International Ocean Carbon Coordination Project

Progress Report for SCOR, July 2023

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EXECUTIVE SUMMARY

In the past 12 months the IOCCP continued to support the development of a global network of ocean carbon and biogeochemistry observations, coordinate the development of globally acceptable strategies and provide technical coordination developing operating methodologies, practices and standards, homogenizing efforts of the research community and scientific advisory groups.

In our effort to identify priority measurements for implementation of GOOS observations of ocean carbon and biogeochemistry, and to promote development and adoption of necessary measurements and measurement technology, in partnership with the GOOS BioEco Panel, EU ECOTIP Project and the EU4OceanObs Project, we developed concrete recommendations for enhanced and optimised design of plankton and related biogeochemical observations to enable better understanding and prediction of changes in carbon sequestration and related ecosystem services. These recommendations will ultimately inform the report on proposed revisions to the EOV and EBV frameworks which is due to be submitted by the end of 2023.

Through continuous working collaboration with EU ICOS OTC, G7 FSOI, SOCONET, SOCAT and GCP to facilitate a dialogue with stakeholders to implement a scientifically and economically effective, fit-for-purpose observing system for ocean carbon and biogeochemistry we influenced a landmark decision by the World Meteorological Congress (May 2023) to approve new Global Greenhouse Gas Watch (GGGW), which will fill critical information gaps and provide so badly needed operational framework allowing to gradually transform ocean carbon observations from research-based to “operational” where by operational we mean operational resource mobilisation.

Focused on biogeochemical Essential Ocean Variables and to help train the new generation of marine observers in the appropriate use of a suite of biogeochemical sensors, the IOCCP with generous co-sponsorship of the EU ICOS OTC, US NOAA GOMO, OFI (Canada), and Carbon to Sea Initiative (USA), held the 3rd edition of the "Instrumenting our ocean for better observation: a training course on a suite of biogeochemical sensors". The course was attended by 28 very motivated early-career scientists selected from one hundred applications, and was delivered by 25 dedicated instructors providing a unique opportunity to form a tight and long-lasting network of biogeochemical sensor users, combining experts with beginners, coming from a wide range of countries on all continents and representing groups and communities in various phases of technical, logistical and financial development. The importance of networking enabled by this Training Course will be revealed in short, medium and long term strengthening our community as a whole and every individual involved.

Beyond these most impactful recent developments, the IOCCP is heavily involved in several other activities highlighted in the remainder of this report.

PROJECTS & MAJOR ACTIVITIES

Integrated Ocean Carbon Research Working Group

IOCCP is one of five international research and coordination programmes on ocean-climate interaction, which have been working together with IOC-UNESCO since 2018 in the IOC Working Group on Integrated Ocean Carbon Research (IOC-R). The other organizations are: the Integrated Marine Biosphere Research Project (IMBeR), the Surface Ocean Lower Atmosphere Study (SOLAS), the Climate and Ocean Variability, Predictability and Change (CLIVAR) project and the Global Carbon Project (GCP). The Working Group aims at filling knowledge gaps in relation to ocean carbon by designing and promoting the implementation of a new generation of integrated ocean carbon research. The working group fosters active collaboration and synergies amongst the partners and other relevant international efforts on carbon research.

After more than 2 years of in person and online collaboration between the partners, in April 2021, IOCCP was excited to announce the publication of the "Integrated Ocean Carbon Research: A Summary of Ocean Carbon Knowledge and a Vision for Coordinated Ocean Carbon Research and Observations for the Next Decade", a report which set out to accomplish the vital task of indicating the then current gaps and future directions for the integrated ocean carbon cycle research.

The report presents a synthesis of the state of knowledge about the oceans' role in the carbon cycle and points to the way ahead regarding development of climate change mitigation and adaptation policies for the coming decade. Since its publication, it was widely used internationally to communicate specific implementation needs to funding agencies and policy-makers and to emphasize the importance of scientific knowledge to the taking of informed decisions within the United Nations Framework Convention on Climate Change in order to achieve the goals of the Paris Agreement and build more resilient societies.

However, given the latest developments in mitigation strategies (i.e. marine carbon dioxide removal) and rapid advancement in the field of ocean carbon science since the beginning of the decade, the co-conveners of IOC-R, led by the two co-Chairs Christopher Sabine (University of Hawaii, USA, representing IOCCP) and Carol Robinson (UEA, UK, representing IMBER), decided that an updated vision document was needed. In an effort to get a broader community input to the new document, an online meeting was held in December 2022 (workshop report). During that workshop discussions around several topics of the agreed update process were held and included:

- review of the 2021 IOC-R Report and identification of areas requiring an update,
- identification of emerging issues/knowledge gaps and/or areas to focus on in light of existing activities to be articulated in an updated vision document and other communications,
- structure of the revised vision document to allow clear identification of key messages,
- identification of section lead authors and contributors,
- development of draft roadmap/timeline for implementation of the update.

In order to address these issues through continued collaboration amongst IOC-R WG co-conveners, and to develop an innovative joint programme of medium- to long-term, an in-person workshop was developed to be held on May 3-5, 2023 in Brussels. During the three days meeting, the group identified, summarized and discussed the implementation of the update to the existing document with regards to the objectives listed above. It was agreed that the drafting process will be conducted

online and the IOC Secretariat will facilitate the communication between the authors. A possibility for an in-person review/finalization meeting at the end of 2023 will be explored. Furthermore, the goup decided that on top of already involved experts, the updated document will strongly benefit from contributions from experts in the following fields:

- Social science / economics / human behaviour /psychology
- Paleoceanography
- Fish and fisheries
- Ice ocean processes
- Governance, regulatory framework
- Integrated assessment modelling
- Environmental impact assessment community
- Remote sensing

The workshop report from the IOC-R workshop held on May 3-5, 2023 can be accessed online.

Finally, the group agreed that the updated IOC-R Vision document will be published at the UN Ocean Decade Conference to be held on 10-12 April 2024 in Barcelona, Spain.

Operationalizing Surface Ocean Carbon Monitoring - Global Greenhouse Gas Monitoring Infrastructure

In the past 12 months we have made continuous effort to help our community strengthen the integration of the ocean carbon observing system as part of the global, cross-domain greenhouse gas monitoring. Late last year we led the community discussions aimed at developing a coherent and actionable input to the WMO International Greenhouse Gas Monitoring Symposium (January 2023) where almost 200 participants discussed the need for and the means to integration of existing, often independently developed greenhouse gas observing systems across domains. The symposium was held as one of the milestones in a wider attempt to build an internationally coordinated, operational global greenhouse gas monitoring system across all domains. This activity presents an opportunity for our community to further our own efforts towards a sustained, internationally coordinated routine greenhouse gas monitoring infrastructure with a broad group of stakeholders from scientific, operational, and policy-setting entities.

IOCCP played a central role in coordinating the ocean carbon community in providing input to the agenda, filling the agenda with relevant content and developing key messages to be conveyed during discussions at the venue. Our collective presence was pleasantly plentiful in terms of number of attendees as well as their interventions across topical sessions and panel discussions. Participants of the Symposium agreed to develop and distribute the Symposium Statement, which influenced a landmark decision by the World Meteorological Congress (May 2023) to approve new Global Greenhouse Gas Watch (GGGW), which will fill critical information gaps and provide an operational framework, integrated across all space-based and surface-based observing systems, as well as modelling and data assimilation capabilities.

Participants of the Symposium agreed to build the implementation of this activity on WMO's experience with the Global Atmosphere Watch and the Integrated Global Greenhouse Gas Information System. A detailed and costed implementation plan for the GGGW is being developed by a dedicated working group consisting of a broad range of stakeholders across United Nations agencies, international programs (including IOCCP), national and sub-national governments and the private sector, and will be thoroughly scrutinized at the Workshop on Observations within GGGW to be held at WMO HQ in October 2023. The expected outcomes of the workshop are recommendations regarding the structure of the integrated observing system (including the design, measurement techniques, data exchange and several others) in support of GGGW, gap analysis of the existing

capabilities and recommendations on the ways to leverage those, and prioritization of the actions for implementation.

IOCCP's role in this landscape is to ensure that ocean carbon observations remain as a solid foundation for the latter elements of the value chain. To this end, IOCCP will support the global community in gradually transforming ocean carbon observations from research-based to "operational" where by operational we mean operational resource mobilisation. Within that remit, IOCCP's coordination services may include clustering together initiatives which explicitly tackle improving ocean carbon observations. IOCCP should continue to lead the drafting of a detailed document which contains a transition plan from research-based to product-oriented ocean carbon observing system, starting from surface observations. Collaboration within the WMO-led GGGW gives a perfect opportunity for that work.

IOCCP's involvement in the UN Decade of Ocean Science for Sustainable Development Programmes

Ocean Acidification Research for Sustainability (OARS) including the Global Ocean Acidification Observing Network (GOA-ON)

IOCCP's tasks related to Ocean Acidification (OA) are primarily focused on increasing the readiness level of the Inorganic Carbon EOV in terms of observations, data management and knowledge and information production. To allow for thorough, comprehensive and efficient interventions, IOCCP Expert for OA, Kim Currie, as well as Project Office Director, Maciej Telszewski, are heavily involved in coordination and communication with the Global Ocean Acidification Observing Network (GOA-ON) and with the UN Decade Ocean Acidification Research for Sustainability Programme (OARS). GOA-ON and OARS are heavily intertwined in terms of programmatic mission, experts, funding and coordination.

In the past 12 months, several IOCCP Experts in collaboration with around 20 colleagues representing major national, international and intergovernmental institutions and organizations, worked to develop a Blueprint (OARS Outcome 3 White Paper) for the co-design and implementation of observing strategies in response to impacts of ocean acidification on the global ocean.

The ultimate benefits and impacts stemming from implementation of this Blueprint will be putting in place increased observation capabilities allowing to derive an improved understanding of global climatic trends, e.g. ocean pH and oceanic carbon uptake. This information, necessary to the development of societally relevant projections, will also enable the assessment of proposed carbon removal strategies.

By co-locating observations of different parameters (physical, biological, chemical, environmental, social, economic) it will provide us with a much more holistic appreciation of the fundamental processes, relationships and drivers which underpin marine socio-ecological systems and better understand the impacts of ocean acidification, in the context of other stressors (both climate driven and local human activity). Such breadth of data collection will also facilitate the creation and application of Digital Twins to better manage complex environmental challenges (e.g. creating and maintaining climate smart marine protected areas, managing fisheries, supporting marine spatial planning, etc). An additional benefit will be a common and mutually agreed upon knowledge base to support international policy debate and science-based political vision by designing a forward-looking climate decarbonization policy. By co-designing with stakeholders, common goals will be agreed

upon, possibly favouring access to funding which is critical in particular for vulnerable areas to plan their climate response.

White Papers for all 7 Outcomes designed by OARS are planned to be published in time to be presented at the UN Ocean Decade Conference to be held on 10-12 April 2024 in Barcelona, Spain.

Global Ocean Oxygen Decade (GOOD) including the Global Ocean Oxygen Network (GO2NE)

IOCCP's tasks related to the Oxygen EOV are primarily focused on increasing the readiness level of the EOV in terms of observations, data management and knowledge and information production. To allow for thorough, comprehensive and efficient interventions, IOCCP Expert for that EOV, Véronique Garçon, as well as Project Office Director, Maciej Telszewski, are heavily involved in coordination and communication with the IOC-UNESCO's thematic Working Group on the Global Ocean Oxygen Network (GO2NE) and with the UN Decade Global Ocean Oxygen Decade Programme (GOOD). GO2NE and GOOD are heavily intertwined in terms of programmatic mission, experts, funding and coordination.

In the past 12 months, IOCCP's focus remained to be on the development of the Global Ocean Oxygen Database and Atlas (GO2DAT). Following the GO2DAT Kick-off Meeting in September 2022, the main objectives for that period were to collectively contribute to the Best Practices publication, which aims to:

- review, compile and potentially compare the different methods and SOPs for ocean oxygen measurements
- develop and/or evaluate the required and recommended metadata and data specifications, quality control procedures, adjustment protocols and quality flagging schemes

This publication, planned to be in a final draft form at the end of October 2023, will become a "cookbook" for GO2DAT's data QA/QC efforts.

In parallel, IOCCP SSG Experts, Véronique Garçon and Dariia Atamanchuk, continue working on the development of the GO2DAT metadata sheet in collaboration with national data centers (NCEI, BODC) as well as IOC's IODE.

Carbonate System Reference Materials

High-quality measurements of the seawater carbonate system allow us to quantify and understand the oceanic uptake of atmospheric carbon dioxide (CO_2) and monitor ocean acidification. Those seawater carbonate system measurements rely on the availability of reference materials (RMs). The COVID-19 pandemic highlighted the fragility of the production system of the seawater RMs for the carbonate system, currently depending on one single laboratory. With that in mind, a new model for seawater RMs for the carbonate system, centered on regional hubs, is being discussed to create a more resilient system. The proposed new model for seawater RMs for the carbonate system requires unprecedented involvement of National Metrology Institutes (NMIs) on a global level. The integration of the new model into the global metrology landscape will help to produce the RMs that are comparable and metrologically traceable to the International System of Units.

Building on the past activities addressing these challenges, IOCCP has continued to make progress on and undertake new initiatives in close collaboration with our partners according to the three main lines of work agreed by the IOCCP SSG:

- Regular communication around seawater carbonate system RMs and standards
- International community position paper on the importance of and requirements for sustained global production and supply of seawater carbon standards
- Standard Operating Protocol for production of secondary reference materials

In September 2022, IOCCP SSG member Maribel García-Ibáñez presented the new proposed model of seawater carbonate system RM production, certification and distribution at the BIPM-WMO Metrology for Climate Workshop, the report of which is available from here. This presentation was the first opportunity to promote the need and proposed solutions among the broader community which includes members of national metrology labs.

IOCCP's efforts to bridge the gap between the scientific community and the metrology institutes were brought to a climax with the heavily advertised webinar entitled "Multinational Effort in the Search for a Global Solution for the Production and Certification of Reference Materials for Measurements of the Seawater Carbonate System" which IOCCP co-organized with GOA-ON on 31 May 2023 as part of the GOA-ON webinar series. IOCCP SSG member Maribel García-Ibáñez, and Regina Easley (National Institute of Standards and Technology (NIST), USA) gave two complementary presentations, and IOCCP Project Officer Artur Palacz moderated the discussions. The webinar was recorded and is freely available for viewing from the GOA-ON YouTube Channel here.

The event was very well attended by representatives of scientific and non-scientific stakeholder groups many of which expressed interest to engage in and support further developments in this area, most notably two European NMIs and the Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) which is a pan-European intergovernmental platform that increases the efficiency and impact of research and innovation for sustainable, healthy and productive seas and oceans.

The JPI Oceans Knowledge Hub Ocean Carbon Capacities action has stimulated widespread discussions across Europe on a range of Ocean Carbon Cycle (OCC) science topics with recent discussions focused among other on the objective to evaluate the carbon uptake status of European waters and the North Atlantic Ocean in support of national carbon budgets and global climate policymaking. At a meeting in Brussels in December 2022, representatives of the groups addressing these issues concluded that JPI Oceans is uniquely well placed to bring the European Oceanographic Community together to address key issues such as the need to support seawater carbonate system RMs.

IOCCP is currently in dialogue with JPI Oceans to request resources to enable a dedicated JPI Oceans-led task team to bring together all the European players to design a plan to implement a Euro-African hub for seawater carbonate system RMs. Strong involvement of NIST which is leading the RM development in the US ensures that the development of the Euro-African hub benefits from past and ongoing lessons learnt as well as a much needed close collaboration between the future regional hubs.

Global data synthesis activities

IOCCP continues to contribute to overcoming challenges and to developing strategic actions related to the established global data synthesis products (Surface Ocean CO_2 Atlas - SOCAT, and Global Ocean Data Analysis Project - GLODAP), as well as new and emerging data synthesis products as needed (GO2DAT, METS RCN, MEMENTO).

Surface Ocean CO_2 Atlas (SOCAT)

The latest update of the community-led Surface Ocean CO_2 Atlas (www.socat.info), version 2023, has delivered 35.6 million, quality-controlled, in situ surface ocean fCO_2 (fugacity of CO_2) measurements collected between 1957 and 2022 with an estimated accuracy of <5 µatm. The SOCAT synthesis products and the fCO_2 measurements in them are key for quantification of ocean CO_2 uptake at a monthly timescale, providing vital information for climate policy. However, the open ocean data collection effort has dramatically declined since 2017. SOCAT itself is at immediate risk upon losing its European data management team, while facing persistent funding shortfalls. The need for accurate knowledge of ocean CO_2 uptake and its variation now and in the future makes sustained funding of accurate surface ocean CO_2 observations and their synthesis imperative.

In light of the recent decision of the University of Bergen (UiB), Norway, to discontinue funding for the international data management efforts, and the effective disbandment of the SOCAT Data Management group at UiB, the IOCCP in collaboration with the SOCAT Global Group (Steve Jones and Maciej Telszewski are members) works towards resolving this crisis while assessing the implications of that for a wider global marine biogeochemistry data management efforts.

Several online meetings and vast email correspondence across numerous membres of the global community led to identifying some immediate as well as longer term steps which IOCCP is and will be involved in taking:

In the short term

- Include the specific personnel and financial requirements for SOCAT in presentations (and following discussions) at the WMO-led Global Greenhouse Gas Watch Workshop in October 2023 .
- Investigate the potential for a short-term solution for SOCAT support at Norwegian Institute for Marine Research, especially considering that IMR hosts the Norwegian National Oceanographic Data Centre (NODC). This requires negotiations with IMR leadership, perhaps aided by the IODE as the global coordinator of NODCs.
- Investigate the potential for securing appropriate funds at the EU JPI Oceans to cover the immediate staff requirements for SOCAT minimal maintenance.
- The transition period for finding a long term solution will last approximately 2 years and negotiating this sort of timeframe with IMR (or any other relevant entity) is needed.

In the long term:

- A new European hub for SOCAT is needed to complement the US-based group based at NOAA PMEL (Seattle) and led by Kevin O'Brien.
- One challenge is that there are very few organisations where the necessary expertise in marine carbon science and scientific data synthesis co-exist as it was the case at UiB. Such co-location of expertise benefited the development of SOCAT and GLODAP tremendously.

On the other hand, IMR has the expertise in overall biogeochemistry as it is running a biogeochemistry component of Copernicus.

- Collaboration with WMO seems necessary in order to ensure sustainability of SOCAT operations in the long-term. However, it must be recognized that it will take a few years before such a permanent solution with SOCAT at WMO could be completed. Once at WMO, we expect the countries to be more willing if not obliged to invest in SOCAT on a national level.
- At the same time, discussions with IODE are needed regarding their potential for providing long-term support for SOCAT based on coordinated dataflows via NODCs. IODE coordinates the global network of NODCs offering a truly global solution, as for example with SDG 14.3 reporting on pH for ocean acidification. This has potential to create hubs outside of Europe and North America.
- Consider the very successful Argo Data Management model when proposing a long-term solution for SOCAT.

Global Ocean Data Analysis Project (GLODAP)

The Global Ocean Data Analysis Project (GLODAP) is a synthesis effort providing regular compilations of surface-to-bottom ocean biogeochemical bottle data, with an emphasis on seawater inorganic carbon chemistry and related variables determined through chemical analysis of seawater samples. IOCCP continues to financially and organizationally support GLODAP development as the product serves not only as the most accurate record for its 13 variables but its dramatically increasing significance lies in its value as validation data for autonomous sensors mounted on a variety of platforms including AUV's, floats and moorings. Maciej Telszewski is a member of the GLODAP Reference Group.

Released in August 2022, GLODAPv2.2022 is an update of the previous version, with the major following changes: data from 96 new cruises were added, data coverage was extended until 2021, and for the first time the GLODAP team of volunteer PI's performed secondary quality control on all sulfur hexafluoride (SF_6) data. In addition, a number of changes were made to data included in the previous version (GLODAPv2.2021). These changes affect specifically the SF_6 data, which are now subjected to secondary quality control, and carbon data measured on board the RV *Knorr* in the Indian Ocean in 1994–1995, which are now adjusted using certified reference material (CRM) measurements made at the time.

GLODAPv2.2022 includes measurements from almost 1.4 million water samples from the global oceans collected on 1085 cruises. The data for the 13 GLODAP core variables (salinity, oxygen, nitrate, silicate, phosphate, dissolved inorganic carbon, total alkalinity, pH, chlorofluorocarbon-11 (CFC-11), CFC-12, CFC-113, CCl_4, and SF_6) have undergone extensive quality control with a focus on systematic evaluation of bias. The data are available in two formats: (i) as submitted by the data originator but converted to World Ocean Circulation Experiment (WOCE) exchange format and (ii) as a merged data product with adjustments applied to minimize bias. For the present annual update, adjustments for the 96 new cruises were derived by comparing those data with the data from the 989 quality-controlled cruises in the GLODAPv2.2021 data product using crossover analysis. SF_6 data from all cruises were evaluated by comparison with CFC-12 data measured on the same cruises. For nutrients and ocean carbon dioxide (CO_2) chemistry comparisons to estimates based on empirical algorithms provided additional context for adjustment decisions. The adjustments that we applied are intended to remove potential biases from errors related to measurement, calibration, and data handling

practices without removing known or likely time trends or variations in the variables evaluated. The compiled and adjusted data product is believed to be consistent to better than 0.005 in salinity, 1 % in oxygen, 2 % in nitrate, 2 % in silicate, 2 % in phosphate, 4 µmol kg^{-1} in dissolved inorganic carbon, 4 µmol kg^{-1} in total alkalinity, 0.01–0.02 in pH (depending on region), and 5 % in the halogenated transient tracers. The other variables included in the compilation, such as isotopic tracers and discrete CO_2 fugacity (fCO_2), were not subjected to bias comparison or adjustments.

The original data, their documentation, and DOI codes are available at the Ocean Carbon and Acidification Data System of NOAA NCEI (https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/GLODAPv2_2022/, last access: 15 August 2022). This site also provides access to the merged data product, which is provided as a single global file and as four regional ones – the Arctic, Atlantic, Indian, and Pacific oceans – under https://doi.org/10.25921/1f4w-0t92. These bias-adjusted product files also include significant ancillary and approximated data, which were obtained by interpolation of, or calculation from, measured data. This living data update documents the GLODAPv2.2022 methods and provides a broad overview of the secondary quality control procedures and results.

Integrated Marine Debris Observing System: from vision to implementation

IOCCP has continued to play a significant role in bringing the concept of an Integrated Marine Debris Observing System (IMDOS) from an ambitious community vision to gradual implementation.

In February 2023 Mine Tekman (Turkey) was hired as a dedicated IMDOS project officer by Mercator Ocean International (MOI), working part-time as a consultant until September 2023. In addition, Dominik Krzymiński was hired by IOCCP at IO PAN to provide communications support for both IOCCP and IMDOS, at least until May 2024 (EU EuroSea and EU ECOTIP funding). Much effort has been placed on strengthening the communication and community building of IMDOS. As a result, a dedicated website for IMDOS (imdos.org) is about to be publicly launched, while an IMDOS Twitter account (@IMDOS_org) was opened in May 2023.

In April 2023, during the 13th Session of the GOOS Steering Committee, IMDOS was officially endorsed as a GOOS Project following a presentation from IOCCP project officer Artur Palacz. While GOOS SC praised the rapid development of IMDOS and welcomed its addition into the GOOS structures, they also noted the need for providing a clear implementation plan and timeline beyond which IMDOS would become an independent entity.

Building on the past years community events and guidance from the IMDOS Interim Steering Committee, we have developed the IMDOS Strategy which is expected to be launched before the end of 2023. Parallel work on the IMDOS Implementation Plan is expected to be completed in 2024.

As the co-lead of the UNEP Global Partnership on Marine Litter (GPML) Marine Debris Data Harmonization Community of Practice: Ocean and Coasts Domain, IOCCP project officer Artur Palacz has initiated the planning of a large International Marine Debris Data Harmonization Workshop which aims, among other things, to pave the way for a federated and interoperable global data management system for marine debris. Successful organisation of this in-person workshop due to take place in August 2023 required bringing together key players in the marine debris data management landscape: UNEP GPML, the Ministry of Environment Government of Japan (MOEJ), the European Marine Observation and Data Network (EMODnet) and NOAA National Centers for

Environmental Information (NCEI) as well as the Canadian Integrated Ocean Observing System (CIOOS) and the Integrated Marine Observing System (IMOS) in Australia.

The overall goal of this international technical workshop is to enhance the level of data including associated metadata identification to support global data harmonization for selected key marine debris indicators that will underpin the successful mitigation of plastic pollution. The workshop will present the state of the art when it comes to harmonization of monitoring methods and data synthesis efforts but will predominantly include working/discussion sessions in plenary and dedicated breakout groups.

The 3-day workshop will be hosted by MOEJ in Yokohama, Japan on 29-31 August 2023, with organisation support from IMDOS Coordination Office. The event will bring together about 35 invited participants, including international experts in marine debris data management, monitoring, and harmonization of methods. The workshop is co-sponsored by MOEJ and EU's H2020 EuroSea, EU4OceanObs implemented by Mercator Ocean International and H2020 EUROqCHARM projects.

Expected outcomes include:

- A coordinated network (community of practice) of ocean surface microplastic data providers initiated under the auspices of GOOS and IMDOS, with an agreement to adhere to agreed common sampling protocol and metadata and data requirements
- Consensus metadata and data requirements sheet agreed among MOEJ, EMODnet, NOAA NCEI, and any other potential large data integrators
- Recommendations for standardized metadata and data requirements for the UNEP GPML Digital Platform data matrix
- Agreed roadmap towards a federated data management system for ocean surface microplastics and selected global-scale marine debris indicators

Focused Regional Implementation of IOCCP activities

Until 2021, the IOCCP had very limited connection with and impact on the Northern African observing community in the Mediterranean basin. Appointing a new SSG member from Tunisia (Dr Sana ben Ismail) in 2021 provided a new opportunity to better picture the landscape of requirements and observing capacities in this region of the world. Throughout 2022 we worked to develop communication channels with individual groups and learned about the key scientific, logistical and strategic issues of the N. African observing community, as well as the current status of needs in that region.

General unfavourable economic situation in the N. African region was deepened by the COVID pandemic, which had a strong impact on science. The relative cost of equipment and related consumables is much higher than in neighbouring regions, namely southern Europe. This discrepancy allowed us to realize that any regional implementation initiatives that IOCCP might want to lead in the region need to involve partners from both sides of the Mediterranean.

Realizing our minimal understanding of the relevant landscape in the region, in mid-2022 we partnered with WMO-IOC's Data Buoy Cooperation Panel (an intergovernmental construct with strong presence in the region regarding physical oceanography observations) to develop a scoping workshop for all countries in the region and use it as a first step in developing a catalogue of capacity building needs for the future regional biogeochemistry observing system. Most key partners in the region: Algeria, Morocco, Tunisia and Egypt accepted our invitation and respective scientific and administrative representatives joined the 3-day event held in a hybrid mode on 2-4 May 2023 in Tunis, Tunisia. Representatives of southern European countries (Spain, France, Italy, Cyprus) as well

as intergovernmental organizations (WMO, IOC, UNEP, MOI) were also present and actively contributed to discussions and development of a timlined forward looking strategy. IOCCP was represented by Marta Álvarez (CSIC, Spain) and Artur Palacz and Maciej Telszewski from the Project Office.

The main objective of the workshop was to assess the Mediterranean region's perspective for development of a sustainable marine biogeochemistry observing network and their current capacity to utilize information generated from ocean biogeochemistry observations for social-economic benefit. The themes discussed at the workshop included information on the role of ocean observations in regional weather prediction and climatology, socio-economic benefits of ocean observations related to fisheries, tourism and transportation, best practices in observations, data quality control protocols and ocean observing with new technologies.

The workshop revealed that not only we at global coordination bodies have very fragmented knowledge of scientific, technical and financial capacity in the region, but even the groups in neighbouring countries were not familiar with their respective scientific and strategic objectives, their personnel and technical capacities, their potential to expand those, their ambitions beyond current capacities etc. Ocean acidification and Blue Carbon were named as most promising areas of expertise in the region across board. At the same time strong uncertainty was expressed regarding availability of champions in carbonate chemistry observations. It became clear that colleagues working in countries bordering the southern part of the Mediterranean Sea are largely not familiar with the global ocean observing networks, their operations, benefits of joining them or opportunities to be included. Lack of organized coordination and collaboration between the African countries in the Mediterranean basin was identified as one of the key issues preventing regional development of marine science in general and marine biogeochemistry in particular .

Somewhat expected shortages in instrumentation were highlighted across board and a number of requests were made to include hands-on training on instrument handling, deployment and calibration checks and other related practical modules in future workshops.

A post-training survey was circulated to participants for future planning and to allow qualitative assessment of existing and lacking scientific expertise and to identify gaps and develop steps to increase readiness level across marine biogeochemistry domain as a whole. Based on the synthesised knowledge from this workshop, IOCCP is in a better position to offer coordination in organising, co-sponsoring and/or fundraising for activities specifically tailored to the regional needs, keeping in mind a wider perspective including data-sharing, contribution to existing activities, utilising available funding streams etc.

We will continue to work with Sana to strengthen the local and regional network of biogeochemical observations in an environment where the observing and data management needs are not prioritized by most of the local stakeholders. We hope that the activities developed and implemented around the southern Mediterranean community, will be applicable in other regions facing similar challenges.

Refining EOV Requirements for Carbon Sequestration

Collaboration with and participation in the EU H2020 ECOTIP project, which has been providing financial support for the IOCCP project officer, provided numerous opportunities for advancing the implementation of the IOCCP mission, in particular with regard to the organic carbon component of the sustained marine biogeochemistry observing system.

There remain significant knowledge gaps when it comes to our ability to understand and forecast future changes in marine carbon cycling, in particular in terms of the changing role of biological processes in the uptake and sequestration of carbon from the atmosphere (e.g. IOCR Report). At the

same time, there has long been a mismatch between the requirements for data needed to inform and evaluate climate and ecosystem models, and the provision of data and data synthesis products based on in-situ and remote sensing observations. The challenge is perhaps greatest in the polar regions, especially in the Arctic, where we observe the greatest impacts of climate change while suffering from scarcity of observations. Insufficient or ineffective communication among researchers across the observations-modelling interface as well as across the inorganic-organic interface exacerbates the problem with our capacity to map and predict changes in marine carbon cycling.

In October 2022, as part of the ECOTIP project, we convened the "Plankton EOV & carbon sequestration requirements workshop," attended by a dozen experts including representatives of the IOCCP, the GOOS Biology & Ecosystems Panel of Experts, ECOTIP and the EU4OceanObs projects. The workshop resulted in a set of concrete recommendations for enhanced and optimised design of plankton and related biogeochemical observations to enable better understanding and prediction of changes in carbon sequestration and related ecosystem services. These recommendations will ultimately inform the report on proposed revisions to the EOV and EBV frameworks which is due to be submitted by the end of 2023.

As direct follow-up of the workshop, IOCCP has provided coordination support for a new working group action co-organized by the EU H2020 ECOTIP and EU4OceanObs projects with a goal to identify the top 10 biogenic data products which would advance the modelling of carbon sequestration and the biological carbon pump in the ocean, with a special focus on the Arctic Ocean and its ecosystems. Through the proposed activity we have gathered a group of multidisciplinary experts from both the observing and modelling communities who provided guidance on how to best determine priority data products to address the challenges outlined above.

An online workshop planned for 18-19 October 2023 will engage a broader group of invited members of the observing and modelling community who will jointly co-design the types of data products most needed and most feasible to obtain to better understand and predict changes in ocean carbon sequestration in the Arctic. In general, we seek input on products which roughly inform three categories of processes: (i) biological uptake and export of carbon, (ii) residence time through remineralization and (iii) sedimentation.

The final outcome of the workshop will be a peer-reviewed publication providing a foresight view on the new data product priorities, with additional publications outlining the roadmaps towards individual proposed products implementation.

3rd Training Course on a Suite of Biogeochemical Sensors

While it is well recognized that the ocean plays a critical role in climate variability, seasonal-to-decadal climate forecast as well as weather forecast, it is paramount to remember that the evaluation of all models allowing us to understand ocean's role in the weather/climate system relies on ocean observations to improve their skill and to enable them to provide reliable information. Well ground-truthed models are also essential for guiding national and international policies that relate to resources such as fisheries, aquaculture or water supply as well as warning systems and a variety of coastal applications such as energy production, recreation, pollution and more.

Thus the quality of the weather and climate services as well as the assessment of the current state of the ocean ecosystem regionally and locally, relies on a comprehensive and timely set of ocean observations. The ocean observing system is used by an increasingly diverse user group from

fundamental underpinning ocean research to real-time numerical weather forecast, near-term prediction services, all the way to governmental and non-governmental management and policy making.

The biggest challenge in ocean observing is that the ocean properties vary on a number of spatio-temporal scales and it is necessary to obtain high quality, high resolution measurements across all these scales in order to inform this ever-increasing portfolio of needs. Ocean technology has leapt to the aid of scientists by providing them with cost-effective sensors that can take autonomous measurements of essential ocean variables with the aim of improving data coverage worldwide and therefore complement efforts carried out by traditional ship-based sampling.

However, there remains a gap between the technology and the end-user. This gap is born primarily out of lack of training in sensors' use as well as disconnect between data gathering and data quality assurance as required for various applications across the ocean domain.

Focused on biogeochemical Essential Ocean Variables and to help train the new generation of marine observers in the appropriate use of a suite of biogeochemical sensors and to assure the best possible quality of the data produced, the IOCCP with generous co-sponsorship of the EU Integrated Carbon Observation System Ocean Thematic Centre (ICOS OTC), US NOAA Global Ocean Monitoring & Observing Program, Ocean Frontier Institute (Canada), and Carbon to Sea Initiative (USA), held the 3rd edition of the "Instrumenting our ocean for better observation: a training course on a suite of biogeochemical sensors", which took place on June 5-17, 2023, and was hosted by Kristineberg Center for Marine Research and Innovation in Kristineberg, Sweden.

This intensive workshop provided trainees with lectures and hands-on experience 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. While teaching established best practices for selected biogeochemical sensors and autonomous measurement systems, Course instructors provided ample guidelines and practical tips regarding specific reporting requirements (e.g. meta-data, calibration, validation, error estimates, formats, etc.). This training course is ideally suited for the next generation of users of large scale biogeochemical ocean observation networks centred around profiling floats, moorings and gliders as well as research and commercial vessels.

The course was attended by 28 very motivated early-career scientists selected from one hundred applications, representing a variety of backgrounds in our community. For two weeks 25 dedicated instructors delivered a reach program which consisted of lectures, practicals and group assignments designed around the following specific objectives:

- Teach best practices for biogeochemical sensors with the aim of improving the data currently generated encompassing all steps from pre-deployment calibration to data synthesis and dissemination.
- Work on data reduction and data quality control practices for sensor data, including specific reporting requirements (e.g. meta-data, calibration, validation, error estimates, formats, etc.).
- Present selected methods (statistical modelling, intelligent data exploration techniques) and tools (remote sensing data, mathematical model outputs) for the development of secondary data products (parameter distribution maps, fluxes and budgets).
- Foster critical thinking regarding the design of an optimum sampling strategy dedicated to solving specific problem.
- Develop the ability to place specific observing activity in the wider context of local, regional and global ocean's role in climate, operational services and ocean health.

During the course, we focused on sensors related to five groups of parameters:

- Oxygen - with optode and electrochemical sensors,
- Particulate Organic Carbon - with e.g. fluorometer, backscatter and radiometers,
- pH - with a range of sensors available: a) colorimetric reagent method, b) field effect transistor type sensor, and also c) benchtop surface application,
- pCO_2 - with a range of sensors available: a) membrane based sensors with NDIR, b) colorimetric, c) otpodes, and d) underway General Oceanic system
- Nitrate - with spectrophotometric and colorimetric reagent method sensors

Perhaps most importantly, as stated consistently by the participants in their evaluations, the course provided a unique opportunity to form a tight and long-lasting network of biogeochemical sensor users, combining experts with beginners, coming from a wide range of countries on all continents and representing groups and communities in various phases of technical, logistical and financial development. The importance of networking enabled by this workshop will be revealed in short, medium and long term strengthening our community as a whole and every individual involved.

We are indebted to all the amazing course instructors and participants for making this such a successful event. We want to especially acknowledge members of the Organizing Committee who dedicated their time and energy over the past many months of preparations: Daria Atamanchuk (Dalhousie University, Canada), Craig Neill (CSIRO, Australia), Anders Tengberg (Xylem, Norway) and Tobias Steinhoff (NORCE, Norway).

Enhancing Integration of Biogeochemical Observations and Modelling

One of the current goals in IOCCP's mission is to help our community close the gap between those responsible for designing and implementing observations and resulting data streams and those involved in the use of data to enable modelling and forecasting of the observed system.

Ocean circulation models and Earth System Models (ESMs) now incorporate the carbon cycle and other biogeochemical processes, allowing for estimation of the ocean's uptake, transport, and storage of carbon dioxide. However, the performance of these models varies, particularly on regional and interannual scales, due to inconsistencies in simulating physical processes and inadequate parameterizations. To improve these models, it is crucial to enhance the communication between the two parts of our community in order to address mutually critical issues such as observational coverage and distribution, the necessity of processing of multiple datasets simultaneously, development of standardized and mutually understood uncertainty assessments, and integration of a variety of modelling approaches and observing strategies across spatial and temporal scales, just to name a few.

Integrating observational datasets with models, from local to global scales, will identify model shortcomings and drive improvements in structure, parameterizations, and algorithms. Data assimilation and remote sensing can further refine model estimation by quantifying biogeochemical fluxes consistently with re-analyses, nowcasts, and forecasts. Guided expansion of biogeochemical observing systems will greatly enhance the performance of biogeochemical models, enabling the development of applications and prediction systems with numerous scientific and societal benefits.

To tackle these challenges, in the past 12 months the IOCCP initiated and developed an effective dialog with a joint IOC-WMO Team on Expert Team on Operational Ocean Forecasting Systems (ETOOFS) and the OceanPredict community focused on advancing the science of ocean prediction. IOCCP SSG members, Veronique Garcon and Fei Chai lead this activity in collaboration with their counterparts representing the named partners.

During the initial online scoping meetings, it was quickly established that a workshop focused on developing synergies between Ocean Observations and Biogeochemical Models is badly needed. Serving as a platform to bring together the ocean observing and modelling community, fostering collaboration and knowledge exchange. The main objective of this workshop needs to be to bridge the gap that exists between these two communities, recognizing that their synergy is crucial for achieving a comprehensive understanding of the ocean. An initial structure for a workshop to be held in Xiamen, China in March 2024, was developed. Xiamen University, IOCCP and ETOOFs were identified as "seed funders" and further support is being sought via several avenues.

During the workshop, participants are expected to explore topics of mutual interest such as data assimilation, model validation, emerging constraints, and deep learning techniques. These discussions aim to identify effective strategies for incorporating observational data into models, enhancing their accuracy and reliability. The workshop agenda will also encourage participants to consider novel approaches to data collection and model development. Leveraging emerging technologies, such as autonomous platforms and remote sensing techniques, can significantly enhance our ability to observe and model the ocean. For example, the deployment of BGC-Argo floats equipped with biogeochemical sensors enables high-resolution observations of biogeochemical parameters, providing valuable data for model validation and improvement. Integrating these advanced observational techniques with sophisticated modelling frameworks can lead to breakthroughs in our understanding of the ocean's biogeochemical dynamics.

In summary we hope to further IOCCP's mission by exploiting our newly developed partnership with ETOOFS, OceanPredict and relevant PI's at Xiamen University by taking a first step towards bridging the gap between the ocean observing and modelling communities. By recognizing the discrepancies between model simulations and field observations, the planned workshop aims to drive increased data collection efforts and model refinement, hopefully resulting in enhanced scientific understanding and more accurate predictions of the ocean's behaviour.

PUBLICATIONS

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Esteban Acevedo-Trejos, Mathilde Cadier, Subhendu Chakraborty, Bingzhang Chen, Shun Yan Cheung, Maria Grigoratou, Christian Guill, Christiane Hassenrück, Onur Kerimoglu, Toni Klauschies, Christian Lindemann, Artur Palacz, Alexey Ryabov, Marco Scotti, S. Lan Smith, Selina Våge and Friederike Prowe.: **Modelling approaches for capturing plankton diversity (MODIV), their societal applications and data needs**, Frontiers in Marine Science, https://doi.org/10.3389/fmars.2022.975414

Siv K. Lauvset, Nico Lange, Toste Tanhua, Henry C. Bittig, Are Olsen, Alex Kozyr, Simone Alin, Marta Álvarez, Kumiko Azetsu-Scott, Leticia Barbero, Susan Becker, Peter J. Brown, Brendan R. Carter, Leticia Cotrim da Cunha, Richard A. Feely, Mario Hoppema, Matthew P. Humphreys, Masao Ishii, Emil Jeansson, Li-Qing Jiang, Steve D. Jones, Claire Lo Monaco, Akihiko Murata, Jens Daniel Müller, Fiz F. Pérez, Benjamin Pfeil, Carsten Schirnick, Reiner Steinfeldt, Toru Suzuki, Bronte Tilbrook, Adam Ulfsbo, Anton Velo, Ryan J. Woosley, and Robert M. Key.: **GLODAPv2.2022: the latest version of the global interior ocean biogeochemical data product**, Earth Syst. Sci. Data, 14, 5543–5572, https://doi.org/10.5194/essd-14-5543-2022