



Deliverable D2.1

Work Package 2 Implementation plan and datasets

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About this document

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1. Abstract

Work Package 2 of Ocean ICU is aimed at a constructive synthesis of critical aspects of our present understanding of the ocean carbon cycle that are currently uncertain. These aspects comprise (1) the magnitude of the ocean sink for atmospheric and anthropogenic CO₂, (2) the role of the biological vs physical controls of the ocean carbon sink in key regions, and (3) what is presently known about the influence of fishing, trawling and industrial processes such as seabed mining. The activity of this work package is important in providing a solid foundation of present knowledge which can be communicated to our stakeholders, and which can provide a baseline from which progress in other work packages in the project can be measured. This document outlines our proposed implementation plan for the work package.

2. Introduction

2.1. General description

The Ocean plays a crucial role in the global C cycle, taking up approximately 25% of the CO₂ we emit to the atmosphere, and thus slowing the rate of climate change. Ocean ICU is a project that aims to advance our knowledge of this sink and the mechanisms driving it, including how direct human pressures (such as fishing, energy and mineral extraction) influence it now and in the future decades, and to present this knowledge in a way that can guide us in efforts to mitigate climate change and stabilise atmospheric CO₂. Ocean ICU aims to measure key processes and evaluate their overall significance.

Current understanding is however hampered by a mismatch between model and observation-based estimates of the overall ocean sink for atmospheric carbon. This represents a major difficulty for bodies such as the Global Carbon Project (GCP) and the Intergovernmental Panel on Climate Change (IPCC) who are charged with regular reporting of the current state of the global carbon cycle, and projections of future climate. Furthermore, there has been no systematic previous attempt to incorporate into these estimates, the impact, current or future, of human activities that perturb the ocean carbon cycle, such as fishing and deep sea mining.

The objectives of this work package address these discrepancies with our objectives, as follows:

1. Perform a whole ocean Carbon budget evaluation attempting to resolve current major discrepancy between modelled and observed estimates of



ocean and anthropogenic C uptake and storage and to provide diagnostics in support of the GCP and IPCC.

2. Establish the size of and controls of the different biological pumps to test the classical assumption that they are unchanged by climate change.
3. Establish the role of fishing and industrial extraction processes on the Ocean C cycle.

From these activities, we will fulfil our 4th objective:

Deliver an estimate of the current state of the Ocean C cycle to WP7 of the project, as the basis for DST1

2.2. Deliverables and milestones

Deliverable	Name	Type	Due Date
2.1	Implementation plan and dataset	Public report	Month 16
2.2	Report on data delivered to WP7 for DST construction	Public report	Month 34
2.3	Report regarding Main results around reconciliation of C uptake mechanisms and scales including glacial-interglacial and alkalinity focused work	Public report	Month 44
2.4	Report on main results of WP including submitted manuscripts	Public report	Month 54
Milestones	Name	Means of verification	Due Date
	Data transfer #1 from WP2 to WP7	Report	Month 21
	Data transfer #2 from WP2 to WP7	Report	Month 34

3. WP2 implementation

Task 2.1: The current ocean C cycle



Current understanding and new estimates of the ocean sink for anthropogenic CO₂: (lead: Exeter):

We have identified the following distinct methodologies that quantify the ocean C sink. We will write a report and publication that review the outputs from these methods, arriving at a best estimate and uncertainty on the global and regional fluxes.

- 1) Air-sea gas exchange calculated globally from surface ocean CO₂ data in the Surface Ocean CO₂ Atlas (SOCAT). Typically regression or machine learning methods are used to interpolate this sparse data using a variety of auxiliary data sets (temperatures, salinities, mixed layer depths) from satellite or in-situ measurements. Several such “pCO₂ data products” are available, produced annually for the Global Carbon Budget.
- 2) Rate of increase in the inventory of inorganic carbon in the ocean: We will improve estimates of this, by the following actions:
 - a. A full depth crossover analysis of internal ocean measurements in the GLODAP database, and determining the rate of change by evaluating the crossover offsets as a function of time separation between the various cruises. The crossover analysis will be conducted in 23 ocean regions and summed up also to give a global estimate.
 - b. A full-depth machine learning analysis applied to the GLODAP database.

These estimates are entirely independent of the air-sea exchange technique.

- 3) Atmospheric O₂/N₂ and CO₂ observations: since uptake of CO₂ by the ocean does not release oxygen, but uptake by net photosynthesis does, O₂ observations in the atmosphere can be used to separately estimate the amount of total fossil fuel CO₂ being absorbed by these two processes. We are conducting a review and re-evaluation of the available observations and what they say about the ocean carbon sink.
- 4) Ocean Biogeochemical models (OGBMs) These have been widely used, for example in the Global Carbon Project. The models are frequently the ocean component of Earth System models used to inform the Intergovernmental Panel on climate change (IPCC) projections of future climate.

The individual steps to be undertaken in this task are:

- a) New quantification of the ocean carbon sink using atmospheric O₂/N₂ data (months 6 – 18), including comparison with earlier results (Exeter)
- b) New quantification of the ocean carbon sink using internal ocean observations of biogeochemistry and carbon data (months 12-30) (Exeter, NORCE)



- c) Develop new estimates of the changes in DIC by consistent analysis of the GLODAP data product using a full depth crossover approach (Months 25-45, UIB). This will lead to accurate estimates of the change in regional and global ocean DIC inventories since the 1990s
- d) Review of estimates from ocean biogeochemical models, including development of metrics for model evaluation (Months 12 -35, AWI).
- e) Extension of these analyses to projections of CMIP6 models. Download model outputs from ESGF; benchmark models performance in simulating spatial pattern of contemporary ocean carbon source and sink; perform AOU (apparent oxygen utilization) and water-mass age analysis to separate physically- and biologically- mediated anthropogenic carbon sequestration in the ocean interior and compare against observation; assess long-term changes in their projections and determine key drivers. (NORCE)
- f) Analysis of abrupt changes and potential tipping dynamics in modelled primary production and its driving mechanisms in the North Atlantic in zero-and negative emission scenarios (UiB)
- g) Analysis of uncertainties in the air-sea gas exchange methods (EXE, months 18-48)
- h) Review publication and report (months 36 – 54)

Task 2.2: Biological vs Physical control of the Ocean C sink in key regions

Understanding the role of biology in controlling the oceanic sink of carbon as determined from satellite, in situ and re-analyses (Exeter):

Previous work has identified how i) regional satellite observations of biology can be used to improve observation-based estimates of the ocean sink of carbon, and ii) how regions of the global ocean sink can be partially or significantly modulated by biological activity. To date this work has focussed on isolated regional assessments or over short time scales. We will analyse the satellite data era (e.g., 1982 to present) to assess these aspects to understand the role that biology plays globally and regionally in altering the sink. This will include a complete uncertainty analysis and a focus on exploiting climate data records. This work will have these individual steps:

- a) Develop a new framework and approach for including and propagating uncertainties through observation-based carbon sink methodologies.
- b) Publish the new uncertainties methodology along with the underlying source code (to allow others to use it within OceanICU and beyond).
- c) Develop an experimental framework for assessing the impact and importance of including a selection of different surface ocean biology



observation datasets into exemplar observation-based carbon sink methodologies.

- d) Use the framework to evaluate the role of physical versus biological drivers and modulators of the oceanic sink based on satellite observations (e.g. for 1982 to present, globally and regionally).
- e) Evaluate the impact of uncertainties on the identified role of biology (and physics) by propagating the uncertainties through all calculations.
- f) Review the results and publish.

Review on the links between AMOC variability and the carbon cycle (NORCE, months 6-48). This work will have a focus on the North Atlantic, and lead to a review paper. We will include an analysis of AMOC variability at the RAPID array and biological carbon uptake in the North Atlantic.

Assess the ocean carbon pumps in the context of glacial-interglacial change (UiB). This task will take the form of an extensive literature review focused on how the role of biology has changed with time. This will result in enhanced ability to provide a baseline for modeling studies of how changes in the ocean carbon sequestration mechanisms have altered atmospheric CO₂.

Reassessing the carbonate pump and its biological controls (Heriot-Watt, LSCE, Exeter). Currently, the carbonate pump is most often considered only in a geochemical sense, in terms of alkalinity, rather than as a biological pump of diverse organisms with unique ecologies that potentially influence their role in carbonate production, export and dissolution. This work will synthesise global and regional data on oceanic carbonate (e.g., pelagic standing stocks, production rates, export fluxes) from different calcifying organisms (plankton to fish) in order to understand how diversity and ecology impacts on the magnitude and dynamics of the carbonate pump. This will be part of deliverable 2.2 in month 44, with the global assessment as part of a publication in month 32 and targeted regional assessments (e.g., North Atlantic, Eastern Boundary Current) in month 44. A modelling component will incorporate different pelagic calcifiers (coccolithophores, foraminifera, pteropods) into carbonate production and export fluxes in order to explore how differences in ecology and mineralogy influence the fate of carbonate produced and exported from the upper ocean. The modelling will improve on previous parameterizations of carbonate production using new and existing global datasets for the different organisms involved, as well as explore the magnitude of dissolution required to replicate alkalinity observations and the degree to which abiotic and/or biologically-enhanced dissolution control the fate of carbonate. This will be a publication and part of deliverable 2.2 in month 44.



Task 2.3: Fishing and Industrial process control over the Ocean C sink

This task is closely linked to WP5. One focus of WP5 is to examine the implications of fishing on the biological carbon pump both on the continental shelf and off-shelf in the open ocean. For this several model systems will be utilized. Another focus of WP5 is to close scientific knowledge gaps of impacts from deep-sea mining, which is a priority in marine policy, particularly since the International Seabed Authority is currently drafting the regulation for the exploitation of mineral resources in the ocean. For this a modelling approach will be used to quantify impacts from mining of polymetallic nodules, suspended sediment plumes, and return waste-water streams from production platforms on benthic carbon fluxes and processes. As a precursor to the model work in WP5 we will in T2.3 review existing knowledge on the impact of human stressors such as fishing, mining, trawling and dredging on the ocean carbon cycle. Historic time series of magnitude of activities in terms of scale of removal and distribution activities will be established based on data from e.g., FAO and ICES. These data will be part of deliverable 2.2 in month 34.

Task 2.4: Data flow to DST.

This task will transfer process information and time series data from tasks 2.1 to 2.3 to the DST in WP7. (Lead NORCE, All WP Partners) (M06-M34). The data to be used and produced in WP2 will all be publicly available, and is listed in the Data Management Plan. Task 2.4 will establish and maintain communication with WP7 to ensure that regular progress reports are well communicated. At the end of the task a joint WP2-WP7 meeting will be organised to make sure that the preliminary results are useful for WP7. Outcomes of this meeting will also feed back to tasks 2.1-2.2 which continue until M54 and 45 respectively.

3.1. Critical risks for implementation

Description of risk	Likelihood	Consequence	Proposed risk mitigation measures
Delays in recruitment	likely	moderate	Good communication between institutions and task leaders. Set up contingency plan(s).



Loss of key personnel	low	severe	Redundancy and good planning. Also overlapping competence to some degree
Delays in data delivery for DST1	l	moderate	Good communication with WP7 about alternative data sources

3.2. Expected results

#Identifier	Result	Partner responsible	Expected time
1	Review publication on the current understanding and new estimates of the ocean sink for anthropogenic CO ₂	UNEXE	M54
2	New framework and approach for including and propagating major uncertainties through observation-based carbon sink methodologies (journal publication and open-source analysis framework on github)	UNEXE	M24
3	Experimental framework for assessing the impact and importance of including a selection of different surface ocean biology observation datasets into exemplar observation-based carbon sink methodologies and guidance on their importance (journal publication and open-source analysis framework on github)	UNEXE	M48
4	Regional and global estimates of the rate of	UiB	M45



#Identifier	Result	Partner responsible	Expected time
	change of dissolved inorganic carbon in the ocean		
5	Analysis of future projections of biologically-mediated ocean carbon sequestration from CMIP6 models	NORCE	M36
6	Review paper on the links between AMOC variability and the carbon cycle	NORCE	M48
7	Report on current knowledge on the impact of fishing and industrial processes	MI	M24
8	modelling scenarios for sediment plume dispersal, including different injection depths for waste-water streams, for industrial-scale mining operations of polymetallic nodules	GEOMAR	M18
9	analysis of sediment plume interaction with water-column carbon processes	GEOMAR	M36
10	Quantification of impacts on benthic carbon fluxes and processes based on results of footprints from sediment plume scenarios	GEOMAR	M42
11	Metrics for model evaluation and default benchmarking scheme	AWI	M35
12	review paper focused on how the role of biology has	UiB	M36



#Identifier	Result	Partner responsible	Expected time
	changed with glacial/interglacial cycles		
13	Paper analysing of AMOC variability at RAPID array and impact on biological carbon uptake in the North Atlantic	NOC	M48
14	Paper presenting a global assessment of the contribution of different carbonate producers to the carbonate budget and its dynamics	HW	M32
15	Paper presenting regional assessments (e.g., N Atlantic, Coastal Upwelling) of the contribution of different carbonate producers to the carbonate budgets	HW	M44
16	Paper modelling different pelagic calcifiers and exploring how their ecology impacts the carbonate pump on a global scale	HW (LSCE)	M44
17	Assessment of abrupt changes and tipping dynamics in primary productivity	UiB	M30



3.3. Gantt Chart

Task	Months									
	0-6	07-12	13-18	19-24	25-30	30-36	37-42	43-48	49-54	55-60
2.1 Current C cycle										
a	O2/N2 method									
b	Internal observations mthd									
c	New Estimates GLODAP									
d	Review model estimates									
e	analysis using CMIP 6 models									
f	surface-based methods revision									
	Report									
2.2 Bio-vs-physical controls										
a	uncertainty framework									
b	publication									
c	biology assessment framework									
d	assess biological data									
e	impact of uncertainties									
f	publication and report									
	AMOC and C Cycle review									
	C Cycle and glacial/interglacials									
	Re-assess carbonate pump									
2.3 Fishing and Industrial Proceses C sink										
a	develop fishing impact models									
b	report fishing impact									
a	develop plume dispersal scenarios									
b	simulate plume dispersal scenarios									
c	report mining quantitavie impacts									
2.4 Data flow to DST										
	Communicate results to WP7									
	Meeting WP2-WP7									

4. WP2 management

4.1. WP2 management structure and routines

WP leaders:

Siv K. Lauvset (NORCE)

Andy Watson (UNEXE)

Marion Gehlen (LSCE)

T2.1 leader: Elaine McDonagh (NORCE)

T2.2 leader: Andy Watson (UNEXE)

T2.3 leader: David Reid (MI)

T2.4 leader: Siv K. Lauvset (NORCE)



Task leaders will organize task meetings every 2-3 months to follow up on progress and make sure any deviations from the work plan are caught early and mitigated properly.

The WP leaders will organize WP meetings every 6 months, coinciding with the project reporting schedule.

4.2. Key performance indicators (KPIs)

1. Objective is to close the model/data gap in the estimated ocean carbon sink to better than 10%. KPI to measure this is whether at least one paper is submitted on this topic.
2. Objective is to understand the role of the AMOC in ocean carbon storage with the KPI being to have submitted a paper on this topic.
3. Objective is to address role of biology in anthropogenic carbon uptake, with the KPI being at least one submitted paper on this topic.

5. Interactions with other WPs

The alkalinity work in T2.2 links strongly to work in WP3. T2.3 links strongly to WP5. For both tasks the same key personnel are involved which eases the communication and ensures good interactions.