19 September 2024

OceanICU

Understanding Ocean Carbon

Decision Support Tools

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Project Manager, EDITO-INFRA

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Technical Coordinator EMODnet

Dr. Patrizio Mariani

Professor, DTU, Group Leader

Observation Technology

Welcome and Thank You for Joining Us Today

Co-funded by the European Union

UK Research and Innovation

This work was funded by the European Union under grant agreement no. 101083922 (OceanICU) and UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant number 10054454, 10063673, 10064020, 10059241, 10079684, 10059012, 10048179]. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Agenda

Welcome and Housekeeping

Dr. Conor Delaney, Moderator

Panellist Presentations

Dr. Jorn Bruggeman

Technical challenges of building a DST for modelling the Ocean Carbon Cycle and a live demonstration

Dr. Patrizio Mariani

The role of machine learning in the development of the decision support systems

Dr. Marina Tonani: Digital Twin Platform

The new European Digital Twin of the Ocean Infrastructure (EDITOinfra)

Questions and Answers

About Today's Format

This webinar is being video recorded

- Cameras & Microphones have been disabled
- Questions posted in the chat will not be included in the video recording so your name will not be displayed.

Questions and Answers

- Please use the chat function to ask any questions you have.
- Questions will be directed to the appropriate panellist by the moderator during the Q&A session.
- Questions & Answers covered during the session, along with any that we did not have time to respond to, will be posted in text form on the OceanICU website; a link will be sent to you in a post-webinar email communication.

Any problems or comments during or after the session:

Contact: hello@ocean-icu.eu

OceanICU Decision Support Tools for Ocean Carbon Management

Webinar 19/09/2024
Moderator: Conor Delaney, Seascape Belgium

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UK Research and Innovation

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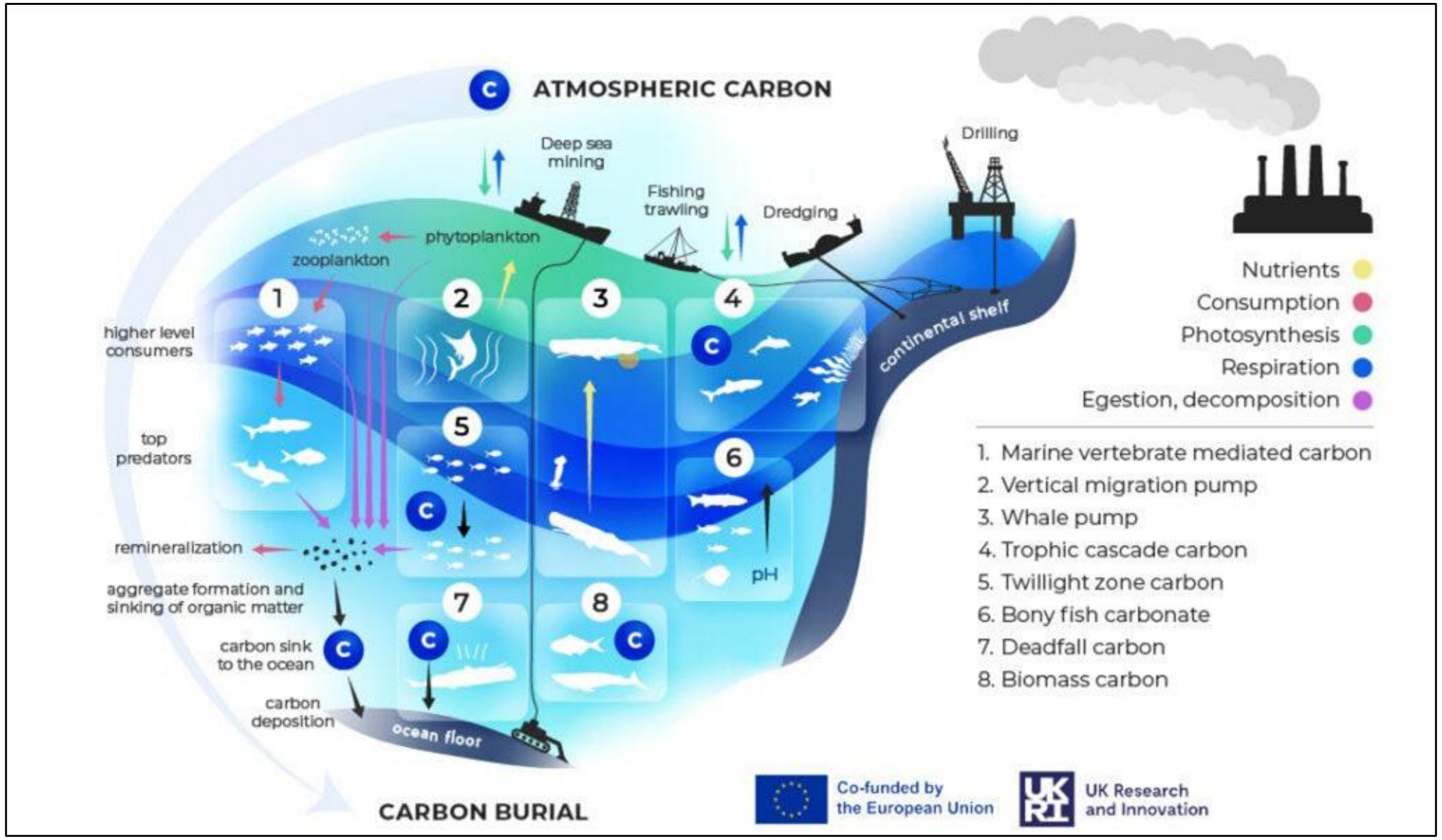
About OceanICU



Help policy makers, practitioners make better decisions on:

- Where to sample the ocean
- What will the effect of extraction pathway x be on the Ocean C cycle
- What will the combined effects of climate change and resource extraction be on the Ocean C cycle
- Combining models and data via machine learning

OceanICU webinar team

In this webinar Ocean ICU colleagues will present the foundational pillars of the Ocean ICU decision support system.

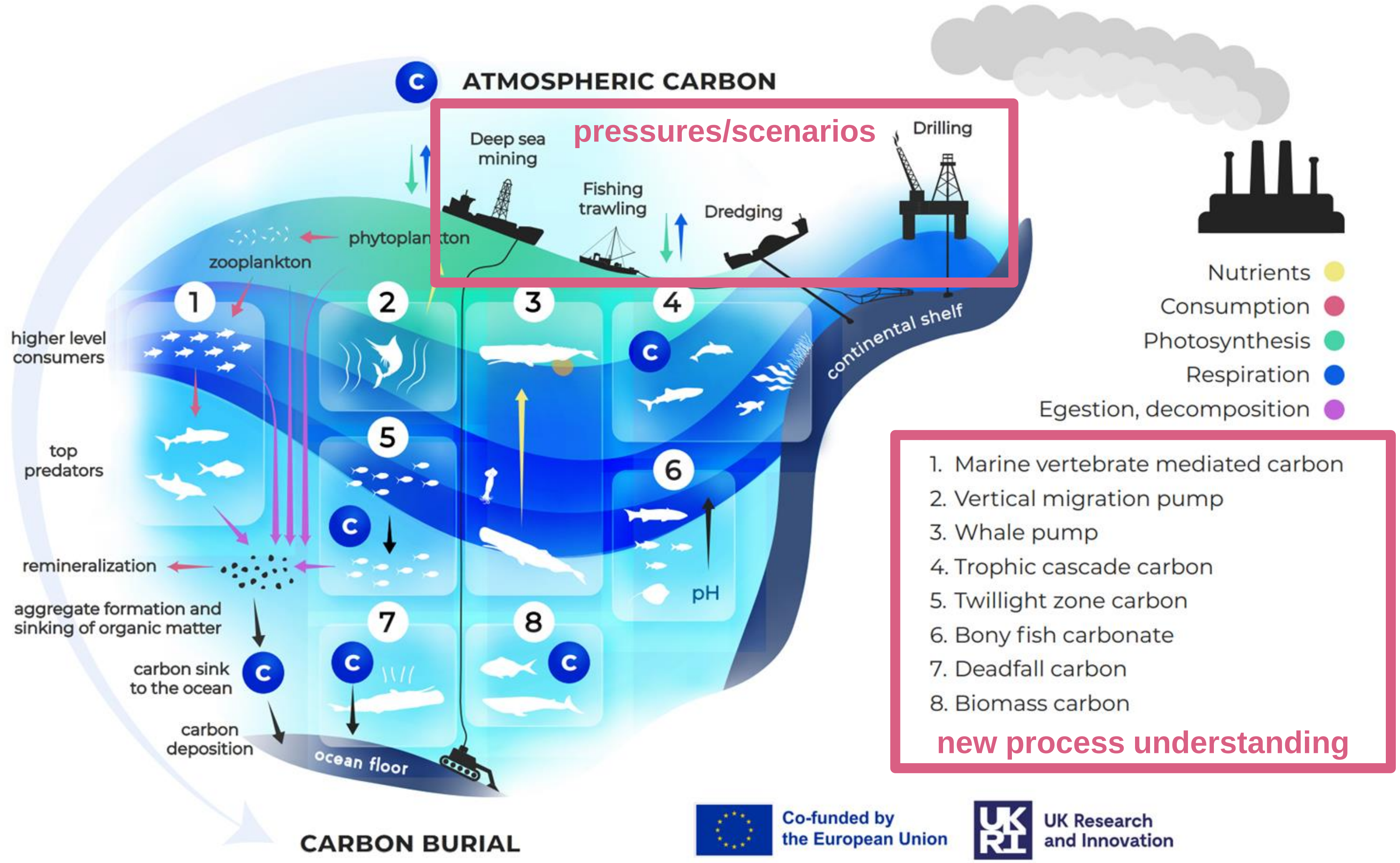
- **Jorn Bruggeman** (from **Bolding & Bruggeman**), will talk about the various aspects of building a decision support system that harnesses Big Data.
- **Patrizio Mariani** (from the **Technical University of Denmark, DTU Aqua**), will talk about the use of Machine Learning in Ocean ICU.
- **Marina Tonani** (**guest presenter** from **Mercator Ocean International** and the project manager of **EDITOinfra**), will talk about the **European Digital Twin of Ocean infrastructure (EDITOinfra)** which was launched in beta mode over the summer.

OceanICU Decision Support Tools

Jorn Bruggeman
Bolding & Bruggeman ApS

OceanICU has received funding from
the European Union HORIZON EUROPE Programme
under Grant Agreement No.101083922

About OceanICU



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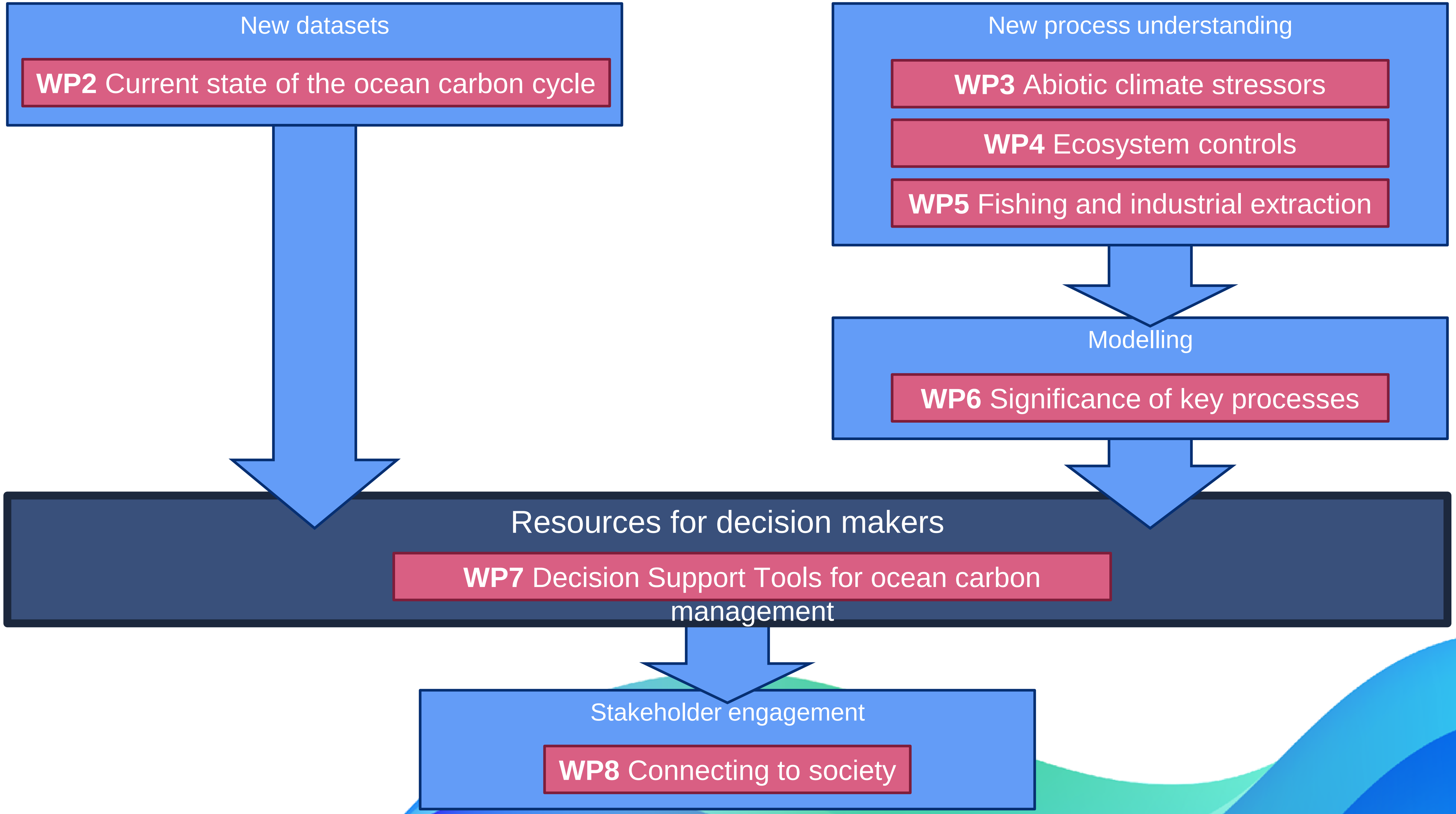
Project structure



Decision making in the marine space

From industry to policy makers

- How does the biological carbon pump feature in “everyday” questions?
  - “Should we issue licenses for mining in this area?”
  - “What quota should be set for fisheries on species x in region y?”
  - “What impact/s can we expect from climate change on fish stocks/distributions?”
  - “Should I invest in new gears or technology for environmental impact mitigation?”
  - “How do we carry out our commercial activities to minimize environmental impact?”
  - “What topics [aspects of our activities] are likely to emerge as hot button issues in policy/public opinion?”
  - “Which areas should be protected from human activity x?”

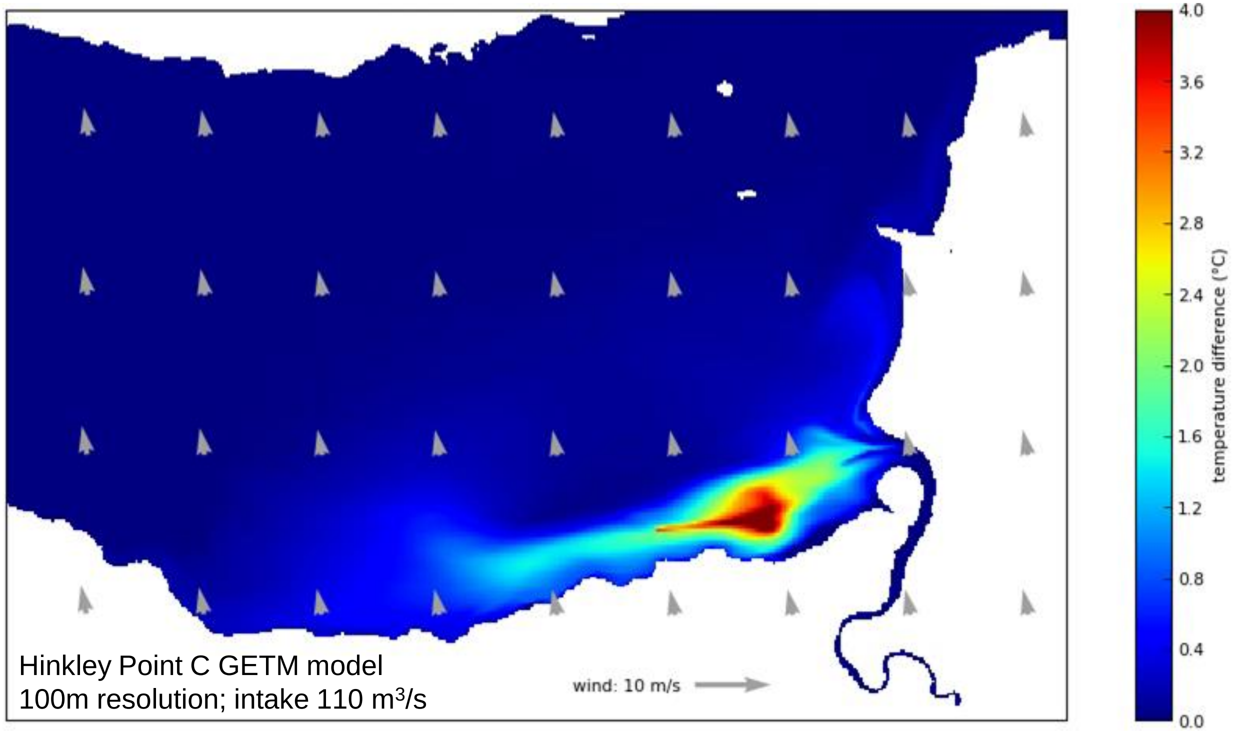
Questions tend to be *specific* – to regions, time periods, species, gears, …
They are therefore not easy to answer with generic tools

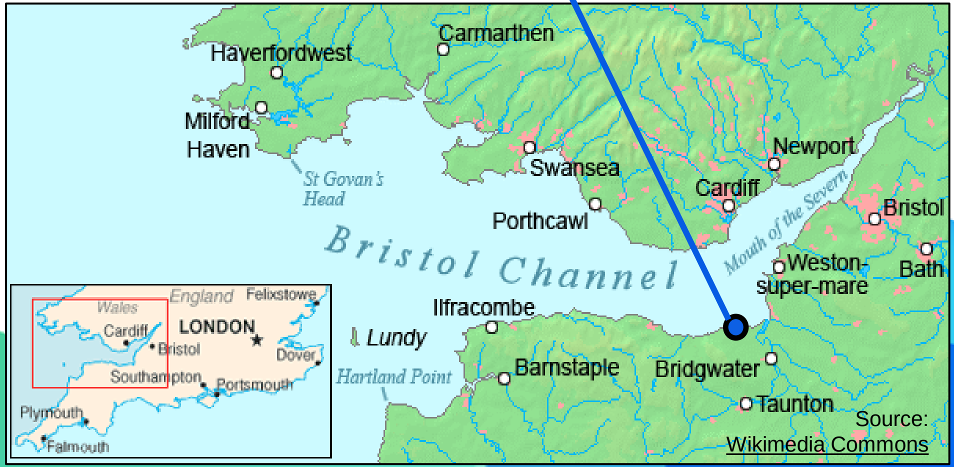
Decision making in the marine space

A real example: environmental impact assessment

- UK nuclear power station: Hinkley Point C
- Environmental Impact Assessment: £65M over 15 years
- Modelers/empiricists, modelling/literature/field work
- Not replaceable by quick automated tools in near future…

So, what do OceanICU DSTs aim to do?





Decision making in the marine space

OceanICU DST target niche and audience

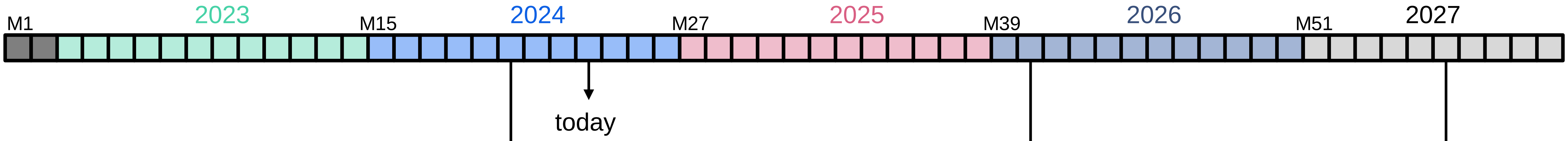
1. OceanICU DSTs can inform the very first phases of decision making and offer clear pathways to state-of-the-art EIA-type studies. For instance, its underlying model framework is capable of scaling to detailed space/time/species simulations.

2. Decision making does not happen in a vacuum. It relies on shared knowledge and understanding by all stakeholders – those making the decisions and those affected by them

   OceanICU DSTs can help stakeholders explore and understand how pressures impact the marine carbon cycle. This benefits all – from decision-makers, managers, industry stakeholders to civil society (e.g. eNGOs), indigenous groups, students, and the general public

OceanICU DSTs

Three releases over the duration of the project



DST V1: a description of pre-existing resources for decision makers Developed by, authored by, or contributed to by OceanICU partners

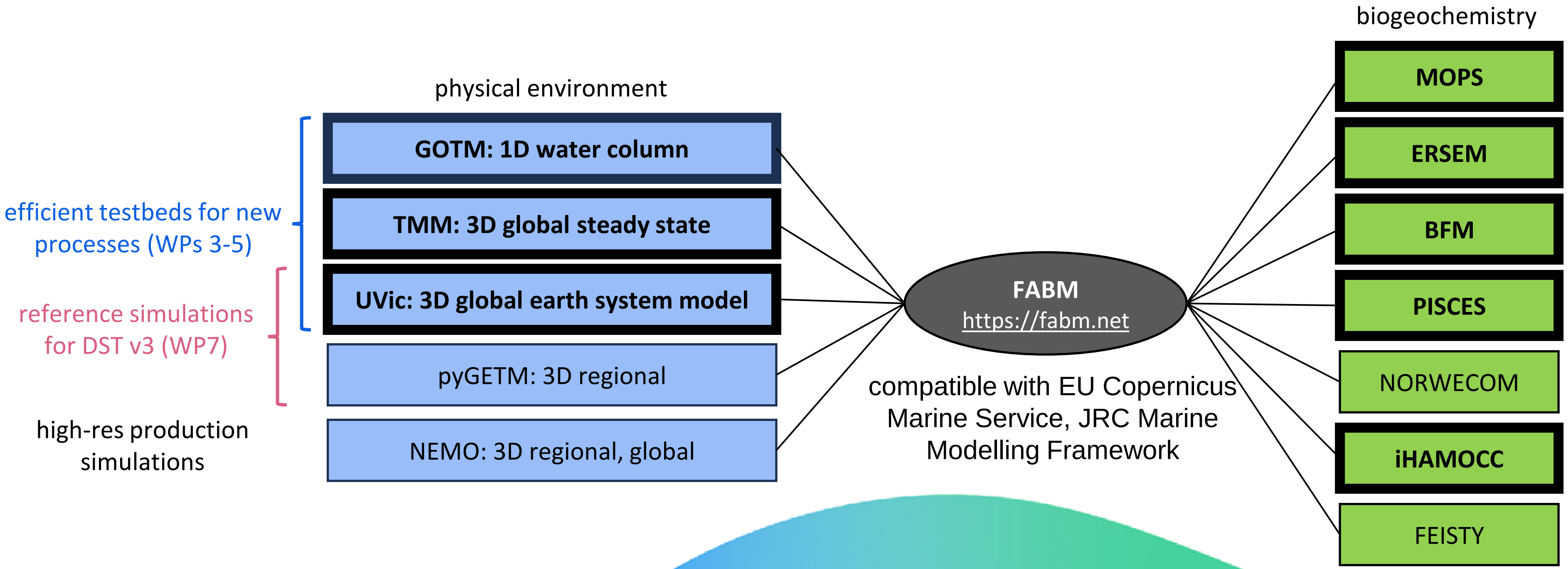
DST V2: interactive tools for idealised multi-stressor simulation and visualization Simulate effects under different scenarios and management levers (e.g., trawling, drilling, deep-sea mining and dredging). This tool will integrate new and updated process models generated in WPs 2-5 through the WP6 model platform

DST V3: an interactive machine learning-based tool for exploration of management and climate scenarios

DST V2: Tools based on process-based models

The OceanICU model framework (WP6)

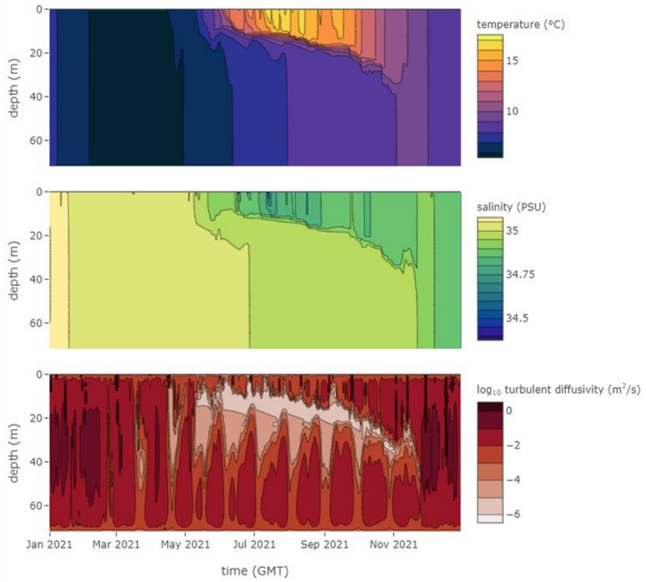
- State of the art hydrodynamics and biogeochemistry (e.g. IPCC class)
- Compatible with higher trophic level models [mizer, FEISTY, SEAPODYM]
- A range of model testbeds
- Broad model compatibility: direct pathway from testbeds to production (CMEMS, IPCC)
- New developments (WP3-5) to be folded in over course of project

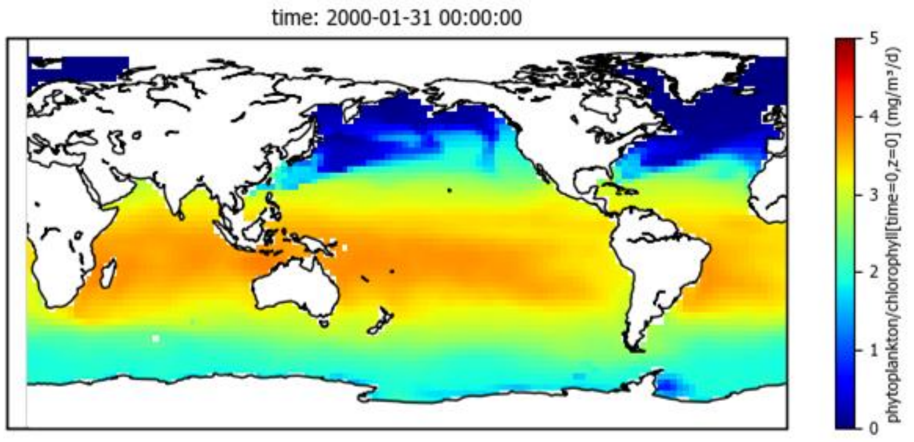


Testbeds for simulating ocean biogeochemistry

… and the compromises they make

Model	Summary	Circulation	Horizontal detail	Vertical detail	Temporal detail	Runtime per simulated year
GOTM	water column at one location	simulated	none	high: ~100 layers	real time periods, interannual variability, historical and projection	10-30 seconds
TMM	global ocean at equilibrium	pre-calculated	low: 1-3˚	low: 15-25 layers	climatology: “normal year” on repeat	30 s – 5 minutes
UVic	earth system model of intermediate complexity	simulated	low: 3.6×1.8˚	low: 19 layers	interannual variability, historical and projections	2.5 – 20 min





Concepts

1. User-configurable scenarios
Levers representing pressures

2. Live simulation
Process-based models of hydrodynamics and ecosystems

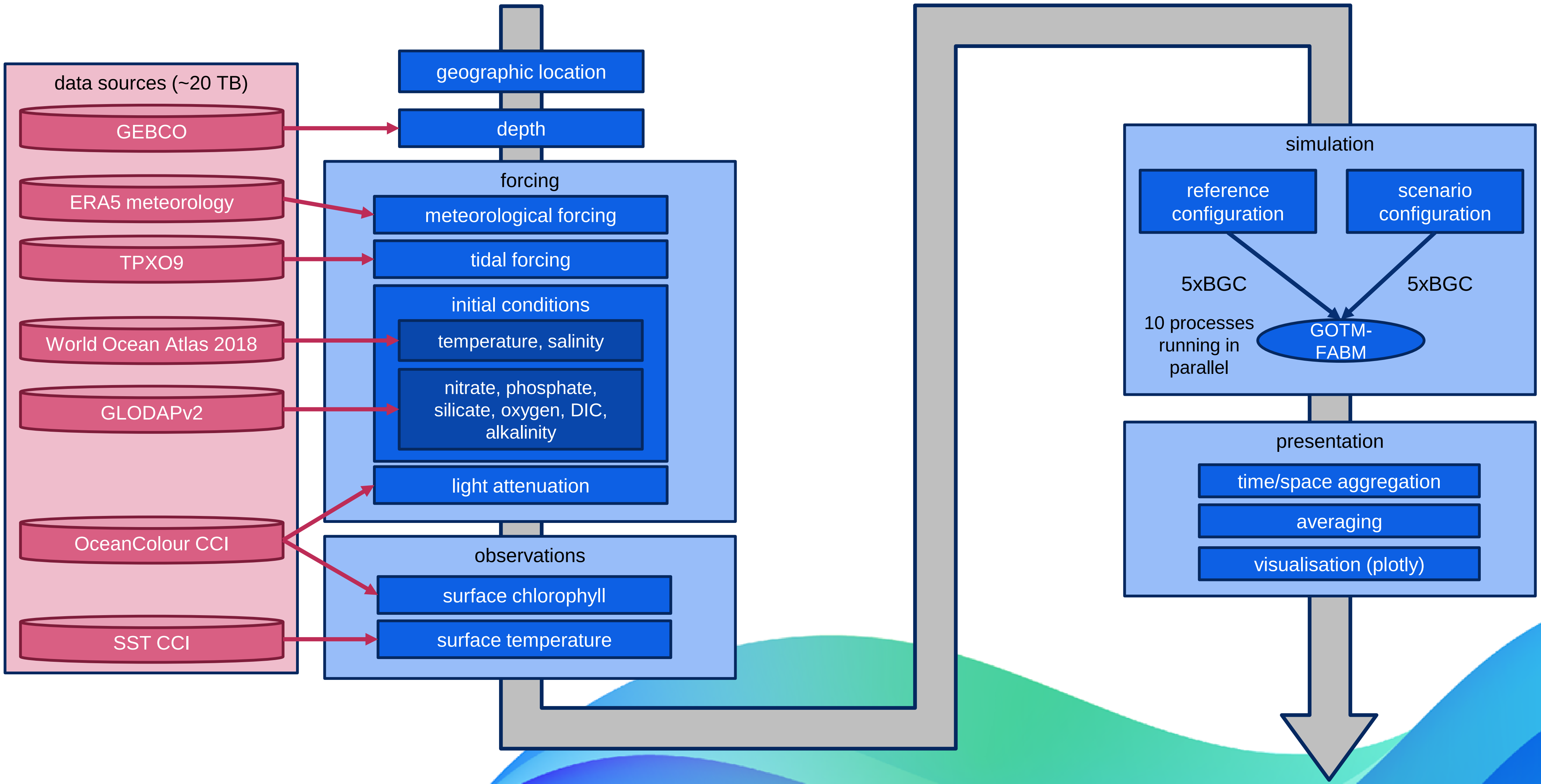
3. Analysis and visualisation
Impact on key carbon cycle metrics

All through a *responsive* web interface
simulation time of seconds, not hours/days/months

Proof of concept

https://ocean-icu.lab.dive.edito.eu

Underlying Infrastructure

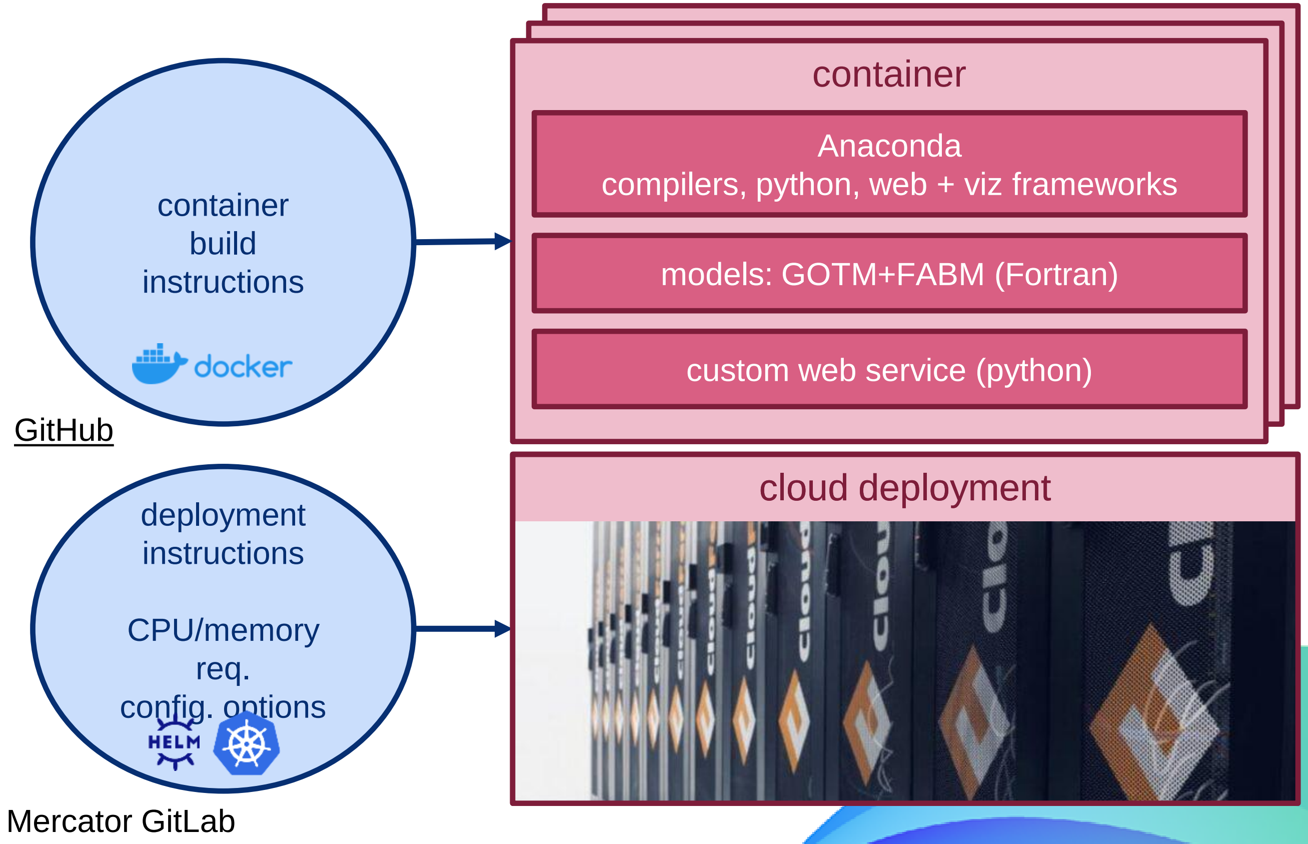


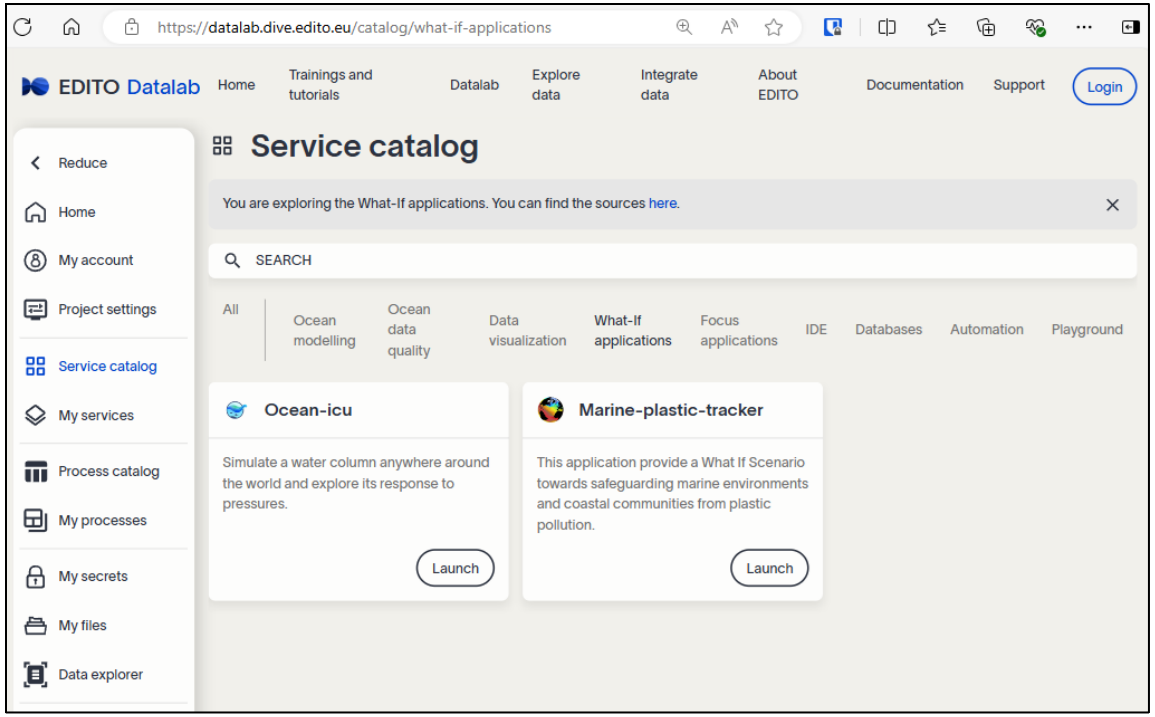
The EU Digital Twin of the Ocean

OceanICU

About the infrastructure

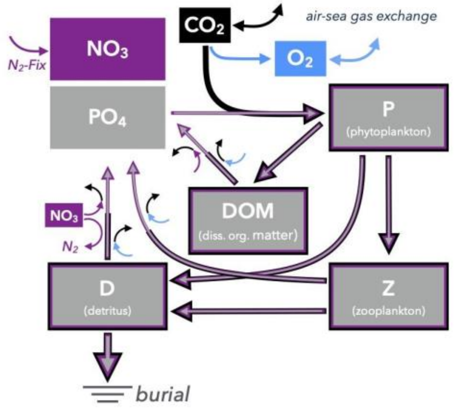
- Containerised applications
- Cloud-based computing
- Co-located with CMEMS/EMODnet data



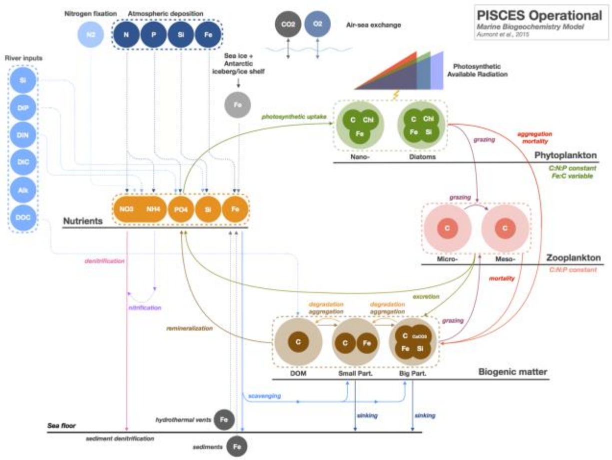


Dealing with uncertainty

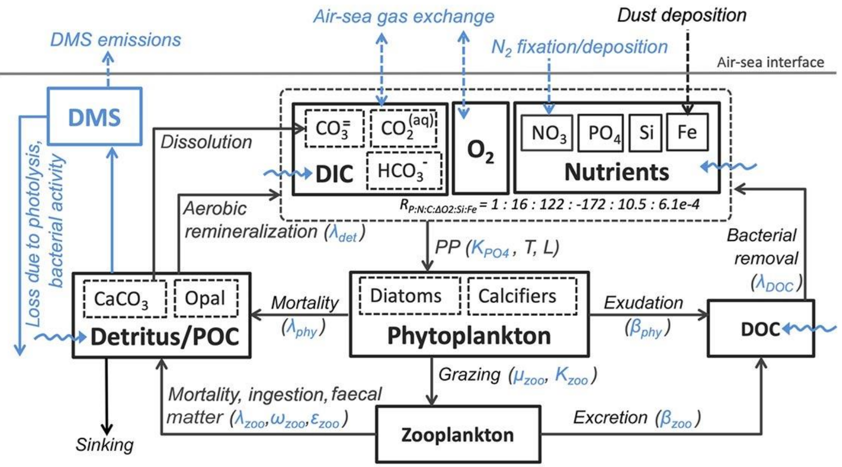
- Technical implementation: how to quantify uncertainty? [use of ensembles]
- User presentation: how best to summarise and visualise uncertainty



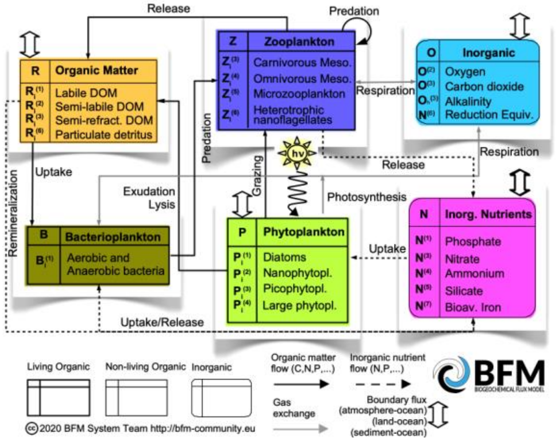
Source: https://doi.org/10.5194/gmd-8-2929-2015



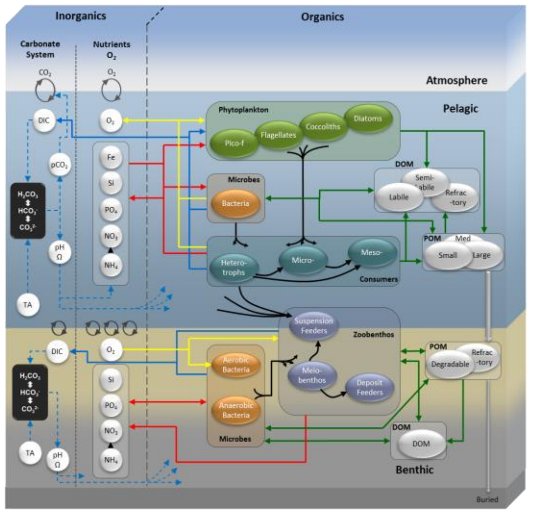
Source: https://www.pisces-community.org



Source: https://doi.org/10.5194/gmd-13-2393-2020



Source: https://bfm-community.github.io



Source: https://pml.ac.uk

What's next?

Mid-term

- Additional pressures
  - fishing, mining … plus implementation of supporting models
- Scenario development
  - Translating lever settings to model/scenario parameterisations
- Result presentation
  - Selection of metrics
  - Visualising right level of detail

Long-term

- Quality control and documentation
  - Can transparency/traceability safeguard against misinterpretation/cherry picking/abuse?
- Fast model emulators based on Machine Learning (DST V3)
  - Underpinned by process-based regional and global simulations under a range of scenarios

OceanICU
Understanding Ocean Carbon

Towards Earth system model emulators for ocean carbon export

Webinar 19/09/2024

Panellist: Patrizio Mariani - Technical University of Denmark

DTU Danmarks Tekniske Universitet

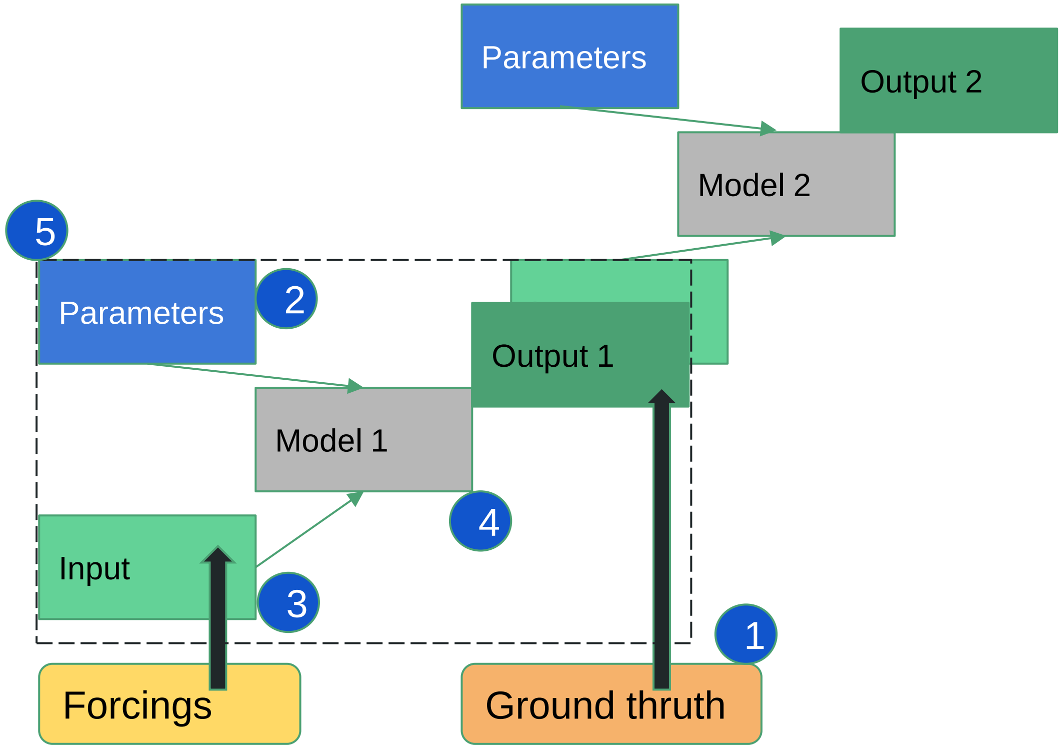
OceanICU has received funding from
the European Union HORIZON EUROPE Programme
under Grant Agreement No.101083922

Use of deep learning in Earth system science

Given the development in hardware, software and data, there are several initiatives to use those tools to improve the science we do

A central focus is on Earth system science where AI can play several roles

1. **Data assimilation**
1. **Parameters Optimization**
1. **Input optimization**
1. **Hybrid modeling**
1. **Model emulator => DST**



PERSPECTIVE

https://doi.org/10.1038/s41586-019-0912-1

Deep learning and process understanding for data-driven Earth system science

Markus Reichstein[1,2*], Gustau Camps-Valls[3], Bjorn Stevens[4], Martin Jung[1], Joachim Denzler[2,5], Nuno Carvalhais[1,6] & Prabhat[7]

IPCC emulator

AR6 WG1 2021, The Physical Science Basis

Climate model emulators are physically based models used to approximate large-scale climate responses of Earth system models

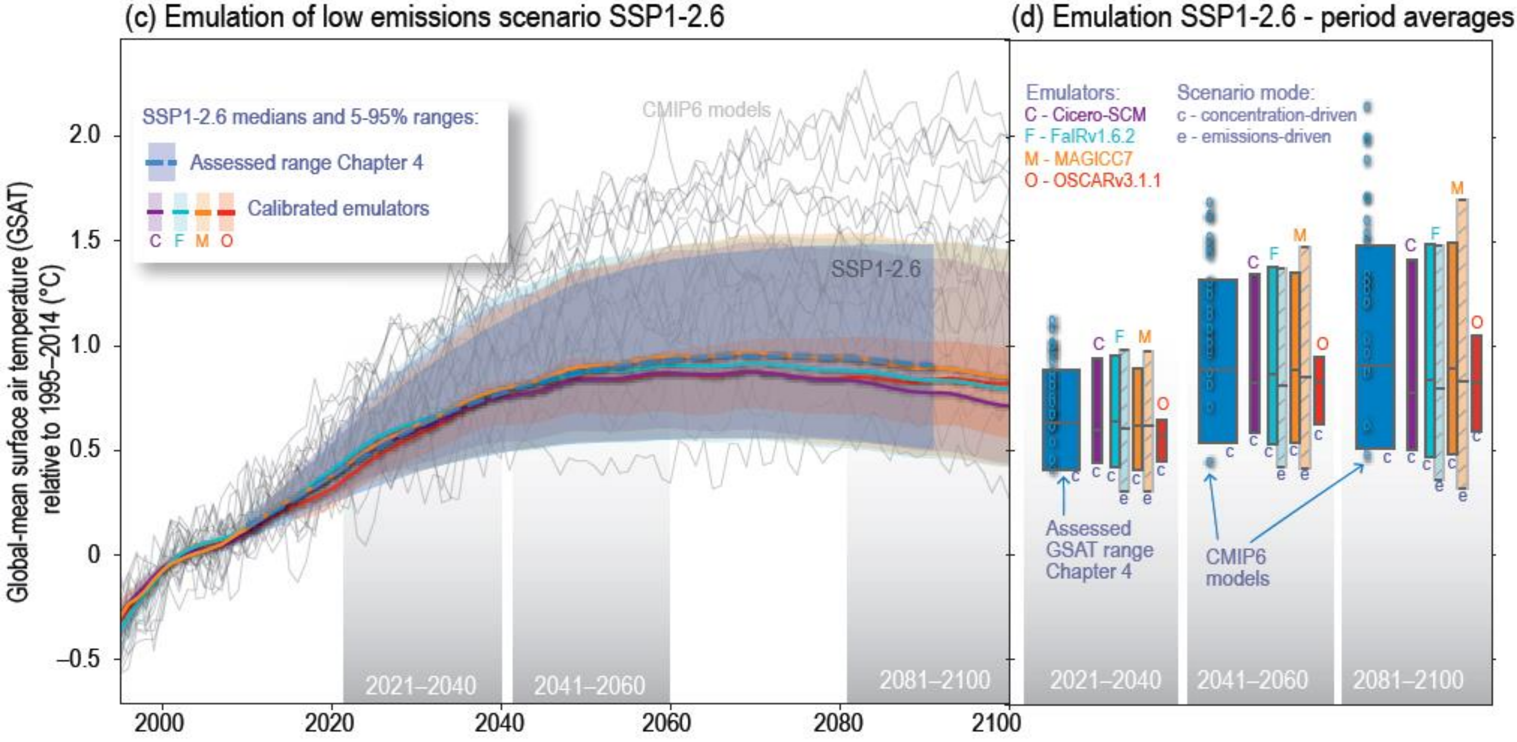
Emulator types:

- MAGICC7
- FaIRv1.6.2
- CICERO-SCM
- OSCARv3.1.1
- ….

Overall, there is high confidence that emulated historical and future ranges of GSAT change can be calibrated to be internally consistent with the assessment of key physical-climate indicators

Cross-Chapter Box 7.1 | Physical Emulation of Earth System Models for Scenario Classification and Knowledge Integration in AR6

Contributors: Zebedee R.J. Nicholls (Australia), Malte Meinshausen (Australia/Germany), Piers Forster (United Kingdom), Kyle Armour (United States of America), Terje Berntsen (Norway), William Collins (United Kingdom), Christopher Jones (United Kingdom), Jared Lewis (Australia/New Zealand), Jochem Marotzke (Germany), Sebastian Milinski (Germany), Joeri Rogelj (United Kingdom/Belgium), Chris Smith (United Kingdom)



doi:10.1017/9781009157896.

Deep learning emulators in Earth system science

OceanICU

Climate modeling

Weather forecasting

Downscaling

Carbon cycle modeling

Emulators can help simulating carbon fluxes between the atmosphere, biosphere, and oceans, improving the representation of the carbon export in the ocean

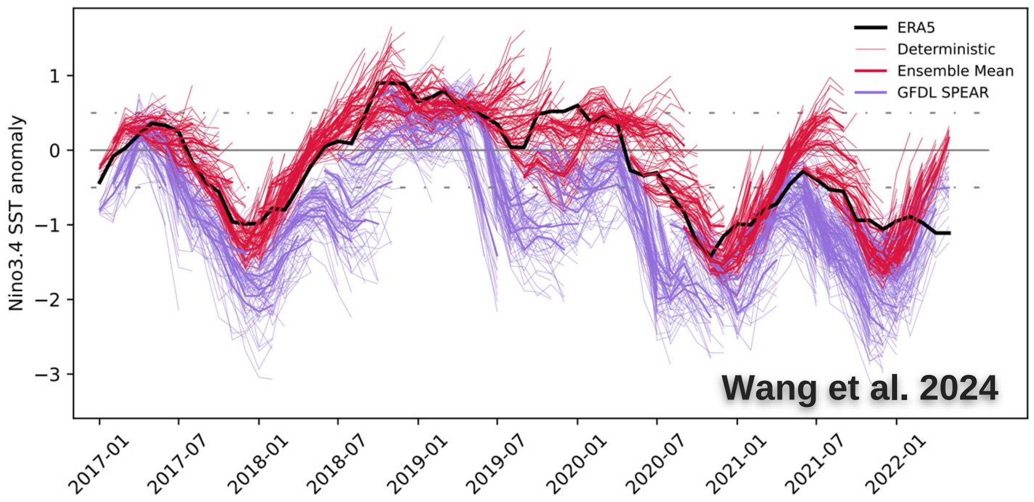
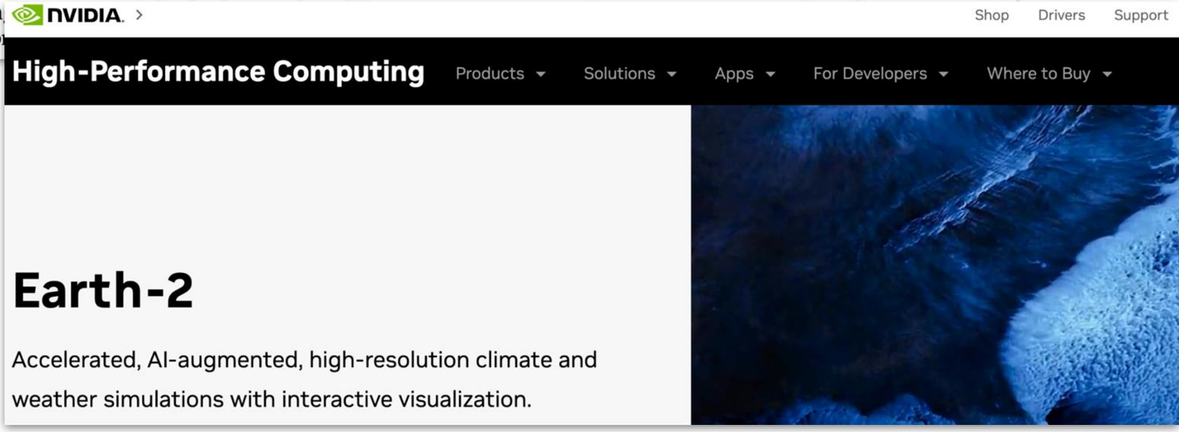


Figure 1: Sea Surface Temperature (SST) anomaly in the Niño 3.4 region of the Pacific Ocean (5°N to 5°S, 170°-120°W) from 6-month ensemble forecasts generated by the coupled AI/ML ESM Ola(light red lines) and the physics-based model GFDL-SPEAR (light purple lines). Lagged Ensemble Forecasts (see Sec. 4.4 for details) are generated at the beginnin[g] correspo[…]



https://www.nvidia.com/en-in/high-performance-computing/earth-2/

Challenge

Need to calibrating AI tools for impact-response and management simulations

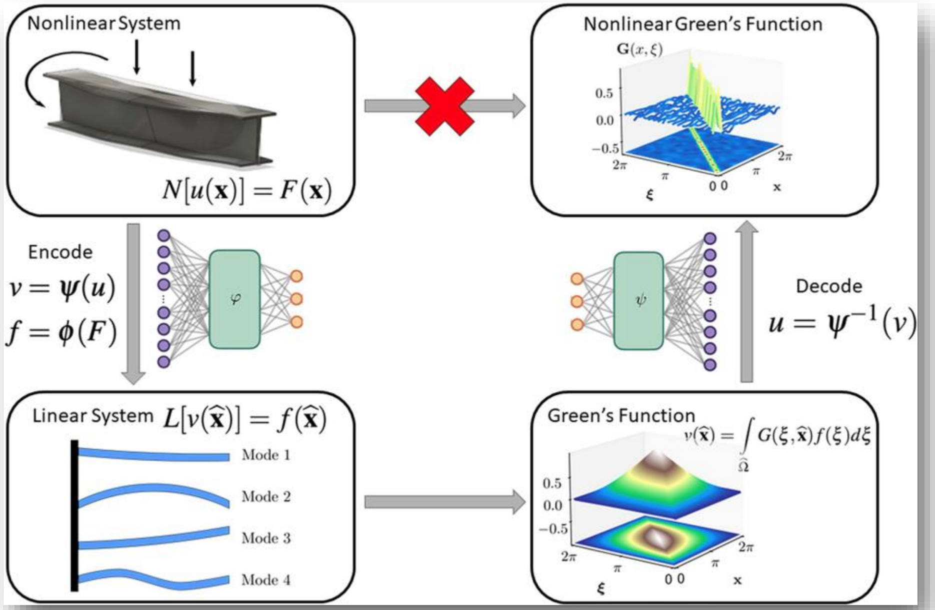
$$dY(x,t) = \int K(x,t,x',t')dZ(x',t')dx', dt'$$

Where dY(x,t) is response at (x,t) given impact dZ(x',t') at (x',t').

A null model for the response kernel K is

$$K(x,t,x',t') = K_0 exp\left(\frac{-(x-x')}{dx}\right) exp\left(\frac{-(t-t')}{dt}\right) \mu(x-x')\mu(t-t')$$

This can be compared to more advanced derivation of the non linear kernel function using deep learning method (autoencoder / decoder methods)




scientific reports

Check for updates

OPEN DeepGreen: deep learning of Green's functions for nonlinear boundary value problems

Craig R. Gin, Daniel E. Shea, Steven L. Brunton & J. Nathan Kutz

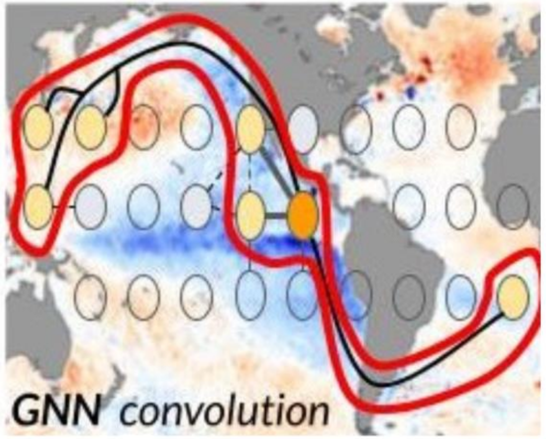
[3] Gin et al 2021. DeepGreen: deep learning of Green's functions for nonlinear boundary value problems Scientifi Reports, *https://doi.org/10.1038/s41598-021-00773-x*

Emulators

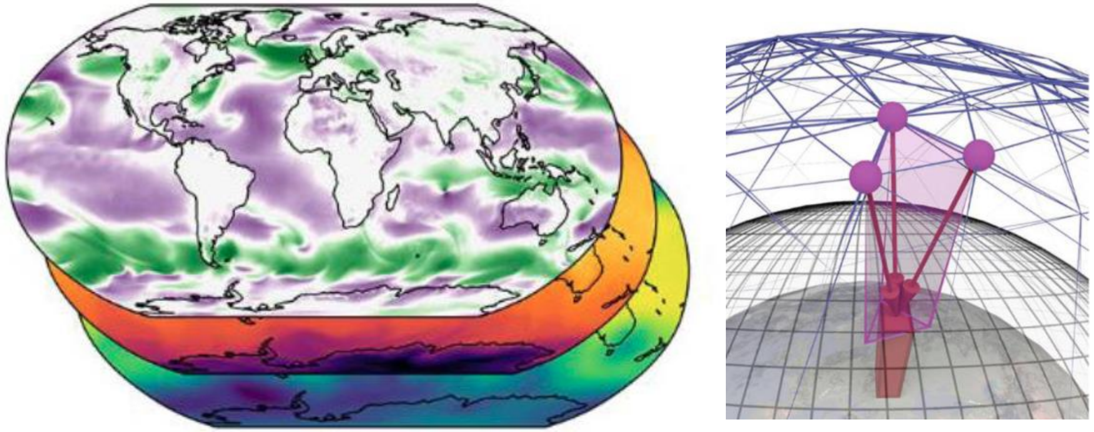
Graph Neural Networks

- Graph Neural Networks (GNNs) are widely used for capturing spatial interactions
- Often combined with Recurrent Neural Networks (RNNs) for capturing temporal correlations as well
- Many success stories for spatio-temporal data in various domains

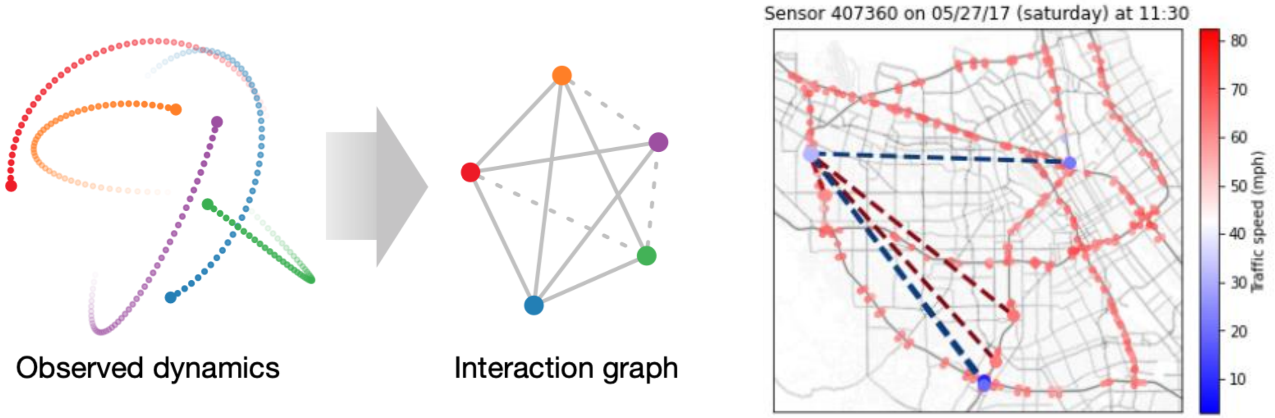
Modelling El Niño events [2]



Forecasting weather [1]



Modelling road traffic [3]

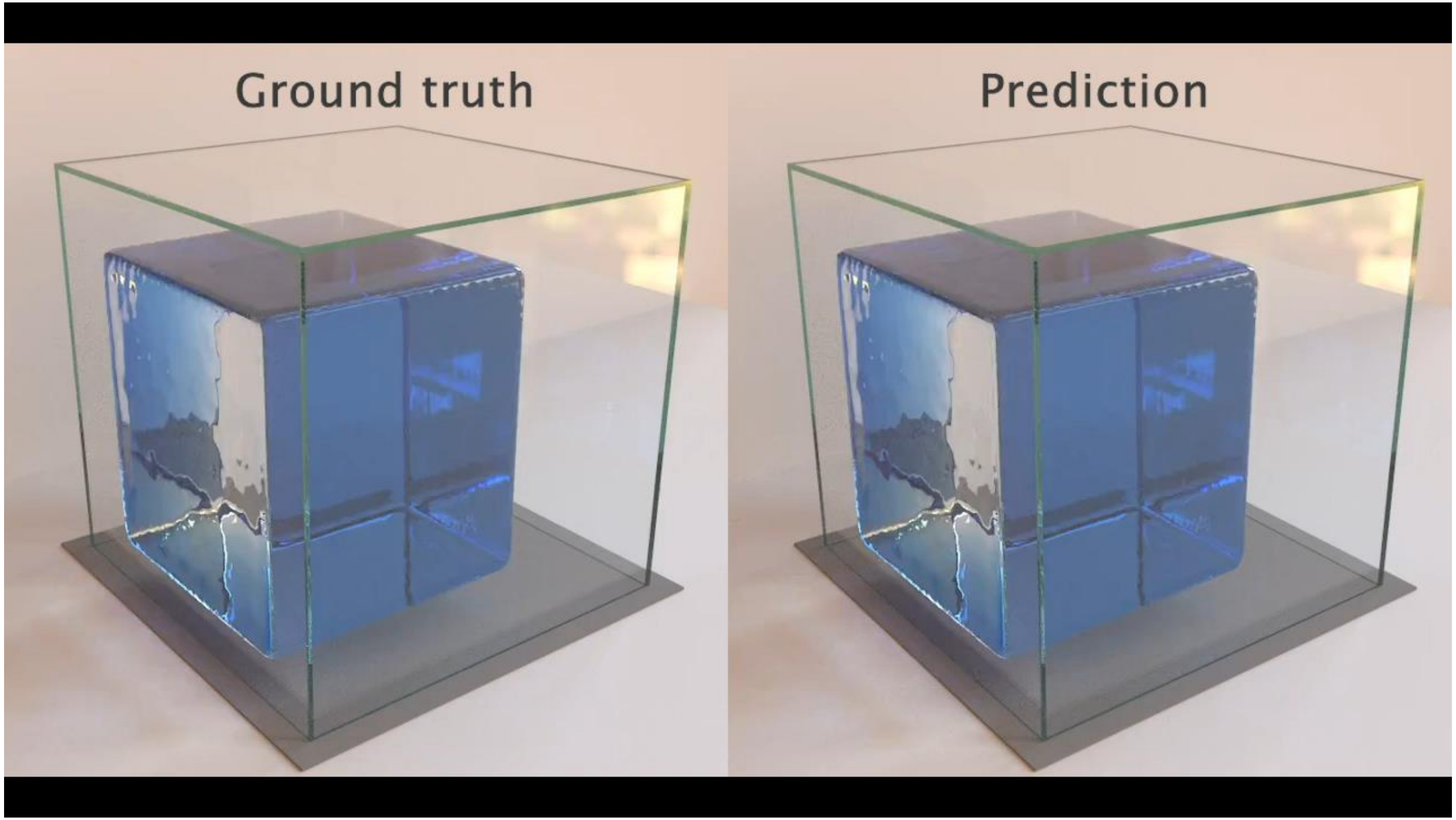


[1] Lam, R., Sanchez-Gonzalez, A., Willson, M., Wirnsberger, P., Fortunato, M., Alet, F., Ravuri, S., Ewalds, T., Eaton-Rosen, Z., Hu, W. and Merose, A., 2023. Learning skillful medium-range global weather forecasting. Science.
[2] Cachay, S.R., Erickson, E., Bucker, A.F.C., Pokropek, E., Potosnak, W., Bire, S., Osei, S. and Lütjens, B., 2021. The World as a Graph: Improving El Niño Forecasts with Graph Neural Networks. *arXiv preprint arXiv:2104.05089.*
[3] Tygesen, M.N., Pereira, F.C. and Rodrigues, F., 2023. Unboxing the graph: Towards interpretable graph neural networks for transport prediction through neural relational inference. Transportation research part C: emerging technologies.

Emulators

Graph Neural Networks

- Learning to simulate fluids and complex materials [1]



[1] Sanchez-Gonzalez, A., Godwin, J., Pfaff, T., Ying, R., Leskovec, J. and Battaglia, P., 2020, November. Learning to simulate complex physics with graph networks. In International conference on machine learning (pp. 8459-8468). PMLR.

Developments in OceanICU

Strategy towards the development of carbon export emulators

- Large climate model ensembles from the latest climate models (CIMP6) are now available in the cloud, hence next to tremendous computing power
- This includes ensembles of climate simulations exploring scenario uncertainty, model uncertainty and natural variability
- Develop simple physically constrained emulators able to capture spatial and temporal dynamics of ESMs
- Training the emulator over combinations of complimentary ensembles to appropriately sample the phase space
- Both causal constrained emulators and physically constrained will be explored (possibly within a GNN architecture)
- Further train the developed emulators using Ocean ICU based model output (i.e., from UVic + Feisty and GETM+ERSEM) can tailor predictions on the effects of different levers of change

Developments in OceanICU

Next steps

- **Recruit a postdoc at DTU for the ESM Emulator**
- Start by using the CIMP6 resources either via cloud or locally
- First toy model developed for GNN approaches to climate
- Tailor the emulator based on end user interests
- Source model and data from OceanICU consortium
- First complete version Mid 2026

Thank you!

Understanding Carbon Ocean

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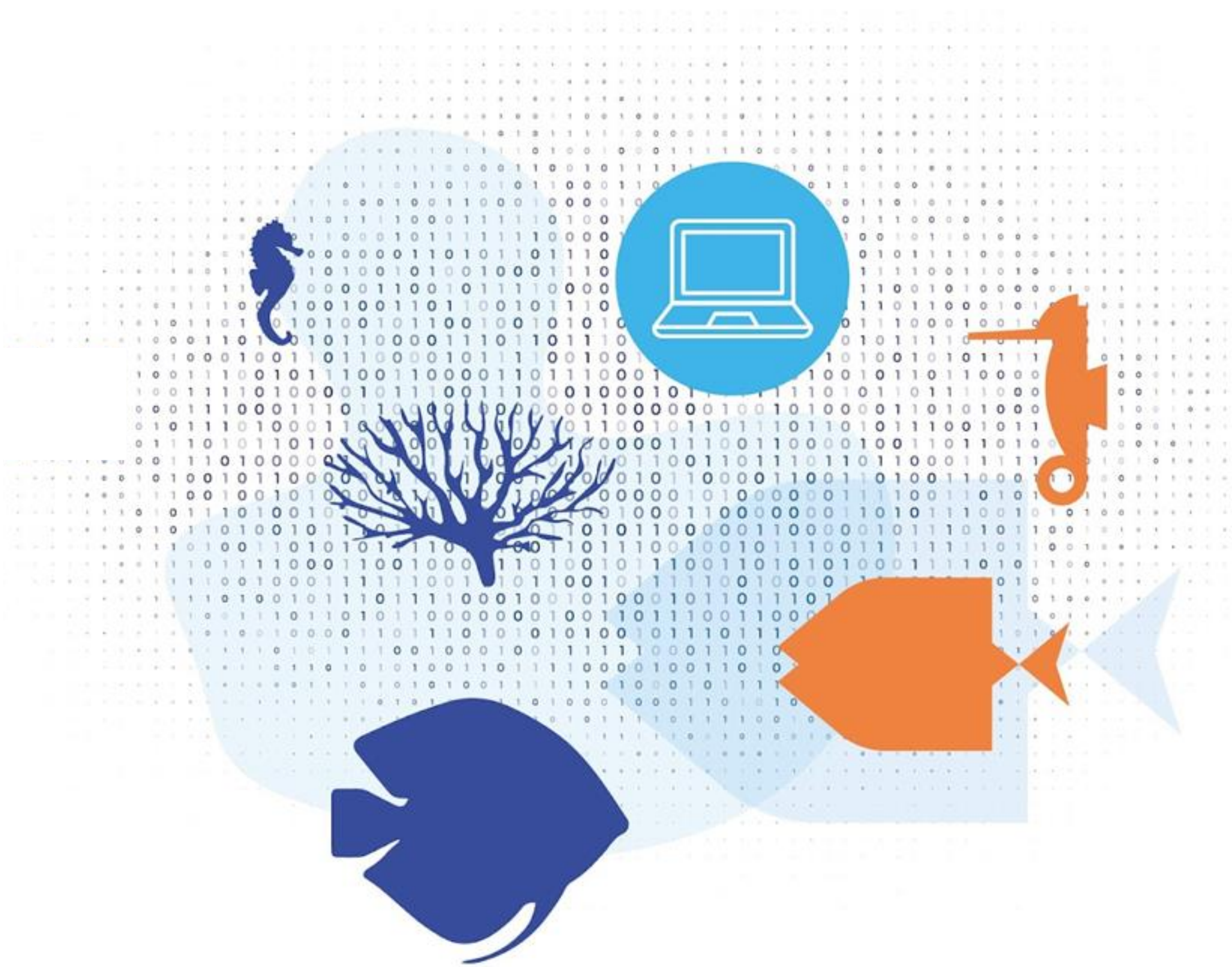
EU Digital Twin of the Ocean



Marina Tonani – Mercator Ocean International
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EU MISSIONS
RESTORE OUR OCEAN & WATERS

EDITO European Digital Twin Ocean
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EMODnet European Marine Observation and Data Network
Copernicus Marine Service
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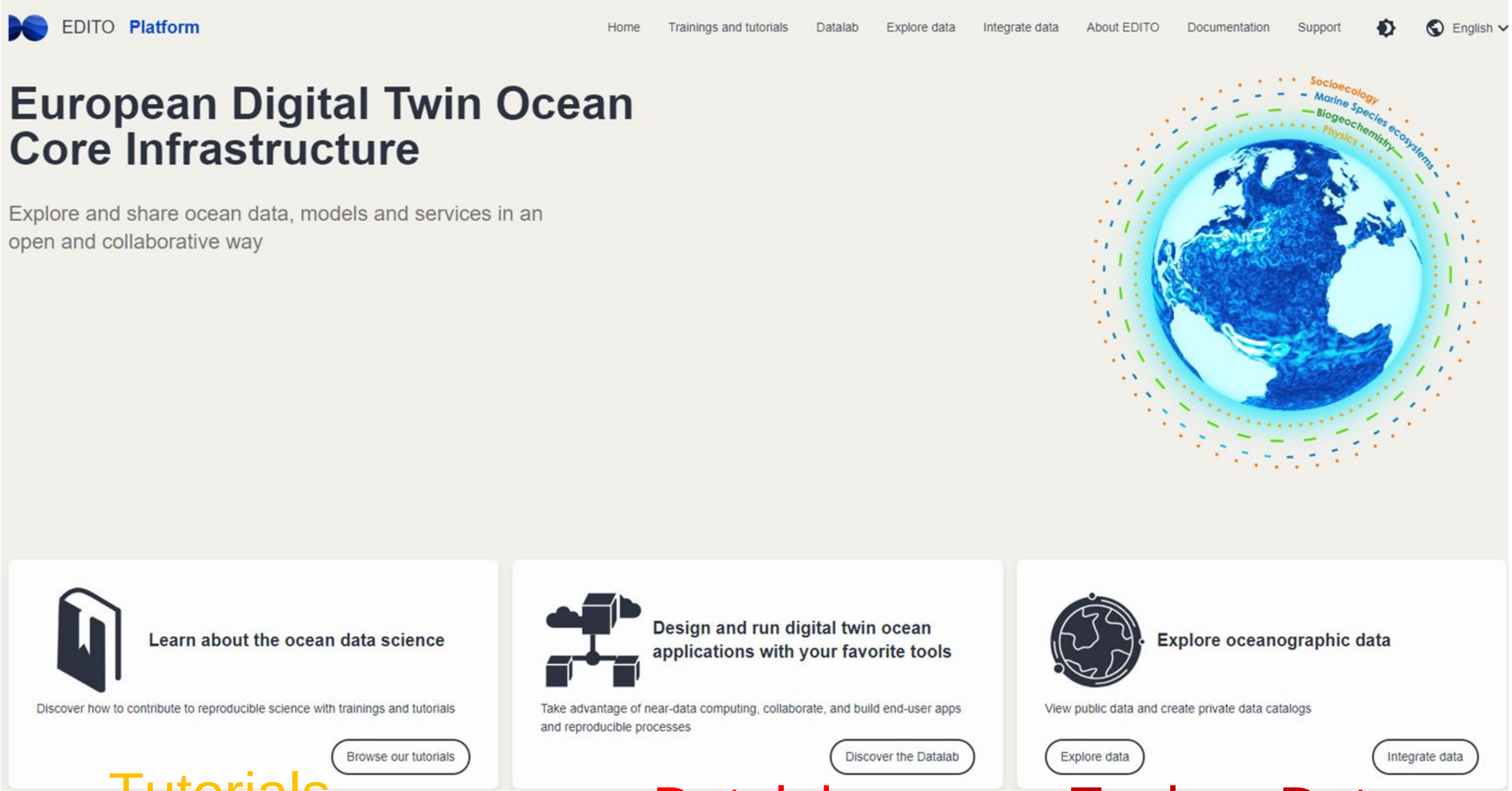
European Digital Twin of the Ocean

A leap in ocean knowledge and sustainable action

The European DTO Offer

EDITO platform overview

https://dive.edito.eu



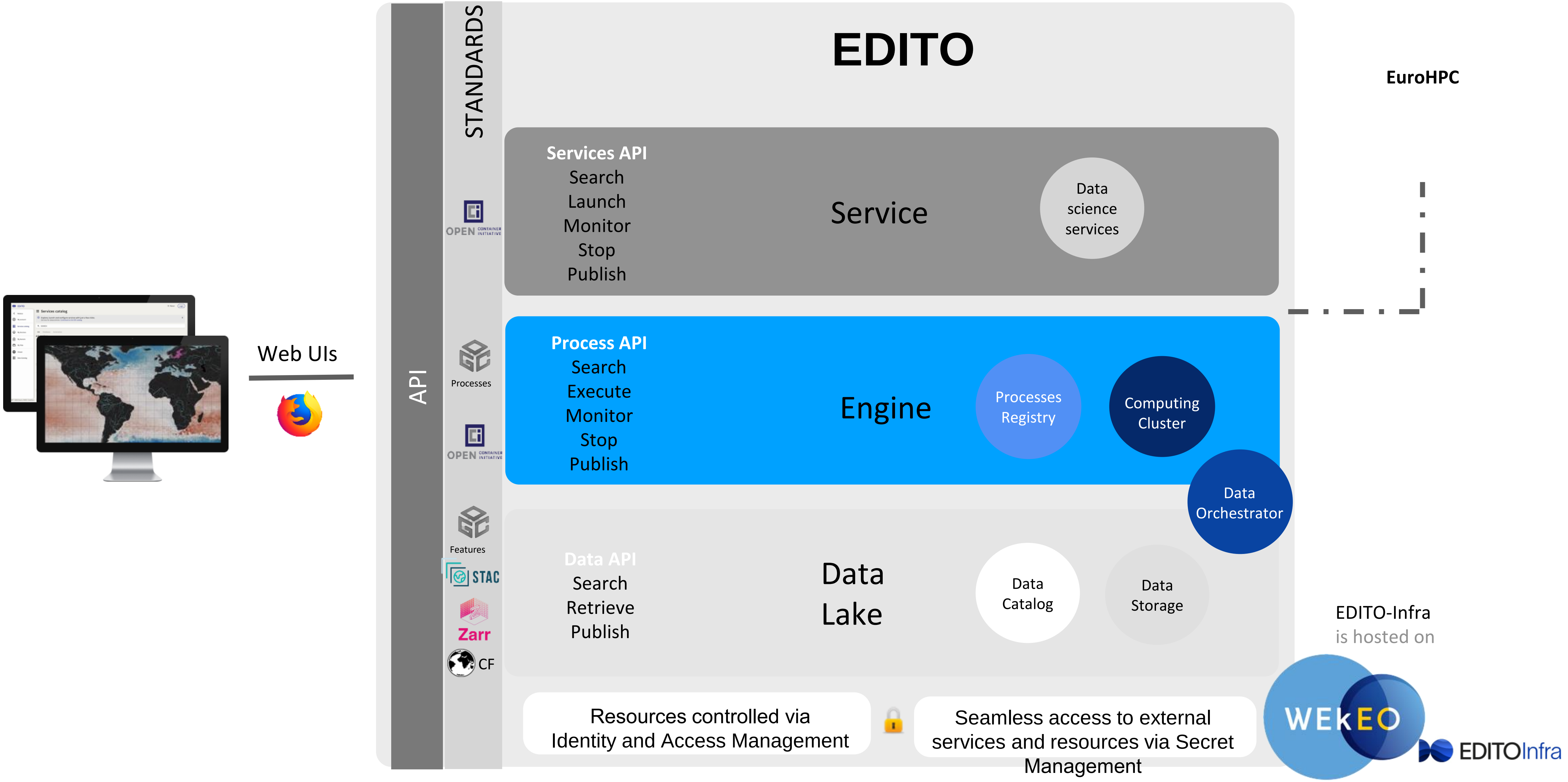
Tutorials

Datalab

Explore Data

EDITOInfra

EDITO architecture



Thanks for your attention

*…"This is why we got to the moon and back, it is because people were **inspired**, and people **felt part of it** "*

by John Bell, Digital Ocean Forum 2023

OceanICU

Do you work in a blue economy industry such as fishing, mining, offshore renewable energy, tourism or oil and gas?

Are you a manager, decision-maker, scientist or policy-maker?

Or are you a citizen interested in climate change and its relationship with a sustainable blue future?

If any of these apply to you, why not join us?

Get in touch via the sign-up form to join our stakeholder panels.

SIGN UP

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Questions & Answers

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