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## Integrated Ocean Carbon Research workshop

*8 December 2022 18:00-21:00 CET*



Recording of the meeting can be accessed [online](#).



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## 1. Background

Established in 2018, the IOC Expert Working Group the [Integrated Ocean Carbon Research \(IOC-R\)](#) 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 IOC, IOCCP, SOLAS, IMBeR, GCP, CLICAR, WCRP and relevant international efforts on carbon research.

The objectives of this first meeting after the publication of the vision document were:

- I. To gather the ocean carbon community, to appraise everyone of new and existing ocean carbon projects, programmes and initiatives within and outside of the Ocean Decade framework,
- II. To provide a platform to discuss knowledge gaps and emerging ocean carbon questions,
- III. To start a review of the IOC-R vision document,
- IV. To scope and plan an in-person workshop to, for example, help to develop an updated version of the 2021 [IOC-R review and vision document](#), and
- V. To establish an [Ocean Decade Community of Practice](#) focussing on ocean carbon.

The vision document identified **4 Themes** with several underlying research questions:

<b>1) Will the ocean uptake of anthropogenic CO<sub>2</sub> continue primarily as an abiotic process?</b>	
1	Will the oceans continue to act as a sink proportional to the carbon that is being emitted into the atmosphere as a result of human activities?
2	How will global ocean carbon uptake change in the future with decreasing C anthropogenic emissions?
3	Will deep water production and the meridional overturning circulation change in an evolving climate, and what will the consequences be for ocean carbon uptake?
4	What is the historical and future impact of a changing Southern Ocean on the global carbon cycle/budget?
5	What are the trends of ocean acidification within polar regions (Arctic/Antarctic)?
6	What are the causes and magnitude of temporal variability of the Southern Ocean carbon sink?
7	What is the role of western boundary systems as poleward conveyors of carbon, including the role of mesoscale variability (eddies)?
8	How can we maintain and enhance sustained high-quality ocean carbon observations critical for quantifying the strength and variability of the ocean carbon sink?
9	How can we support best practices in measurements and data sharing to quantify uncertainty?
<b>2) What is the (changing) role of biology in the ocean carbon cycle?</b>	
1	What are the important natural and human anthropogenic factors that impact the biological carbon cycle and ocean health?

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2	Are the twilight zone food webs changing, and what effect will this have on the evolution of the ocean carbon cycle?
3	Is the changing partitioning between PIC and POC affecting the inorganic carbon cycle, its transport, and fluxes?
4	Is the dissolved organic carbon pool changing, and what are its impacts on climate and environmental change?
5	How can the regional budgeting of carbon sources and sinks be improved over the range of ecosystems?
6	What is the impact of ocean acidification on high latitude biota, and how will the impact affect other global biogeochemical cycles and higher trophic levels?
7	What are the impacts of acidification on marine ecosystems in Eastern Boundary Upwelling Systems?
8	How can we enhance linkages between biogeochemistry and ecology as they pertain to the ocean carbon cycle?
9	How can we build reliable and comprehensive ocean carbon biogeochemistry and biological forecasting systems through enhanced synthesis products, modeling and model-data fusion activities?
<b>3) What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?</b>	
1	How is carbon burial storage in key reservoirs of the land-ocean continuum changing?
2	What is the impact of (changing) sea ice on the ocean carbon cycle?
3	What is the role of tropical ocean margins in the carbon budget, and is this changing?
4	How will carbon cycling on the shelves and lateral carbon export to open ocean areas change?
5	How can we integrate the land-ocean continuum more fully into global carbon cycle assessments and earth system models?
6	How will the Arctic ocean carbon cycle respond to increasing freshwater input and ocean area due to a reduction in sea ice extent?
7	How will rising sea level change coastal ocean dynamics and carbon cycling?
<b>4) How are humans altering the ocean carbon cycle and what are the resulting feedbacks?</b>	
1	Can we safely enhance sequestration and storage of carbon by the ocean?
2	What is the vulnerability of the ocean to increasing CO <sub>2</sub> levels and what is our ability and need to mitigate increasing CO <sub>2</sub> levels?
3	How can multiple stressors (e.g. warming, deoxygenation, acidification) on the ocean carbon system be incorporated in assessing observations and model results?
4	What is the impact of deoxygenation on ocean carbon cycling?
5	How does effluent, such as sewage and runoff, from large coastal cities influence lateral organic and inorganic carbon input and the resulting coastal air-sea carbon fluxes?

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6	What are the combined socio-economic impacts of changes in ocean carbon chemistry, and climate change driven by ocean warming and sea level rise?
7	How should marine management strategies in estuaries and shelf seas be improved to support fisheries, aquaculture, tourism, carbon storage and other marine activities?
8	How can we close important gaps in our knowledge through laboratory and field based process studies, including properly scaled geoengineering studies, to elucidate mechanisms and contribute to model parameterization?
9	How will mesopelagic fishing, seabed mining, and the discharge of mine tailings from land to the ocean affect the biological carbon cycle?
10	How can we assess, prioritize and implement adaptation, mitigation and remediation activities based on a knowledge of the past and current state of the affected marine environment?

Each expert was asked to provide **one slide introducing their work on ocean carbon research**. These slides can be accessed using the following [link](#).

**Representatives of these groups, programmes, institutions, projects were invited (list might be incomplete at the date of the meeting):**

- Authors of the IOC-R vision document and recommended experts
- Relevant Ocean Decade programmes: Biomolecular Observing Network, Global Ocean Oxygen Decade, One Ocean Network for Deep Observation, An Observing Air Sea interactions strategy, Sustainability, predictability and resilience of marine ecosystems, Deep Ocean Observing Strategy, Digital Twins of the Ocean, CoastPredict, Global Ecosystem for Ocean Solutions, Joint Exploration of the Twilight Zone, Ocean Acidification Research for Sustainability, Global Ocean Negative Carbon Emissions, Global Ocean Decade Programme for Blue Carbon.
- IMBeR, SOLAS, IOCCP, CLIVAR/WCRP, GCP and IOC representatives
- SCOR Infrastructure project COBS
- Ocean nets
- Ocean Solutions
- Blue Carbon Initiative
- Jamstec
- ICOS
- G7 Future Seas and Ocean

## **2. Introduction**

After a short welcome by Carol Robinson and Christopher Sabine, co-chairs of the IOC working group IOC-R, the participants were invited to present themselves.

Following the introductions Christopher Sabine provided an overview about IOC-R, in which he introduced the origin and supporting organizations, IOC, IOCCP, CLIVAR, the Global Carbon Project, SOLAS and IMBEE. He also presented the four fundamental questions, extracted from the IOC-R vision document with some suggestions for the current level of understanding for each (Figure 1).

### IOC-R frames ocean carbon research around 4 foundational questions

- ☒ Will the ocean uptake of anthropogenic carbon dioxide (CO<sub>2</sub>) continue as primarily an abiotic process?
- ☒ What is the role of biology in the ocean carbon cycle, and how is it changing?
- ☒ What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?
- ☒ How are humans altering the ocean carbon cycle and resulting feedbacks, including possible purposeful carbon dioxide removal (CDR) from the atmosphere?



Figure 1. Current understanding of IOC-R questions. Source: Chris Sabine.

At the end of the presentation he introduced the main objectives of the meeting and future activities.

Although many attending this meeting contributed to the Report, it is important to

- readdress how best to move forward from here.
- Update who is doing what with respect to these four questions.
- Explore where there are still gaps that need to be addressed.
- Discuss how the ocean carbon community can work together to move this research forward.
- Decide what role IOC-R can play in developing an integrated research approach

### **3. Four themes: presentations and discussion**

In order to facilitate further discussion each theme/question was introduced by one expert. The presentations can be found [here](#).

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Theme 1: Will the ocean uptake of anthropogenic CO<sub>2</sub> continue primarily as an abiotic process? - Nicholas Gruber

Theme 2: What is the (changing) role of biology in the ocean carbon cycle? - Stephanie Henson

Theme 3: What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time? - Pierre Regnier

Theme 4: How are humans altering the ocean carbon cycle and what are the resulting feedbacks? -David Keller

After these overview presentations four breakout groups were formed. During the breakout groups jamboards were used to reflect the discussions on a) knowledge gaps and emerging questions, as well as b) programmes and expertise to bring on board, guided by the chairs of the different groups (Theme 1: Chris Sabine, Theme 2: Adrian Martin, Theme 3: Leticia Cotrim Da Cunha, Theme 4: Carol Robinson).

The rapporteurs reported back to the whole group (Theme 1: Doug Wallace, Theme 2: Marja Koski, Theme 3: Ute Schuster, Theme 4: Sonya Legg).

### **Some key knowledge gaps highlighted by the different themes were:**

#### **Theme 1: Will the ocean uptake of anthropogenic CO<sub>2</sub> continue primarily as an abiotic process?**

1. Alkalinity measurement – The measurement uncertainty has major implications for abiotic carbon uptake estimates from observations and use of BGC-Argo float data. There is also an issue as to how important errors in modelled alkalinity are for carbon uptake estimates; do errors/ bias cancel?
2. Cool skin effect remains a serious knowledge gap for the interpretation of *p*CO<sub>2</sub> observational data
3. Lateral and vertical/ diapycnal transports of anthropogenic carbon, especially in a situation where atmospheric growth rate of CO<sub>2</sub> changes. How do we assess these transports and how they are changing?
4. Observing system - Our current GO-SHIP program was designed for a steady-state ocean, more or less. Maybe it is time to re-evaluate the current system and increase the frequency of measurements, to be able to compare for example with the BGC Argo measurements. An alternative, complementary system would be a suite of reference sites with advanced instrumentation? Do we need to get advanced, multiplatform ocean observing systems implemented now rather than waiting for even more advanced ones for the future? Would a process study focussed on observing system design provide a test-bed for data assimilation approaches?
5. Changes in the “natural” component of the air-sea CO<sub>2</sub> flux - How do we relate changes in remineralized nutrients or changes in ocean oxygen to changes of the CO<sub>2</sub> flux with the atmosphere. Here we are comparing inventory changes and fluxes that are connected over a range of timescales and large distances.

6. Does the growing interest and financing of ocean-based CDR open a door to financing required advances in observation and modeling? Should/ could there be a “research levy” for use of the global ocean carbon sink for deliberate carbon sequestration? Could this support an international research effort?

### Theme 2: What is the (changing) role of biology in the ocean carbon cycle?

The discussion focused on two topics: 1) The need to connect scientific thinking and policy, and 2) to identify the knowledge gaps apart from those mentioned in the IOCR report from 2021. For the policy side, it was pointed out that it is often difficult for policymakers to distinguish information which is based on solid scientific research, and information which is not. Policymakers would appreciate to know what can be said about the ocean carbon cycle based on good science, and what cannot be said.

Concrete knowledge gaps identified were:

1. How much carbon is stored in different biological entities / groups, and how do these interact?
2. Lacking baseline for the natural variation for most biological components and processes; for instance, abundances, biomasses, behavior (e.g., vertical migrations), metabolic rates of calcifying organisms and metazoans, species interactions
3. Ocean acidification, calcification vs. dissolution of biogenic  $\text{CaCO}_3$
4. Effect of extreme events such as heat waves vs. slow climate-induced changes (with regard to e.g., species adaptation), linear changes vs. tipping dynamics
5. Linkages to CDR approaches and how can different observation technologies contribute to measurements

### Theme 3: What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?

Changes on land and ice are impacting the carbon cycle in the ocean. However in order to describe these impacts and to identify key research questions, it will be indispensable to clearly define some of the key phrases, e.g.

1. Changing cryosphere - glaciers, ice sheets, sea ice and permafrost are undergoing major and accelerating changes, causing maybe shifts in freshwater input, however the impact on carbon and nutrient fluxes is still attributed with high uncertainty.
2. LOAC (land to ocean loops) - how well is the regional cycling of TA in the LOAC carbon loop and the coupling of the C and TA cycles constrained; how to integrate the human factor? How well known are changes of DOC and POC? How to better integrate LOAC in global ESMs and assessments?
3. What is the role of organic TA?
4. How do eutrophication and the interaction between human uses (fishing aquaculture, energy generation, conservation/protection and rewilding influence the distribution of ocean carbon?



5. What are the processes that connect carbon sources and sinks within the coastal zone and how is the carbon transformed as it is transported between different parts of the coastal zone?
6. What is the influence of sea level rise?

### **Theme 4: How are humans altering the ocean carbon cycle and what are the resulting feedbacks?**

1. This theme must address new developments related to Carbon Dioxide Removal (CDR), the impacts, the benefits and risks, as well as governance, monitoring, reporting and verification, e.g. via establishing verification protocols, evaluation of methods and costs.
2. Impact of multiple ocean stressors caused by anthropogenic interventions on the marine carbon cycle, including climate change, deoxygenation, eutrophication.
3. How do abrupt shifts affect the carbon cycle? Are they reversible with negative emission scenarios and what are the tipping points?
4. Can perturbation studies and model thought experiments help to identify the source and impact of change?

### **Programmes and expertise to bring on board:**

Across the different themes missing expertise was identified which is needed to update and expand the IOC-R vision document.

- Emerging technologies
- Governance expertise
- Communication experts
- NGOs and other stakeholders working in and using the coastal and open ocean
- CDR implementing companies
- Social scientists
- Ocean/Blue economy experts
- Fisheries experts

### **4. Affiliation with the Ocean Decade**

Kirsten Isensee presented the possibility to have the IOC-R efforts recognized within the [UN Decade of Ocean Science for Sustainable Development](#), allowing for broader engagement with the wider ocean community. IOC-R will remain an IOC working group supported by IOCCP, CLIVAR, IMBeR, SOLAS and the Global Carbon Project. In addition it is possible to establish a 'Subject matter network' which will allow, similar to the Ocean Decade Communities of Practice, ocean carbon activities to find each other and to collaborate, co-design and create

synergies to meet common goals in the implementation of their actions. This network would be open to Ocean Decade and non-Ocean Decade activities. It is expected that the workload related to this network will be minimal and taken on by the IOC Secretariat

**Action item:**

Kirsten Isensee to engage with the Decade Coordination Unit to identify the next steps necessary to establish a 'Subject matter network' (January 2023).

### **5. IOC-R and G7 FSOI**

Maria Hood introduced the G7 Future of the Seas and Oceans Initiative. She presented the currently under review plan of a broadened mandate for the FSOI to include research priorities of the G7 Ocean Decade Navigation Plan, which would build on advances in knowledge and the innovations of the Decade to focus and drive infrastructure evolution and capacity to respond to multilateral agreements. For carbon, the G7 FSOI will:

- Create a 'Resource Strategy Group' for the data synthesis activities SOCAT and GLODAP (regular review by G7 delegations to identify needs.)
- Continue working with the community (obs + research) to develop a strategy for surface ocean CO<sub>2</sub> monitoring, which will then become an 'RSG'.
- Create a regular 'Ocean Carbon dialogue topic' for the Informal Consultative Process to review status and gaps on ocean carbon knowledge and observing, including Marine CDR issues.
- Submit regular information briefs on ocean carbon issues to the G7 Science and Environment ministerial tracks.

Future joint activities of IOC-R and the G7 FSOI initiative would directly inform the 'Ocean Carbon dialogue'. They could help to strengthen financial support for fundamental infrastructure: sustained observing networks (G7 finances approx 75% of the system), data sharing infrastructure and synthesis programmes, and ocean prediction programmes. It is also expected that this collaboration would support linkages between the IOC-R scientists and G7 national focal points and G7 Ministerial tracks, to communicate fundamental and emerging research questions, capacities, and gaps for priority investment.

**Action item:**

Kirsten Isensee and IOC-R co-chairs to engage with Maria Hood to collaborate on the upcoming in person workshop in the first quarter of 2023.

### 6. Next steps

Based on discussions before, during and after the meeting, it is envisaged that an in-person meeting of IOC-R affiliated experts will be organized in the first quarter of 2023.

The objective of this workshop is to continue the discussions started during the workshop 8 December 2022, to start the drafting process of an updated IOC-R vision document, taking into account remaining and upcoming ocean carbon research questions.

A survey to further define the remaining research questions as well as new ones will help to determine the experts to be involved in this exercise, i.e. in the meeting and drafting the report.

#### **Action item:**

Experts are asked to provide comments on this Draft report by **12 January 2022**.

Experts are invited to fill in [this online survey](#) to identify additional experts to be included in the IOC-R effort and reevaluate previously identified research questions by **20 January 2023**.

IOC secretariat and IOC-R co-chairs analyze survey results and communicate the results to IOC-R experts by **3 February 2023**.

IOC-R experts are asked to provide additional comments on how to advance with ocean carbon research to IOC-Secretariat and IOC-R co-chairs by **15 February 2022**.

IOC secretariat, IOC-R co-chairs, representatives of supporting organizations and G7 FSOI plan the IOC-R workshop based on this workshop report and survey results.

### **7. Participant list**

<b>Name</b>	<b>First name</b>	<b>Affiliation</b>	<b>Country</b>
Arrieta	Jesus M.	Instituto Español de Oceanografía	Spain
Atamanchuk	Dariia	Dalhousie Univeristy	Canada
Bednarsek	Nina	National Institute of Biology, IMBeR	Slovenia
Bracco	Annalisa	Georgia Institute of Technology	USA
Cotrim da Cunha	Leticia	Universidade do Estado do Rio de Janeiro	Brazil
Currie	Kim	National Institute of Water and Atmospheric Research, IOCCP	New Zealand
Fay	Amanda	Columbia University	USA
Feely	Richard	National Oceanic and Atmospheric Administration	USA
Fröb	Friederike	University of Bergen	Norway
Grigoratou	Maria	Mercator Ocean International	France
Gruber	Nicolas P.	Eidgenössische Technische Hochschule Zürich	Switzerland
Hauck	Judith	Alfred Wegener Institute, Global Carbon Project	Germany
Henson	Stephanie A.	National Oceanography Centre	UK
Hood	Maria	G7 Future of the Seas and Oceans Initiative Coordination Centre	France
Isensee	Kirsten	IOC-UNESCO	
Jiao	Nianzhi	Xiamen University	China
Keller	David	GEOMAR	Germany
Koski	Marja	Technical University of Denmark	Denmark
Lauvset	Siv K.	University of Bergen	Norway
Legg	Sonya A.	Princeton University, CLIVAR	USA
Martin	Adrian	National Oceanography Centre	UK
Mastroni	Sarah	Ocean Visions	USA
Morris	Paul J.	IOC-UNESCO	
Newton	Jan A.	University of Washington	USA
Olsen	Are	University of Bergen	Norway
Palacz	Artur	IOCCP	
Park	Keyhong	Korea Polar Research Institute	Republic of Korea
Pei	Mengqi	Xiamen University	China
Pidgeon	Emily	Conservation International	USA
Pinardi	Nadia	University of Bologna	Italy
van Putten	Ingrid	Commonwealth Scientific and Industrial Research Organisation	Australia
Regnier	Pierre	Université Libre de Bruxelles	France



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<b>Name</b>	<b>First name</b>	<b>Affiliation</b>	<b>Country</b>
Robinson	Carol	University of East Anglia, co-chair IOC-R	UK
Sabine	Christopher	University of Hawaii, co-chair-IOC-R	USA
Sanders	Richard	Norwegian Research Centre	Norway
Scheel Monteiro	Pedro	Council for Scientific and Industrial Research	South Africa
Schoo	Katherina L.	IOC-UNESCO	
Schuster	Ute	University of Exeter	UK
Shutler	Jamie	University of Exeter	UK
Siedlecki	Samantha	University of Connecticut	USA
Suntharalingam	Parvadha	University of East Anglia, SOLAS	UK
Telszewski	Maciej	IOCCP	
Thomalla	Sandy	Council for Scientific and Industrial Research	South Africa
Visser	Andre	Technical University of Denmark	
Wadham	Jemma L.	University of Bristol	UK
Wallace	Douglas	Dalhousie University	Canada
Wanninkhof	Rik	National Oceanic and Atmospheric Administration	USA
Watson	Andrew	University of Exeter	UK
Widdicombe	Stephen	Plymouth Marine Laboratory	UK

### 8. Agenda

	Opening	Chair: Christopher Sabine
18.00-18.10	Welcome and introduction to the workshop	Christopher Sabine and Carol Robinson (IOC-R co-chairs)
18.10-18.25	IOC-R overview presentation and discussion	Christopher Sabine (IOC-R co-chair)
	<b>IOC-R themes presentation</b> (each theme 10 min presentation and 5 min discussion)	<b>Chair: Carol Robinson (IOC-R co-chair)</b>
18.25-18.40	Theme 1: Will the ocean uptake of anthropogenic CO <sub>2</sub> continue primarily as an abiotic process?	Nicholas Gruber
18.40-18.55	Theme 2: What is the (changing) role of biology in the ocean carbon cycle?	Stephanie Henson
18.55-19.10	Theme 3: What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?	Pierre Regnier
19.10-19.25	Theme 4: How are humans altering the ocean carbon cycle and what are the resulting feedbacks?	David Keller
19.25-19.40	<i>Health break</i>	
	<b>IOC-R themes breakout groups (35 min + 20 min)</b>	
19.40-20.15	Theme 1: Will the ocean uptake of anthropogenic CO <sub>2</sub> continue primarily as an abiotic process?  <a href="#">Jamboard 1</a>	Chair: Christopher Sabine  Rapporteur: Doug Wallace
19.40-20.15	Theme 2: What is the (changing) role of biology in the ocean carbon cycle?	Chair: Adrian Martin



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	<a href="#">Jamboard 2</a>	Rapporteur: Marja Koski
19.40-20.15	Theme 3: What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?  <a href="#">Jamboard 3</a>	Chair: Leticia Cotrim Da Cunha Rapporteur: Ute Schuster
19.40-20.15	Theme 4: How are humans altering the ocean carbon cycle and what are the resulting feedbacks?  <a href="#">Jamboard 4</a>	Chair: Carol Robinson Rapporteur: Sonya Legg
20.15-20.35	Breakouts reporting back to plenary	Chair : Chris Sabine Rapporteurs
	<b>Summary and way forward</b>	Chair : Kirsten Isensee
20.35-20.40	Introduction to Ocean Decade Communities of Practice	Kirsten Isensee
20.40-20.45	Priorities and reflections by representative G7 FSOI	Maria Hood
20.45-21.00	Recap and next steps	
21.00	End	