



Deliverable D7.1

WP7 Implementation Plan

July 2023/0.1





About this document

Title	D7.1, WP7 Implementation Plan
Work Package	WP7, DSTs for ocean carbon management
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Reviewers	NORCE Norwegian Research Center
Due Date	30.06.2023, M6
Submission Date	20.12.2023
Version	1.1

Dissemination Level

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OceanICU: Improving Carbon Understanding is a Research and Innovation action (RIA) funded by the Horizon Europe Work programme topics addressed: HORIZON-CL6-2022-CLIMATE-01-02. Start date: 01 November 2022. End date: 31 October 2027.

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OceanICU is co-funded by the European Union, Horizon Europe Funding Programme for research and innovation under grant agreement No.101083922 and by UK Research and Innovation



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1. Abstract

The goal of WP7 is to synthesise activities in earlier WPs and to provide a basis for presentation of results to stakeholders in WP8. It will use 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 report provides a roadmap to guide the activities of WP7 in OceanICU, in order to ensure the successful integration of activities of WPs 2-6 as well as understanding of stakeholder needs based on engagement in WP8.

Over its three releases (V1, V2, V3), the DST library will evolve from a static description of numerous pre-existing datasets and tools (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). The detailed specification for each subsequent release will be decided in consultation with stakeholders (WP8).

2. Introduction

2.1. General Description

The Decision Support Tools produced by this WP will provide insight for policy makers into the effects of multiple stressors (e.g., trawling, drilling, overfishing, deep-sea mining and dredging) on carbon sequestration, as impacted upon by management levers. The DSTs will also consider climate scenarios, supported by earth system modelling in WP6.

The DST library will be built incrementally, with three releases over the course of the project:

DST V1: an overview of datasets and tools from WP2-6 that are immediately (i.e., at the start of OceanICU) available to support decision makers (M20)



DST V2: further development of the most promising elements of DST V1 to incorporate advances in process understanding, model developments and new datasets (including model simulations) from WPs 2-6 (M40).

DST V3: a machine learning (ML) model, capable of emulating regional and Earth System models under multiple management and climate scenarios. The ML model will be trained with datasets and model simulations identified as part of DST V1 and V2 (M50).

As it evolves, the DST library will be presented to stakeholders (in collaboration with WP8) to identify the elements that are to be taken forward into subsequent DST releases, and to decide on user interface and interactivity options in the final releases of the library. The capabilities of the tools (V2, V3) will be designed to enable discussion of crucial vulnerabilities, trace pressure-impact linkage chains, and evaluate the resilience of carbon pumps (solubility, carbonate, and biological) in relation to multi-stressors.

The development of DSTs is underpinned by the following specific activities:

1. Creation of a software library designed to acquire, analyse, and visualise both observational and model data. This library will be leveraged when presenting data to stakeholders (V2, V3) and when preparing datasets for ingestion by the machine learning tool (V3). The capabilities of this library will be demonstrated with user-friendly tools (e.g. iGOTM+FABM) for exploring the impact of pre-defined climate and management scenarios on carbon sequestration (to be included in V2). This will directly use the process-based models and testbeds developed in WP6, and through those, it will directly incorporate advances in process understanding from WPs 2-5.
2. Development of an interactive modelling tool, powered by machine learning and based on emulating present day Earth System Models, to allow rapid inspection of the impact of different management options. The development process will be driven by feedback from stakeholders who will customise management options in relation to their area of expertise and simulate potential ramifications of their decisions. As such, this will provide a basis for mitigation of cumulative impacts and



risks on ocean carbon sequestration resulting from trawling, drilling, overfishing, deep-sea mining and dredging.

Hence, the objectives in WP7 are:

1. Development of a library for data handling, analysis and visualisation of observations and model data, and demonstrating its functionality with a light-weight, user-friendly tool.
2. Provide stakeholders with analysis tools to identify key vulnerabilities, pressure-impact linkage chains and the resilience of the solubility, carbonate and biological carbon pumps to multi-stressors including evaluation of geoengineering- and nature-based-solutions at regional scale.
3. Develop and demonstrate a user-friendly, machine-learning-based interactive tool allowing stakeholders to set management options and evaluate the ramification of management actions and thereby reduce cumulative impacts and risks.

2.2.Deliverables and milestones

The following milestones will be used to monitor progress in this WP:

- **MS27** Information received from WP2-5,8 identifying pre-existing tools and datasets that can support decision making in the context of multiple ecosystem stressors. **lead:** BB data set archived M12 as presented in table 1 in the current document.
- **MS28** Information received from WP2-5,8 to WP7. This includes description of model outputs, observational data and process understanding **lead:** GEOMAR data sets archived M20
- **MS29** Information received from WP2-5,8 to WP7. This includes model outputs,observational data and process understanding **lead:** DTU data sets archived M26
- **MS30** Information received from WP6 & 8 to WP7. This includes an overview of stakeholder needs that will guide development of DST v2 (e.g., desired visualisation options), as well as and regional (e.g. North-Eastern Atlantic) model simulations (GETM-ERSEM) under different multi-



stressor scenarios that will inform DST v3 **lead:** BB data sets archived M30

- **MS31** Information received from WP6 & 8 to WP7. This includes an overview of stakeholder needs that will guide development of DST v3 (e.g., relevant management questions/scenarios) as well as and global model simulations (UVic-FEISTY) under different multi-stressor scenarios **lead:** DTU data sets archived M46

WP7-related deliverables are:

D7.1 WP implementation plan developed at first GA (Lead: DTU R — report PU - Public M8), which corresponds to the current report.

D7.2 Report describing the DST V1 WP7 (Lead: BB R — report PU - Public M20). Report describing pre-existing tools and datasets that can support decision making in the context of multiple ecosystem stressors, based on data received in MS27. This will 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 will be built on the newly developed data processing and visualisation library (T7.1) and the unified model platform created in WP6 (T6.1, MS21). Available tools and datasets will be presented to stakeholders in WP8, as a basis for discussion to identify users' requirements for subsequent DST releases (V2 and V3).

D7. 3 & 4 *A request to the EC will be sent to merge D7.3 and 7.4 due to redundancy:* Report describing DST V2. This is an update to the suite of datasets and tools (V1) based on data and stakeholder feedback received in MS28 and MS29 (Lead: BB R — report PU - Public M40). DST V2 will include an update of the process-based model tool (e.g. iGOTM+FABM) (V1) 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. DST V2 will also leverage the newly developed data processing and visualisation library (T7.1) to derive multi-stressor impacts



from a comprehensive collection of global and regional model results from within and outside OceanICU, and to present these impacts to stakeholders.

D7.5 Report describing DST V3 WP7 (Lead: DTU R — report PU - Public M 56). This will be an interactive tool providing the basis for improved management of ecological processes regulating the biological carbon pump. It will build on datasets from DST V1 and V2 and integrate additional model outputs from WP6 (Table 1), metrics and empirical formulations capturing advances in process understanding in WP2-5, and stakeholder feedback from WP8. Outputs from preceding WPs will be used to train a machine learning-based emulator of regional and Earth System processes (based on artificial neural networks) to (1) identify major drivers regulating carbon export (2) provide a lightweight version of those models enabling evaluation of scenarios under multiple stressor effects. Based on the presentation of the DST V3 to stakeholders (WP8), this report will include an assessment of the DST's contribution in supporting decisions of key stakeholder groups in their efforts to mitigate and manage climate change in their sectors.

Inputs from other WPs

WP7 relies on inputs from other WPs both in terms of process understanding and available numerical models (i.e., Table 1). Especially for V1 and V2 existing datasets and tools will be mapped and integrated in a common digital framework. To enable these exchanges specific milestones have been established both in WP7 (see above) and under each contributing WP. In detail:

WP2 - 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 publically 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.

WP5 - Task 5.5 Transfer knowledge to DSTs. (Lead: MI; Contributors: DTU, GEOMAR, NIOZ, English Nature, Agrocampus Rennes, Strathclyde U) This task will deliver information around the role of fishing and industrial exploitation to WP7.

WP6 - Task 6.7 Transfer of Data to DST development. Lead: B&B; Contributors: All WP partners) (M06-M48) This task will deliver spatial and temporal maps of key habitats for carbon sequestration as well as time series of abiotic and biotic stressors and carbon sequestration to WP7 for the OceanICU DST development.

WP8 - Connecting OCEANICU to Society will work closely with WP7 to ensure that the DST meets user needs and to support uptake of tools and outputs. The interaction between WPs 7 & 8 is also detailed in D8.1, the WP8 Implementation Plan. WP8 provides input on decision and policy maker, industry (fishing, mining, etc.), civil and wider society needs and future trajectories which will inform scenario development. WP8 will facilitate specific workshops testing and providing feedback on the DST development thus supporting the iterative development of the DST to ensure accessibility, applicability and uptake.

3.WP7 implementation

3.1. Task 7.1: DST library of demonstration tools

This task is ongoing and will continue to evolve until Month 30.

Lead organisation: B&B; Contributors: DTU, METU, SSBE

Implementation period: M6 -M30

This task focuses on designing and implementing a toolbox for data handling (e.g., spatial/temporal aggregation of multi-TB datasets including observations and models' outputs), analysis (e.g., anomaly detection, tipping



point, trends, etc.) and visualisation (maps, time series) to support the interactive presentation of observational datasets and model outputs to stakeholders. This infrastructure allows the user to explore the response of solubility, carbonate and biological carbon pumps under a range of future scenarios from e.g., CMIP6 and those produced under OceanICU. The infrastructure will be implemented in Python using packages for data handling (xarray), visualization (plotly) and interactive presentation (Jupyter Notebooks, <https://jupyter.org>) and accessible online.

BIG DATA: A core component of the toolbox will focus on efficient access to Big Earth Data, specifically climate data sets such as CMIP6. We will exploit the fact that the big 3 cloud providers (Amazon, Google and Microsoft) are now hosting some of these data sets for free to demonstrate their respective capabilities. We will investigate the potential of these data services to provide quick and reliable access to strategic climate data sets, and specifically evaluate the usability of new cloud optimised data formats, such as Cloud Optimised GeoTIFFS.

ANALYSIS TOOLS: Tools employed will incorporate methods selected by other WPs as well as other projects: e.g., to identify tipping points, methods adopted by the COMFORT project (<https://comfort.w.uib.no>) will be used, while for anomaly products delivered under MISSION ATLANTIC (<https://missionatlantic.eu/>). Products available under BRIDGE-BS for the Black Sea will be integrated when relevant under the advice of METU.

The DSTs will be designed in such a way that they can be easily integrated into the emerging Digital Twin of the Ocean, with SSBE advising on this architecture.

Responsibilities:

B&B – Will carry on the technical development of the library.

DTU – Will contribute with anomaly detection tools developed under the MISSION ATLANTIC project.

METU – Provide advice stemming from knowledge gleaned from the BRIDGE-BS project.



SSBE – Will advise and monitor activities to align this task with stakeholder requirements (collected under WP8) and technical development of the Digital Twin of the Ocean.

3.2. Task 7.2: Systemic controls on Carbon Sequestration

This will include the evaluation of different management options as discussed with stakeholders (in WP8)

Lead organization: DTU; Contributors: B&B, METU, SSBE

Implementation period: M12 -M57

This task creates three DST versions,

- DST V1 based on published historic data and pre-existing outputs and tools, all identified and provided by WPs 2-6. It will also include the first release of a tool for exploring stressor impacts, built on the unified model platform built in WP6 and the software library developed under T7.1. Completion: M20.
- DST V2 will further develop the most promising elements of DST V1, incorporating partner data assembled before and during OceanICU as well as simulation model outputs. Selected tools will integrate advanced process parameterizations stemming from OceanICU, as well as those from the broader community, through updates of the unified model platform in WP6. The new data processing and visualisation library (T7.1) will be leveraged to distil multi-stressor impacts from a wide variety of model results (Table 1) and present these in a unified way to stakeholders Completion: M40.
- DST V3 will be a machine learning emulator of regional and Earth System models that will utilise the latest outputs from modelling activities, including perturbation experiments specifically designed to train the ML emulator (WP6), and potentially also selected metrics and/or empirical formulations of relevant process impacts on carbon sequestration (WP 2-5). Completion: M50.

Incrementally, the DST tools will evolve from a static catalogue of available data and tools (V1) to new, interactive, multi stressor user-friendly simulation



tool allowing stakeholders to assess the impacts of different pressures and management options (trawling, drilling, overfishing, deep-sea mining and dredging) on carbon sequestration under different climate scenarios (V2 and V3).

ENGINE. The ML tool for DST V3 will be built with PyTorch, and consist of a spatio-temporal neural network architecture combining, i.e., Graph Neural Networks based on the Graph Network (GN) and Recurrent Neural Networks to model the temporal dependencies. The GN framework allows for a global feature vector describing global properties of the observed data at time t , which will represent the state of the individual levers (pressures and management measures), thereby allowing the spatio-temporal neural network to model the effects of the levers in the observed data for the indicators

TRAINING. The ML engine will ingest spatially explicit, time varying results from 3D coupled hydrodynamic-biogeochemical global ocean and regional models. In particular, it will be trained with results from dedicated perturbation experiments from WP6, covering a wide range of multi-stressor scenarios in global setting (the UVic-FEISTY earth system model) and regional setting (the GETM-ERSEM model for the NW European Shelf). Further training data will potentially include results from additional model simulations (WP6) and empirical metrics and formulations (WP2-5), as far as these are compatible (comparable units, domains, temporal and spatial resolution) with the ML model.

Responsibilities:

B&B – Will be responsible for integrating results from WP2-6 into DST V1 and DST V2, and ensure the data handling library (T7.1) is capable of driving DST V3

DTU – Will be responsible for developing, training and testing the ML-based DST V3

METU –Actions will contribute to the development and testing of DST V3



Table 1. Candidate model, tools, datasets to be included in different releases of the DST. Over the course of the project, additional datasets and models may be identified and included.

Model/tool/dataset	Major features	Stressors	How into DSTs?	V1 M20	V2 M40	V3 M50	Resp. institute
CMIP6 archive	Ensemble of earth system model projections	climate	Datasets supporting decision making, forcing provider for some tools (e.g., GOTM)	x	x	x ¹	UEXE NORCE, CMCC
GOTM + various BGC ²	Water column model (1D)	climate (V1), fisheries (V2)	Web app, configurable for any geographic location	x	x		BB
BLOM + iHAMOCC (NorESM)	Earth System Model	climate	Prior results transitioning to results based on updated process descriptions	x	x	x ¹	NORCE (Tjiputra)
NEMO + BFM (CMCC ESM)	Earth System Model	climate	prior results transitioning to results with updated process descriptions	x	x	x ¹	CMCC
NEMO + MOPS (FOCI)	global	climate	prior results transitioning to results based on updated process descriptions	x	x	x ¹	GEOMAR (Kriest)



NEMO ERSEM	+	North- west European Shelf	climate, trawling	prior results transitioning to results based on updated process descriptions	-	x	x ¹	PML (Blackford)
NEMO PISCES	+	global with regional zooms in North Atlantic	pCO ₂ pH	high resolution data sets - change in seasonal cycle of carbonate system variables	-	x	x ¹	IPSL (Gehlen)
GETM ERSEM + fish (e.g. FEISTY, MIZER)	+	North- west European Shelf	Climate, fisheries, trawling,all other stressors meaningful on regional scales	dedicated perturbation experiments (> 20) for training of DST V3		x	x	BB (Bolding)
UVic + FEISTY		Coarse- resolution ESM	climate, fisheries, all other stressors meaningful on global scales>	dedicated perturbation experiments (> 20) for training of DST V3	X	X	x	DTU (Andersen)
ROMS NORWECOM	+	Region? Norwegia n Seas?	TBD	prior results transitioning to results based on updated process descriptions	-	x	x ¹	IMR (Skogen)
C CANDI () benthic- BGC)		Regional e.g. Pacific	Deep-sea Mining	prior results transitioning to results based on	-	x	x ¹	GEOMAR (Haeckel)



			updated process				
OMEXDIA (coupled to physics ? benthic BGC ?)	Regional E.g. Pacific Atlantic region	Bottom trawling	prior results transitioning to results based on updated process	-	x	x ¹	NIOZ (Soetaert)
StrathE2E	Regional Scale	Fisheries Climate	Web app	x	x	x ¹	STRATH (Heath/ Speirs)
FEISTY	Basin Scale	zooplankton production, and benthic detrital flux (V1), fishing, temperature (V2)	web app to simulate the fish model and the interaction with fishes suggested optimal monitoring strategies	x	x	x ¹	DTU (Andersen)
Ecopath, Ecosim, Ecospace	Celtic Sea	Fisheries	impacts of shelf sea fisheries on carbon flux directly via pellets and deadfall, indirectly via food web interactions	x	x	x ¹	MI (Reid) & NE (Bentley)
Ecopath and Ecotroph	Celtic sea and North-East Atlantic	Fisheries	prior results transitioning to results based on updated process	-	x ¹	x ¹	IA (Gascuel)
FluxEngine	global	TBD	toolbox for estimation of	x	-	-	UEXE (Shutler/



			ocean CO ₂ uptake				Watson)
CMEMS-LSCE-V2	North Atlantic	pCO ₂ pH	for coastal ocean pCO ₂ and pH		X	X	IPSL (Gehlen)



¹ As far as data are compatible with the variables that the DST V3 emulator represents, in terms of units, domain, spatial and temporal resolution

² At minimum: MOPS, ERSEM, iHAMOCC, BFM, PISCES

³ If available on time for DST V2 delivery

3.3. Critical risks for implementation

Risks as identified in Part B of the Grant Agreement as well as WP 7 specific risks and proposed mitigation measures.

1 Cruise Programme Fails to Occur due to COVID or increases in fuel prices (Low risk, low severity). Impact is no new information regarding how key processes operate.

- Low severity as multiple dataset exist already
- low risk as cruises mainly postponed
- not cancelled and we are not reliant on a single campaign

Project Strategy: using extant data sets identified in Grant Agreement's Part B, risk is spread by operating on multiple vessels from different nations.

Status for WP7. At present not an issue as COVID situation is lowered, however could impact on validation of process models in WP 6 thus impacting on DSTs V 2 and 3

2) Transfer of Information between WPs breaks down (low risk, high severity) due to COVID induced lockdowns preventing face to face meetings . Severity is potentially high, efficient comms between experimentalists, modellers and data scientists is key to delivering the complex workflow and for the validation of process models. Low risk as project partners have worked together before and we will manage the transfer of information very carefully and monitor it very strong.

Project Strategy: devote considerable resources in WP1 to monitoring the interactions between WPs.taged approach to data transfer between WPs to ensure that there is some flex in the system and it is resilient to a milestone being delayed. Use VC based technologies for meetings if required.

Risk level reduced due to COVID status



Specific to WP7.

- Activities in WP 7 are largely supported by the technical work on ecosystem models developed in WP5 and WP6 and parameterisations developed in e.g. WP2.
- It is critical that the decision support tools developed can meet the requirements of relevant stakeholders, hence the engagement under WP8 is critical to the success of WP7.

Work Package Strategy: To avoid this risk, clear alignments between the detailed implementation plans of WP5, WP6 and WP8 are being developed in particular, regular meetings are planned to share updates and information. Issues emerging will be discussed in this group and together with the management team in WP1 to define the best strategy for mitigation.

3 Stakeholder engagement is Poor (low risk, medium severity) e.g. due to COVID induced lock downs preventing face to face meetings. **(At present not an issue)**

- stakeholders fail to engage in providing scenarios or by not discussing their needs then developing relevant projections is more complex. WP7, WP5, WP8

Project Strategy: Devote substantial resources (10% of project budget) to engaging with end users.

- Create log of interactions with key end users outside OCEAN ICU
- hold regular intra-project calls to capitalise on these links.
- Use VC based technologies for meetings if required.

Specific to WP 7: A dedicated work package (WP8) coordinates all engagement activities to reduce stakeholder fatigue and to aggregate results under OceanICU for discussion in relevant meetings. In WP7 we plan to keep a close dialogue with WP8 including common activities in preparation of those meetings to identify questionnaires and communication tools relevant to WP7 technical development.



WP 7 specific issues: The following risks and mitigation measures are considered as they have the potential to impact the technical development of DSTs V1, V2 and V3.

Poor performances in emulating Earth System models (medium risk, medium severity). While the model used in DST V1 and DST V2 are well established computational frameworks with documented strengths and weaknesses, the machine learning tool developed in connection with DST V3 will be based on a new artificial neural network framework that will be trained on different model outputs. Different architectures will be tested to obtain the highest performance in reproducing those outcomes however we cannot anticipate at this stage the uncertainties around model results. We note however that previous attempts (available in the literature) to simulate Earth System models with deep convolutional neural networks have produced good results.

Work Package Strategy: WP7 will dedicate substantial effort on this task and will adapt the computation strategy based on preliminary results and merging different approaches to maximise the performance of the surrogate models (also accounting of the requirements on accuracy and precision of relevant stakeholders).

Digital infrastructure for the DST library is unreliable (low risk, medium severity). Some (or all) of the models used for DST V1, V2 and V3 will be offered as webservices. Hence this requires a reliable digital infrastructure. We foresee that initial tests on DST V1 and DST V2 could be conducted with present infrastructure available at partner B&B. However, as complexity will increase, we consider the present infrastructure sub-optimal and not stable.

Work Package Strategy: To mitigate a risk of a breakdown in the webservices we will maintain a close alignment of the technical development in WP7 and activities conducted in other EU funded project responsible for the development of the Digital Ocean Twin.

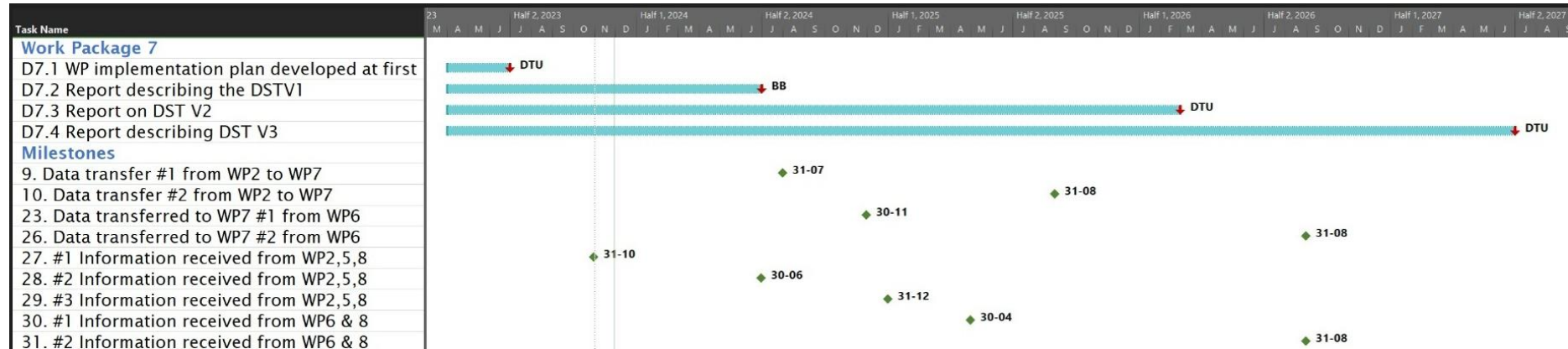


3.4. Expected results

#Identifier	Result	Partner responsible	Expected time
DST V1	Initial library based on existing modelling tools and published data	B&B	Month 20
DST V2	Advanced modelling tools from DST V1 incorporating new process understanding resulting from WP2-6	B&B	Month 40
DST V3	A new multi stressor machine learning tool able to emulate Earth System	DTU	Month 50



3.5. Gantt Chart



Legend:

Deadline ↓ Milestone ◆



4. WP7 management

4.1. WP7 management structure and routines

DTU (Patrizio Mariani and Mike St. John) are leading WP7 and T7.2 with B&B (Jorn Bruggeman) co-leading WP7 and task leader of T7.1. METU and SSBE are directly involved in both WP7 tasks while other OceanICU Partners are engaged for contributing numerical models of carbon sequestration to WP7. Regular online meetings with all partners will be organised by WP7 leads (every six months) while more frequent interactions will occur between task leaders (every second month). Deliverables and milestones have clearly identified responsibilities and draft deliverables will be circulated to all WP7 Partners (and WP1 lead) before submission.

4.2. Key performance indicators (KPIs)

- Number of numerical models from which results are integrated into the DST Library.
- Number of levers for which scenarios can be tested with DST models.
- Number of non-specialist scientists and other stakeholders introduced to simulations performed with the DST tools.
- Number and impact of peer-reviewed papers developed under WP7.

5. Interactions with other WPs

Under Task 7.1 we plan interactions with WP8 to shape the library and DST functionalities based on stakeholder requirements and WP5 and WP6 to agree on the models used for the different DST versions. WP2 will contribute to define parameterizations suitable for DST models.

WP involved	Aim	Method	Responsible in WP7
WP5-6-7	Discussion of models included in DST V1	Online meeting	B&B



WP involved	Aim	Method	Responsible in WP7
WP7-8	First outcome from stakeholder engagement	Online meeting	DTU
WP2,5,6,7	Plan for MS28, MS29, MS30	Online meeting	B&B/DTU
WP7-8	Identify steps to refine DSTs based on stakeholder feedbacks	Online meeting	DTU/B&B