Deliverable D7.2

Report describing the DSTV1

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UK Research and Innovation

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Contents

Key messages for the OceanICU stakeholders

Over its lifetime, OceanICU will produce a series of Decision Support Tools (DSTs) that allow us to explore the effect of different management options on carbon sequestration. This report delivers the first of these DSTs ("DST V1"): a description of pre-existing datasets and tools that can support decision making. The resources presented here summarize the state of play at the start of OceanICU; in most cases, they do not yet incorporate new developments from within the project. Accordingly, most are stand-alone, independently produced datasets and tools, offering insight in specific processes and/or management options only. Many of these will be further developed within OceanICU. Where this is the case, plans for such development are described in this report. Together, the resources presented here exemplify the types of processes, management options, temporal and spatial detail, presentation options and interactivity that could be incorporated in the next version of OceanICU decision support tools. As such, they will provide the foundation for upcoming discussions with stakeholders and for the co-development of future DST releases.

Abstract

WP7 uses the outputs of earlier WPs to produce a library of Decision Support Tools (DSTs), combining observations, process-based models and artificial intelligence to allow stakeholders to investigate the effects of different management options on carbon sequestration. This DST library will evolve from a static description of pre-existing datasets and tools can that support decision making (V1) to interactive tools for idealised multi-stressor simulation and visualisation (V2), to an interactive machine learning-based tool for exploration of management and climate scenarios (V3). Early versions of the DSTs will be presented to stakeholders in WP8 to gather feedback that can guide the development of subsequent versions.

This report delivers DST V1: a description of pre-existing resources for decision makers, developed by, authored by, or contributed to by OceanICU partners. These resources comprise outputs of previous model simulations, as well as software libraries and interactive modelling tools. They include the first version of a process-based model tool for exploring the evolution of key ecosystem metrics under selected perturbations (e.g. climate scenarios), which incorporates two OceanICU developments: the unified model platform created in WP6 (T6.1, MS21) and the data processing and visualisation library (T7.1).

Introduction

Numerous OceanICU partners have previously developed tools and produced datasets that provide information about the ocean carbon cycle and its response to human pressures such as climate change. For example, several OceanICU partners contribute model simulations to the Coupled Model Intercomparison Project (CMIP), which underpins the work of Intergovernmental Panel on Climate Change. Other partners develop interactive tools (e.g., web interfaces to models) for performing simulations of ocean processes, while allowing the user to control settings including management options.

Here, we collate information about these different resources in order to provide (1) a comprehensive overview of the expertise, tools and datasets available within the consortium, and (2) specific information about how to access these resources. This fulfils several purposes. First, it allows stakeholders to explore what resources are available today to guide decision making. Second, it provides a basis for future WP8-led discussions with stakeholders, in which we will determine what functionality – which processes, management options, metrics, spatial and temporal detail, visualizations, type of interactivity – are most relevant to stakeholders and should be informed in the next generation of DSTs produced by OceanICU. To facilitate the latter, this document also describes initial steps taken within OceanICU to develop a proof of concept of an interactive DST, now available on the European Digital Twin of the Ocean.

This report was developed by continuously cataloguing partner-produced datasets and tools that provide information on the ocean carbon cycle. This started during the initial development of OceanICU, with a comprehensive list of used physical, biogeochemical and ecological models being included in the proposal and grant agreement. These resources and their potential contribution to the different iterations of the Decision Support Tools were further enumerated in the WP7 implementation plan (Table 1 in D7.1).

Existing OceanICU datasets and tools that can support decision making

1.1. The CMIP6 archive

The Coupled Model Intercomparison Project (CMIP) is a project of the World Climate Research Programme (WCRP)'s Working Group of Coupled Modelling (WGCM). The main goal of this project is to advance out understanding of the

Earth's climate system, particularly through advanced scientific research on three overarching questions:

1. How does the Earth system respond to forcing?
2. What are the origins and consequences of systematic model biases?
3. How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios?

The CMIP6 exercise has generated a wealth amount of Earth system model simulations from various climate modelling centres worldwide. The majority of these simulations aim at improving our understanding of key mechanisms driving the observed historical climate change and providing projections of future climate across predefined sets of anthropogenic forcing scenarios.

For a detailed description and background of CMIP see the official page at WCRP: https://wcrp-cmip.org/cmip6/, and this simple overview is a good starting point: https://www.wcrp-climate.org/images/modelling/WGCM/CMIP/CMIP6FinalDesign_GMD_180329.pdf
There is a special issue in Geoscientific Model Development (GMD) dedicated to CMIP6. This contains peer-reviewed papers on the experimental design, the different scenarios, and description of the various forcing data sets.

1.1.1. Availability

All CMIP6 data output ensemble model outputs are publicly available, and can be downloaded from, the Earth System Grid Federation (ESGF, e.g. https://aims2.llnl.gov/search/cmip6). Note that there are several ESGF nodes. The Program for Climate Model Diagnosis and Intercomparison at the Lawrence Livermore National Laboratory has made a nice guide for data users: https://pcmdi.llnl.gov/CMIP6/Guide/dataUsers.html This guide includes links to further documentation, the data archive(s), as well as useful information about data structure and governance.

In OceanICU, a subset of CMIP6 datasets has been downloaded onto the Norwegian server. Particularly, model outputs from historical and future scenarios projections that comprise key climate metrics/variables from the majority of Earth system models could be shared efficiently among the project partners. These will also be available to support the development of decision support tools (DST) in WP7. In addition to analysing the model outputs directly, OceanICU partners also have experiences in various methodologies to constrain the inter-model spread in the ocean carbon sink projections, which will contribute to the DST development as well. For the purpose of analysing the current and future state of the ocean biological carbon pump in WP2, essential ocean biogeochemical variables such as oxygen, nutrients, and water mass age have been downloaded and are currently being analysed (Partner NORCE).

OceanICU-related request for CMIP6 datasets stored in the Norwegian server can be made by contacting Jerry Tjiputra (jetj@norceresearch.no).

1.2. FluxEngine

The FluxEngine Python toolbox is an extensively verified community open-source toolbox that was originally developed via European Space Agency funding and then later extended within EU and UK government research projects (Holding et al., 2019; Shutler et al., 2016; https://github.com/JamieLab/FluxEngine) and it has been used extensively within research publications (e.g., Watson et al., 2020; Woolf et al., 2019), for teaching and within one ocean carbon submission to the annual assessments used to guide policy (Friedlingstein et al., 2023). It allows user configurable calculations of air-sea gas fluxes and net source/sinks (of multiple gases) from in situ, model and satellite Earth observation data (and any combination of these data).

1.2.1. Availability

The toolbox is actively maintained and extended (current version is v4.0.7) and is available as a Python library (https://pypi.org/project/fluxengine/) and as source code on GitHub.

1.2.2. Future work in OceanICU

Within OceanICU the FluxEngine toolbox is being used as the underlying basis of the framework for assessing all known uncertainties that exist within the air-sea gas flux calculations and the ocean carbon net sink estimates. This framework will then be provided (as open source) on GitHub alongside the FluxEngine toolbox code. This uncertainty framework (and the FluxEngine tools) will then be used to evaluate and investigate the role that biology has in modulating and controlling the oceanic sink of carbon. This work is being undertaken because the majority of current ocean carbon sink assessments focus on physical constraints and controls, whereas it is likely that future regional changes in the ocean sink may be strongly governed by biological processes. And some regions (e.g. the Southern Ocean) can strongly influence the global ocean carbon sink.

1.3. EwE

Ecopath with Ecosim (EwE) is a strategic trophic dynamic modelling package that can be used to simulate the dynamics of marine food webs, interspecific interactions, top-down and bottom-up processes, and how they are influenced by prevailing environmental and anthropogenic pressures. EwE has been applied globally to explore fishery management options in the context of ecosystem impacts and to simulate the cumulative impacts of climate change, Marine Protected Areas, bioaccumulation of contaminants, infrastructure development such as offshore wind, and social and economic impacts. EwE has three main components: Ecopath is the static component that provides a mass-balanced snapshot of the system. Ecosim is the temporal component, which enables the modelling of temporal changes in the ecosystem. Ecospace is the spatial and temporal dynamic module designed for exploring the spatial-temporal impact of pressures and the placement of protected areas as well as other management interventions.

EwE models are being increasingly used to inform management and policy decisions and advice, particularly through the lens of Ecosystem-Based Management and Ecosystem-Based Fisheries Management. They are one of the few tools capable of simulative cumulative impacts of multiple pressures on marine food webs and have thus been used in marine planning and impact assessment. EwE models have also been used to enhance single-species catch advice with ecosystem information, through the development of harvest control rules, ecosystem-informed Management Strategy Evaluation routines, and Ecological Reference Points.

1.3.1. Availability

The software, with frequent version updates, is freely available from the Ecopath website (Ecopath with Ecosim – Ecopath with Ecosim food web modeling approach). The spatial-temporal framework (required to effectively utilise the capabilities of Ecospace) requires a professional version license. Regional models are shared via an online repository (EcoBase; EcoPath with EcoSim repository). For access and more information on the models being used as part of Ocean ICU (EwE models of the Irish Sea and Celtic Sea) contact Jacob Bentley (Jacob.Bentley@naturalengland.org.uk), Paula Silvar (Paula.Silvar@Marine.ie), and Maximilien Cosme (maximilien.cosme@institut-agro.fr).

1.3.2. Future work in OceanICU

As part of OceanICU, work is ongoing, in collaboration with the Marine Institute in Galway and the Ecopath Research and Development Consortium, to develop a framework which integrates biogeochemical equations to the EwE pipeline to simulate the flow of carbon from fish. This work is being developed in alignment with the priorities of the ICES Workshop on Assessing the Impact of Fishing on Oceanic Carbon (WKFISHCARBON) and is currently being used to inform the development of a Policy Brief for the Department for Environment, Food & Rural Affairs (Defra, UK). Progress was recently disseminated at the Ecopath 40-year conference in Ostend, Belgium. Next steps for this work include:

1. refinement of model structures to better address policy and management questions related to the biological carbon pump (in collaboration with L'Institut Agro)
2. a review and sensitivity analysis of the uncertainty associated with parameters required to understand the fate of carbon that flows from fish (e.g., sinking rates, faecal composition, and remineralisation rates).

1.4. StrathE2E

Pressure to find ecologically sustainable strategies for harvesting food from the sea is getting ever stronger, especially in the face of changing climate. In addition, the role of fisheries in ocean carbon sequestration is becoming a source of concern. However, the questions are complex because the harvestable species live in a complex food web where everything is directly or indirectly connected to everything else. Models for carrying out scenario analyses on the impact of fisheries management options on food webs and carbon fluxes are usually the preserve of trained experts. The ICU team at the University of Strathclyde have developed a marine modelling package and online app that makes these analyses easily accessible to anyone with just basic website skills.

1.4.1. Fish in a food web

In the sea, the food web is tightly linked to ocean physics. Currents and mixing determine how dissolved nutrients such as nitrate, phosphate and silicate are available to micro-algae – phytoplankton, the primary producers of the sea. Many forms of zooplankton, fish, and seabed animals channel the primary production through a network of prey and predator linkages to the charismatic high trophic levels – whales, seals, and birds. A microbial food web recycles detritus back to dissolved nutrient to close the loop between production and consumption.

The effects of fishing and other pressures on any part of the food web are eventually felt everywhere to some extent through the phenomenon known as a 'trophic cascade'. Cascading effects are attenuated or amplified as they propagate through the food web, depending on the nature of the pressure and details of the ecology. This means that the effects of harvesting, for example herring which is a planktivorous fish species, can extend to both higher and lower trophic levels. However, these effects can be difficult to predict without a model that represents all the linkages.

1.4.2. Fishing and fisheries management

The internationally accepted objective of fisheries management has, for many years, been to harvest each exploitable species at its Maximum Sustainable Yield (MSY). The fishing rate required to generate MSY is called F_{MSY} – this is a key reference point for fisheries management. Stock assessments measure the state of each fish stock by the ratio F/F_{MSY} – the current fishing rate on that species relative to its value of F_{MSY}.

F_{MSY} is a measure of the productivity of a species, which depends on environmental conditions and the abundances of its predators and prey. So, in reality F_{MSY} values must be inter-dependent between species and likely to change with climate.

As we move from a species-by-species fisheries management regime to one where the objectives include the processes and integrity of the ecosystem as a whole, including consideration of carbon fluxes, we need whole-system models which include fishing. Is the traditional focus on F_{MSY} consistent with objectives regarding the whole ecosystem and carbon sequestration?

Fishing itself is a complex process, involving a plethora of different types of fishing gears. Few gears are sufficiently selective to capture only the desired species. Most catch a range of unintended by-catch, which in some cases can include seabirds, whales and seals. Gears also differ in their physical impact on the seabed. All of these factors affect carbon fluxes. This variety of fishing methods complicates efforts to identify eco-efficient harvesting strategies.

1.4.3. Fisheries Ecosystem modelling

In our article “StrathE2E2: An R package for modelling the dynamics of marine food webs and fisheries” (Heath et al., 2021), we described a software package that combines a marine food web model with a fishing fleet model.

The model is intended as a ‘big-picture’ representation of the fisheries-ecosystem, for broad scale strategic experiments. To enable rapid simulations, species are condensed into coarse functional groups, and spatial distributions into coarse compartments. The benefit is that the model takes only a few seconds to run on an ordinary laptop with minimal coding skills, unlike many other models which require high performance computing facilities and/or extensive training.

Since publishing our article, we have developed models for the Celtic Sea, Barents Sea (Heath et al., 2022) and East Greenland. As part of the EU Horizon 2020 Mission Atlantic project (https://missionatlantic.eu/) we are implementing the model for waters off Brazil, South Africa, Ascension Island, St Helena, St Peter & St Paul in the South Atlantic; the Azores, Canary Islands, NW Africa and the Norwegian Sea in the North Atlantic. In each case, the model will be used to support Integrated Ecosystem Assessments in collaboration with stakeholders. In OceanICU we are using these models to assess the sensitivity of carbon fluxes in each of these regions to fishing.

1.4.4. Availability

To make the model accessible to marine stakeholders we have developed a web-app interface to the software package: https://outreach.mathstat.strath.ac.uk/apps/StrathE2EApp/. The app, which includes a training course and links to the model code and resources, and to download the model R-package, enables anyone with an internet connection to select a model area, build their own fishing and climate scenario, and compare their model results against a baseline.

1.5. FEISTY

The FishErIes Size and functional TYpe model (FEISTY) is a mechanistic ecosystem model that fully integrates ecosystem structure across trophic levels and across water depth. The trophic levels are represented by five functional groups of fish:

1. epipelagic fish, such as sardines and anchovies commonly referred to as forage fish, with a small maximum weight that feed in the upper water column on zooplankton
2. large pelagic predators, such as billfish and tunas, that feed on plankton in earlier life stages and prey upon fish later in life
3. large demersal fish, such as cod, haddock and halibut, that feed as larvae in the water column and on benthic invertebrates and pelagic fish later in life
4. mesopelagic fish that perform diel vertical migrations between the mesopelagic zone (during day) and the epipelagic (at night)
5. bento-pelagic predators living in the deep and predating on mesopelagic fish.

Each functional group has a preferred vertical habitat and a prescribed diel vertical migration strategy.

The central process in FEISTY is predation by larger fish on smaller fish in the same habitat. The predation drives a bioenergetic model of an individual fish, leading to growth and reproduction. A size-based structured model handles the scaling from the individual-level growth and mortality to population-level biomass.

1.5.1. Future work in OceanICU

In OceanICU the FEISTY model will be enhanced to resolve the carbon fluxes due to fecal pellets, dead-falls, and respiration at depth. Further, we will develop the FABM interface and couple FEISTY with the University of Victoria Earth System Model. In this way we will calculate the carbon sequestration fluxes from fish. Further, we can calculate the total sequestration of carbon by fish using transport matrices. Finally, we will explore the impacts of fishing on the carbon sequestration.

1.6. BLOM+iHAMOCC (NorESM)

The Bergen Layered Ocean Model (BLOM) and isopycnic-coordinate Hamburg Ocean Carbon Cycle (iHAMOCC) are the ocean physical and biogeochemical modules of the Norwegian Earth System Model (NorESM), which contributed significantly to the CMIP6 exercise. In addition to simulations that support CMIP6, the NorESM model also simulations novel experiments that aims to address ongoing scientific and policy-relevant questions. These include (i) ideal and future projections that include scenarios of negative CO_2 emissions, e.g., through ocean alkalinization, (ii) overshoot scenarios that improve our understanding of delaying emissions reductions, and (iii) fully-interactive prognostic CO_2 simulations to study the feedback of changing ocean carbon cycle on the climate system. In addition, the BLOM+iHAMOCC annually contributes with its hindcast ocean-only simulations to the international initiatives of Global Carbon Project (https://www.globalcarbonproject.org/) and the Regional Carbon Cycle Assessment ad Processes 2 (https://reccap2-ocean.github.io/). These simulations will be available to the OceanICU consortium.

1.6.1. Availability

OceanICU-related requests for BLOM+iHAMOCC (NorESM) model simulations can be made by contacting Jerry Tjiputra (jetj@norceresearch.no).

1.6.2. Future work in OceanICU

In OceanICU, the ocean biological carbon pump representation in the NorESM will be developed further based on the inputs from WPs3-5. Thus, in addition to CMIP6 simulations, NorESM will also generate new OceanICU-specific simulations in WP6 and in close collaboration with WP7 such that the new experiment outputs contribute directly to the development of decision support tools.

1.7. NEMO+BFM (CMCC ESM)

The Nucleus for European Modelling of the Ocean (NEMO) and the Biogeochemical Flux Model (BFM) provide the physical and biogeochemical module of CMCC's Earth System Model (CMCC-ESM). Its last release (CMCC-ESM2) has contributed significantly to CMIP6 simulation catalogue and has been subject to a number of publications related to the assessment of the marine carbon cycle under climate change. In addition to the core products of CMIP6, a number of additional simulations and outputs have been produced complementing the global projections with regional downscaling or addressing specific topics, such as upwelling systems or negative emission pathways, that can be made available to the OceanICU partners.

1.7.1. Availability

Requests for further information on this model system and requests for data can be sent to Momme Butenschön (momme.butenschon@cmcc.it).

1.7.2. Future work in OceanICU

New process parametrisations developed on close collaboration with the project partners within OceanICU will be implemented into the CMCC-ESM system to provide improved projections of the marine carbon cycle feeding into the decision support tool developed within WP7.

1.8. NEMO+MOPS (FOCI)

The physical ocean model component in FOCI is detailed in Matthes et al. (2020). In brief, the ocean model is built on NEMO version 3.6 (Madec & the NEMO team, 2016) with a nominal global ocean resolution of 1/2° on a tri-polar grid (ORCA05), with Louvain-la-Neuve sea Ice Model version 2 (LIM2) as the dynamic–thermodynamic sea ice model (Madec & the NEMO team, 2016). The ocean component has 46 vertical levels, with thicknesses varying from 6 m at the surface to 250 m in the deep ocean.

The implementation of the biogeochemical module MOPS, and results of pre-industrial and historical simulations are described in detail in Chien et al. (2022). In brief, MOPS in FOCI simulates 9 biogeochemical tracers, namely phosphate, nitrate, oxygen, phyto- and zooplankton, dissolved and particulate organic matter, DIC and alkalinity. All simulated tracers have been compared comprehensively to corresponding observations in Chien et al. (2022). Model output has been further compared to observations of AOU in the Atlantic, and guided investigations of true and diagnosed (from AOU and ideal age) respiration rates (Guo et al., 2023). It is currently being analysed with regard to CFCs and mean age derived from TTDs (Guo et al., subm.). Output from a complementary simulation (preindustrial and historical) with different biogeochemical model parameters is also available and will help to determine the impact of parametric uncertainty on simulated carbon flux.

1.8.1. Availability

OceanICU-related requests for output from these model simulations can be made by contacting Iris Kriest (ikriest@geomar.de).

1.8.2. Future work in OceanICU

Within OceanICU MOPS will be refined or extended to include more elaborate process parameterisations as arising from WPs3-5. Specifically, we envisage to include more parameterisations of DVM and particle dynamics. These will first be tested and calibrated in the TMM; once operational, we expect to transfer these parameterisations to FOCI-MOPS (similar to the approach described in Chien et al., 2022).

1.9. On-demand water column simulations with the OceanICU model testbed

iGOTM (https://igotm.bolding-bruggeman.com) is a web application that performs water column simulations at any location in the world ocean. It was originally developed to simulate water column physics (e.g., temperature, salinity, turbulence), and builds upon the "GOTM-FABM" water column model that is one of the key testbeds within OceanICU WP6. In WP7, we are developing this concept to enable on-demand exploration of the response of ocean physics and biogeochemistry to human pressures at any user-selected location. Specifically, we are:

1. Adding support for simulating biogeochemistry using the ensemble of state-of-the-art biogeochemical models developed in OceanICU. This builds on the model platform developed WP6 (task 6.1). This will enable us to ultimately fold in improvements in process descriptions developed in WP 3-6.
2. Adding support for scenarios that describe human pressures. These currently include changes in atmospheric temperature ("climate change"), and they will be extended to other pressures such as fisheries and mining in the future.

3. Integrating with the EU Digital Twin of the Ocean (EDITO). For this purpose, the infrastructure underpinning the simulation tool was redesigned to build upon the new WP7 toolbox for data handling, visualization and interactive presentation (task 7.1). Different components of this toolbox are shown in Figure 1. Additionally, the system for deploying the simulation tool was rebuilt for scratch to integrate with EDITO, using docker-based containerization, kubernetes templates and helm charts for deployment in the EDITO Datalab.

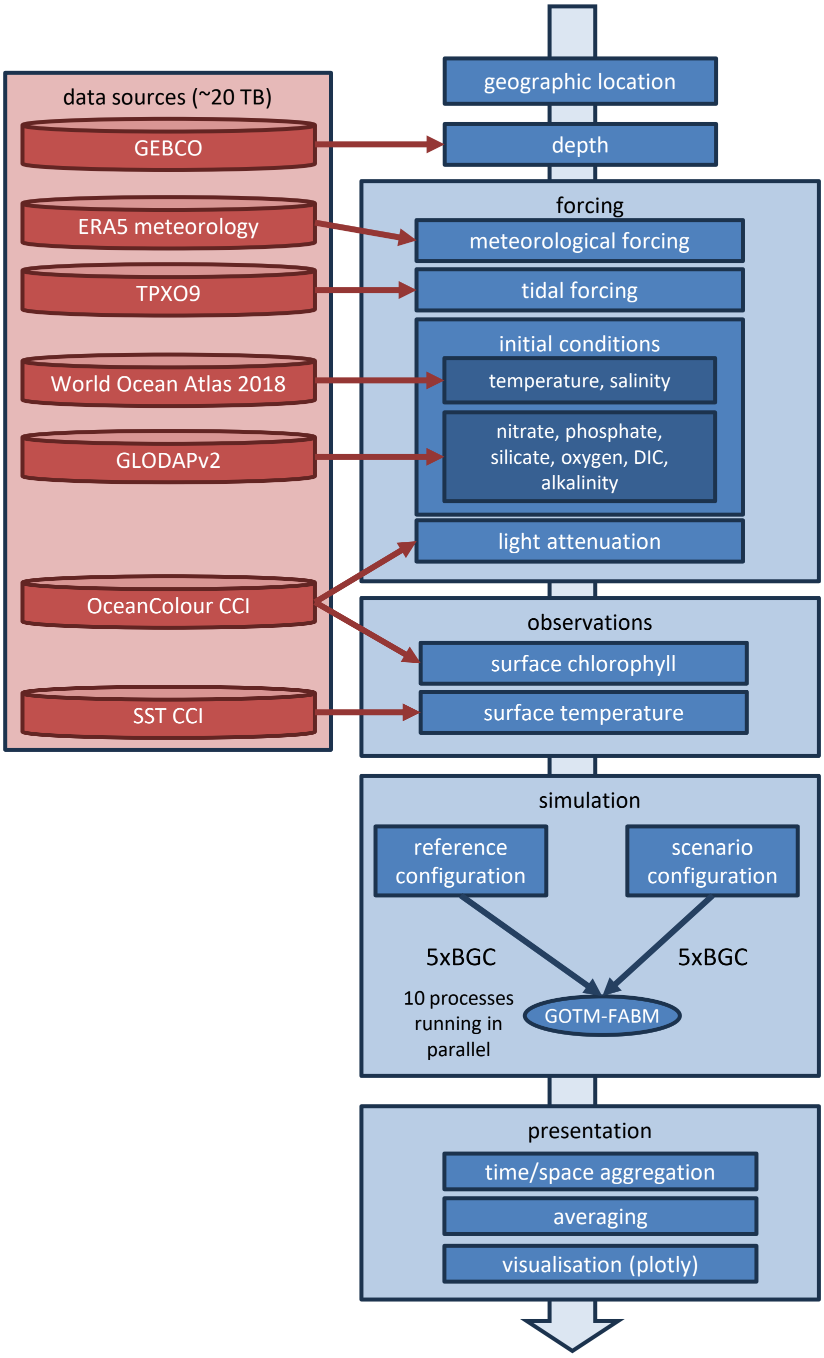

Figure 1. Data flow within the OceanICU "GOTM-FABM" DST prototype. The left panel shows the different datasets used to drive the simulator: GEBCO, ERA5, TPXO9, World Ocean Atlas, GLODAP, OceanColour CCI and SST CCI. The right panel shows the workflow, starting with the user-provided location (top) and finishing with presentation of results in the user's we b browser (bottom).

1.9.1. Availability

A first demonstrator of the interactive "GOTM-FABM" DST is now hosted by the European Digital Twin of the Ocean (EDITO): https://ocean-icu.lab.dive.edito.eu. A screen shot of this tool is shown in Figure 2. This proof-of-principle was demonstrated at the Digital Ocean Forum held in Brussels in June 2024. It enables users to perform water column simulations with an ensemble of OceanICU biogeochemical models at any geographic location, simulating either a reference year, or a scenario where the atmospheric temperature is increased with a user-specified value. It then visualizes how key metrics, such as the air-sea CO_2 flux, have changed under the scenario.

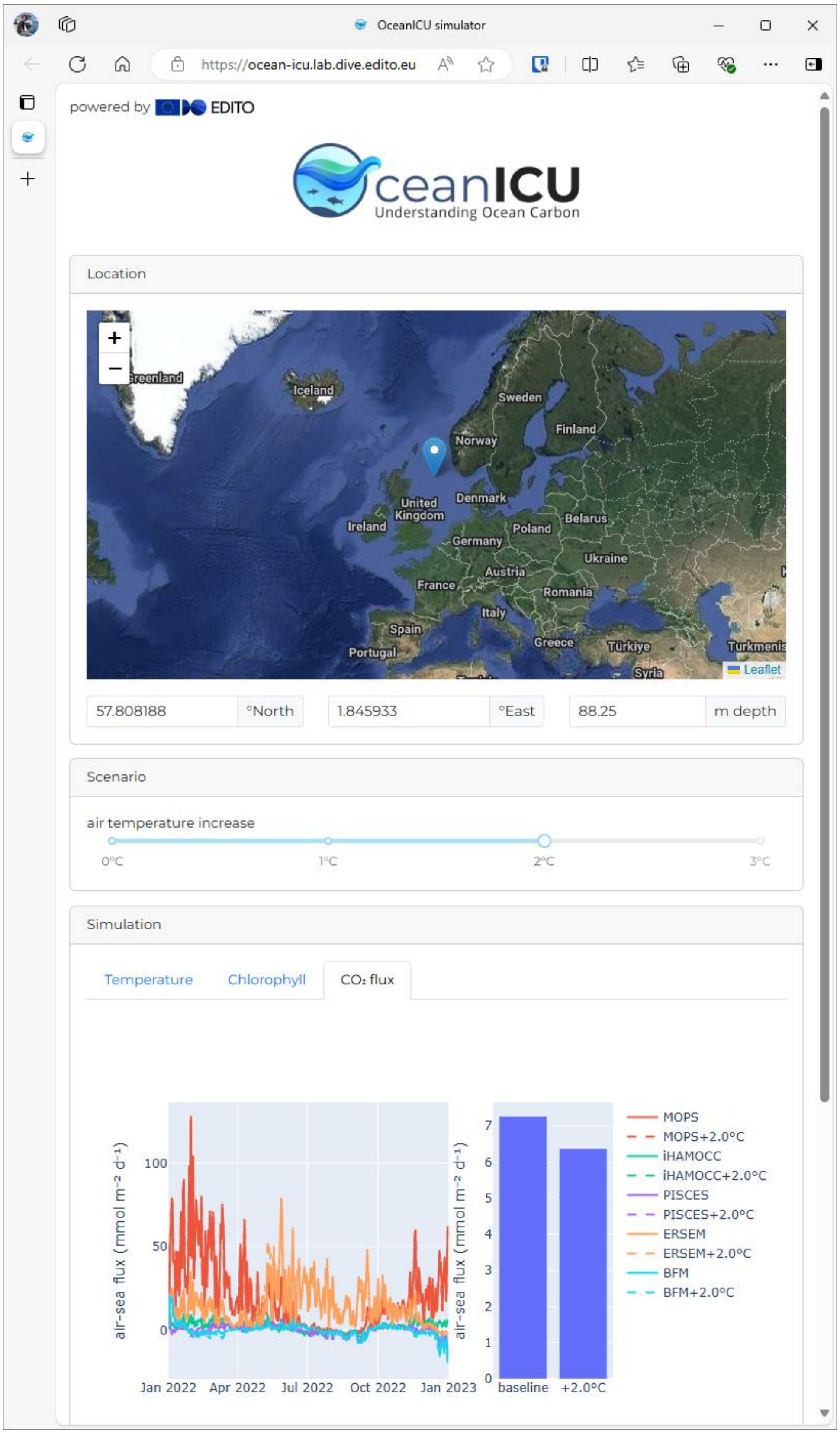

Figure 2. The OceanICU "GOTM-FABM" DST prototype, running within the EU Digital Twin of the Ocean.

In its current state, the tool is a proof of concept, designed to highlight the ability to run OceanICU models (WPs 3-6) on demand, to configure scenarios, and to monitor key metrics for ocean carbon uptake.

Next steps

The next release of OceanICU decision support tools (V2) will be delivered M40 and described in D7.3. This will build on the suite of datasets and tools (V1) presented here, as well as several new developments:

- Most datasets and tools will have been updated within OceanICU as described in previous sections.
- Available tools and datasets will be presented to stakeholders in WP8, as a basis for discussion to identify users' requirements with respect to simulated processes and management options, temporal and spatial detail, presentation options and interactivity. This will directly guide further development of data processing and visualisation library (T7.1) that will underpin future DST components.
- The proof-of-concept OceanICU DST, running on the EU Digital Twin of the Ocean, will be updated to simulate multi stressor effects under different scenarios and management levers (e.g., trawling, drilling, deep-sea mining and dredging). Through the WP6 model platform (T6.1), this tool will integrate new and updated process models generated in WPs 2-5.

Ultimately, the datasets and tools presented here will also contribute to the development of V3 of the DST, which will be an interactive tool providing the basis for improved management of ecological processes regulating the biological carbon pump. This will be machine-learning emulator of regional and Earth System processes (based on artificial neural networks), trained in part on the datasets and tool outputs from DST V1 and V2.

Contribution to the overall objectives and relevant (KPIs)

The first DST release presented here includes numerous tools that can help predict the impact of human pressures on ocean carbon sequestration. As such, it contributes directly to Scientific and Technical Objective 4:

- **ST4** Develop a suite of tools to predict the impact of resource extraction processes on the contemporary ocean C cycle, the optimal measurement of the Ocean C cycle and build Decision Support Tools

(DSTs) to predict the impacts of industrial processes in a future ocean (**WP 5-7**)

Additionally, DST V1 provides a first set of datasets and tools to stakeholders. These can support decision making, but more importantly they provide a basis for discussion and collaboration with stakeholders, ultimately enabling co-development of next DST releases. As such, DST V1 supports both outreach objectives:

- **O1** Co-design, develop and deploy ocean carbon DSTs (ST 4) with a broad range of stakeholders in the industrial, fishing and climate arenas as well as policy makers. **(WP8)**
- **O2** Communicate ***OCEANICU*** outputs in support of science-based management of human activities to protect and increase the role of the ocean in Carbon sequestration. **(WP8)**

While DST V1 on its own does not contribute to KPIs, it lays foundations for realization of several related to the use of OceanICU models and engagement with stakeholders:

- (6) Model predictions of C cycle made using 2 OCEANICU models containing 5 new parameterizations.
- (22) Managers in fishing industry aware of impact on C and integrating this into their planning
- (23) Managers in industry aware of impact on C and including this in their forward planning
- (27) Managers in fishing and other industries, & policymakers in coastal states aware of their impact on C and integrating this into their planning
- (28) Decision-makers and policy advisors briefed on tensions between long term mitigation/ enhancement options and economic growth

Impact and progress beyond state of the art

The new OceanICU-developed DST for on-demand water column simulations was specifically built to integrated with the EU Digital Twin of the Ocean (EDITO) infrastructure, presented to the wider public at the Digital Ocean Forum in June 2024. Close collaboration with the leads of the EDITO infra project (Mercator Ocean International and VLIZ) during development of the proof-of-concept DST has ensured that OceanICU is one of just two “What If” applications now publicly available in the Digital Twin of the Ocean.

Lessons learnt and links built

Close alignment with the EU Digital Twin of the Ocean has provided a promising platform for public dissemination of present and future OceanICU

DSTs. We expect to exploit the links with the EDITO projects and partners more fully in the future to develop and deliver DST V2 and V3.

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