed as replacement for Dr. Kock from 1 October 2017 to 31 March 2018 with 29.6h/week. GEOMAR will use the leftover personnel money to hire Dr. Tobias Steinhoff, GEOMAR, for BONUS INTEGRAL from 15 August 2019 until the end of BONUS INTEGRAL. He will be in charge for sensor maintenance and data management of the data from the Tavastland line.

Despite the requested budget change, the overvall objectives as well as the dates of both milestones and deliverables of WP4 do not need to be modified.

6 Amendments to the description of work and schedule of deliverables

None, except those noted under Chapter 5. However, due to the higher than expected data flow, the change of schedule concerning the scientific cruises (a result of the later starting date of the project, and the assured funding of some of the PhD positions beyond the current end date of BONUS INTEGRAL, it was decided on the 2nd annual meeting to explore the possibilities for a cost neutral 3 month extension of the project.

7 Other information

Publications arising from the project

A: currently under review:

Holding, T., Ashton, I. G., Shutler, J. D., Land, P. E., Nightingale, P. D., Rees, A. P., Brown, I., Piolle, J. F., Kock, A., Bange, H. W., Woolf, D. K., Goddijn-Murphy, L., Pereira, R., Paul, F., Girand-Ardhuin, F., Chapron, B., Rehder, G., Ardhuin, F., and Donlon, C. J.: The FluxEngine air-sea gas flux toolbox: simplified interface and extensions for in situ analyses and multiple sparingly soluble gases, Ocean Sci. Discuss., 2019, 1-28, 2019.

Ma, X., Lennartz, S. T., and Bange, H. W.: A multi-year observation of nitrous oxide at the Boknis Eck Time-Series Station in the Eckernförde Bay (southwestern Baltic Sea), Biogeosciences Discuss., 2019, 1-30, 2019.

Rutgersson, A., Pettersson, H., Nilsson, E, Bergström, H. Wallin, MB., Nilsson, D., Sahlée, E., Wu, L., Mårtensson, M. Using land-based stations for air-sea interaction studies. Tellus accepted (2019).

Stokowski, M., Schneider, B., Rehder, G., Karol Kuliński, K.: The CO_2 System Characteristic of the Odra River Estuary (the Baltic Sea), Limnol. & Oceanogr., under revision.

Steinhoff, T. et al. Constraining the Oceanic Uptake and Fluxes of Greenhouse Gases by Building an Ocean Network of Certified Stations: The Ocean Component of the Integrated Carbon Observation System, ICOS-Oceans, Frontiers of Mar. Sci, accepted (2019)

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.

Björkqvist, J.-V., Pettersson, H., Drennan, W. M., and Kahma, K. K., (2019). A new inverse phase-speed spectrum of non-linear gravity wind waves. Journal of Geophysical Research: Oceans, DOI: 10.1029/2018JC014904.

Honkanen, M., Tuovinen, J.-P., Laurila, T., Mäkelä, T., Hatakka, J., Kielosto, S. and Laakso, L., (2018). Measuring turbulent CO_2 fluxes with a closed-path gas analyzer in a marine environment. Atmos. Meas. Tech., 11, 5335-5350, https://doi.org/10.5194/amt-11-5335-2018.

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.

Kuliński, K., Szymczycha, B., Koziorowska, K., Hammer, K. and Schneider, B., (2018). Anomaly of total boron concentration in the brackish waters of the Baltic Sea and its consequence for the CO_2 system calculations. Marine Chemistry 204, 11-19.

Laakso, L., Mikkonen, S., Drebs, A., Karjalainen, A., Pirinen, P. and Alenius, P., (2018). 100 years of atmospheric and marine observations at the Finnish Utö Island in the Baltic Sea. Ocean Sci., 14, 617-632, https://doi.org/10.5194/os-14-617-2018.

Müller, J. D., Bastkowski, F., Sander, B., Seitz, S., Turner, D. R., Dickson, A. G. and Rehder, G., (2018). Metrology for pH Measurements in Brackish Waters—Part 1: Extending Electrochemical pHT Measurements of TRIS Buffers to Salinities 5–20. Frontiers in Marine Science, 5(July), 1–12. https://doi.org/10.3389/fmars.2018.00176.

Müller, J. D. and Rehder, G., (2018). Metrology of pH Measurements in Brackish Waters—Part 2: Experimental Characterization of Purified meta-Cresol Purple for Spectrophotometric pHT Measurements. Frontiers in Marine Science, 5(July), 1–9. https://doi.org/10.3389/fmars.2018.00177.

Nilsson, E., H. Bergström, A. Rutgersson, E. Podgrajsek, M.B. Wallin, G. Bergström, E. Dellwik, S. Landwehr and Ward, B., (2018). Evaluating Humidity and Sea Salt Disturbances on CO_2 Flux Measurements. J. Atmos. Oceanic Technol., 35, 859–875, https://doi.org/10.1175/JTECH-D-17-0072.1.

Schneider, B. and Müller, J. D., (2018). Biogeochemical Transformations in the Baltic Sea - Observations Through Carbon Dioxide Glasses. Springer Oceanographie. Springer Scientific, Berlin (116 pp).

Schneider, B. and Otto, S., (2019). Organic matter mineralization in the deep water of the Gotland Basin (Baltic Sea): Rates and oxidant demand. Journal of Marine Systems 195, 20-29.

Exchange on Research Vessels during the reporting period

TTU hosted 2 scientists from Germany during 6 Estonian monitoring cruises (2 places, 32 days)
FMI hosted 6 non-Finnish scientists on the BONUS INTEGRAL winter cruise (6 places, 11 days)
IOW hosted 5 non-German scientists on the BONUS INTEGRAL summer cruise, (5 places, 15 days)

8 Acknowledgement

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