Inspire

How to monitor the Ocean?

15:00-16 :00 Ocean models : the numerical ocean in four dimensions

16:00-17:00 EDITO model lab : What-If scenario training workshop

17:00-18:00 MER-EP kick off event

Copernicus
Europe's eyes on Earth

EU MISSIONS
RESTORE OUR OCEAN & WATERS

Copernicus
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Questions & Answers

Join at

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2 - 13 JUNE 2025

How to monitor and forecast the ocean with models?

5th June 2025

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How to monitor the Ocean?

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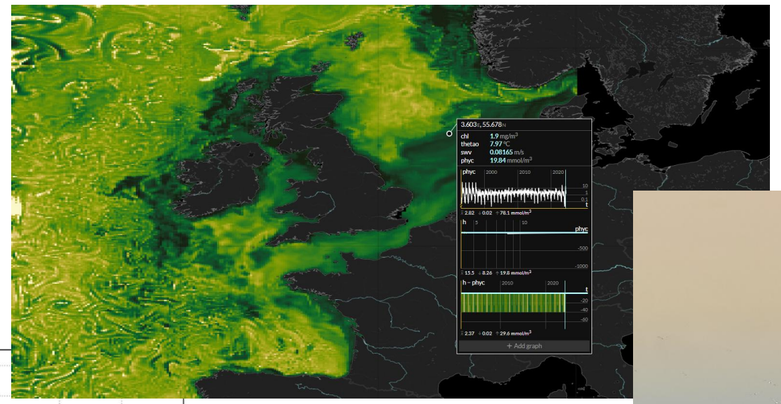
How to monitor the Ocean?

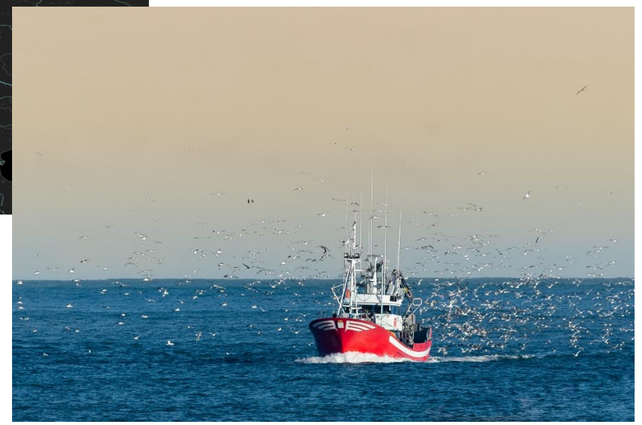
Dr Andy Saulter

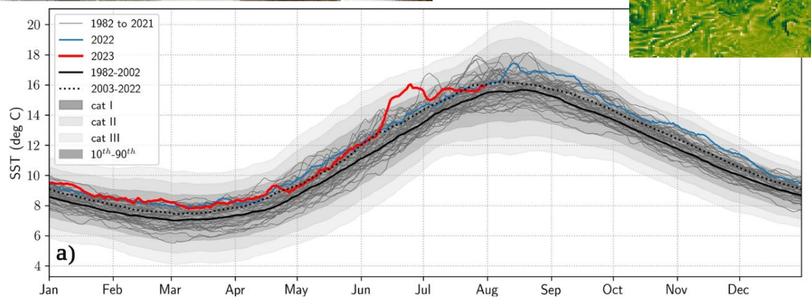
Met Office, United Kingdom

Met Office

Why monitor and forecast the ocean?







People have always needed to understand the sea: whether to know the sea's moods for safe transit, the movement of the tides or how to find food

In our modern world these needs stand and we must also ask other questions

- How can we use the ocean sustainably?
- How do we prevent and mitigate pollution?
- What does climate change mean for the ocean's behaviours and our own wellbeing?

Monitoring and forecasting give us evidence based tools to help answer these questions

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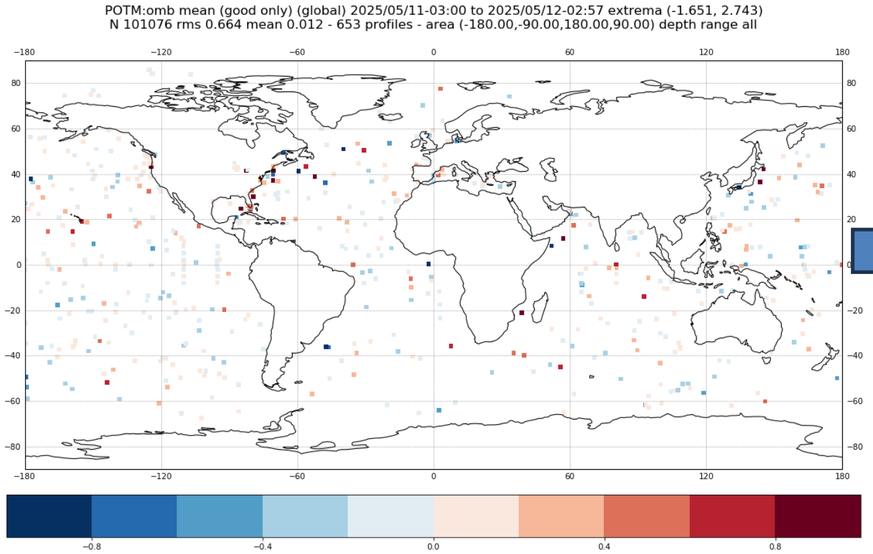
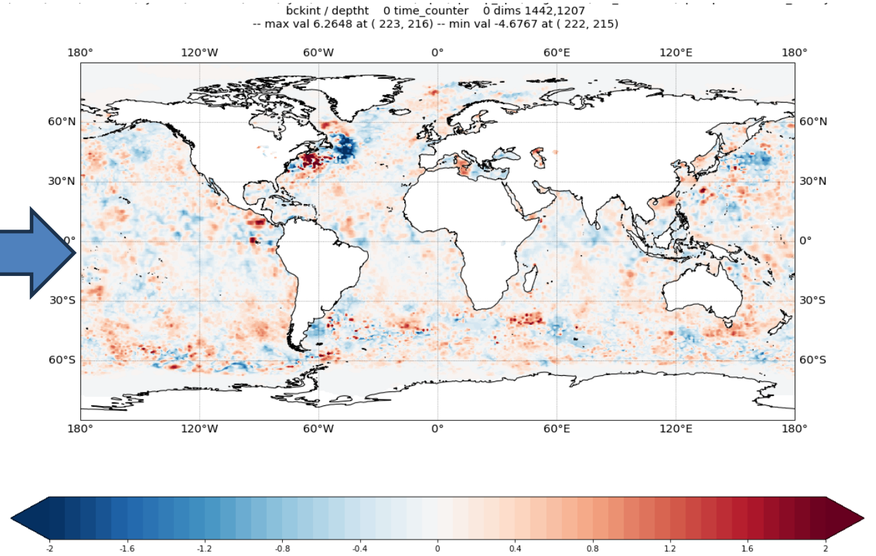
Why model? Extending our ocean knowledge in space and time



Observations



Corrections to gridded model

Observations of the ocean are an incredibly valuable resource – but literally 'only scratch the surface' of the ocean knowledge we need

Models allow us to distribute this information in space

Models allow us to estimate future states

Modelling presents an opportunity to create homogenous information with which we can interact to explore how our behaviours influence the ocean's response and vice versa (e.g. through Digital Twins)

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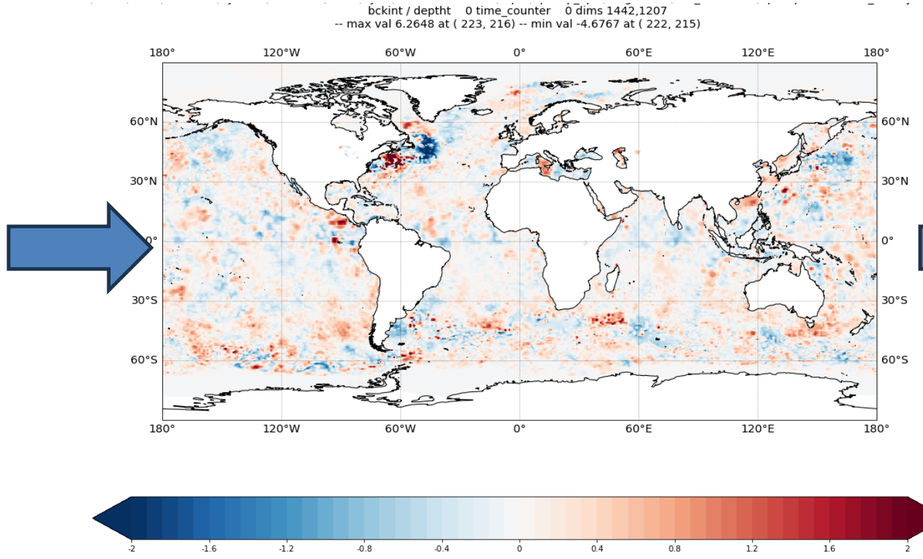
Why model? Extending our ocean knowledge in space and time



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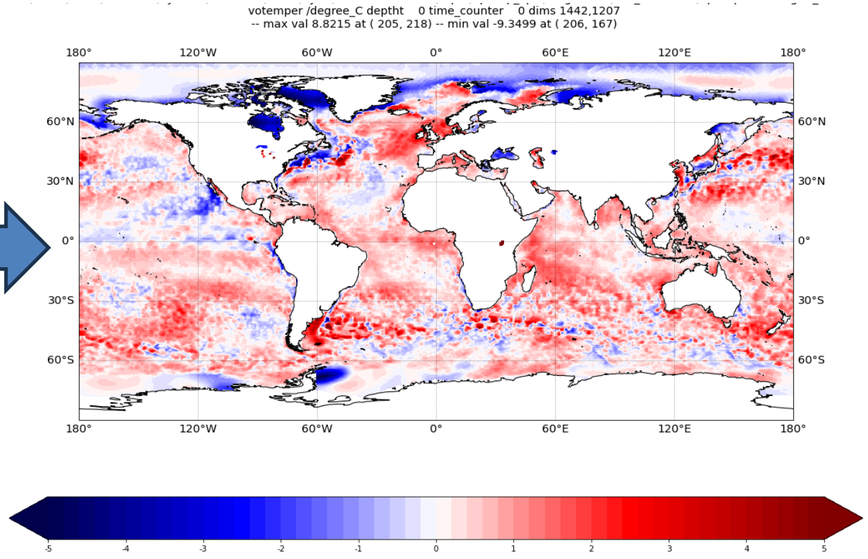

Gridded analysis – status now

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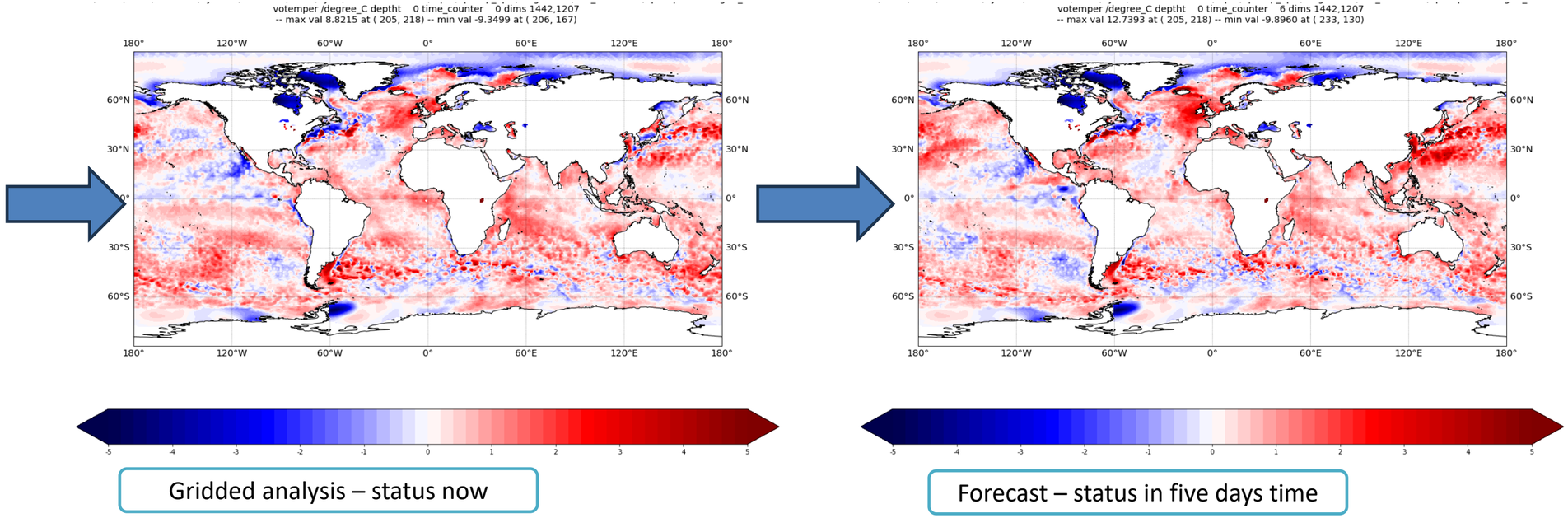

Gridded analysis – status now

Forecast – status in five days time

Observations of the ocean are an incredibly valuable resource – but literally 'only scratch the surface' of the ocean knowledge we need

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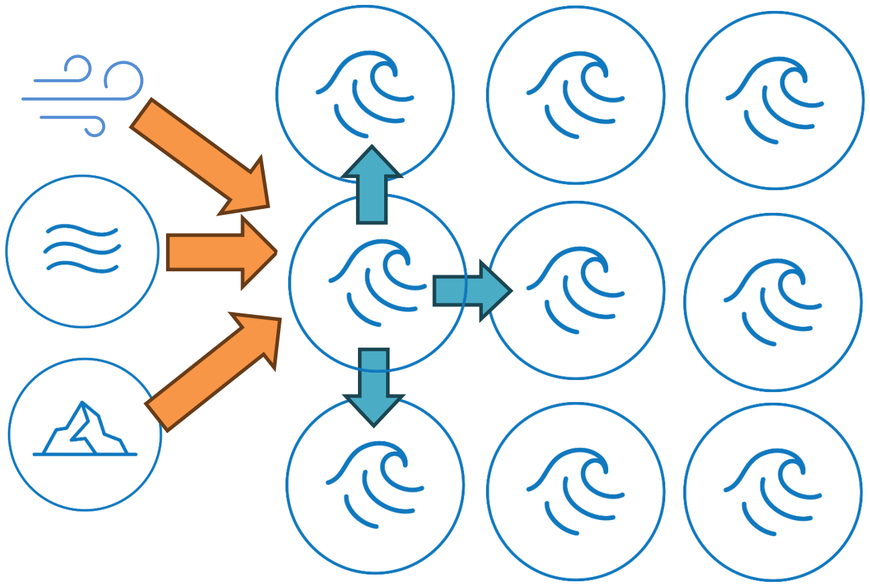
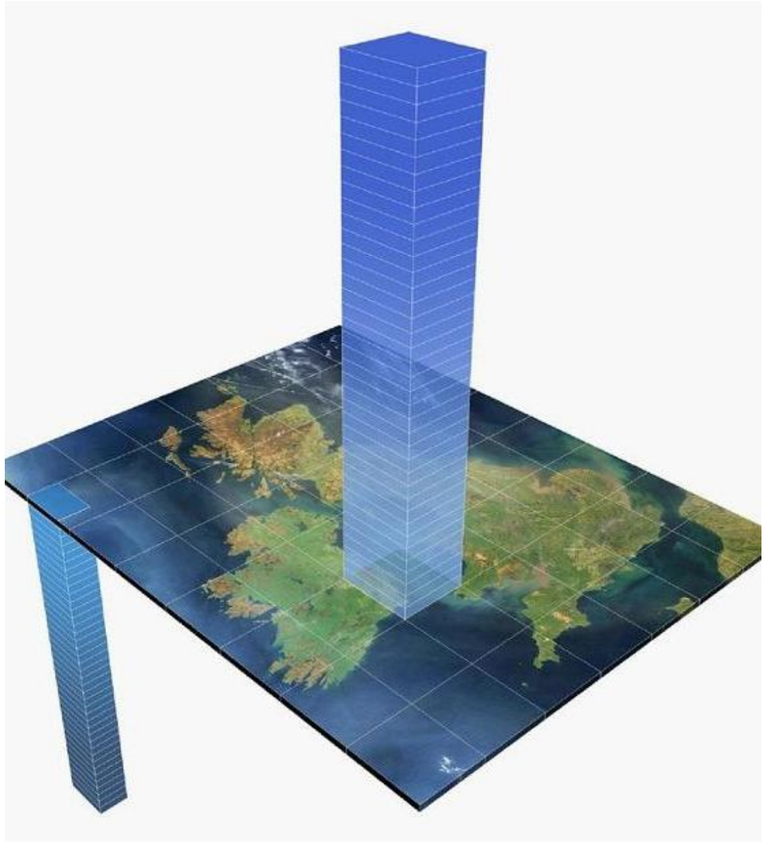
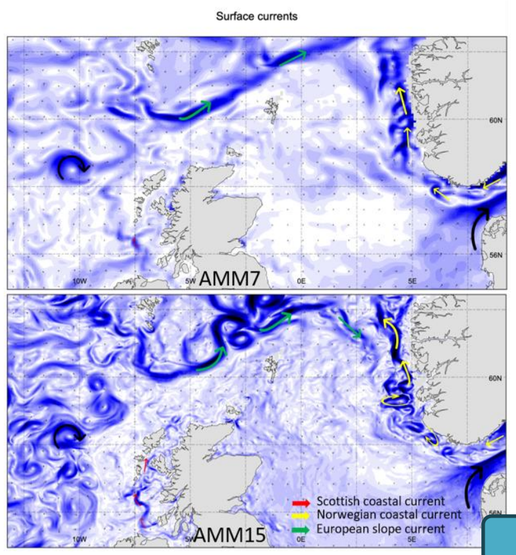
How do we do this? Process models basic concepts

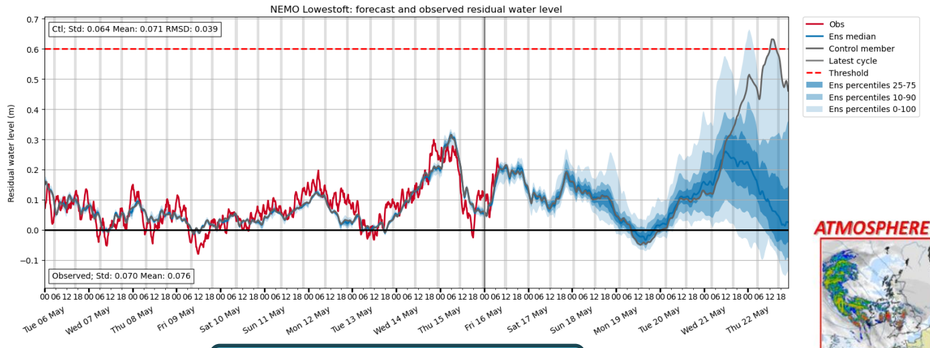
- Divide the ocean into blocks
- Each block behaves according to a set of ‘process rules’
- Each block’s behaviour is constrained by forcing inputs, observations
- Each block ‘talks’ to surrounding blocks, enabling conditions in one part of the model to translate and affect other blocks

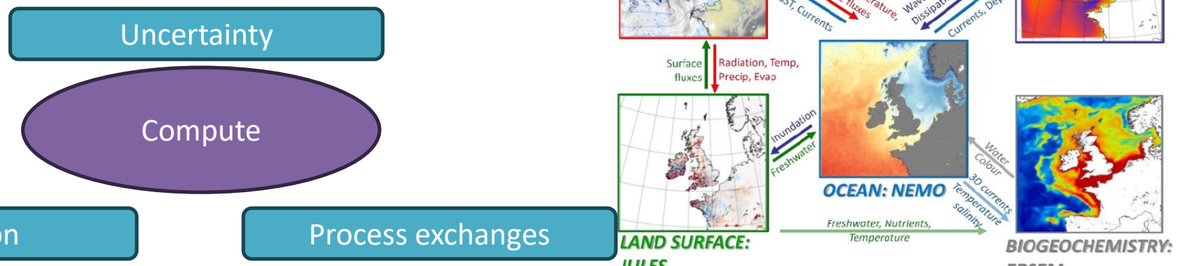




How do we do this? Building complexity







Increasing complexity of the basic model is crucial to delivering information that can be trusted and is anchored to the real world

Constraining our models using observations (analysis) to simulate the present ocean state

Achieving the right resolutions to represent most important ocean processes

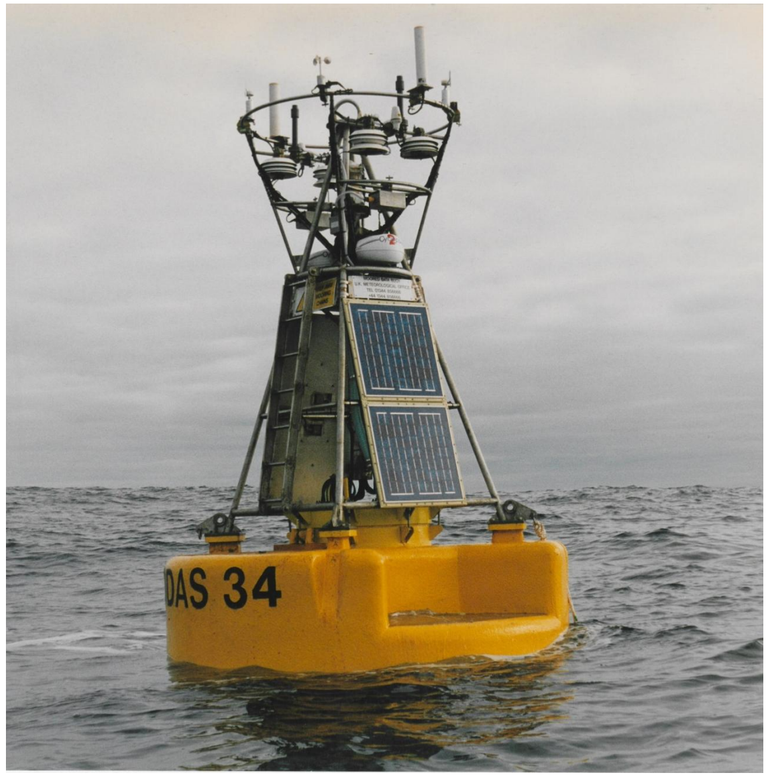
Coupling models together to simulate two-way exchanges between components of the ocean environment and the wider earth system (e.g. atmosphere)

Developing methods to generate useful uncertainty information (error bars) for our analyses and forecasts

Compute resource is finite – so we must optimise our use of compute resource

Our challenges, now and in future

- Sustaining and improving the mix of observations and models
- Communicating uncertainties in useful ways
- Extending what we can skillfully provide and interoperability of data to fit new societal demands
- Working with new technologies and tools (e.g. AI) to improve knowledge and services whilst retaining trust



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Joining our journey

- Users that can help us understand priorities for development
- Communicators that help turn data into policy and decisions evidence
- Software engineers that keep our systems relevant under rapid technological change
- Scientists with a passion for the ocean, people and problem solving

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“But where, after all, would be the poetry of the sea were there no wild waves?” — Joshua Slocum, Sailing Alone Around the World

Thank you for listening

Merci d'avoir écouté

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The (Copernicus) European monitoring and forecasting services

Thursday 5th June

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Dr Marina Tonani

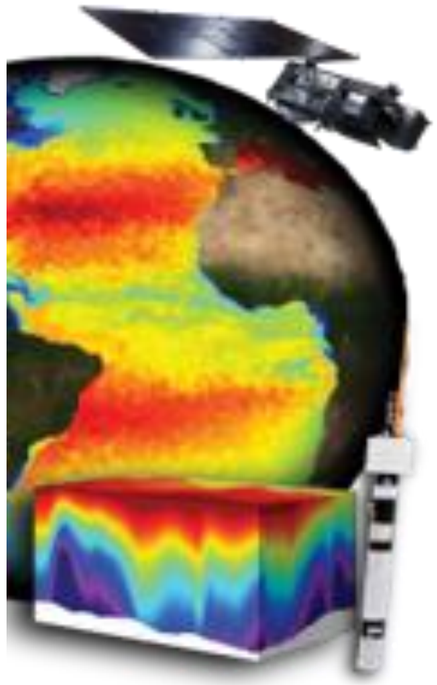
Mercator Ocean International

Copernicus Marine Service

PROGRAMME OF THE EUROPEAN UNION

Earth observation program

Funded by the EU commission and implemented by MERCATOR OCEAN INTERNATIONAL



FREE REGULAR SYSTEMATIC
information
on the state of ocean

BLUE OCEAN

- Temperature
- Salinity
- Currents
- Sea Level
- Mixed layer depth
- Waves

GREEN OCEAN

- Nekton
- Plankton
- Organic carbon
- Nutrients
- Oxygen
- Carbonate System
- Optics

WHITE OCEAN

- Sea Ice Concentration
- Sea Ice Extent
- Sea Ice Thickness
- Sea Ice Type
- Sea Ice Velocity
- Snow thickness
- Sea Ice Albedo
- Sea Ice Age

https://marine.copernicus.eu https://www.copernicus.eu/

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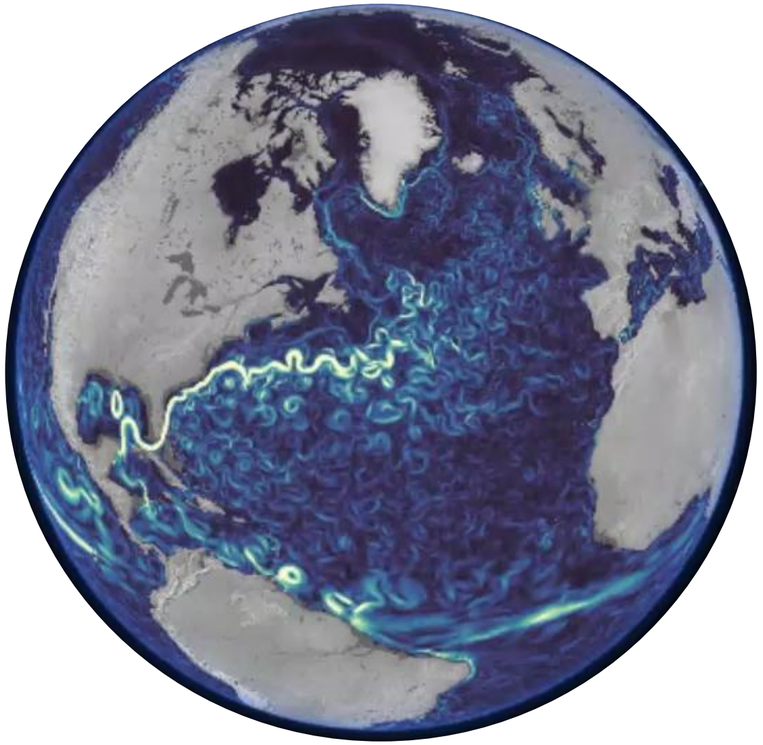
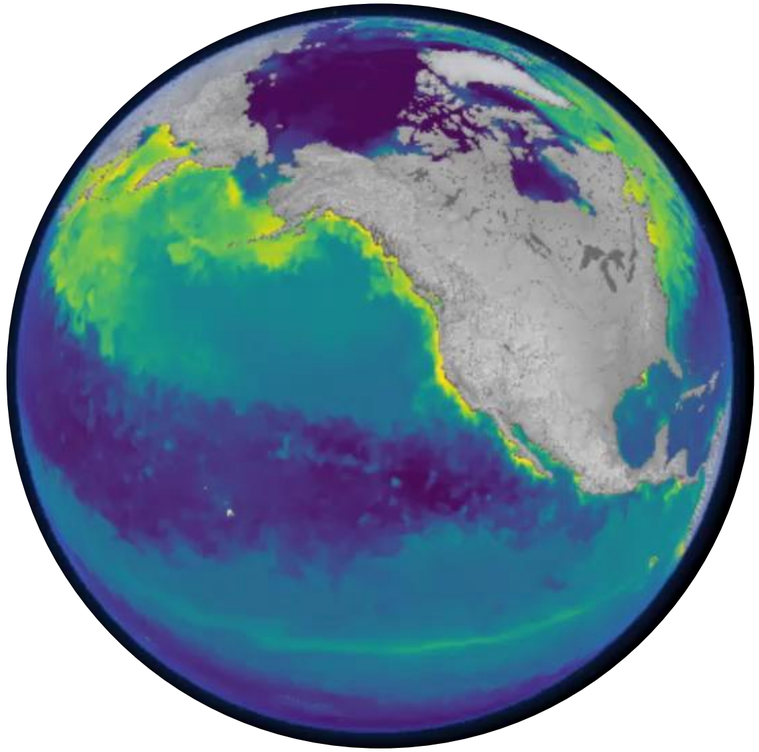
Currents



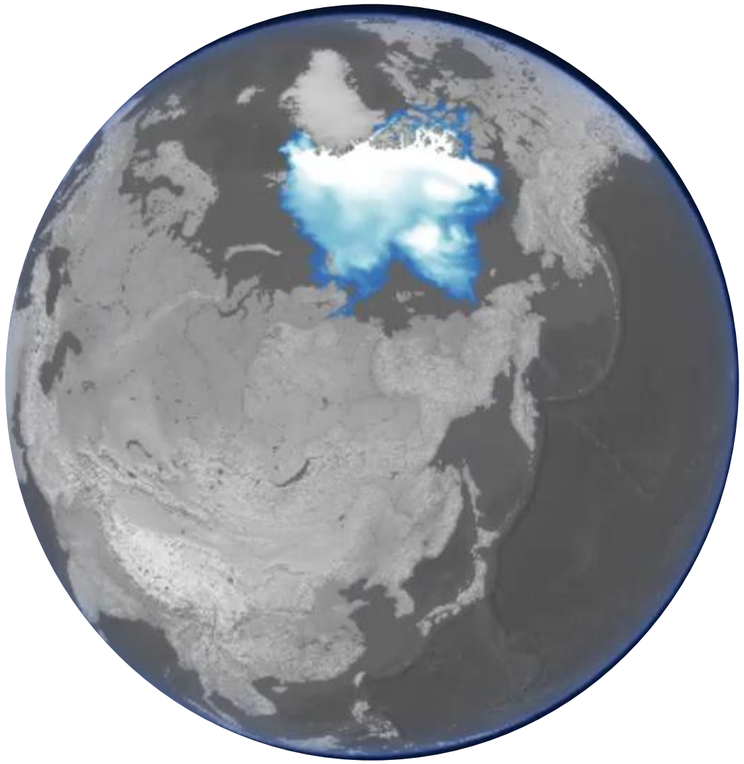
BLUE OCEAN
physical

Chlorophyll



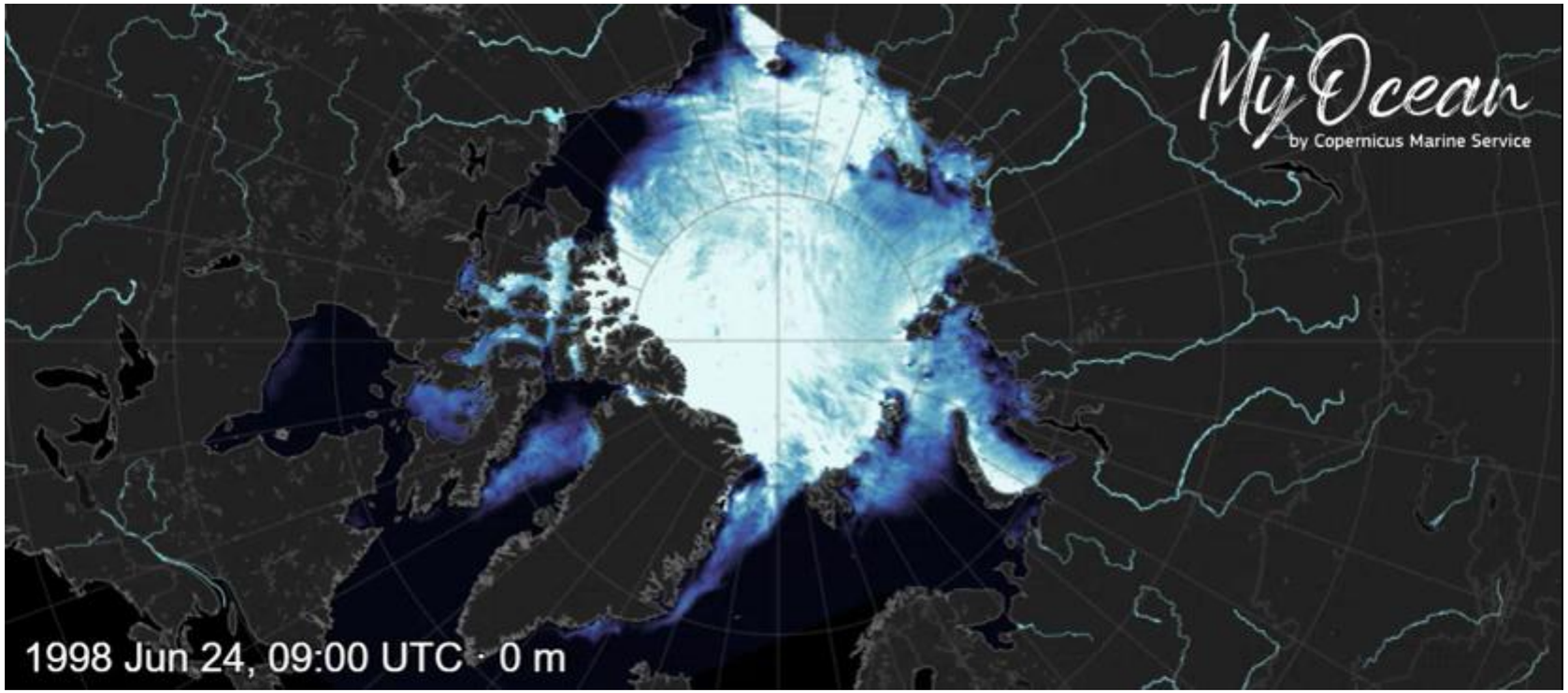
GREEN OCEAN
biogeochemical

Ice



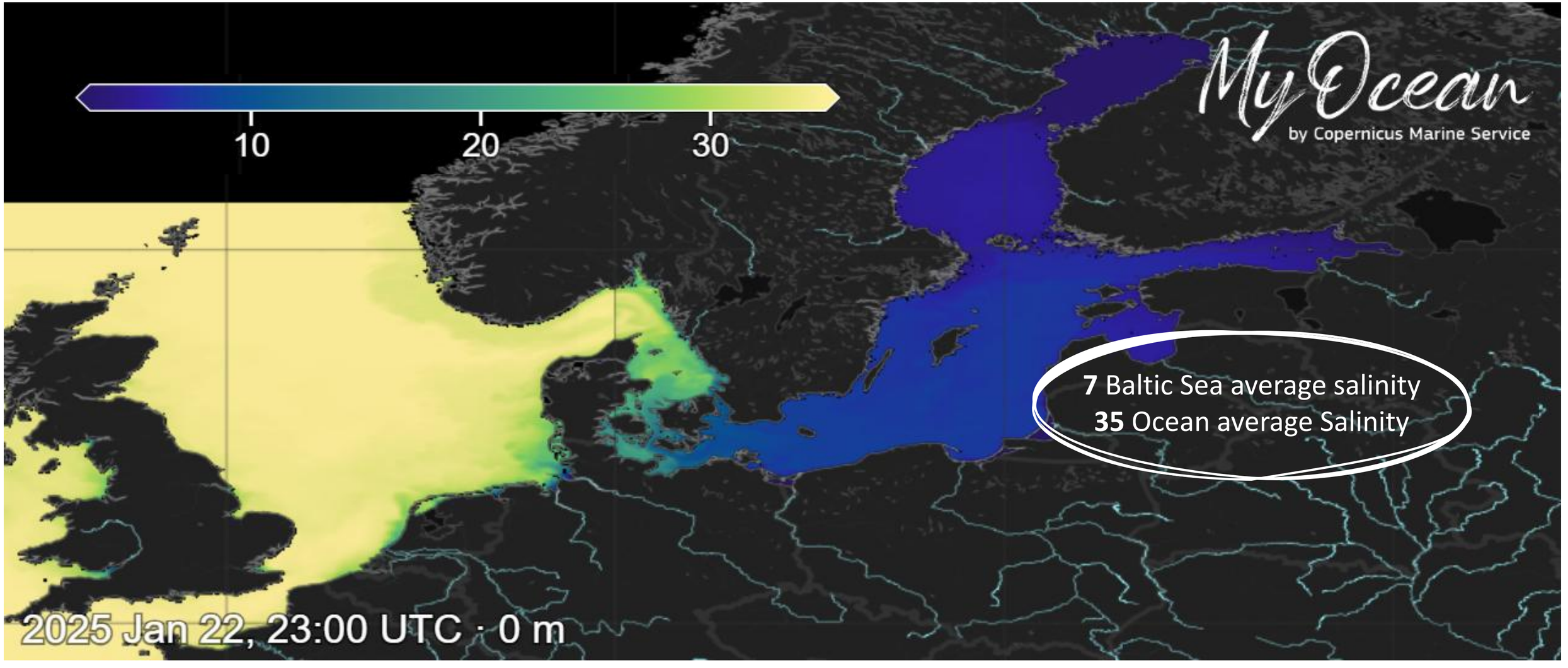
WHITE OCEAN
Sea Ice

Arctic Ocean: a surface warming occurring at twice the global average

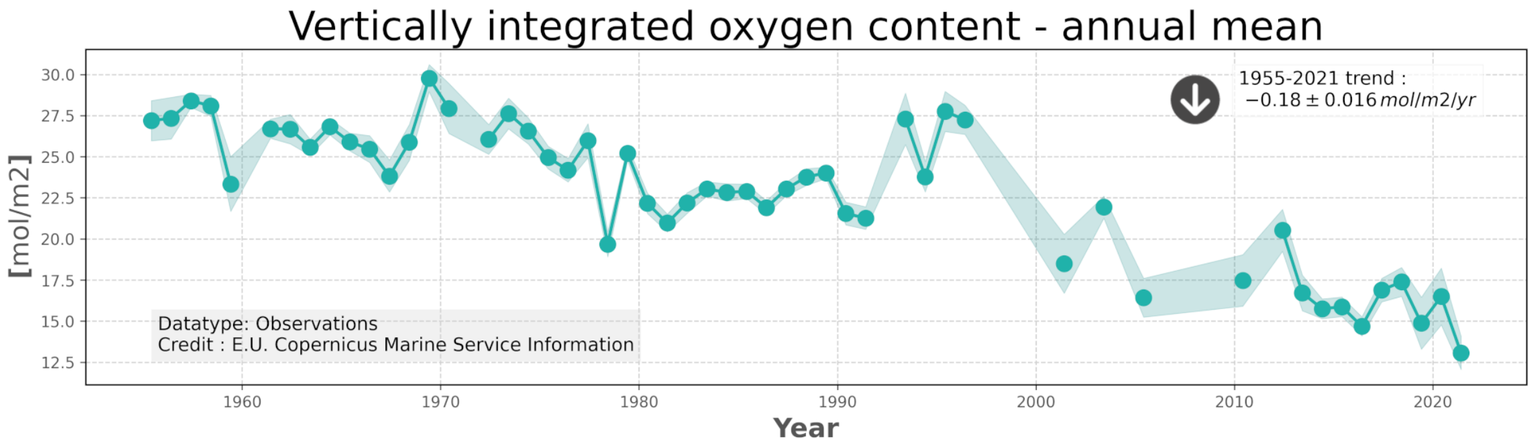


Sea Ice thickness from Ice Reanalysis

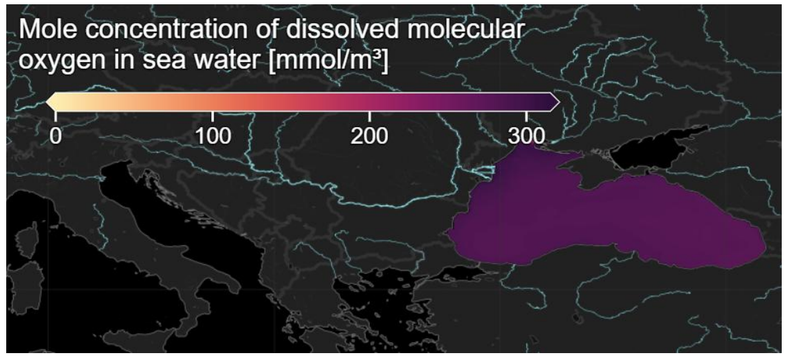
Baltic Sea: semi –enclosed brackish water

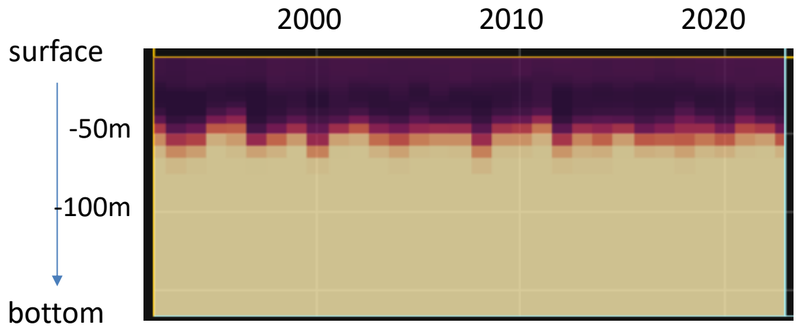


Black Sea the largest euxinic basin in the world

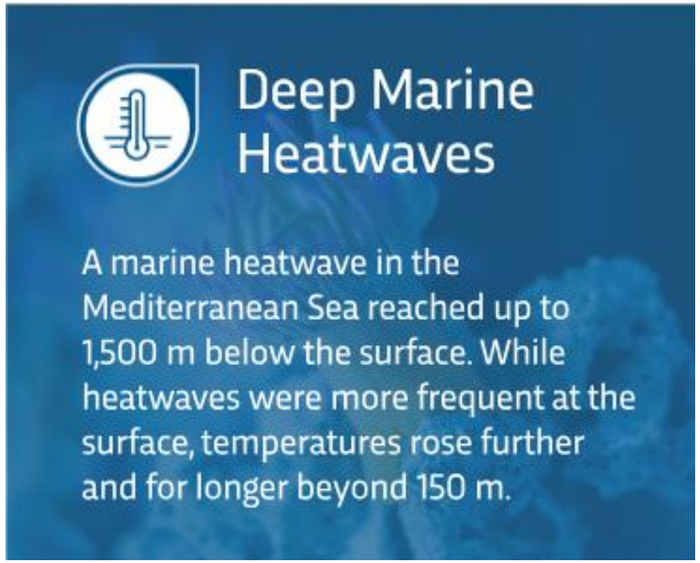


"The Black Sea is entirely anoxic, except for a thin (~ 100 m) ventilated surface layer. Since 1955, the oxygen content of this upper layer has decreased by 44 %. " Capet et al. 2020

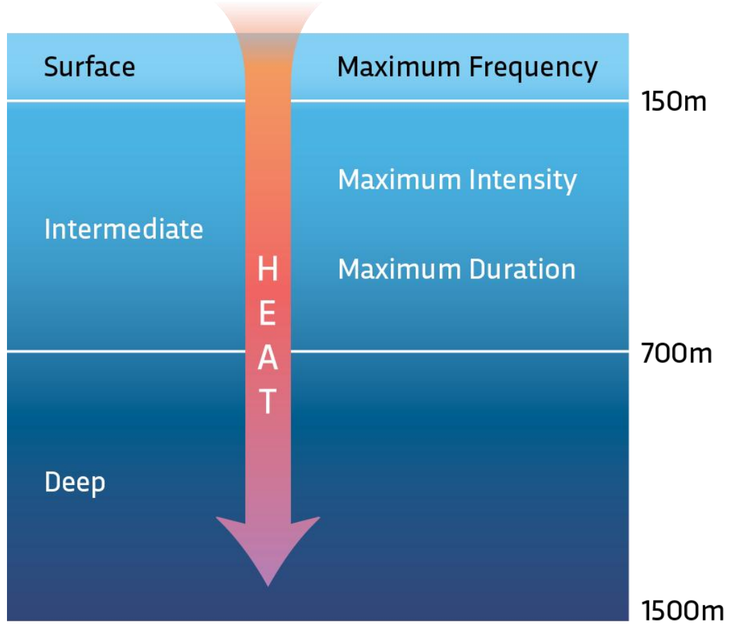




Mediterranean Sea hotspot for climate change

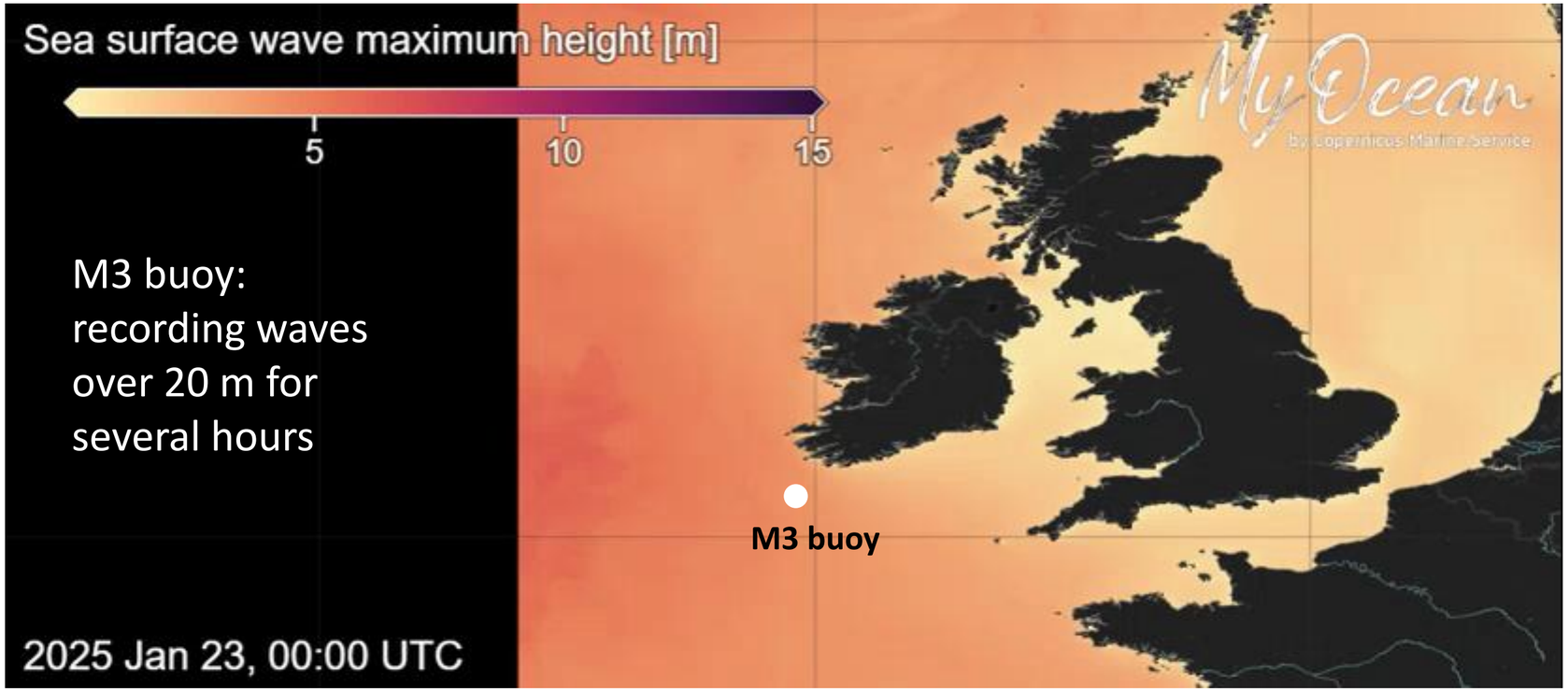


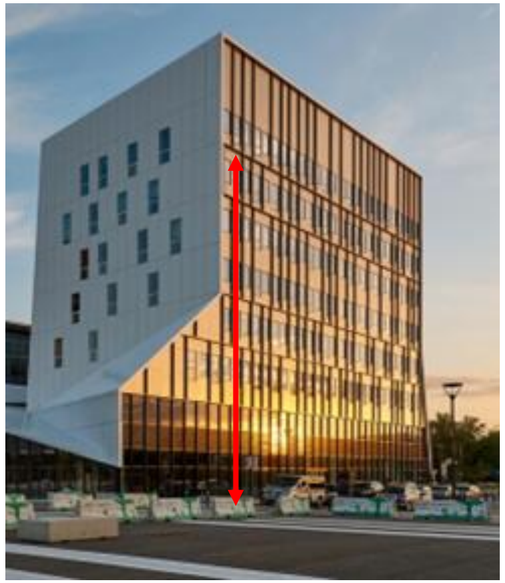
Copernicus Marine Ocean State Report



Heatwave reached 1500m depth!

North West-European Shelf strong storms





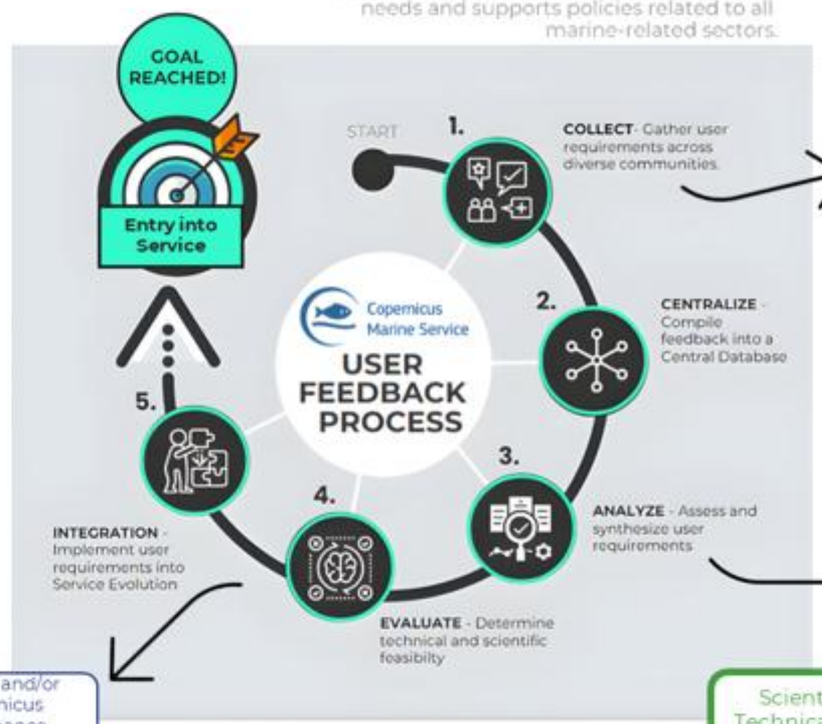
BBC

Éowyn strongest storm in 10 years, says Met Office

USER FEEDBACK PROCESS

A USER-DRIVEN SERVICE

The service responds to public and private user needs and supports policies related to all marine-related sectors.



- User Support
- Training
- Marine Forum
- Champion User Advisory Group
- EUSPA

- Surveys & questionnaires
- Workshops & events
- Policy & Conventions
- Producers
- All website users
- Interaction with other Copernicus Services and Entrusted Entities

Copernicus Marine User Feedback Report

Internal and/or Copernicus Governance validation

Scientific and Technical Advisory Committee (STAC)

→ **CUAG**: 3 meetings a year (2 workshops + 1 meeting at General Assembly)

→ **National Stakeholder Marine Forum**

→ **Annual survey:** sent to all users of the past year

→ **Systematic Survey:** after each event (trainings and workshop)

→ Dedicated interface **with major accounts** (e.g. Regional conventions)

→ Collection of feedback through **user support**

→ Interface **with other Copernicus Entrusted Entities** (C3S, EUSPA)

EU Digital Twin Ocean will improve the Copernicus Marine offer

Responding more quickly to user and policy needs

Increasing flexibility of the offer

Facilitating the coastal extension of the service

The EU DTO is revolutionizing science by bringing together previously separate research fields.

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How do we use artificial intelligence (models) to improve ocean monitoring and forecasting?

Thursday 5th June

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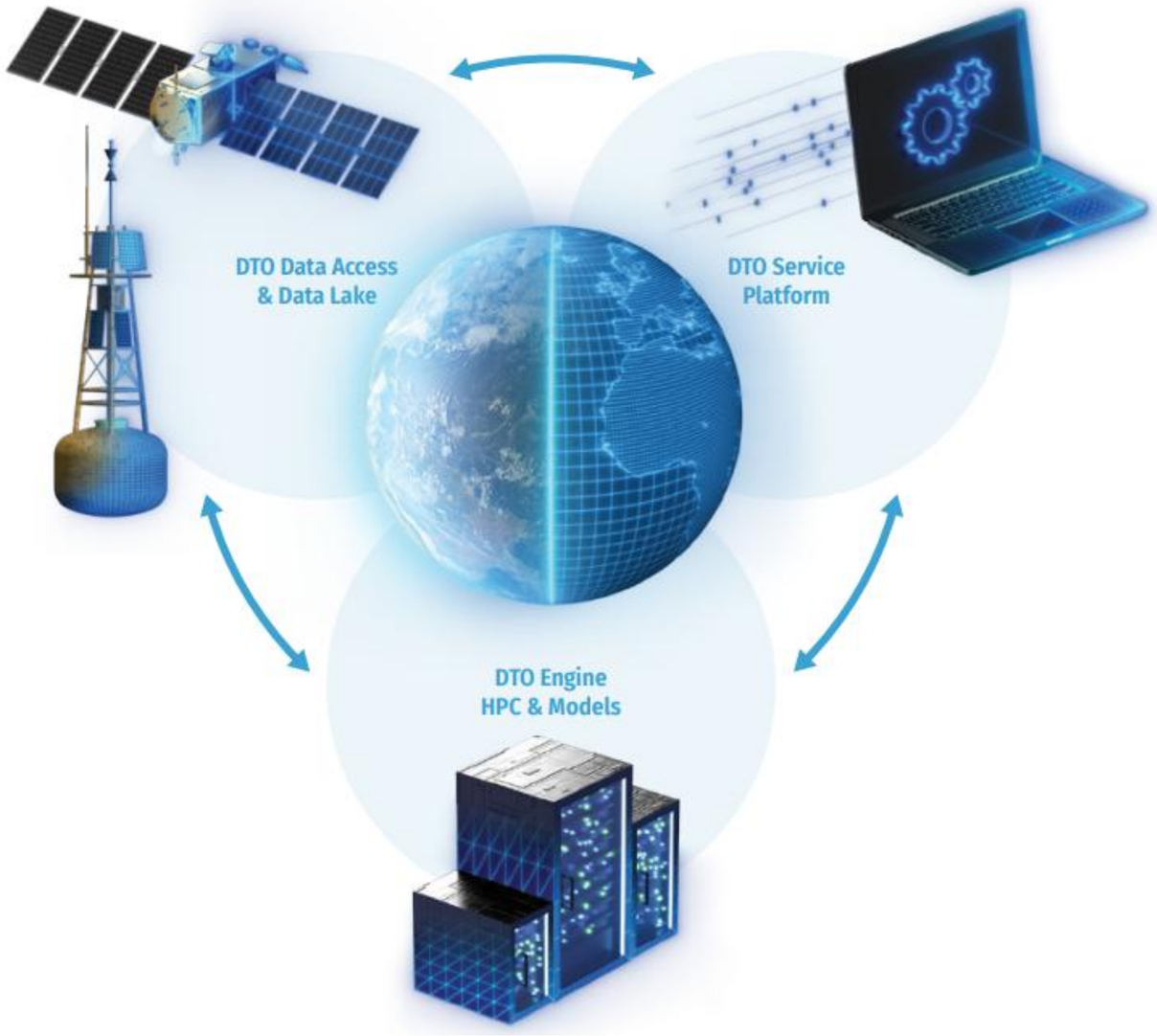
Yann Drillet

Mercator Ocean International

Artificial Intelligence ocean models for new services



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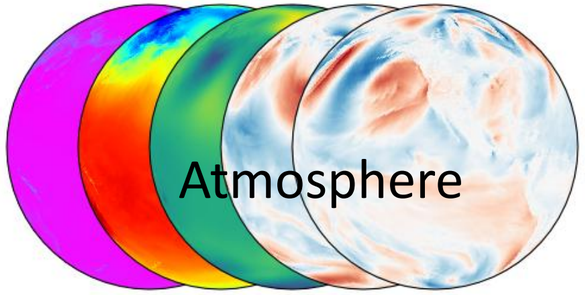
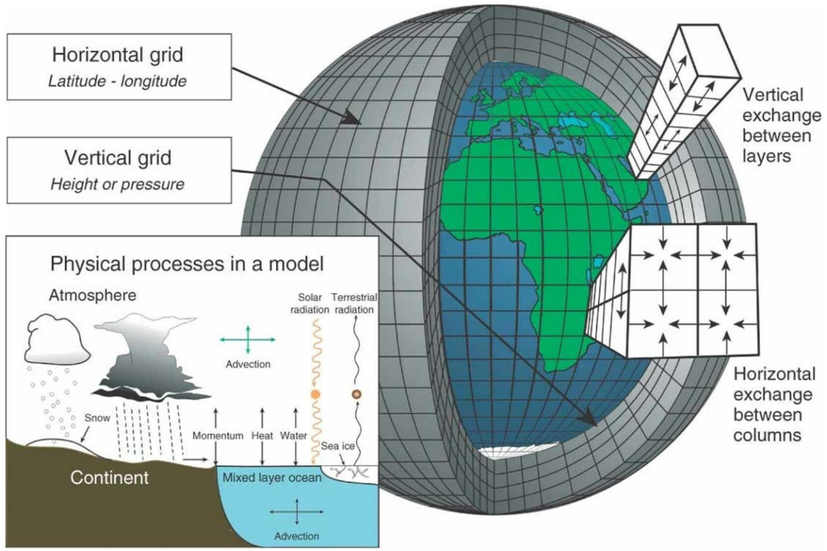
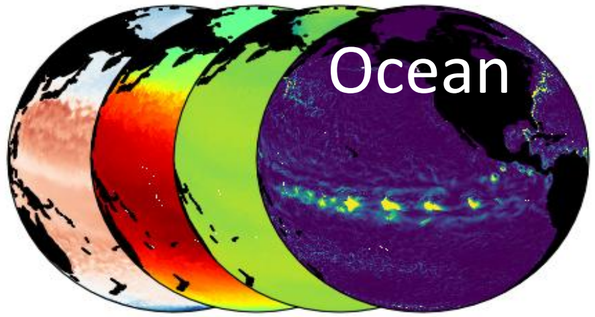
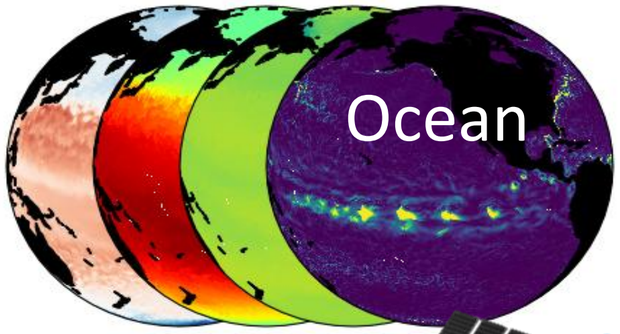
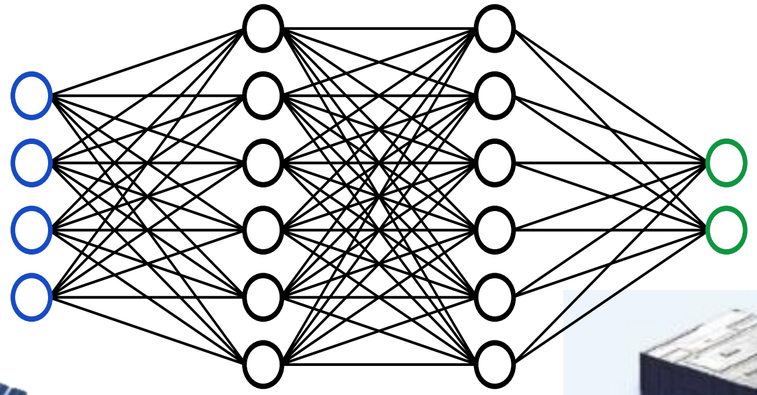
Physical and Artificial Intelligence models











INPUTS

OUTPUTS

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Evaluation of an AI models

AI FORECAST

PHYSICAL MODEL FORECAST

OceanBench

Temperature [0-5m]

RMSE(°C)

	1	3	5	7	10
GLO12	0.588	0.622	0.647	0.679	0.723
GLONET	0.637	0.733	0.753	0.875	0.920
WENHAI	0.549	0.719	0.912	1.095	1.270
XIHE	0.575	0.654	0.660	0.674	0.782

uo [15m]

RMSE (m/s)

	1	3	5	7	10
GLO12	0.167	0.173	0.179	0.184	0.189
GLONET	0.142	0.148	0.148	0.152	0.157
WENHAI	0.163	0.165	0.166	0.171	0.175
XIHE	0.159	0.158	0.158	0.157	0.159

Lead time [days]

Better — Worse

−0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8

Common framework

Open source

Evaluation protocol

Intercomparison

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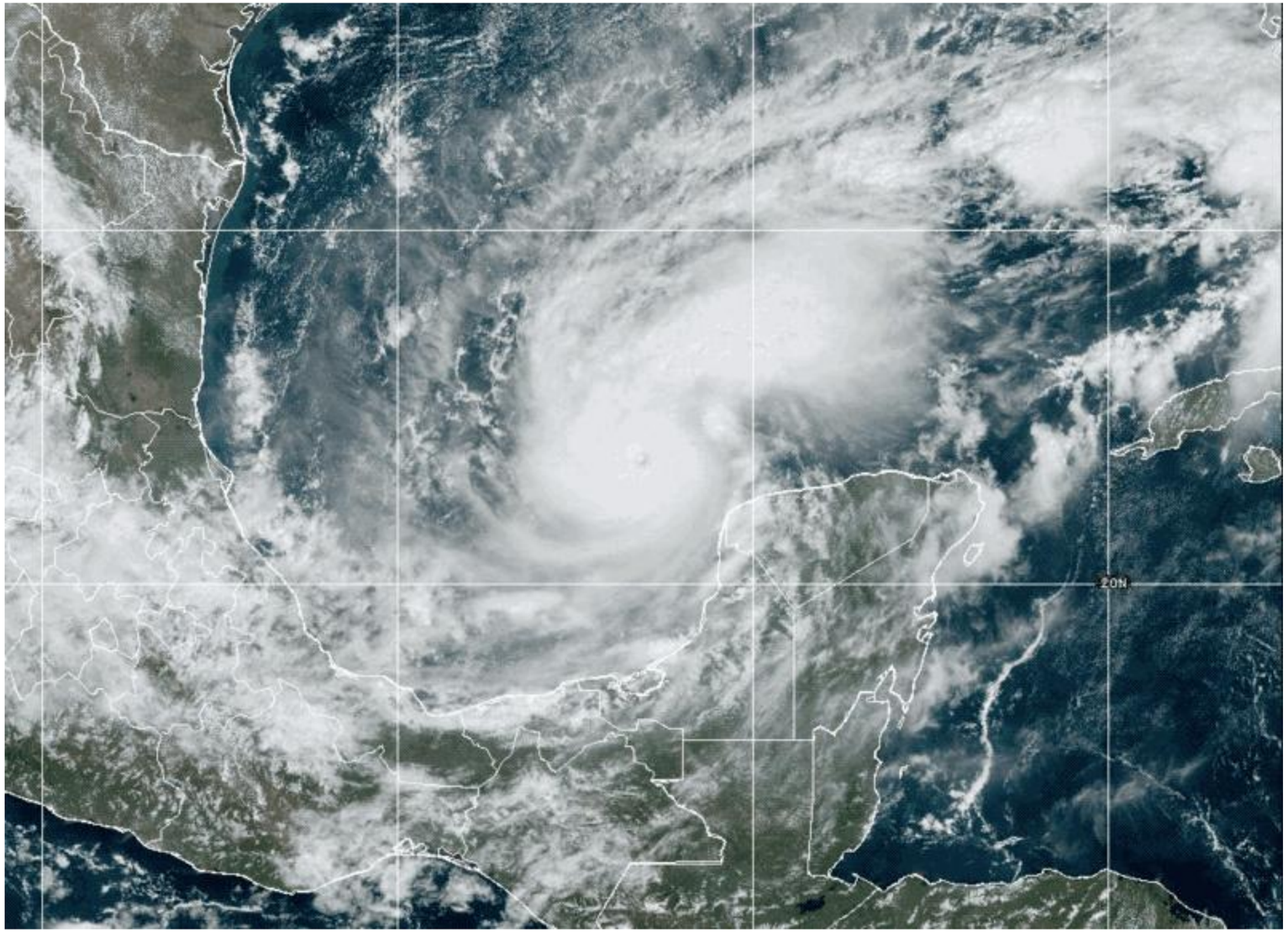
Quentin Febvre

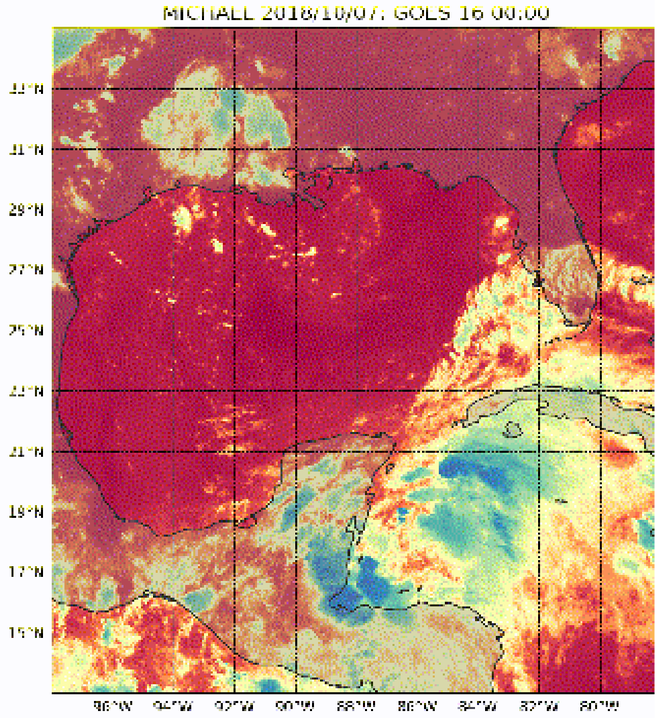
Ifremer

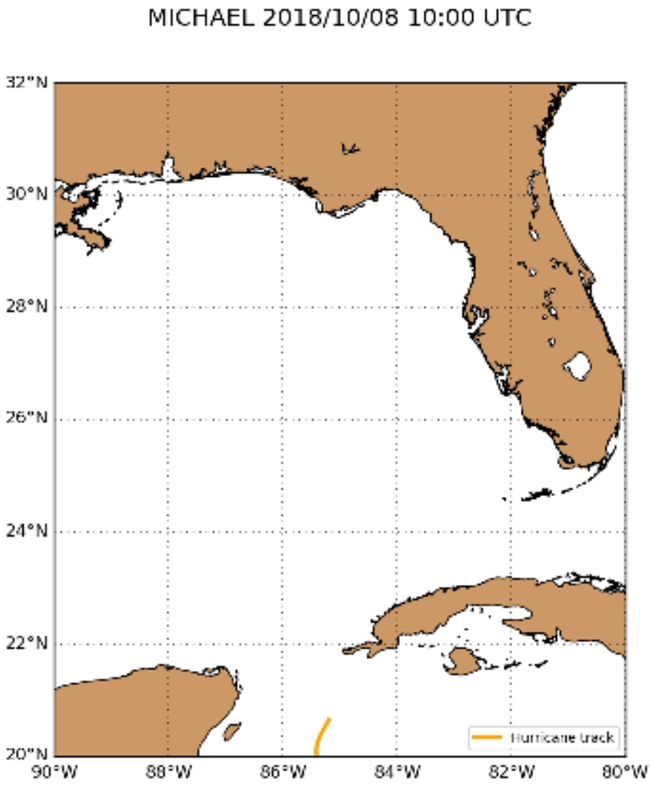
Extreme wind events: tropical cyclones



Hurricane Milton (2024)

Ever improving observations: The "torn pages"





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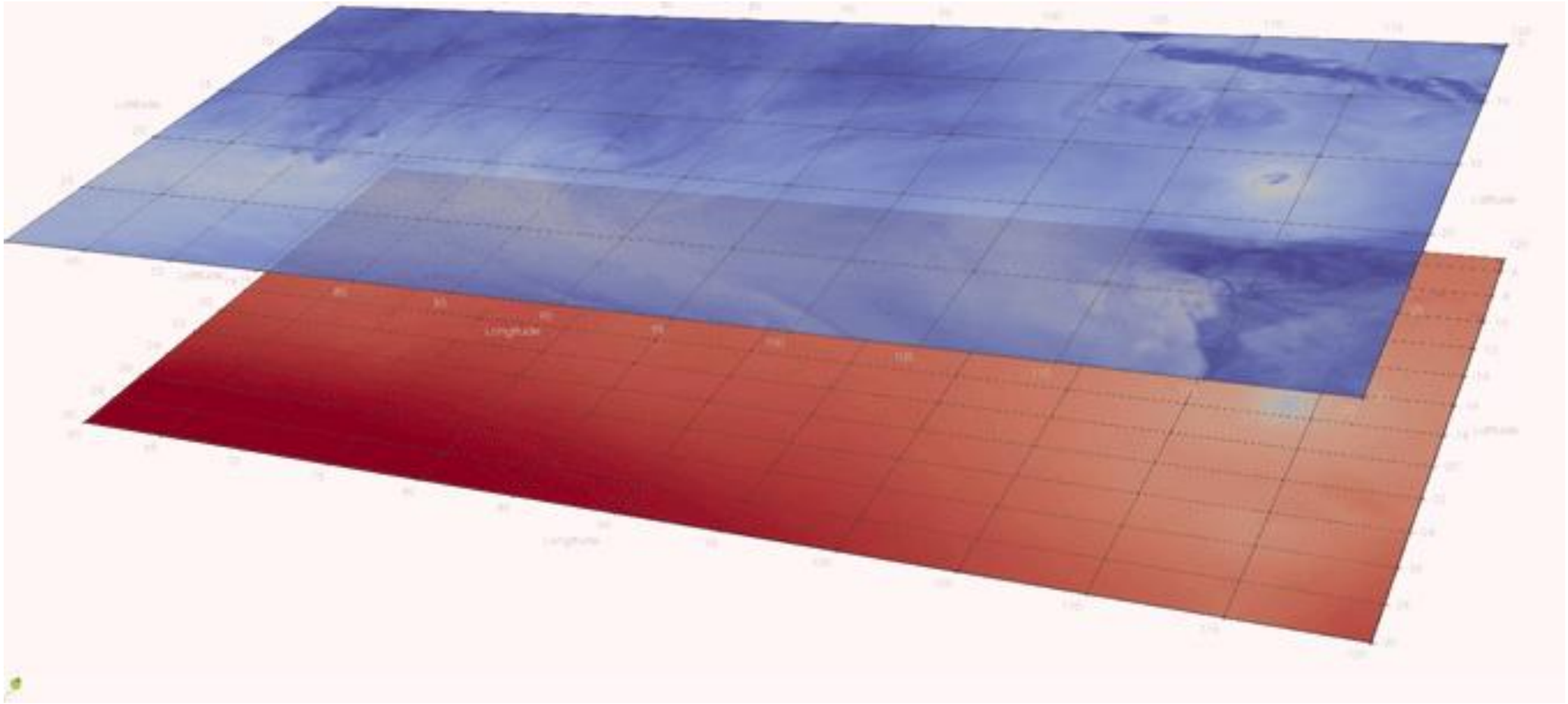
Advances in numerical modeling: The "Perfect Storm" in a Computer



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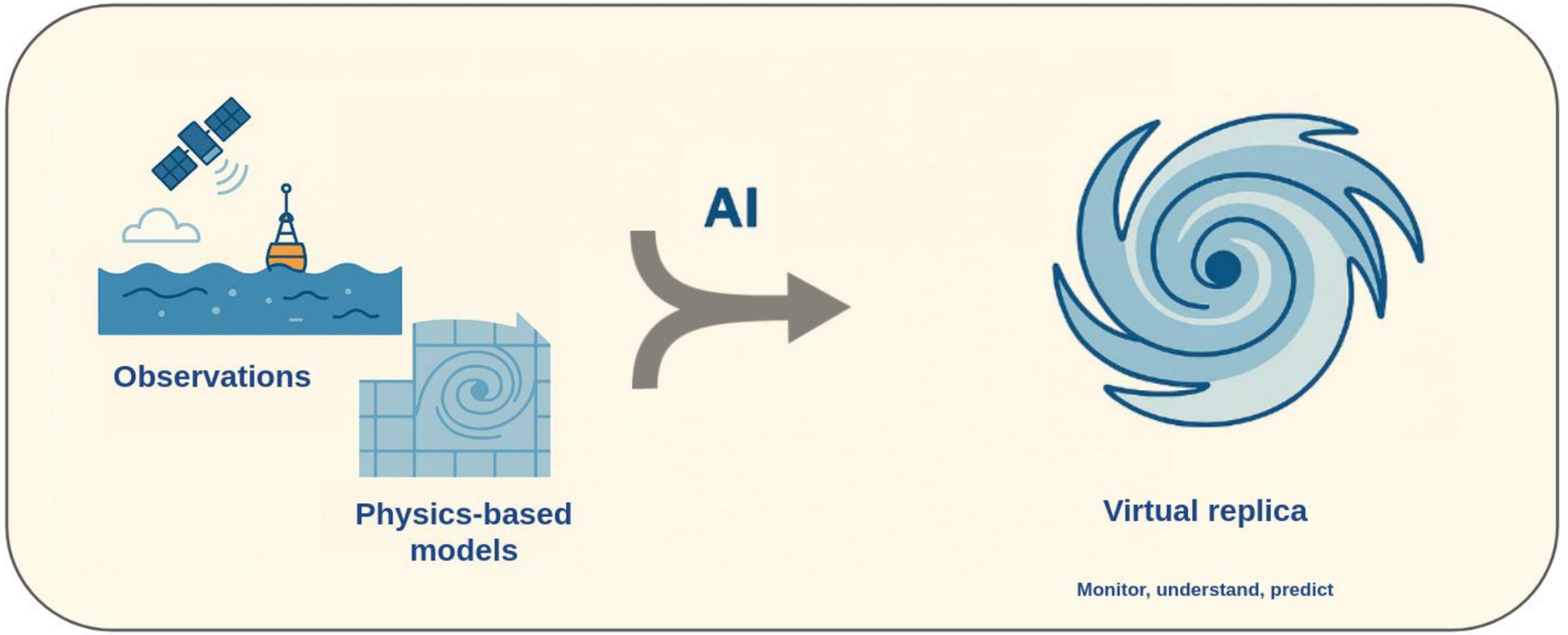
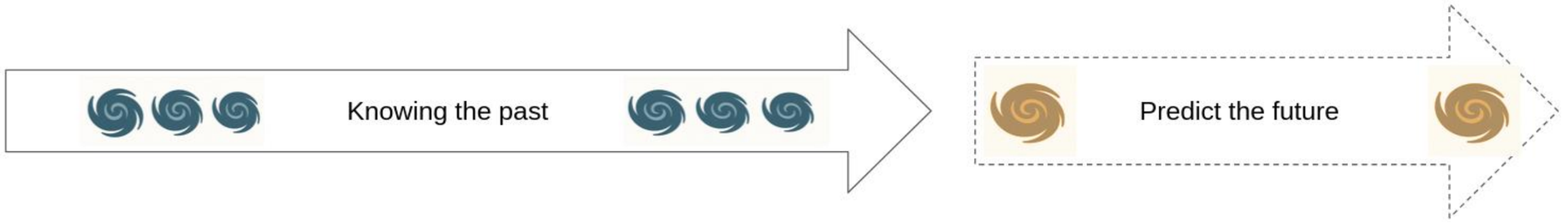
DTO and AI - Weaving the Narrative Together





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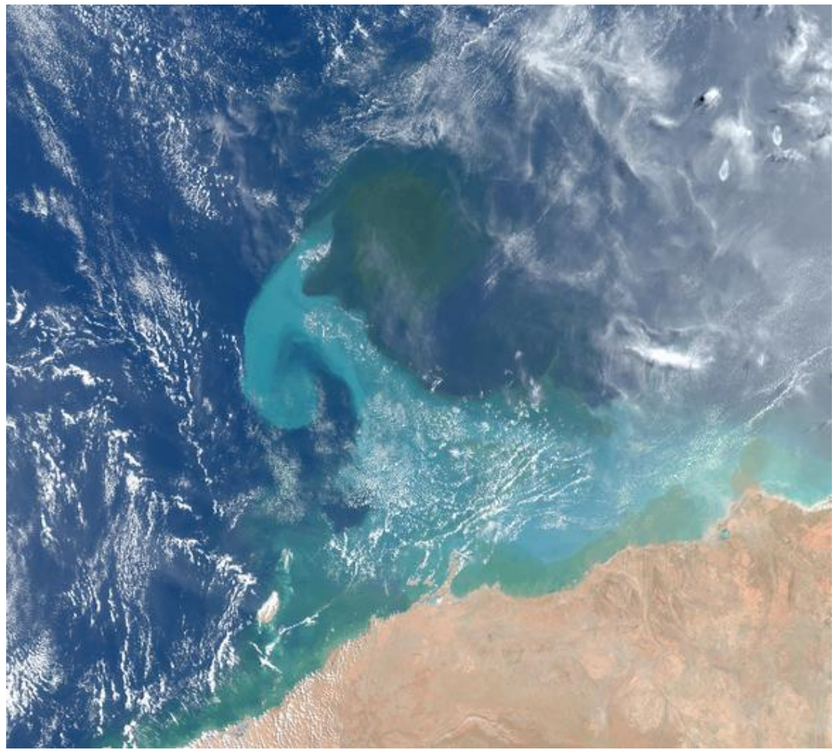
Impacts

Before Hurricane Veronica (2019)



After Hurricane Veronica (2019)

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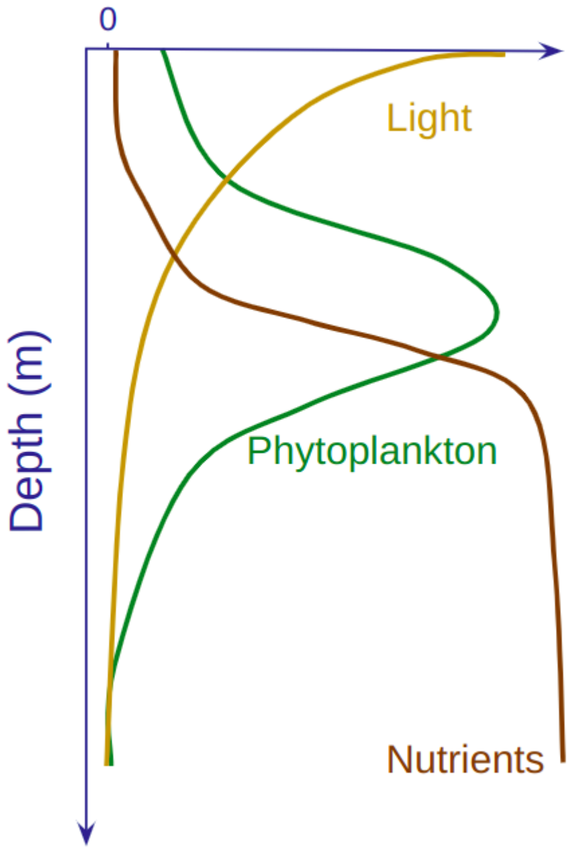
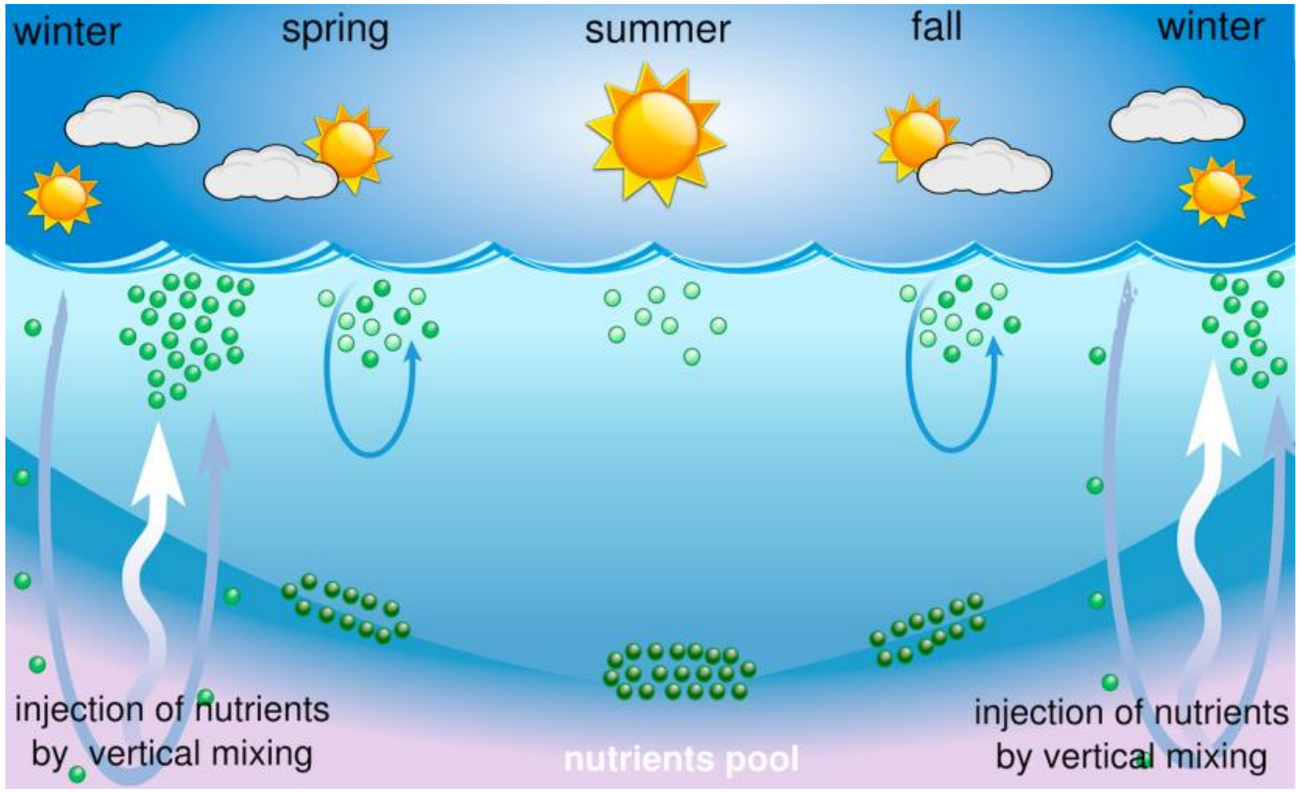
Raphaëlle Sauzède

CNRS

Nutrients: The Ocean's Invisible Fuel





Mignot et al., 2014

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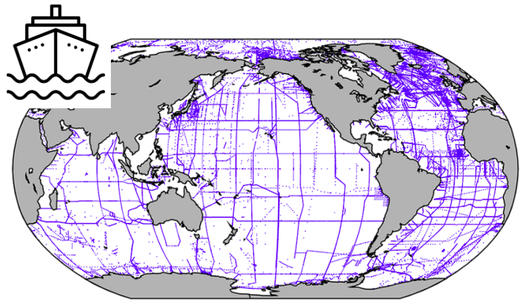
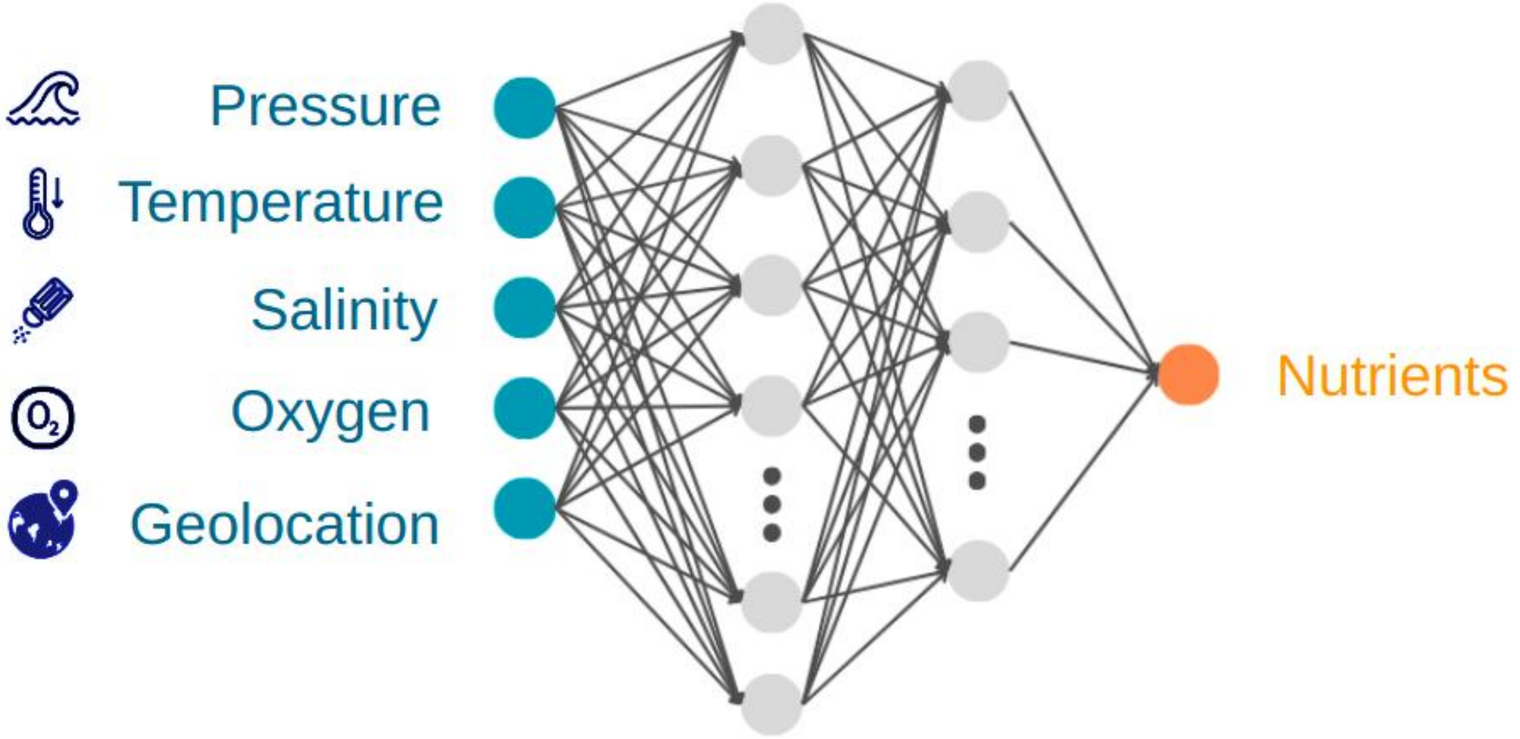
AI to predict nutrients where no observations are available





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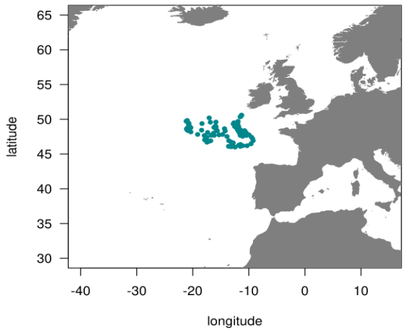
From Sparse Observations to a Global Ocean View

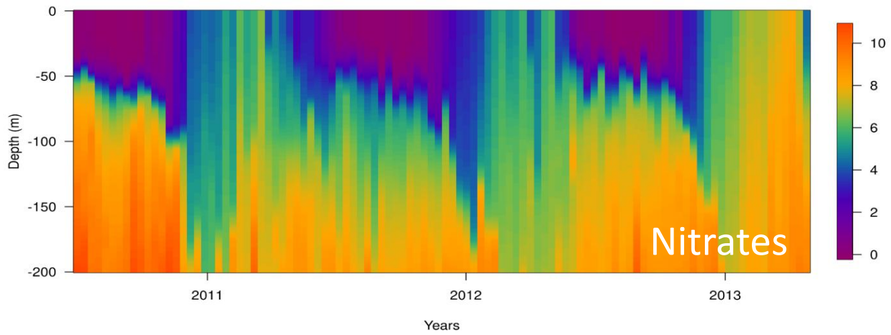
📈 ~30,000 new profiles each year

🌎 Over 330,000 profiles of temperature, salinity & oxygen

🚢 840 active floats measuring oxygen across the global ocean

🤖 AI predicts dnutrients for all these floats





biogeochemical Argo

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Thank you!

Copernicus
Europe's eyes on Earth

EU MISSIONS
RESTORE OUR OCEAN & WATERS

Copernicus
Marine Service

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ACCIBERG : Iceberg forecasts demo

5 June 2025

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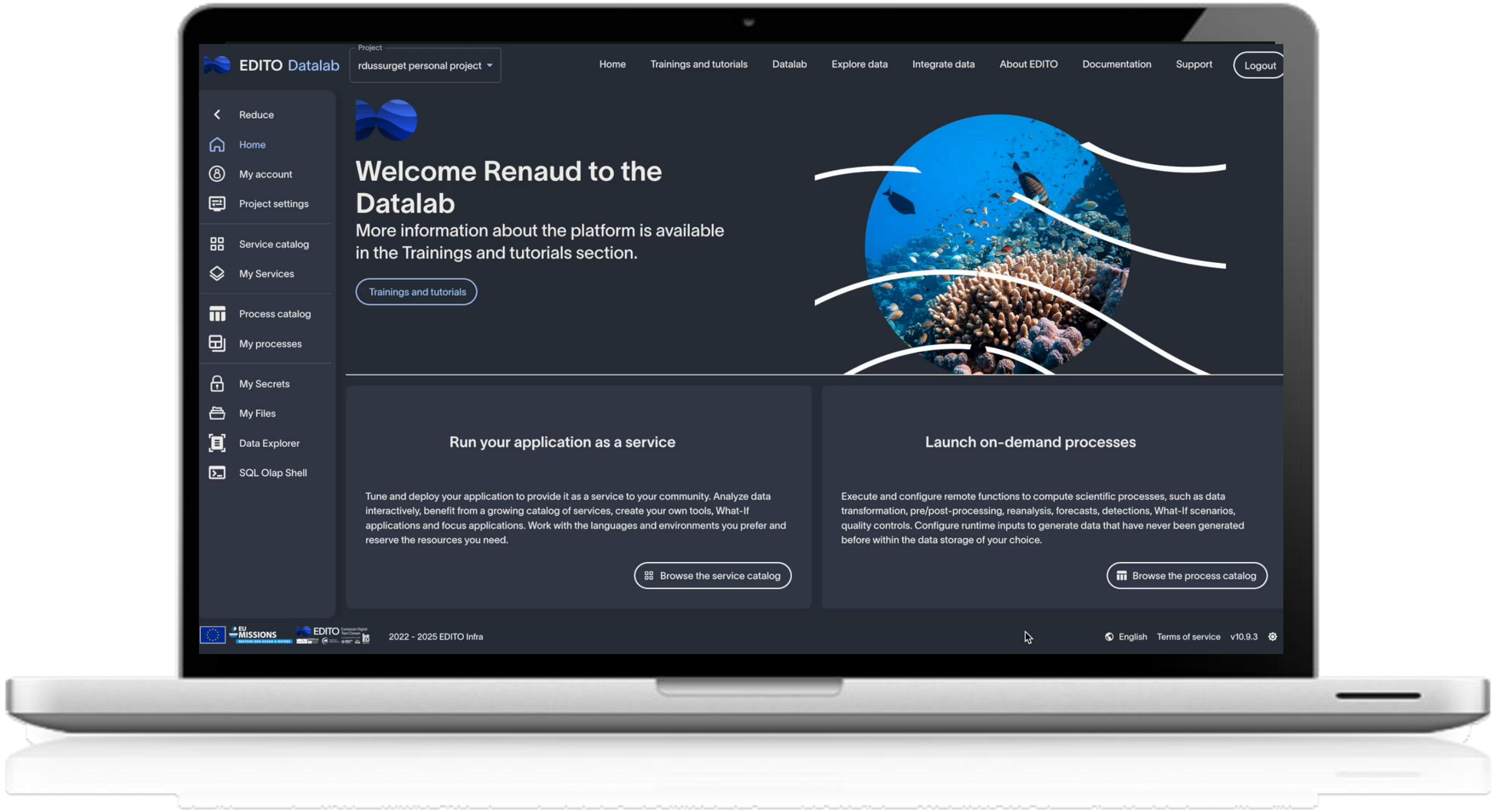
Laurent BERTINO

The Nansen Center, Bergen, Norway

NERSC
NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER
THE NANSEN CENTER · BERGEN · NORWAY



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Questions & Answers

Join at

slido.com

#1784 7616

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EDITO-Model Lab: What-if Scenarios Training Workshop

5 June 2025

Francisco Campuzano
+ATLANTIC CoLAB

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How to monitor the Ocean?

Introduction to EDITO ModelLab

European Digital Twin Ocean

Yann Drillet
Mercator Ocean International

The European platform for **discovering**, **visualizing**, and **leveraging** **products** and **knowledge** to power digital twins of the ocean

EDITO

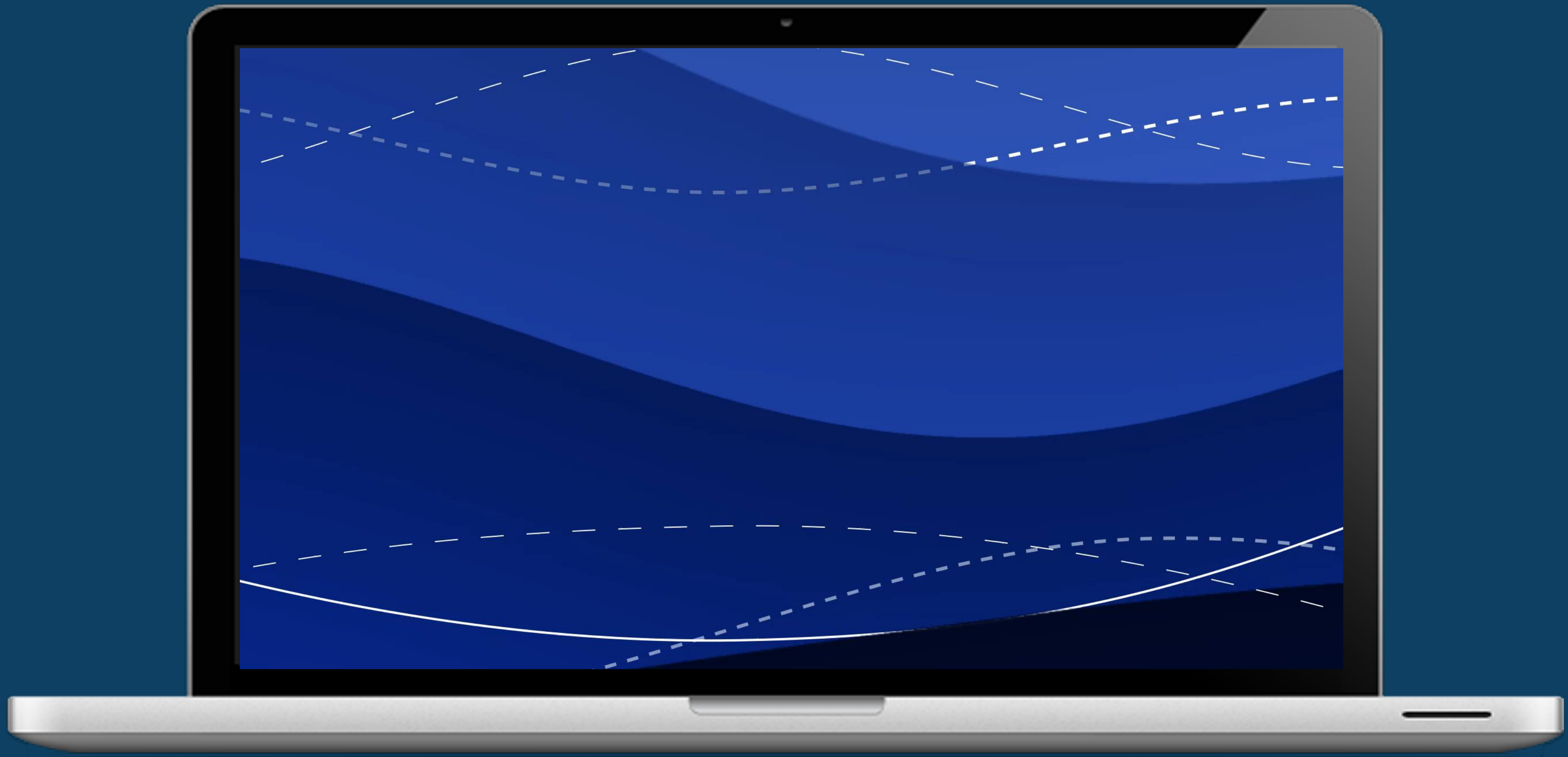
European **DI**gital **T**win of the **O**cean

Funded by the Horizon 2020 Framework Programme of the European Union

EDITO Infra

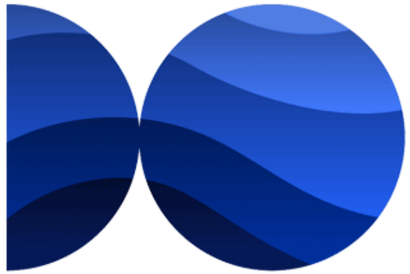
MERCATOR OCEAN INTERNATIONAL

VLIZ



EDITO

A **UN Ocean Decade** Action



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European Digital Twin Ocean

DITTO

Digital Twins of the Ocean

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

EDITO-Model Lab Consortium

European ocean numerical modelling expertise

13 partners

8 countries

— Numerical modelling
— Supercomputing
— Artificial intelligence
— Software development
— Operational oceanography
— Design with and for users
— Science communication

EDITO-Model Lab

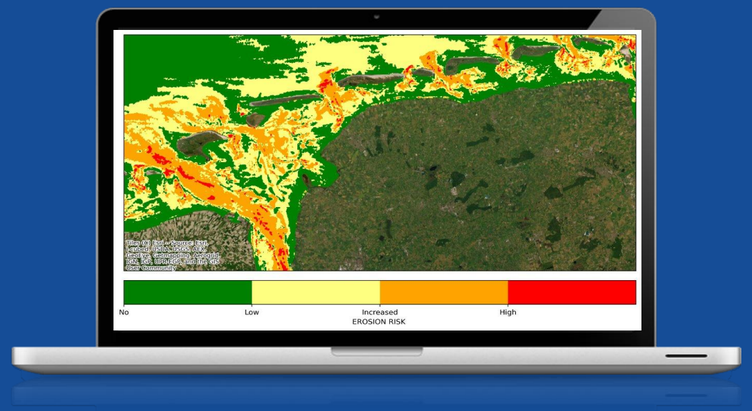
Components on demonstration during the UNOC 2025

Data + Models + Computing resources + Services + On demand processing

What-if Scenarios

5 June 2025

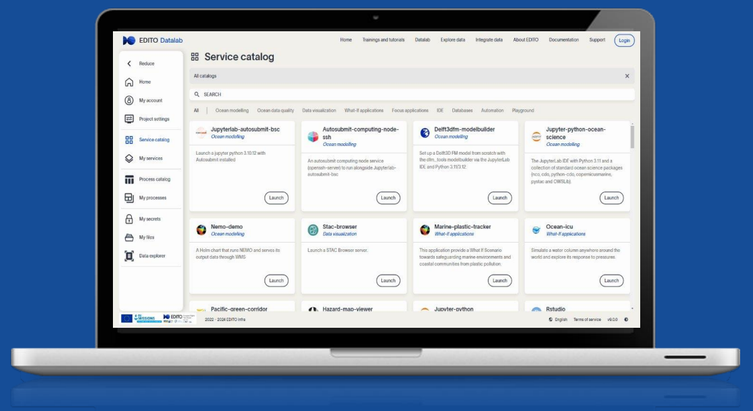
End Users Workshop



Focus Applications

13 June 2025

Intermediate Users Hackathon



EDITO-Model Lab What-If Scenarios

Demonstrating capabilities

Joanna Staneva
Hereon

What-if Scenarios Demonstrations

Key Concepts

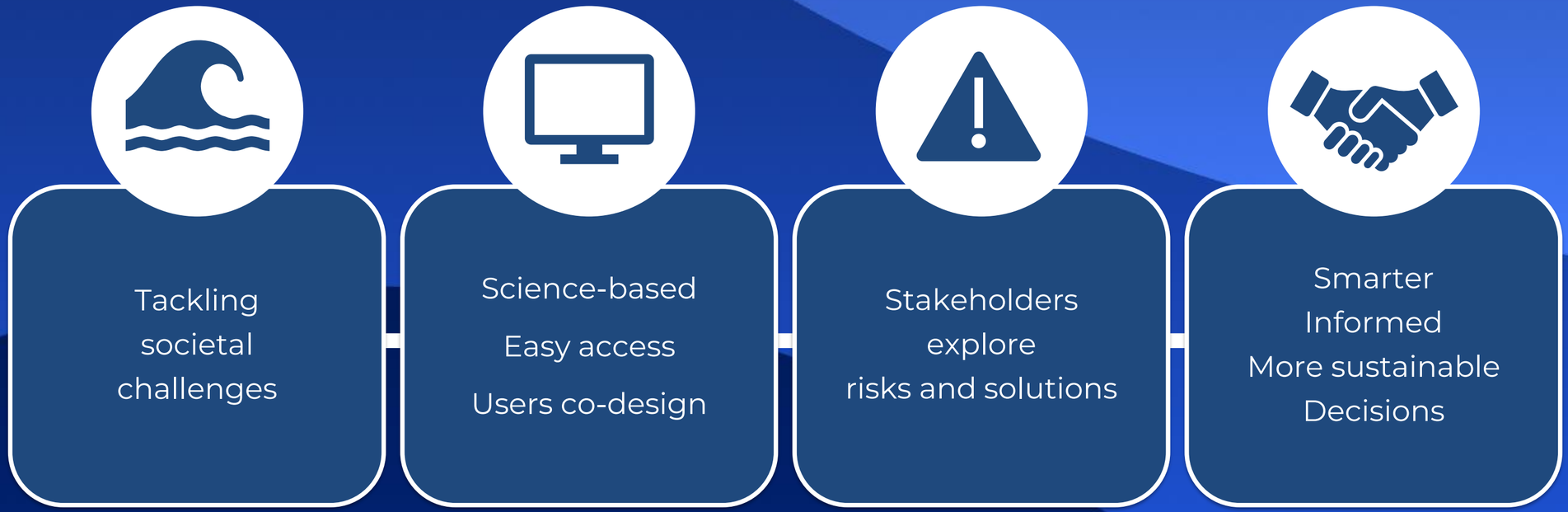
- What?
- For whom?

What-if Scenarios Demonstrations

Contribution to the UN Sustainable Development Goals

What-if Scenarios Demonstrations

How can they help?



What-if Scenarios Demonstrations

Nature-based solution for coastal erosion

? What if we reconstruct seagrass for protecting the coast?

Marine plastics for zero pollution

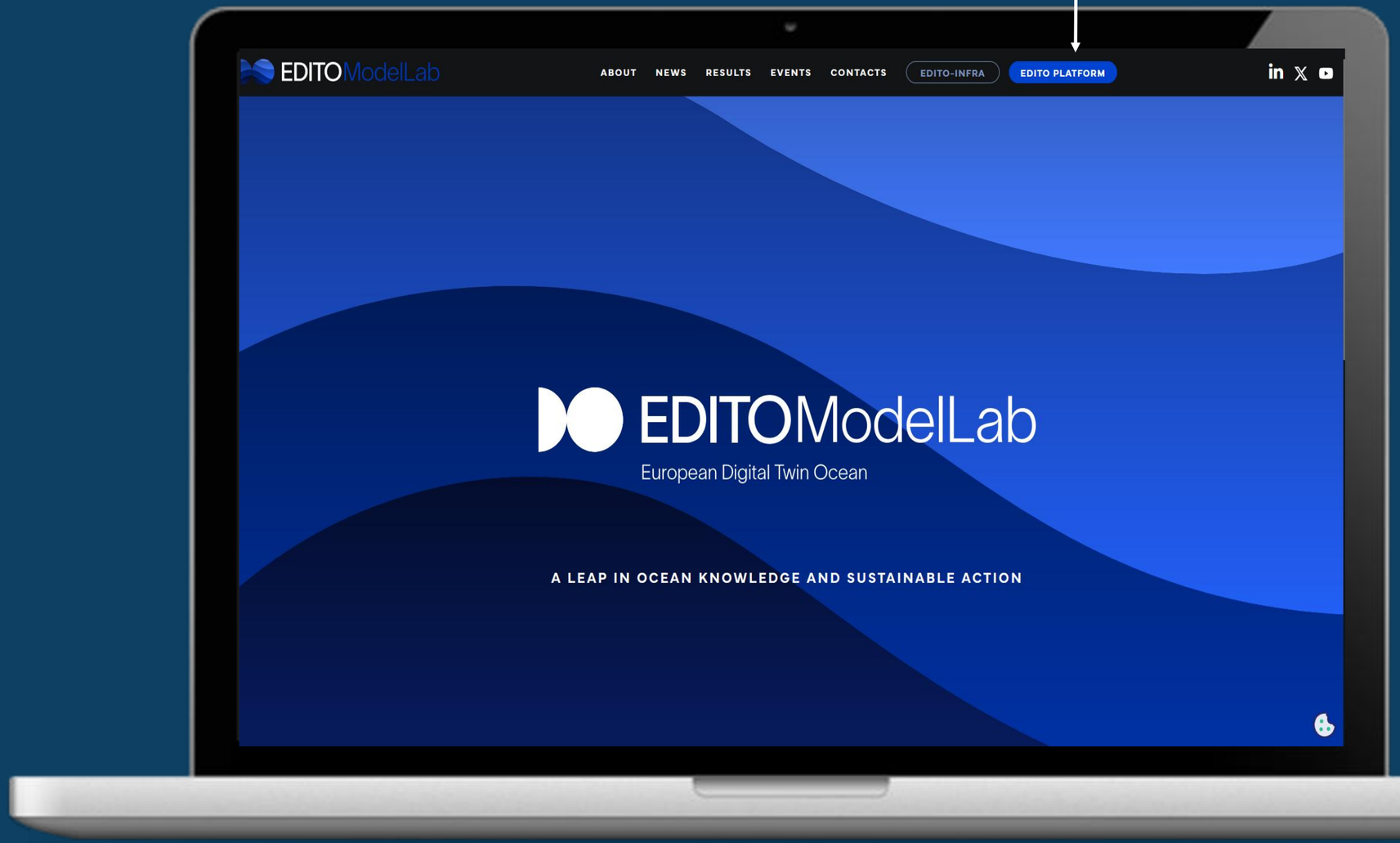
? What if we could capture plastics before they reach our seas?

Aquaculture for zero carbon

? What if we upscale aquaculture in offshore windparks ?

What-if Scenario Demonstrations

Applications in the EDITO Platform



Tutorials
&
Documentation

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Nature-Based Solutions for Biodiversity & Coastal Hazards

Wei Chen

Hereon

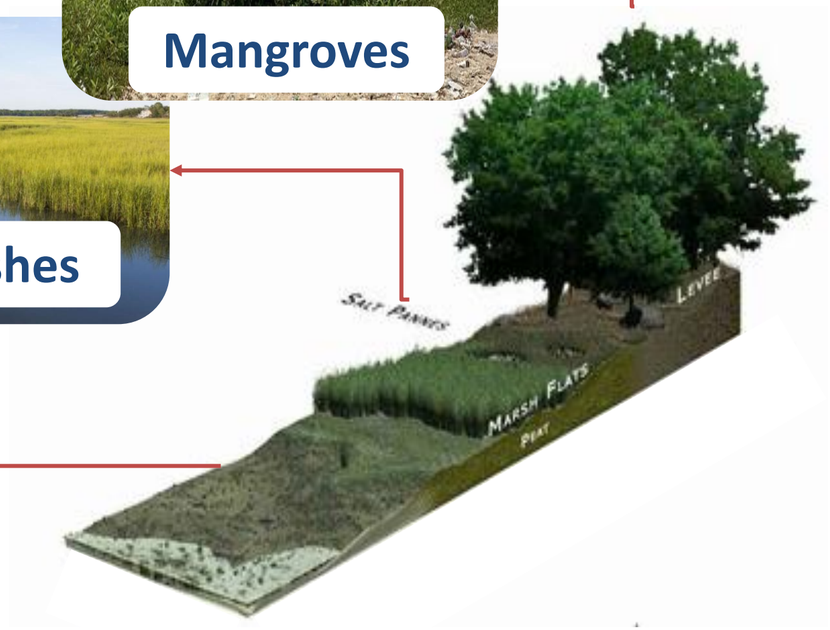
Nature-Based Solutions for Biodiversity & Coastal Hazards

A big problem

Nature-Based Solutions for Biodiversity & Coastal Hazards

Coastal vegetation, a great solution

Impact of vegetation



Nature-Based Solutions for Biodiversity & Coastal Hazards

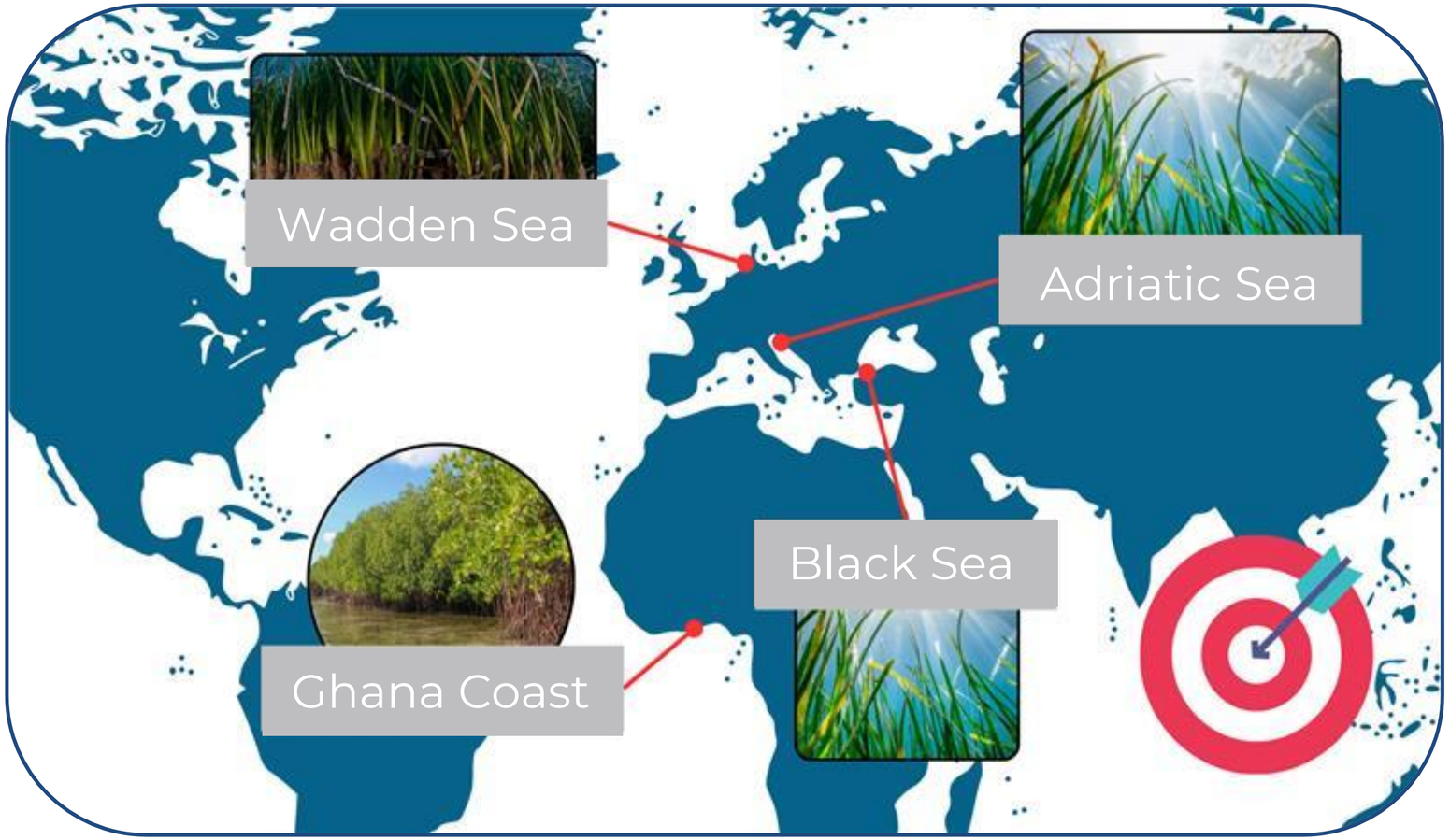
Enhanced Need for Effective Coastal Protection

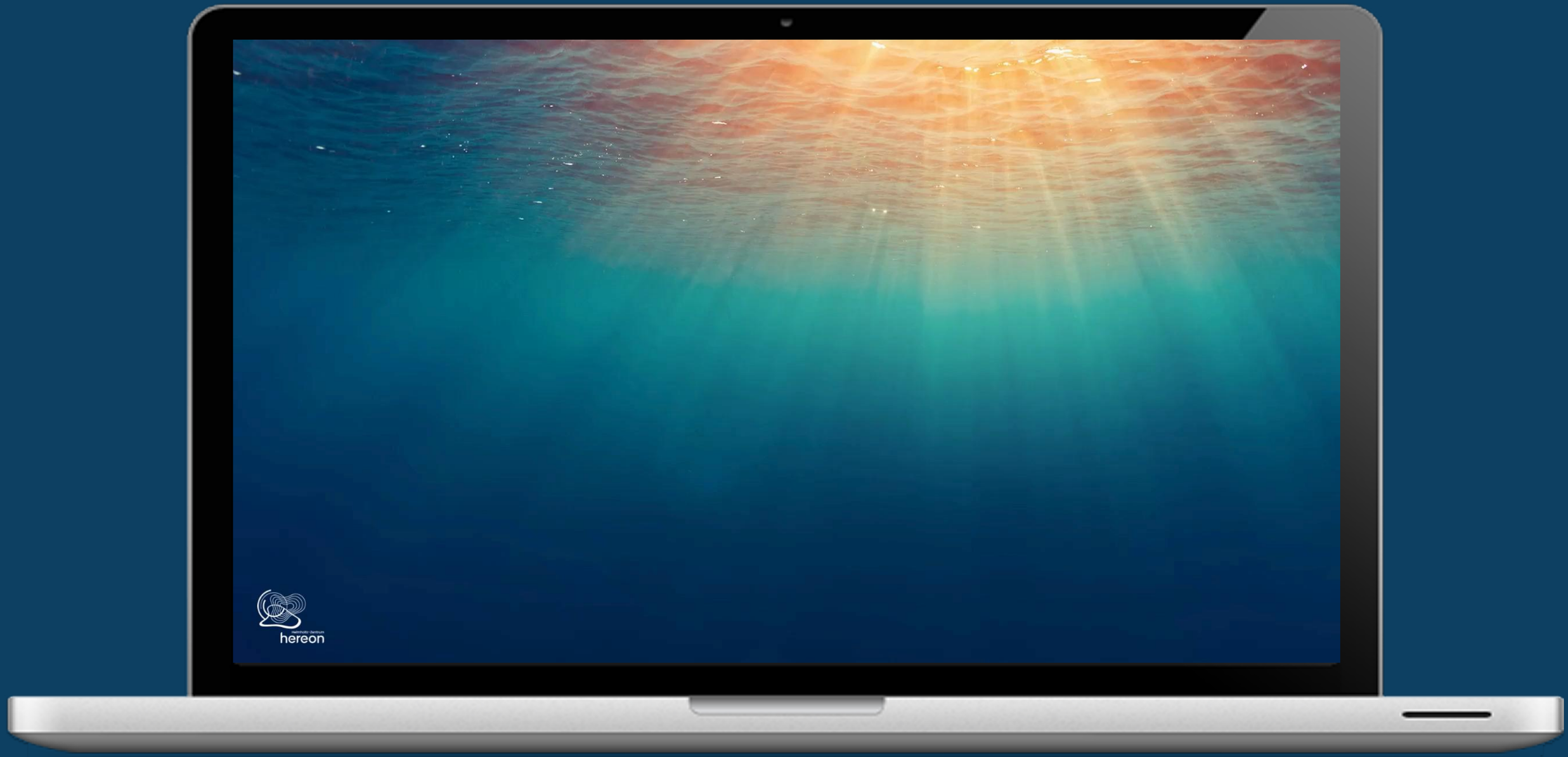
Benefits

- Reduces waves and currents
- Stabilises beaches naturally
- Weakens coastal erosion and flooding
- Protects the environment

Nature-Based Solutions for Biodiversity & Coastal Hazards

Regional Applications




Helmholtz-Zentrum
hereon

"Seagrass can efficiently reduce coastal erosion could help tidal flats keep up with sea level rise, directly contributing to flood risk reduction."

"Seagrass expansion could be a useful addition to engineered coastal protection measures."

Video: MER Marine & Environmental Research Lab Ltd. (2021, August 16). Transplantation of seagrass (Posidonia oceanica)

Nature-Based Solutions for Biodiversity & Coastal Hazards

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4 QUALITY EDUCATION

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

14 LIFE BELOW WATER

Marine Plastic for Zero Pollution

Jens Murawski

Danish Meteorological Institute

Marine Plastic for Zero Pollution

Humans, plastic and the sea...

+9k tons of particles from car tyres

+30 tons of microplastics from cosmetics

Up to 45 tons of plastic fiber from laundry washing enter the Baltic Sea every year


What happens
to microplastic pollution
in the sea
if river pollution is reduced?
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For a given
marine protected area,
where are microplastics
coming from?
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Marine Plastic for Zero Pollution

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Estimates how removing microplastics,
such as car tyre wear,
from rivers
affects marine pollution
in the Baltic Sea

Marine Plastic for Zero Pollution

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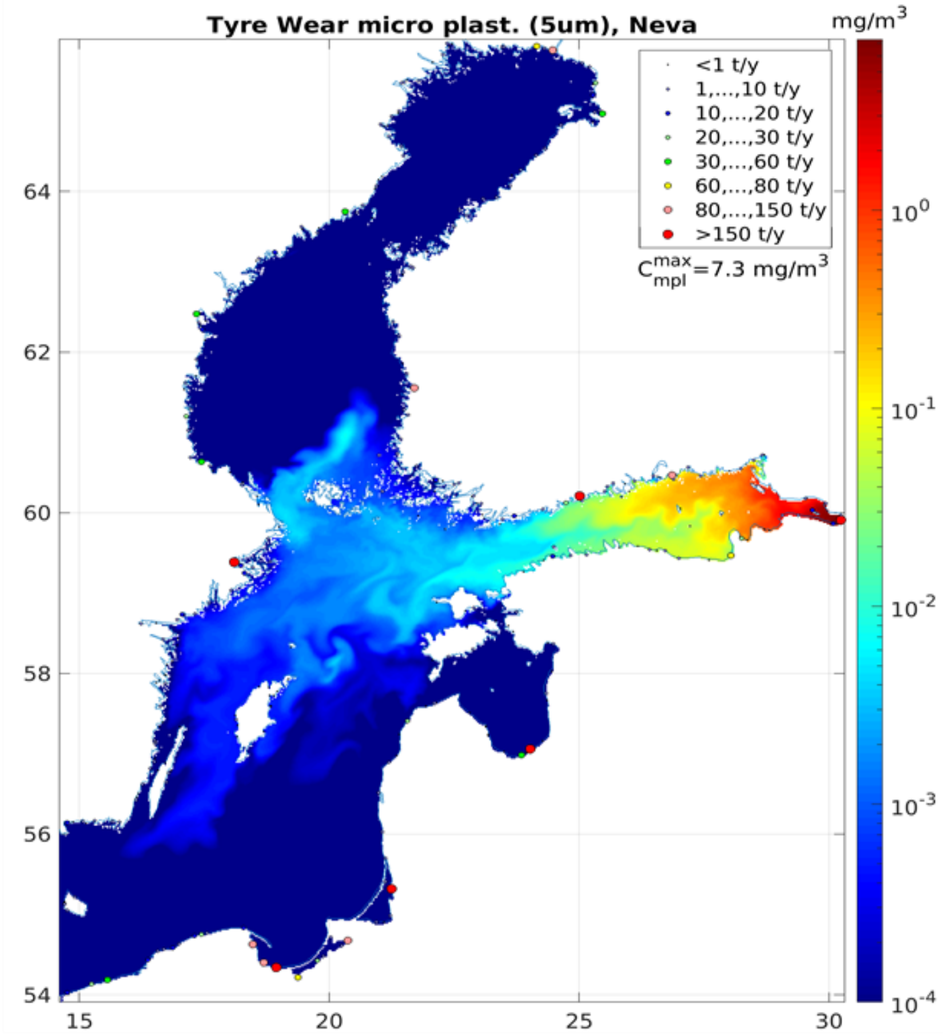
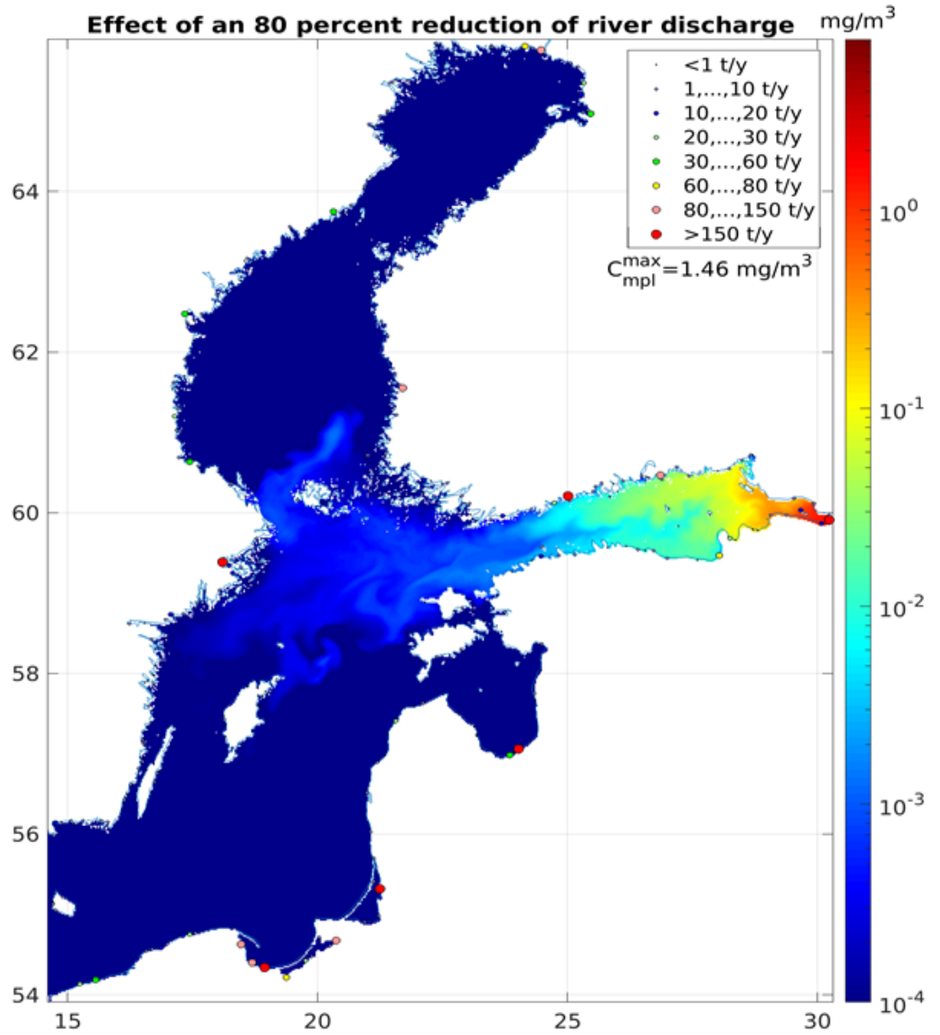


Tyre wear pollution
Neva River, Baltic Sea



Tyre wear pollution
after **80% cleaning**

EDITO-Model Lab — Eu
Datalab EDITO
Microplastic Analysis De
user-jmu-530785-0.lab.dive.edito.eu
Verify it's you
Relaunch to update

River Contributions

Select rivers and their weights:

Use weight sliders to scale the contribution of each river source. Values greater than 1.0 increase the river's impact, values less than 1.0 decrease it.

Enable All

Disable All

- [x] Neva (Russia)
  Weight 1.00 (0.00 – 2.00)
- [ ] Vistula (Poland)
- [ ] Nemunas (Lithuania)
- [ ] Daugava (Latvia)
- [ ] Kemijoki (Finland)
- [ ] Narva (Estonia/Russia)
- [ ] Indalsälven (Sweden)
- [ ] Ume (Sweden)
- [ ] Torne (Finland/Sweden)
- [ ] Gavleån (Sweden)
- [ ] Oder (Poland/Germany)

Baltic Sea Microplastics

Select an application to analyze different aspects of microplastic distribution in the Baltic Sea.

WiS 2 (1.0): Transport Analysis

Transport patterns across different rivers and tracers.

Launch Transport Analysis

FA 3 (1.1): Seasonal Spatial Distribution

Spatial distribution across different months and depths.

Launch Seasonal Analysis

FA 3 (1.2): Time Series Analysis

Temporal patterns through depth profiles.

Launch Time Series

Marine Plastic for Zero Pollution

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Aquaculture for Zero Carbon

Lőrinc Mészáros

Deltares

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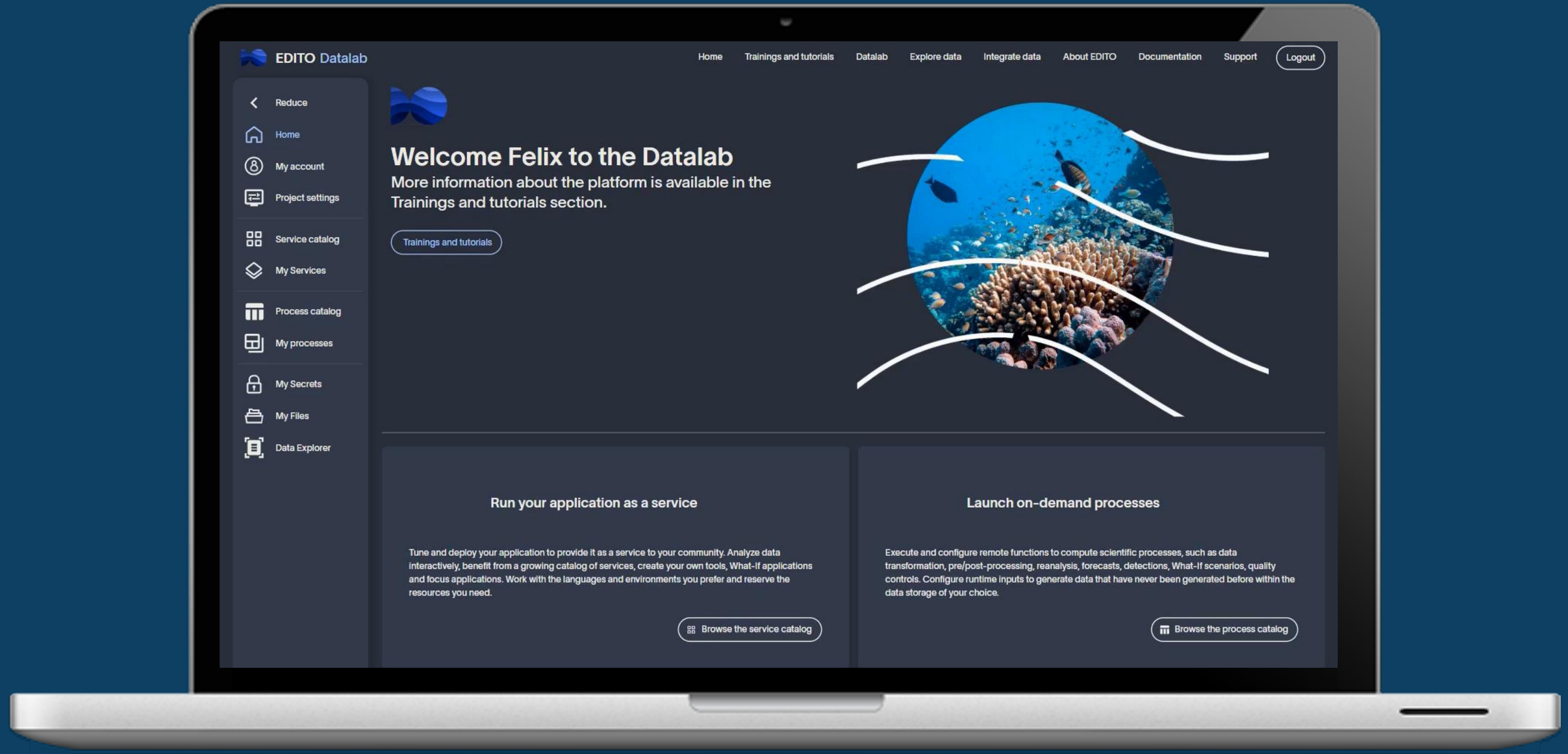
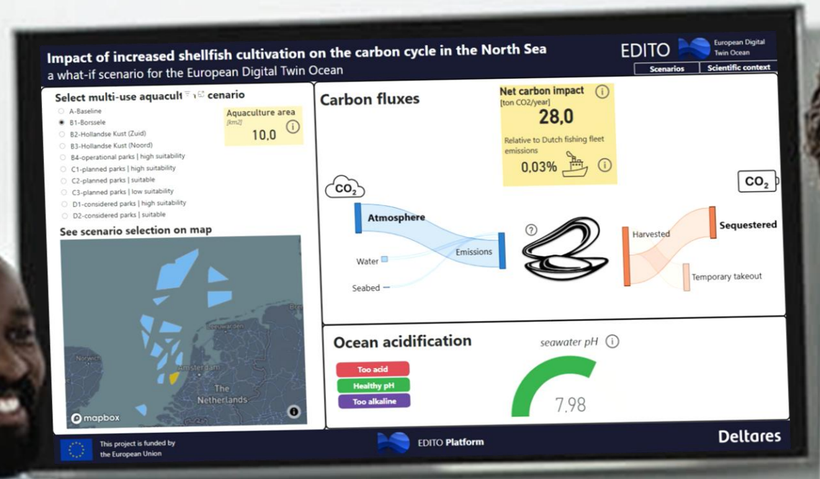
- Many offshore wind parks are built
- The space within these parks could be multi-use
- Which can be used for shellfish aquaculture
- This provides for food
- **Can it also store carbon? Does it make any difference?**



Disclaimer: The scenario simulations are currently in progress. The dashboard presently displays mock-up data.

“A very useful tool for discussions, including within the North Sea Agreement working group on multi-use and area passports.”

Stichting De Noordzee – Dutch NGO



“There will soon be a round table in the Dutch Parliament on wind farms. A dashboard like this would definitely be an asset for us.”

Stichting De Noordzee – Dutch NGO

Aquaculture for Zero Carbon

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Questions & Answers

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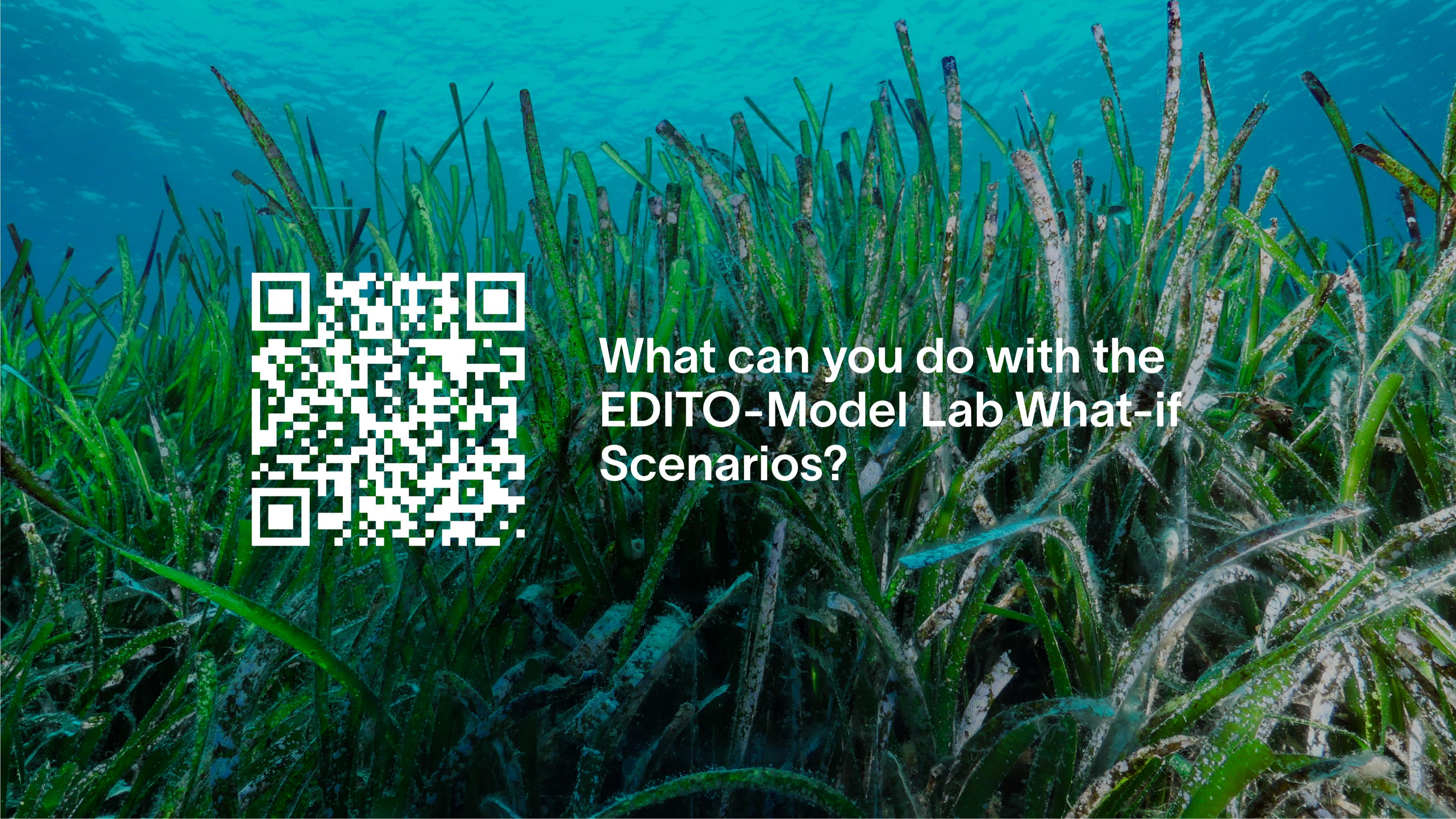
What can you do with the EDITO-Model Lab What-if Scenarios?

European Pavilion
Digital Ocean
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2 - 13 JUNE 2025

5 June 2025

Marine Environment Reanalyses Evaluation Project

Kick off event

MER-EP

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Use Physical Ocean Reanalyses to Monitor Ocean Changes

5th June, 2025

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Chunxue Yang

Institute of Marine Sciences,
National Research Council of Italy
(CNR-ISMAR), Roma, Italy

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ISTITUTO
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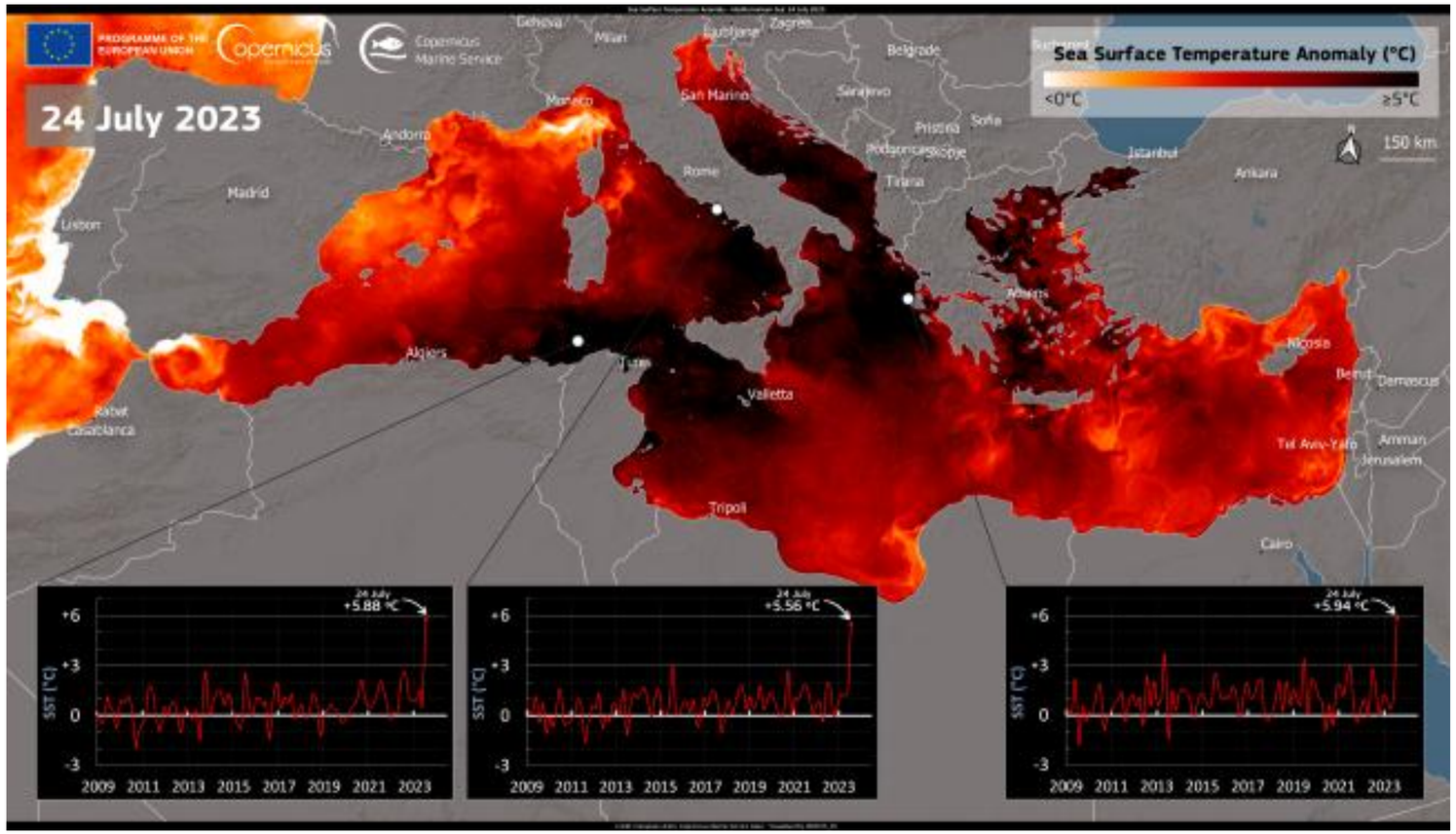
MARINE

Extreme Ocean Warming



- In 2023, the marine heat wave last Over a month in Alboran Sea
- **+5.5 °C** increase of sea surface temperature along the coastlines of Italy, Greece, and North Africa

https://marine.copernicus.eu/news/2023-northern-hemisphere-summer-record-breaking-oceanic-events

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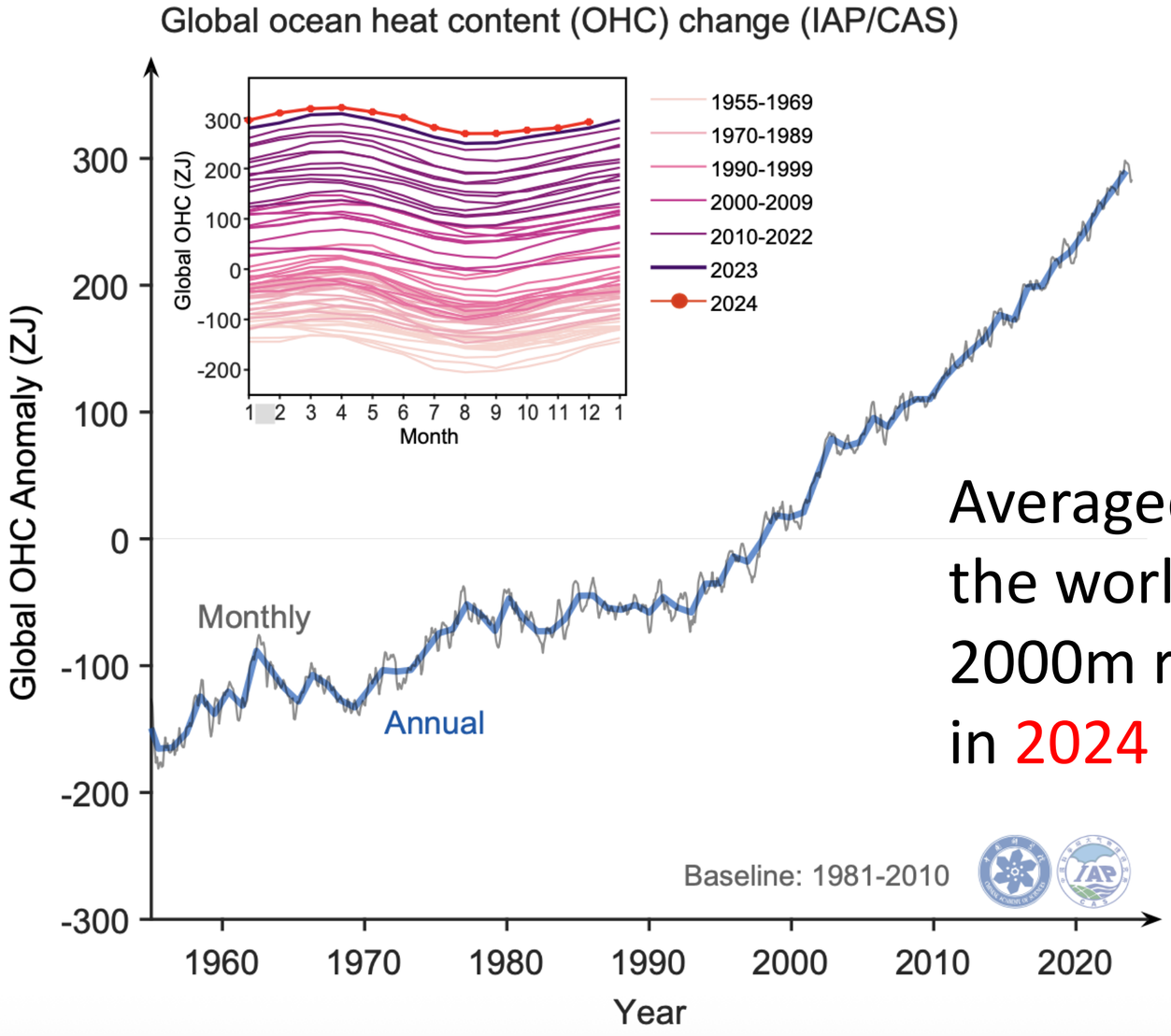
Extreme Ocean Warming



Averaged temperatures across the world's oceans above 2000m reached an all-time high in 2024

Cheng et al., 2025

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Observations

https://www.esa.int/ESA_Multimedia/Images/2019/05/ESA-developed_Earth_observation_missions

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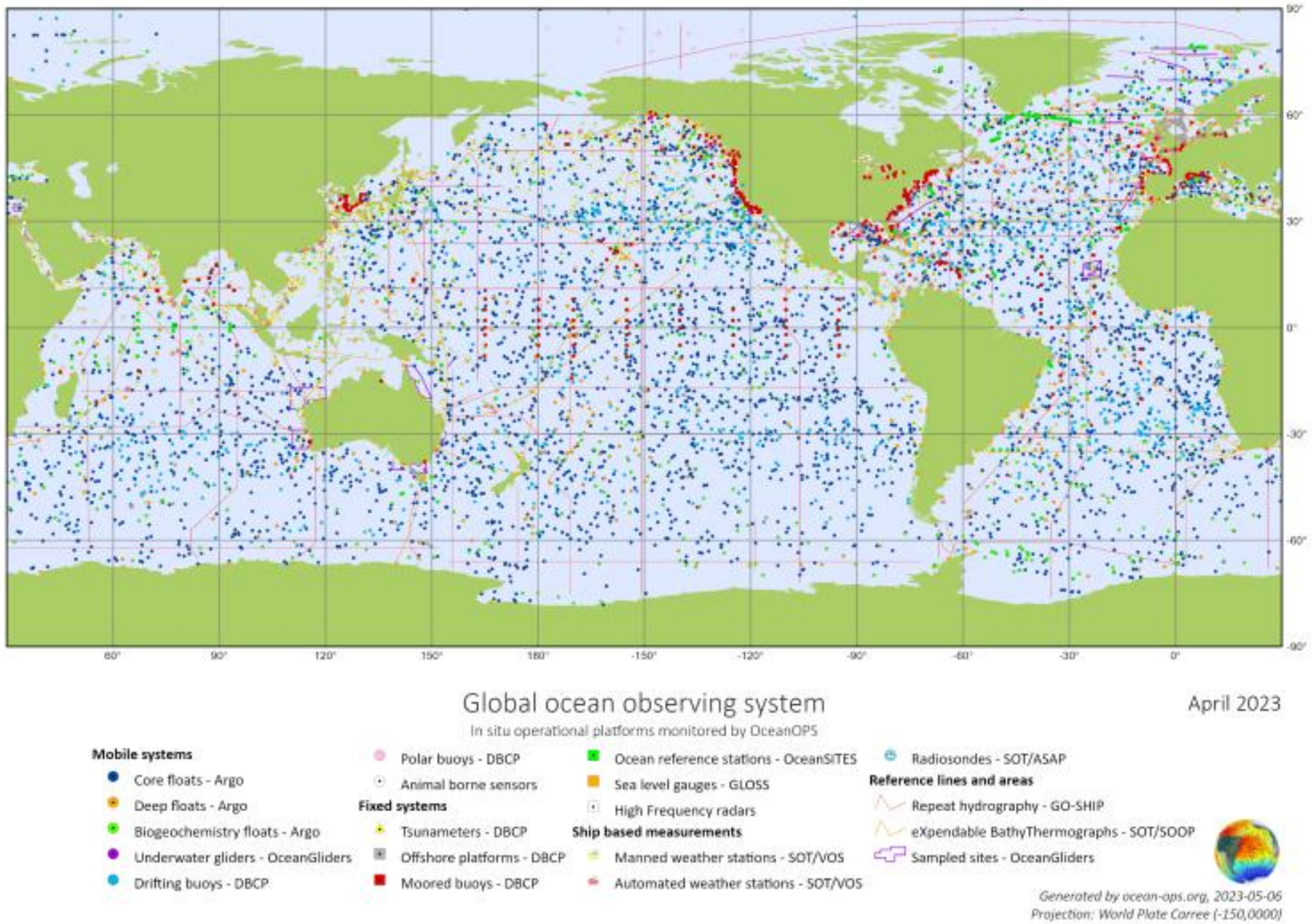
Observations



https://gcos.wmo.int/site/global-climate-observing-system-gcos/networks/oopc-situ

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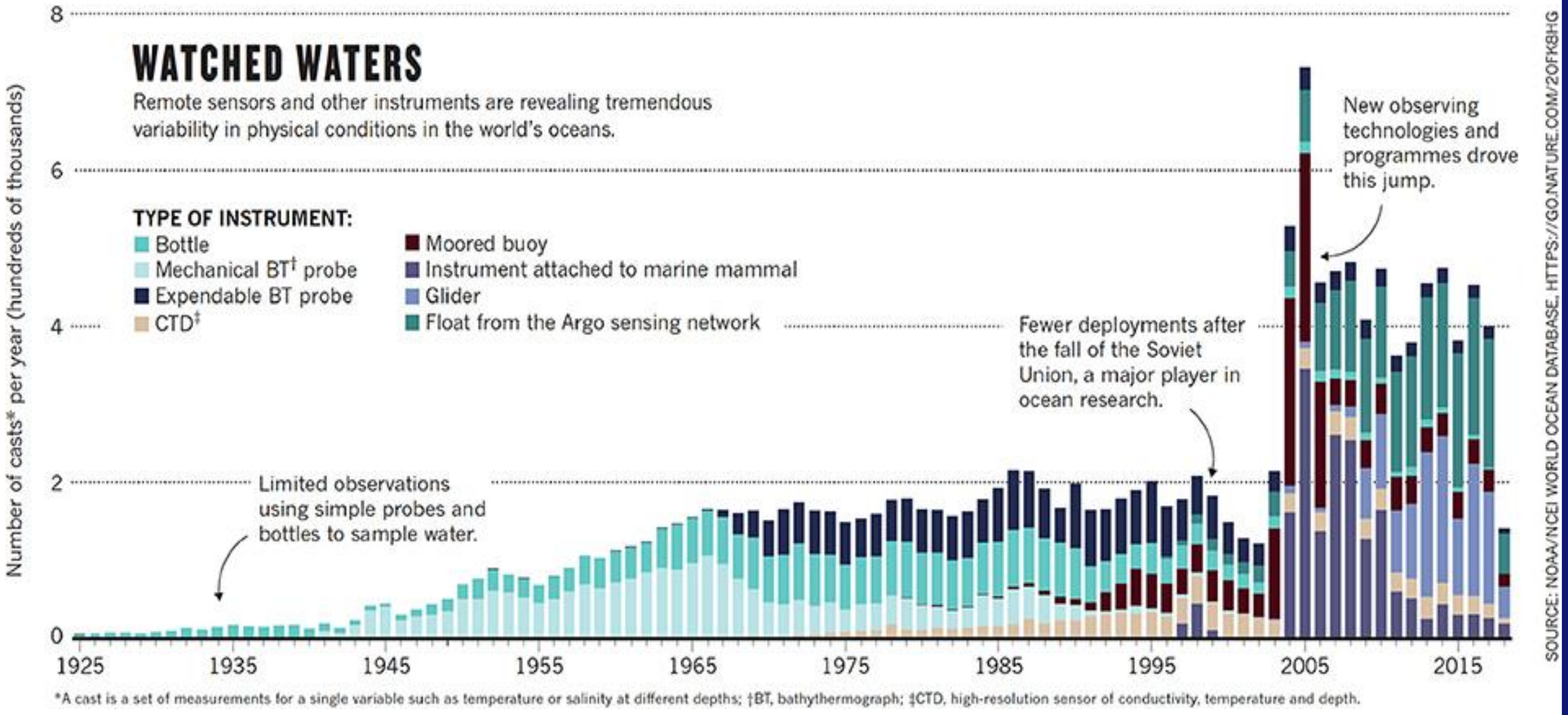
Observations



Bates et al., 2018

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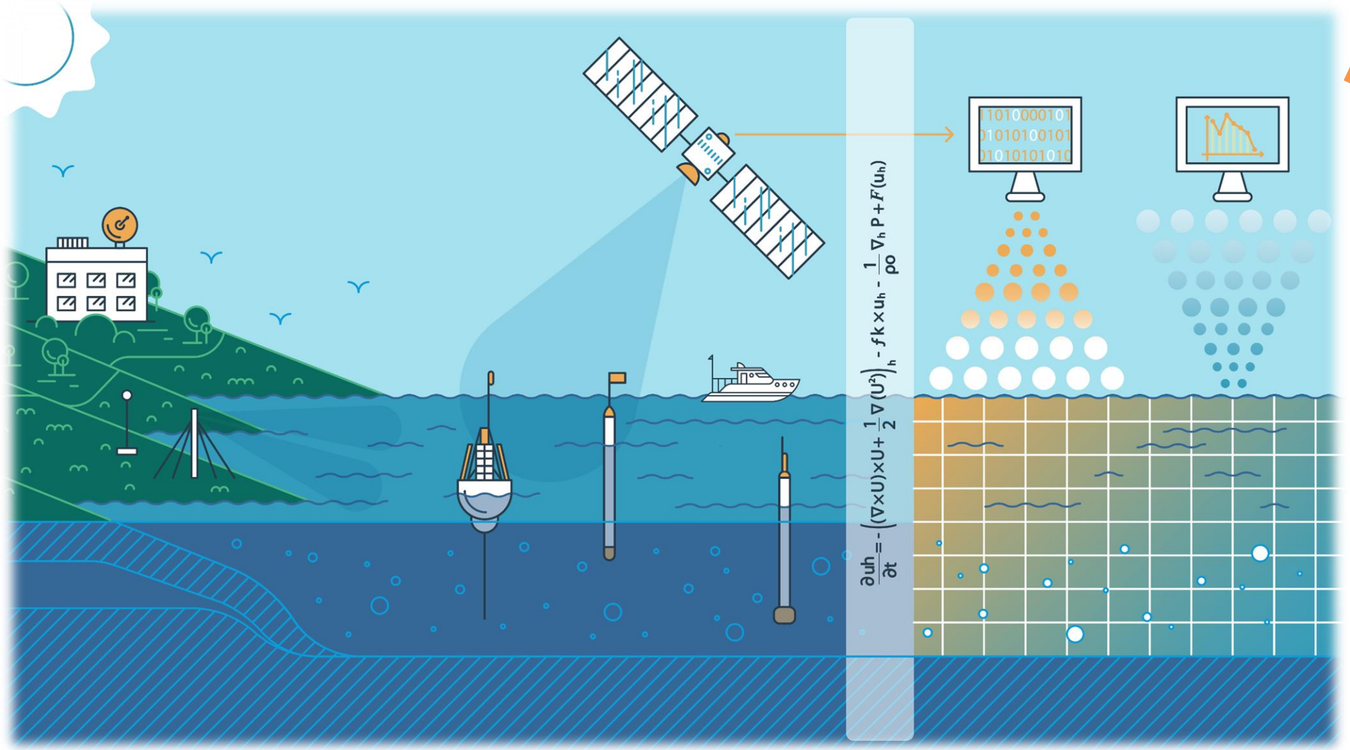
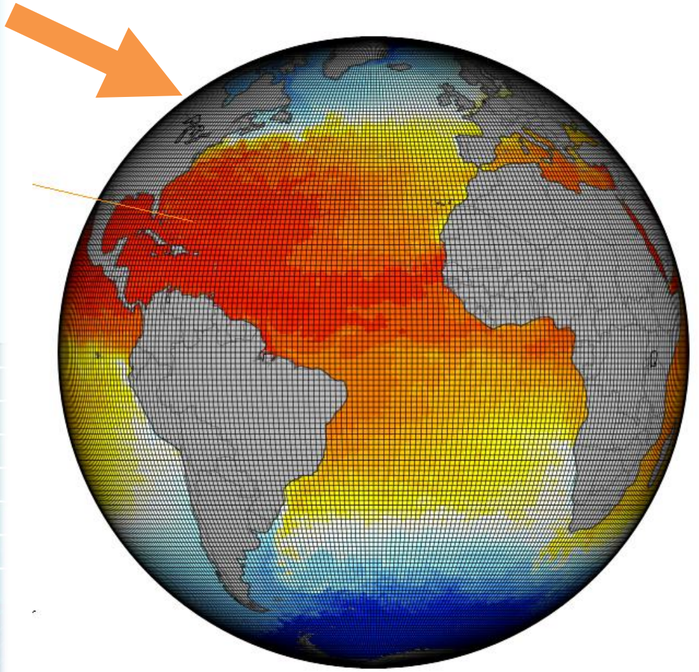
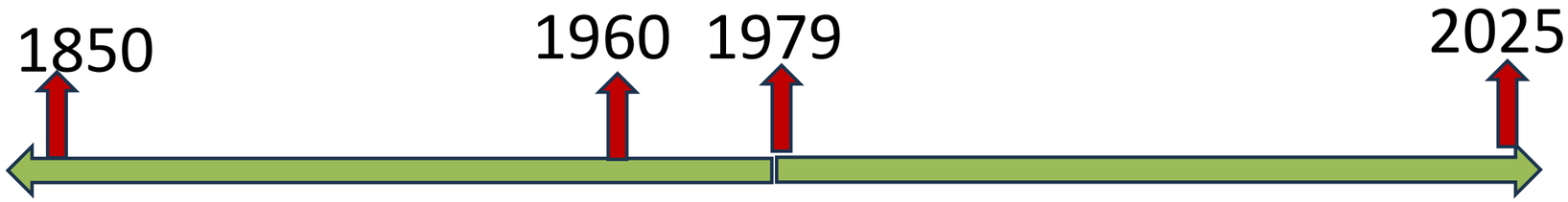
Ocean Reanalyses







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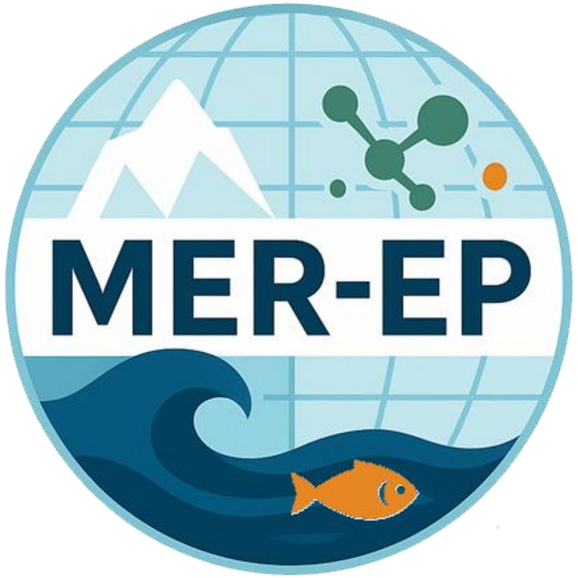
Quality of ocean reanalyses

- Uncertainty
- Accuracy
- Reliability
- Fitness for the purpose of usage of ocean reanalyses

Evaluation of ocean reanalyses



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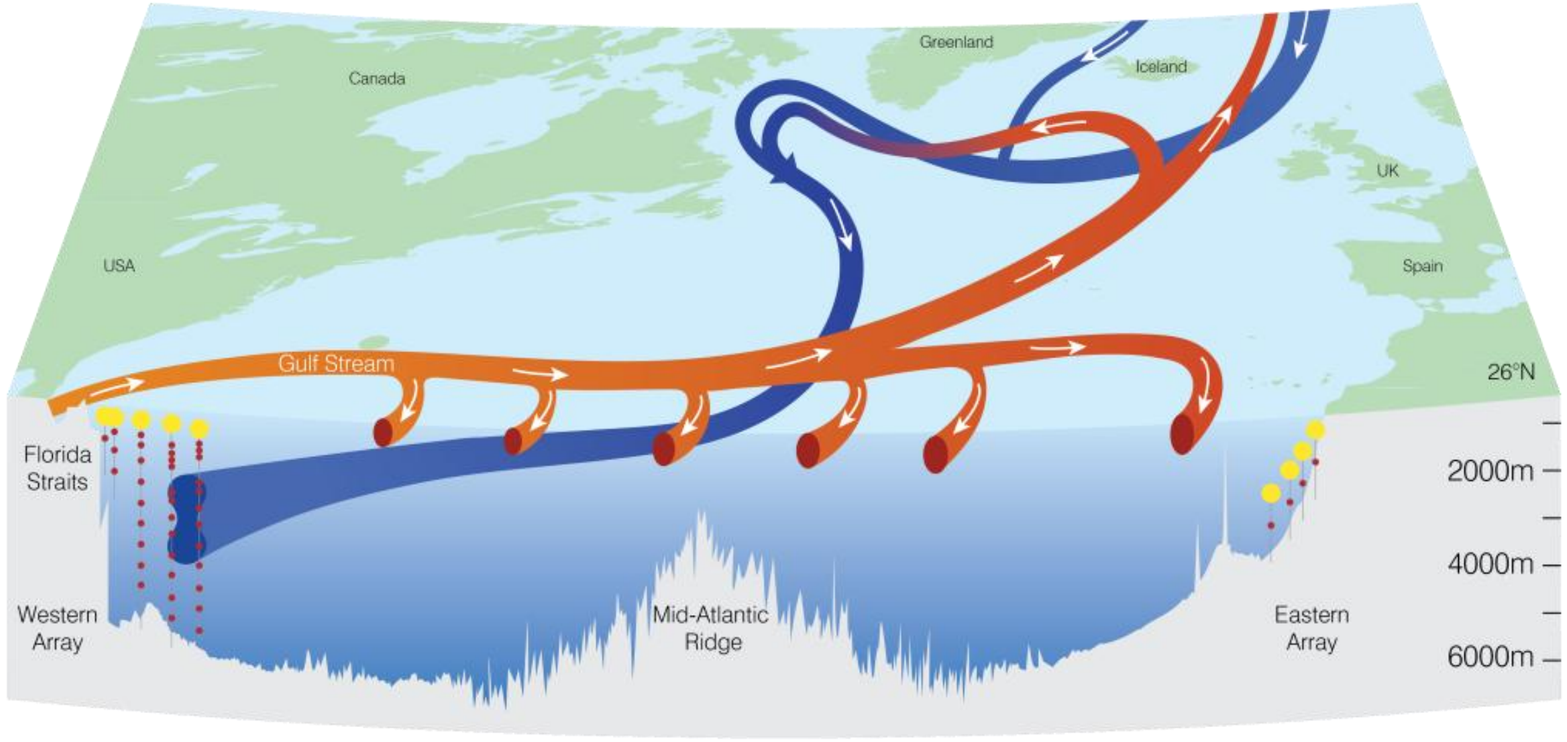
Use reanalyses to monitor ocean changes



https://rapid.ac.uk/methodology

Observation record goes back to 2004

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Thank You!

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Sea ice reanalyses

5 June 2025

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Laurent BERTINO

The Nansen Center, Bergen, Norway

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NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER
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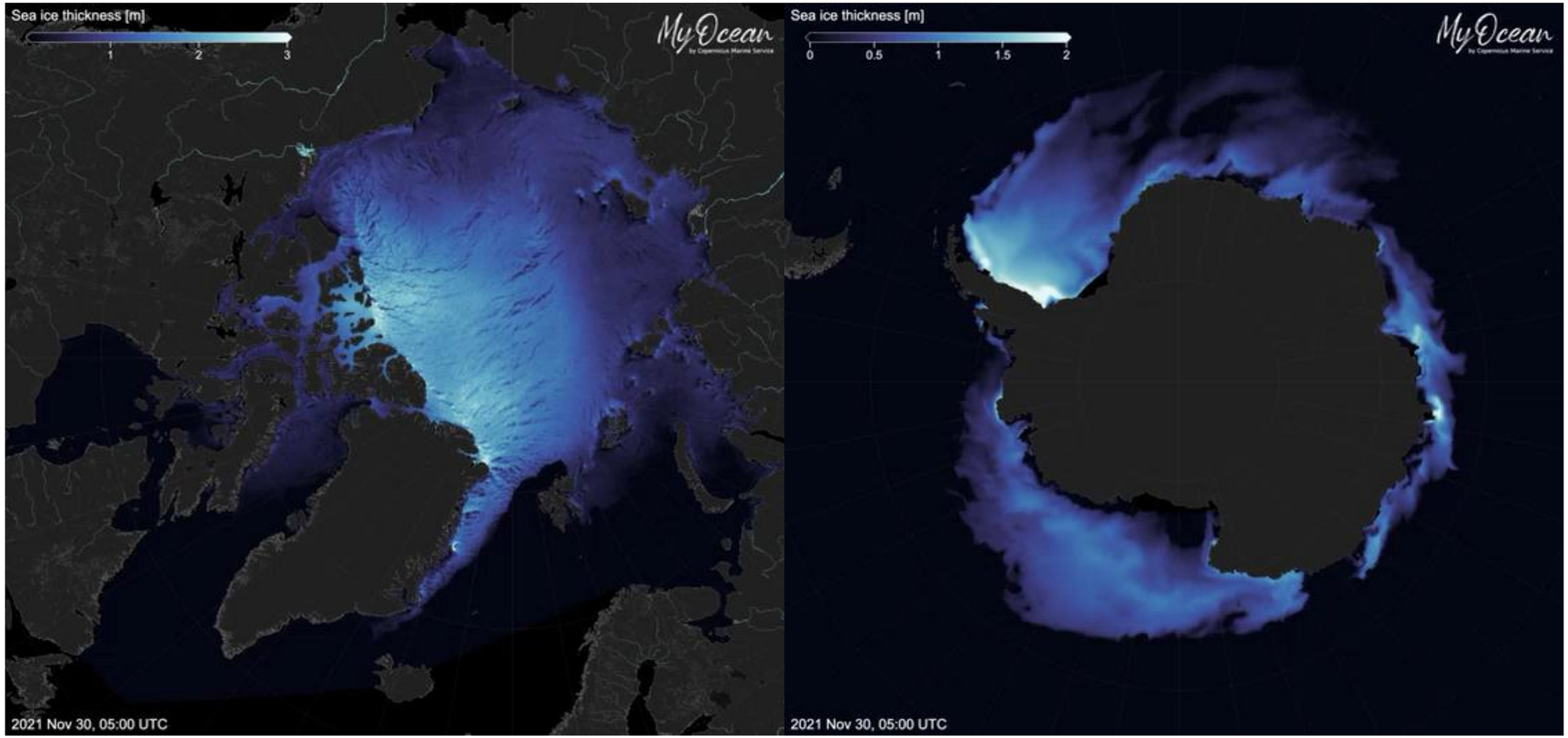
Context



https://data.marine.copernicus.eu/-/38xndl2c6k

For scale…

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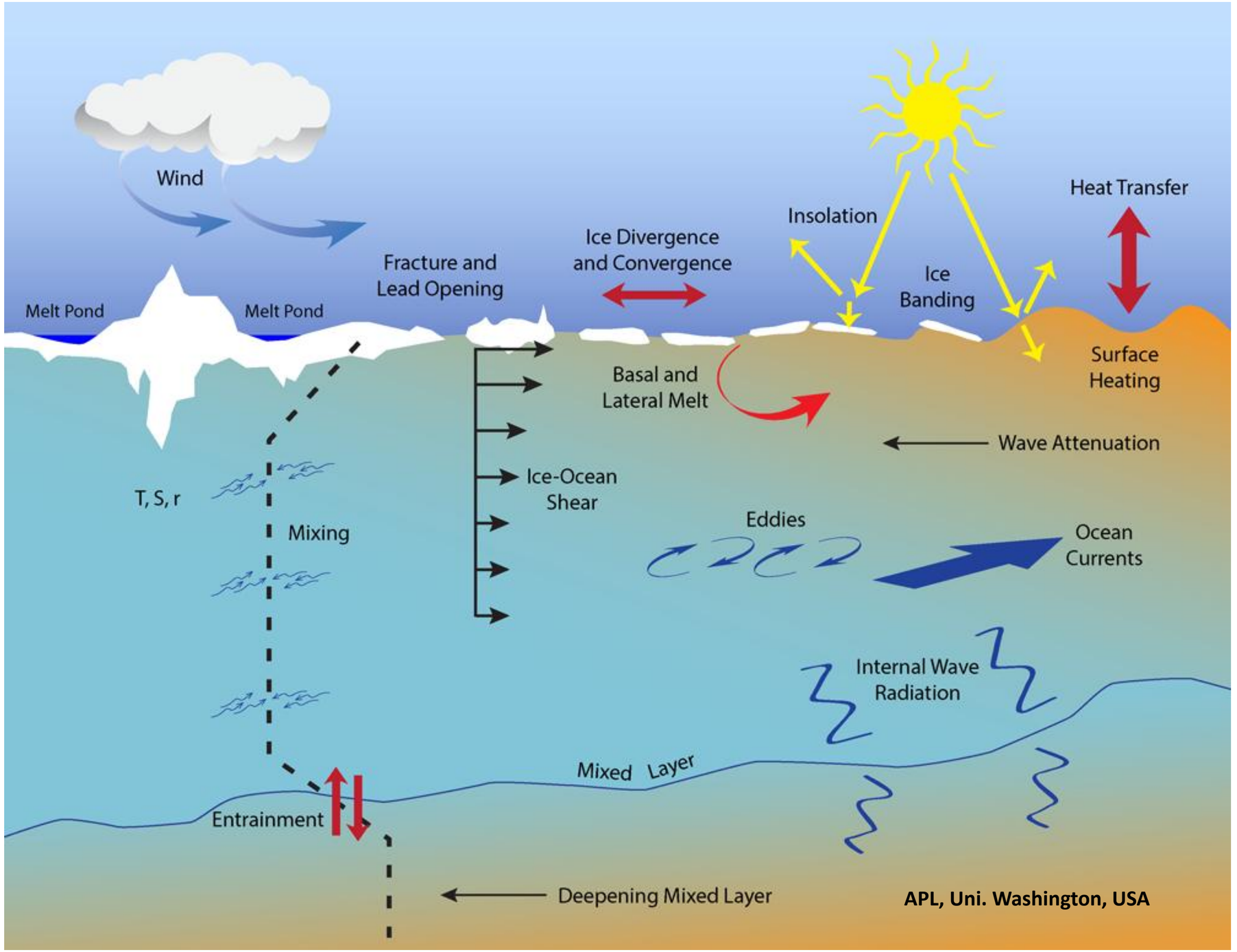

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How do we know? Satellites

1978 1987 1992 2002 2010

Sea ice area concentrations

SMMR

SSMI

AMSR-E

CIMR

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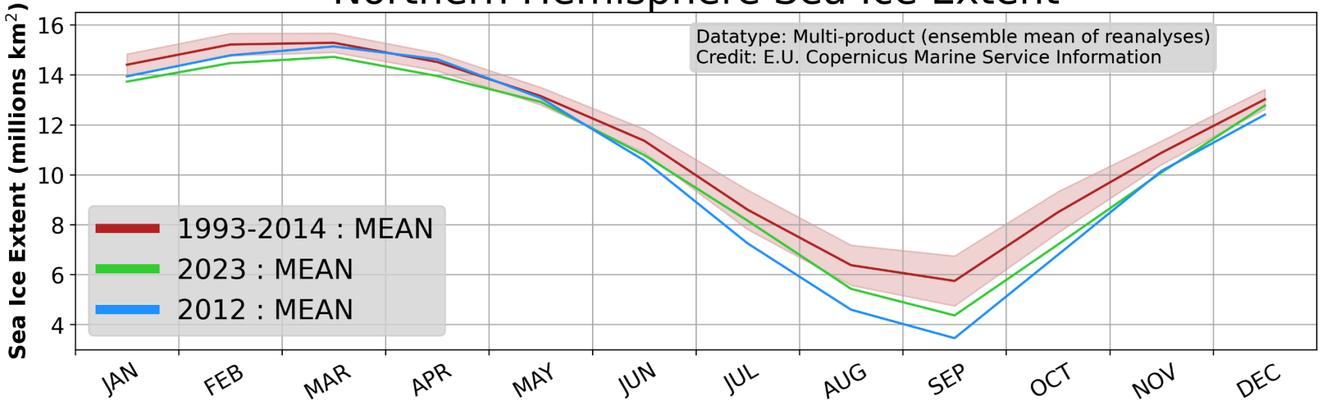
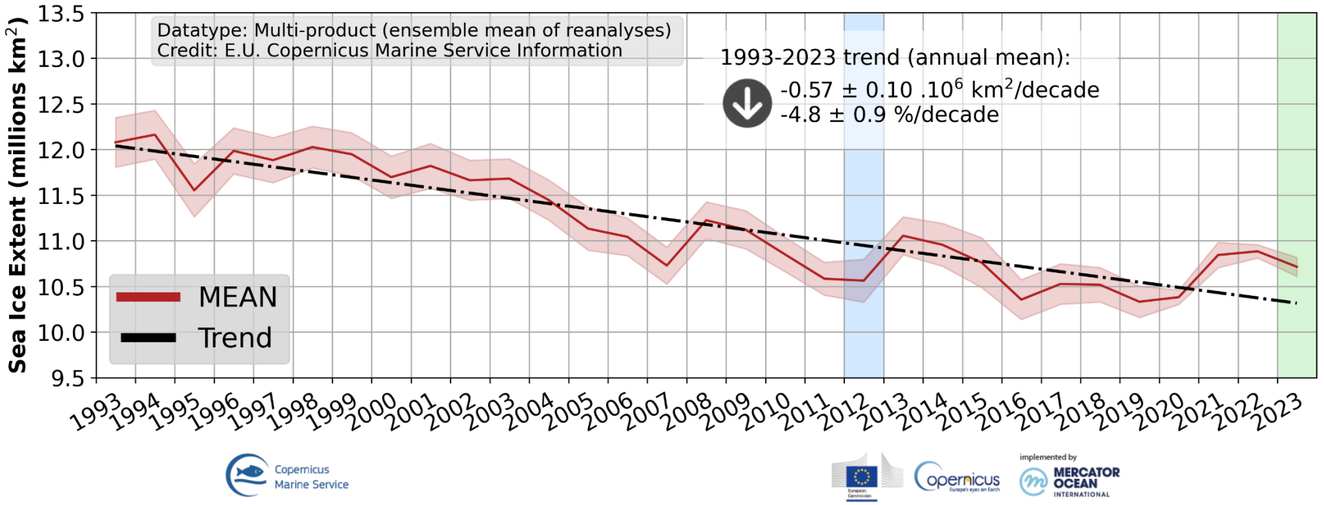
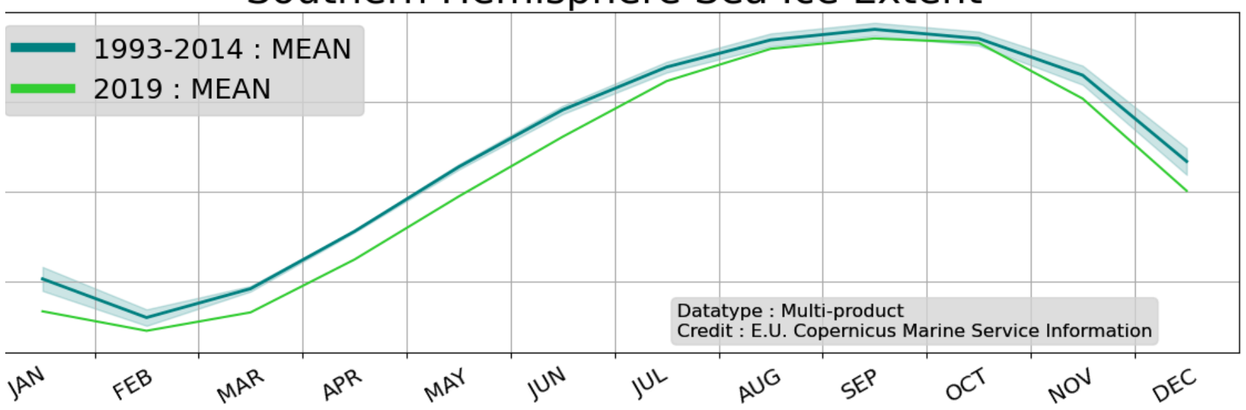
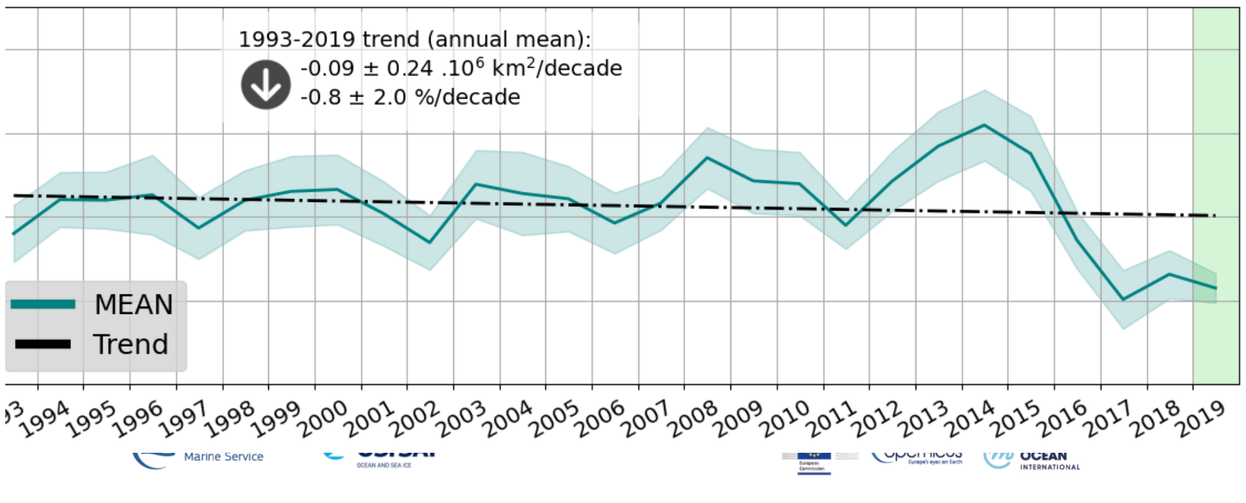
Northern Hemisphere Sea Ice Extent





Southern Hemisphere Sea Ice Extent





a) Mean seasonal cycle for 1993-2014, 2012 and 2023
b) Interannual annual anomalies of Northern Hemisphere sea ice extent expressed in millions of km2.
Time series are based on the multi-model ensemble mean of global reanalysis, e.g. the GREP data product GLOBAL_MULTIYEAR_PHY_ENS_001_031. Ensemble mean together with its spread (light shaded) are given. Details on the GREP product are given in the corresponding PUM for this OMI. The change of sea ice extent over the period 1993-2023 is expressed as trend in millions of square meters per decade, and in % per decade and linear trend is superimposed (dot-dashed line).

https://marine.copernicus.eu/access-data/ocean-monitoring-indicators

Satellites

1978 1987 1992 2002 2010

Sea ice concentrations

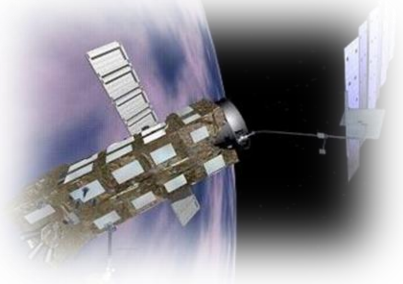
Sea ice drift

Sea ice Thickness

Sea ice Thickness

SMMR

SSMI



ENVISAT

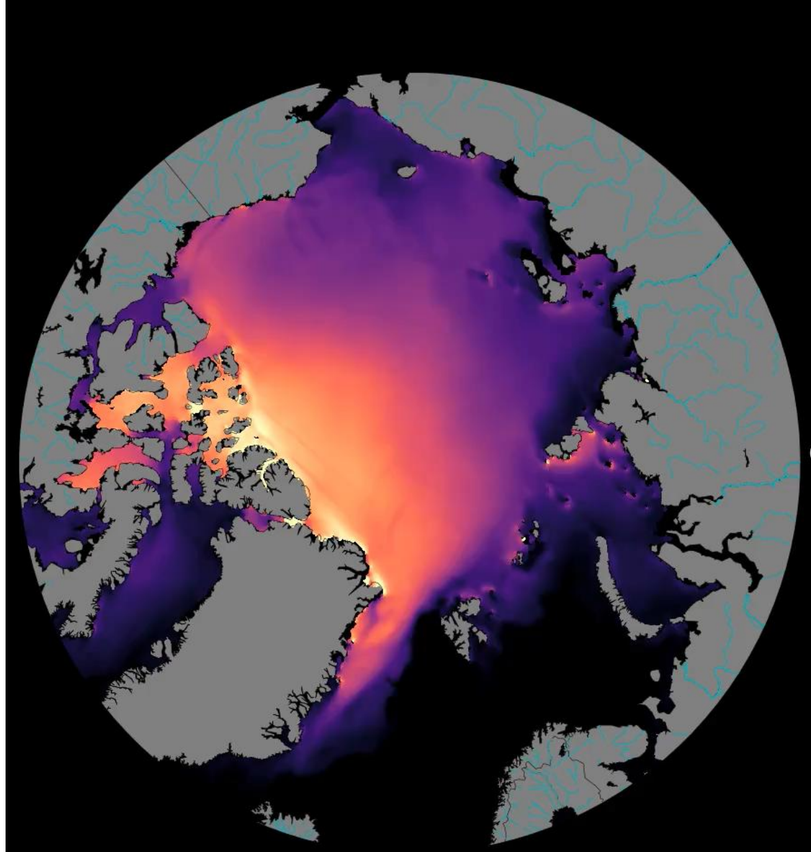
SMOS

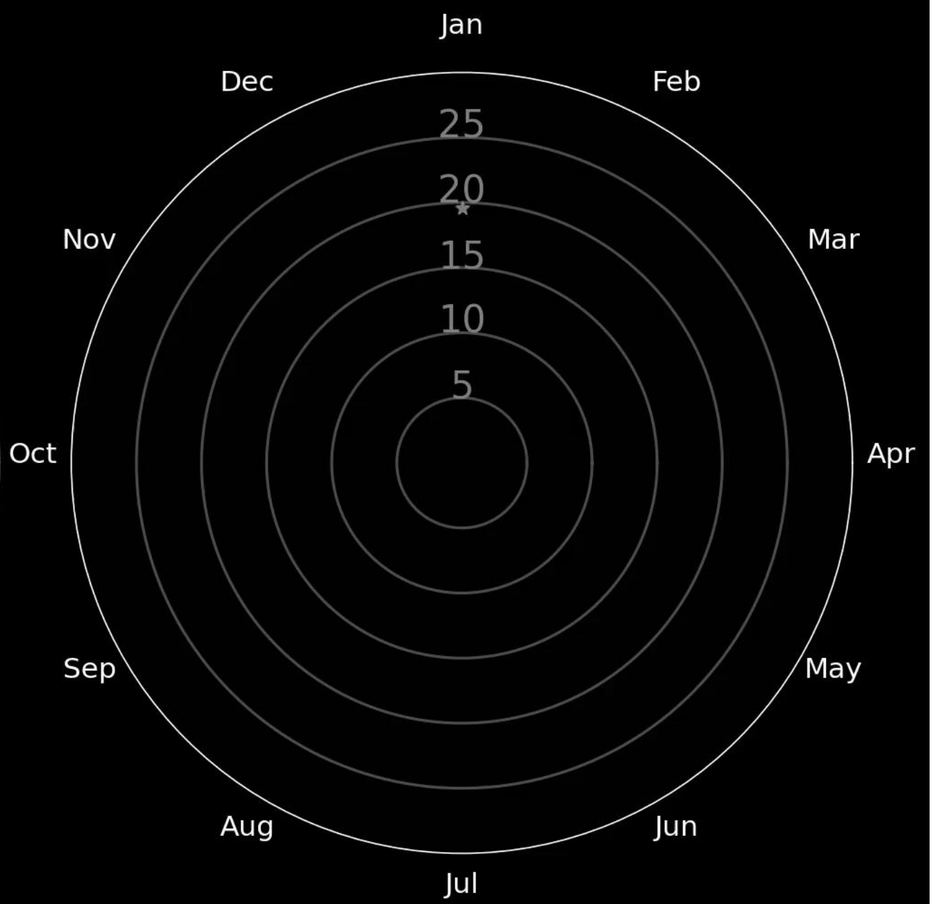
CryoSAT-2

Snow

CIMR

CRISTAL





Sea Ice Thickness (m)

Total Sea Ice Volume (1000 km³)

1992 01 01

SIT : 1.65 m
SIV : 19561 km³

NERSC
TOPAZ4 - TARDIS
Léo Edel

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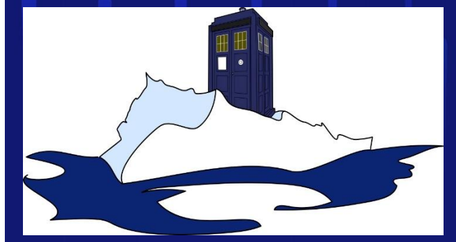

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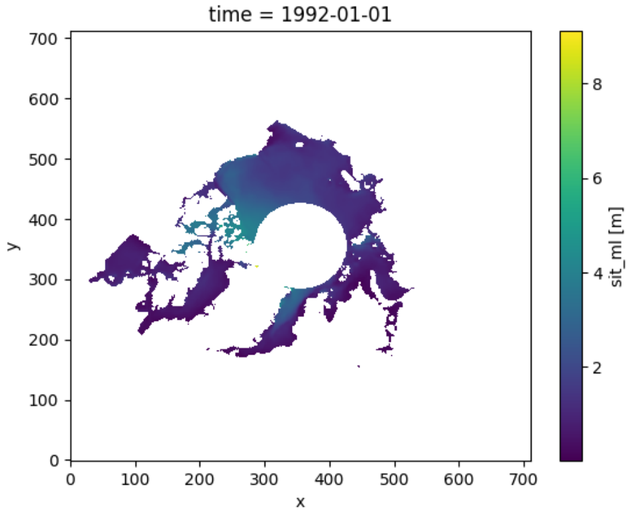
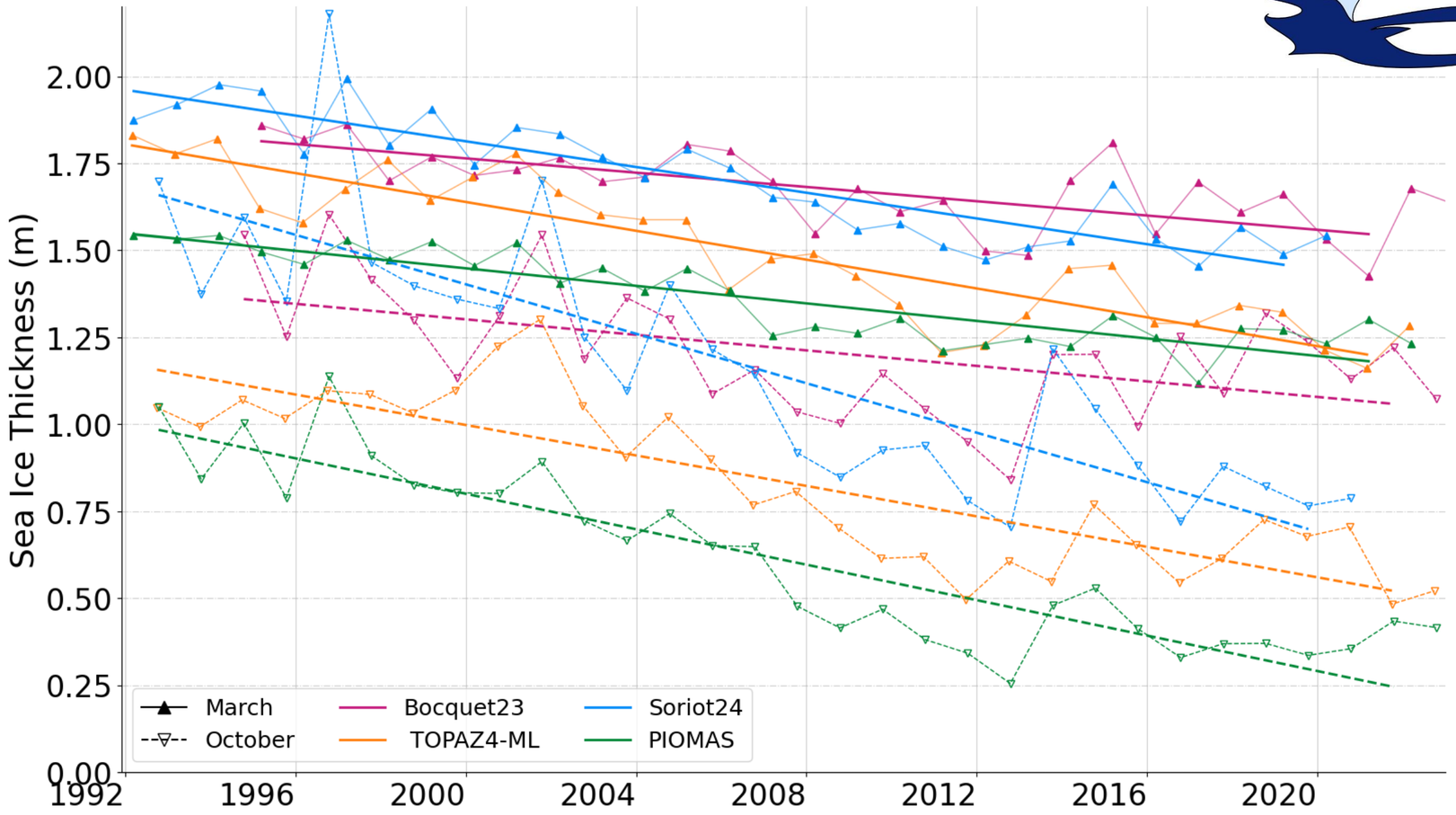
Sea ice thickness
How much do we really know?

Monthly SIT from PIOMAS, Bocquet et al. (2023 - altimeters), Soriot et al. (2024 - PMW)





Edel et al. 2025

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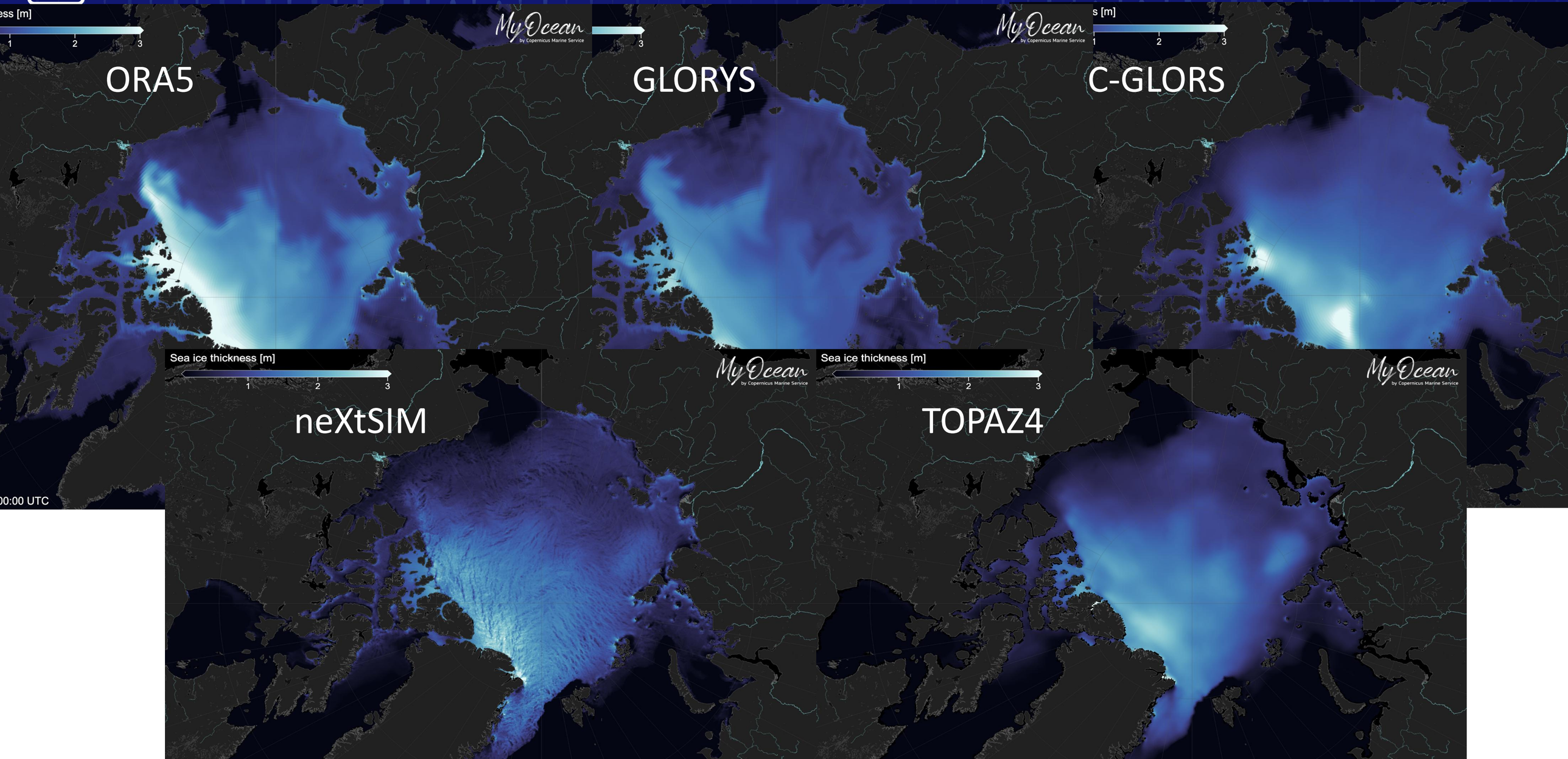

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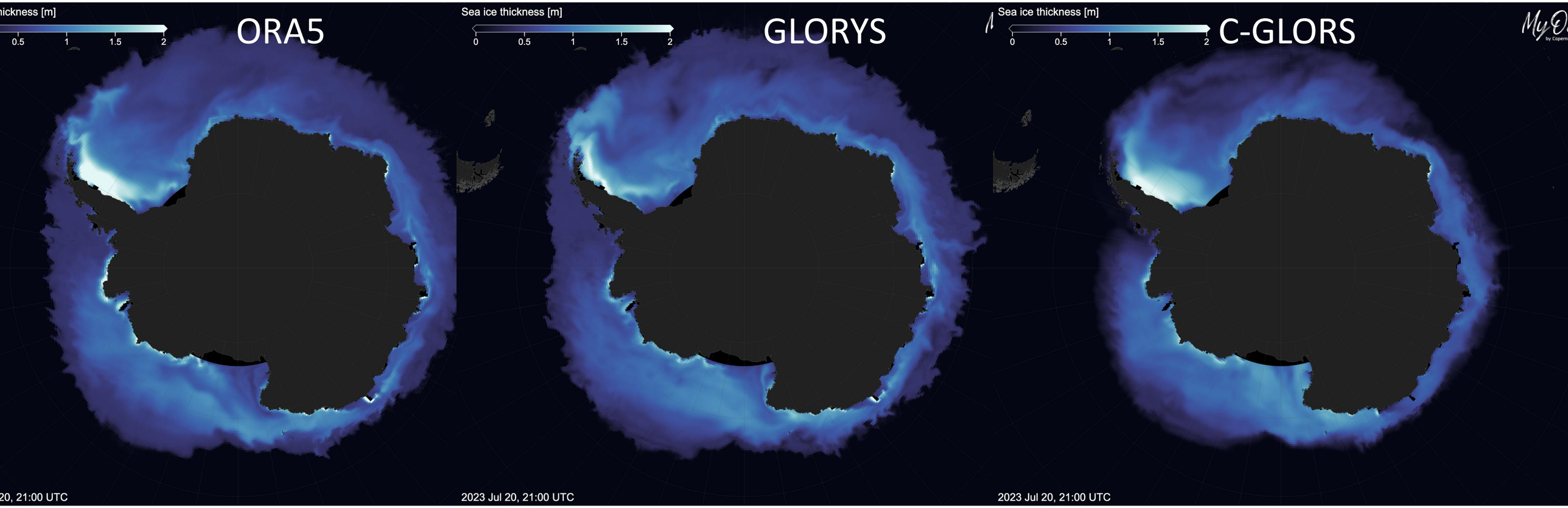

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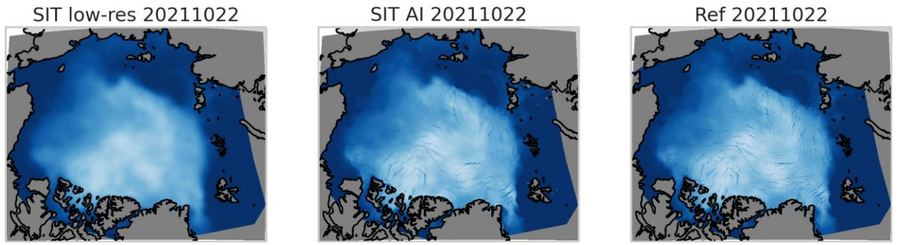
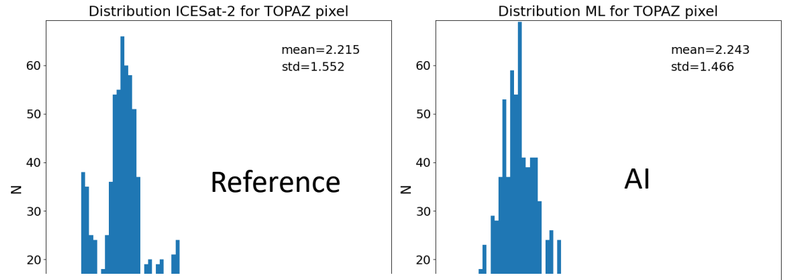
Use of AI in sea ice

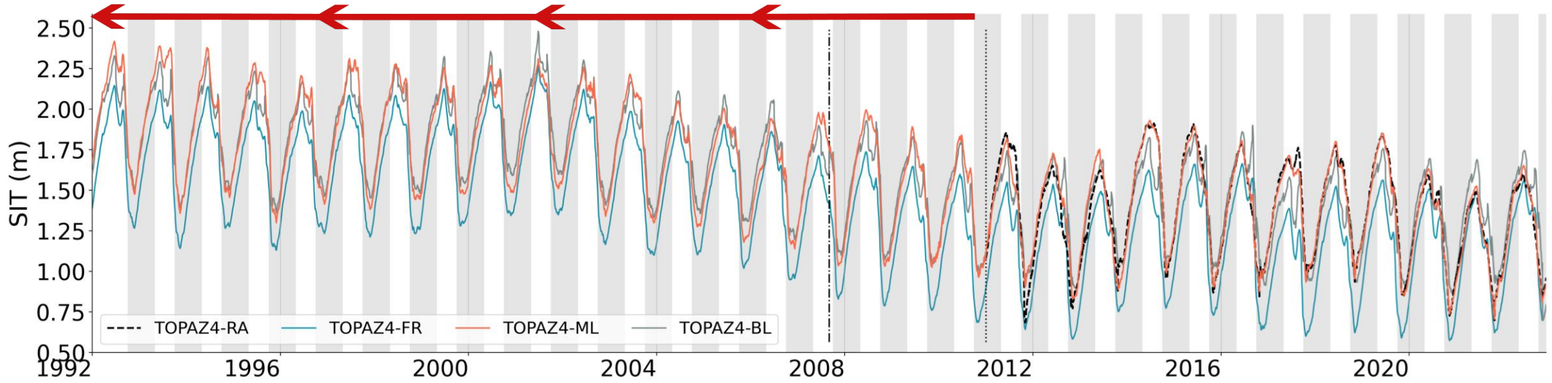
Enhance resolution



Sea ice thickness distribution

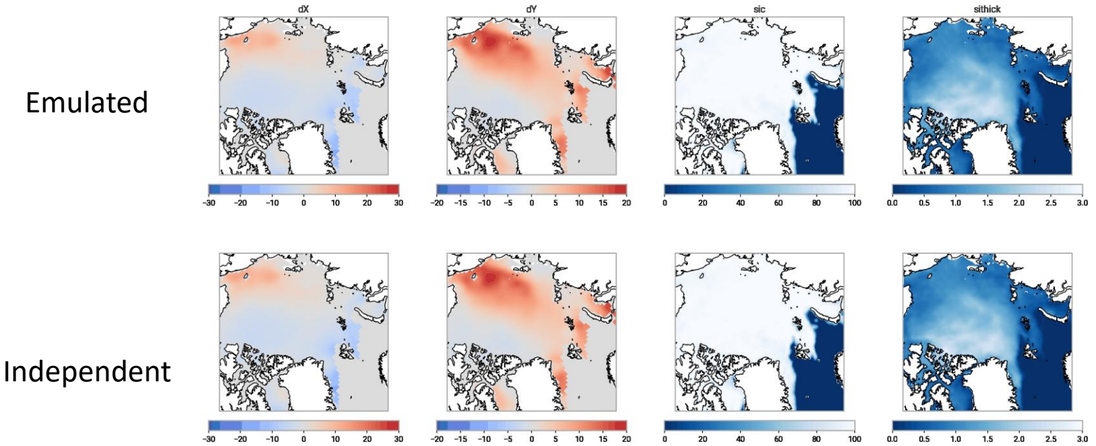


Go back in time



esy of L. Edel

Make forecasts cheaper



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Thank you for your attention!

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Nice | France

2 - 13 JUNE 2025

Marine Environment Reanalyses : Biogeochemistry

June 5th 2025

Marilaure Grégoire, Gianpiero Cossarini, Elodie Gutknecht, Susan Kay, Julien Lamouroux, Helen Morrison, Coralie Perruche, Annette Samuelsen, Lena Spruch, Anna Teruzzi, Luc Vandenbulcke, Tsuyoshi Wakamatsu

LIÈGE université

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Marilaure Grégoire

University of Liège, Belgium

Marilaure Grégoire, Gianpiero Cossarini, Elodie Gutknecht, Susan Kay, Julien Lamouroux, Helen Morrison, Coralie Perruche, Annette Samuelsen, Lena Spruch, Anna Teruzzi, Luc Vandenbulcke, Tsuyoshi Wakamatsu

Marine Environment Reanalyses : Biogeochemistry

- Observing the green ocean
- Modelling the green ocean
- Reanalysis products and connexion with the biology

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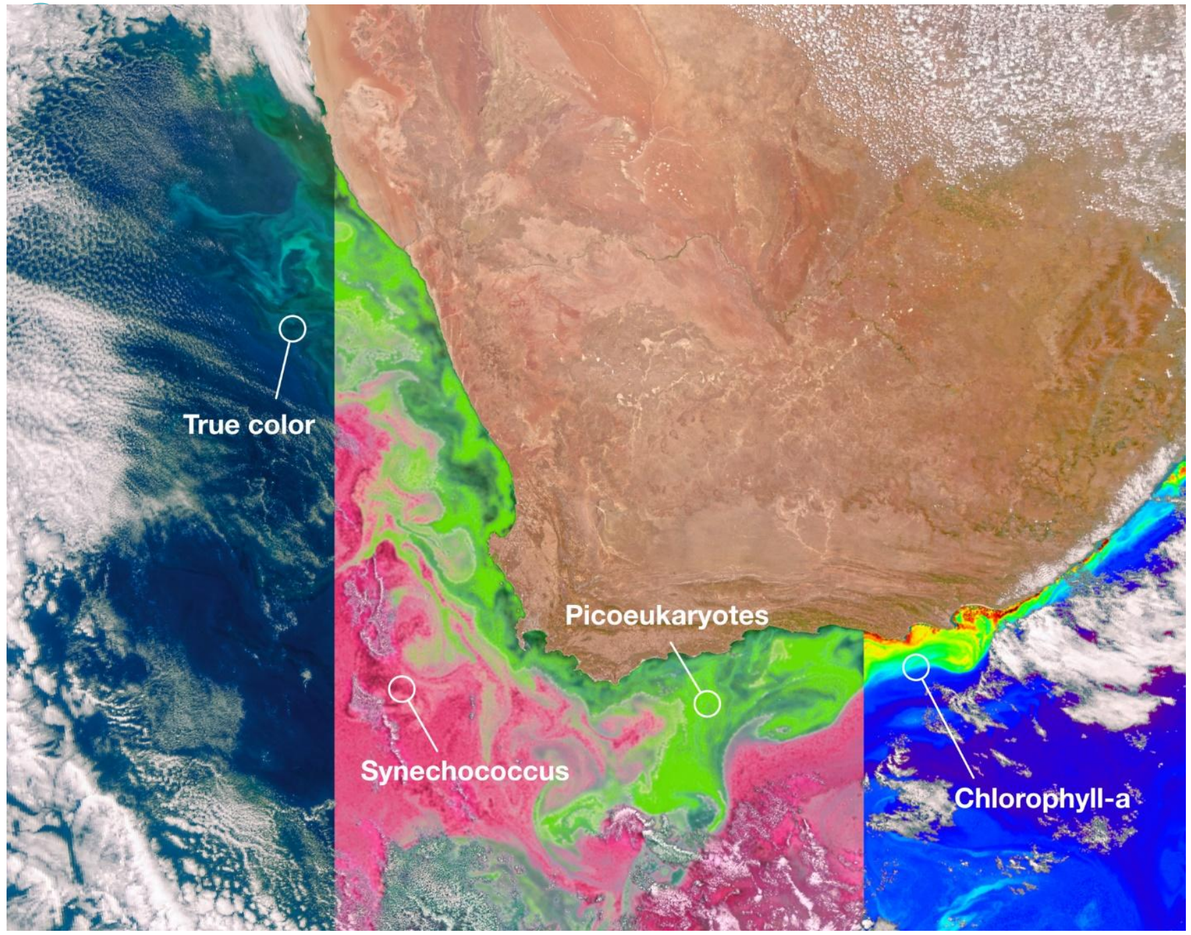
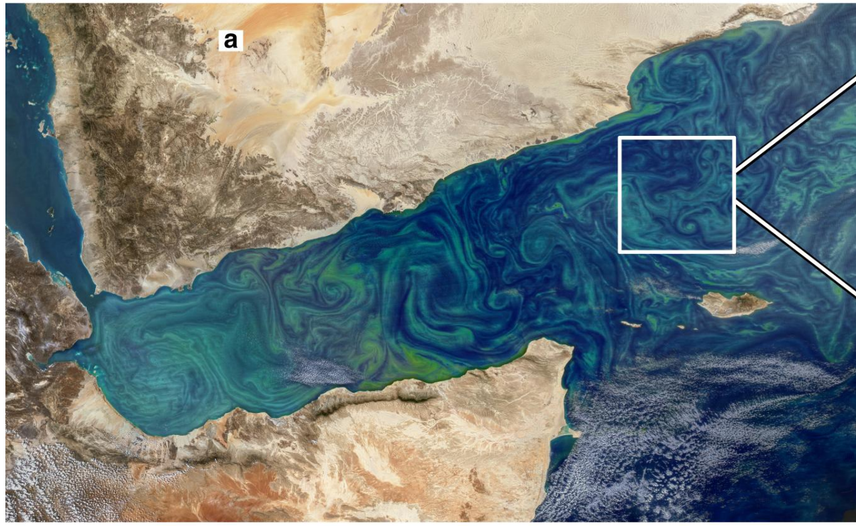
SATELLITE OBSERVATION

- Higher resolution in space, time, spectral
- Hyperspectral data offer a better connection to biology





National Aeronautics and Space Administration

Credit: Nasa

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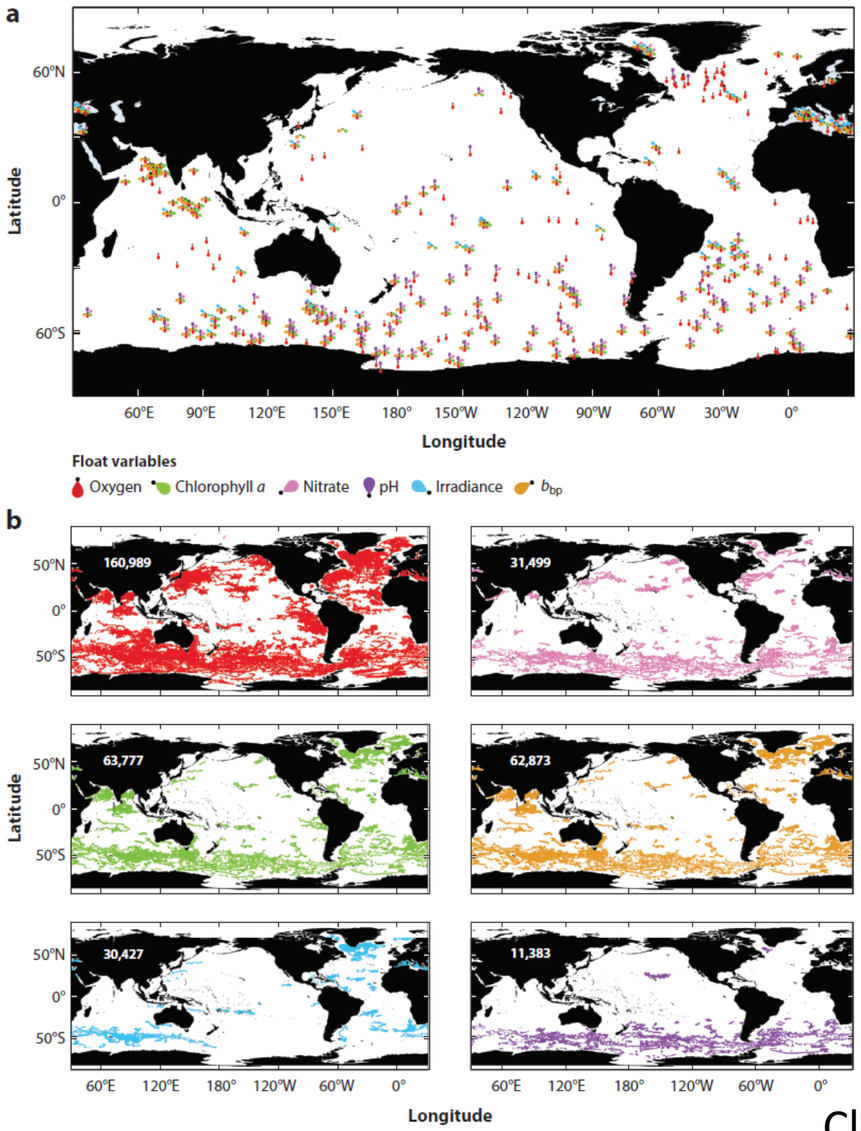
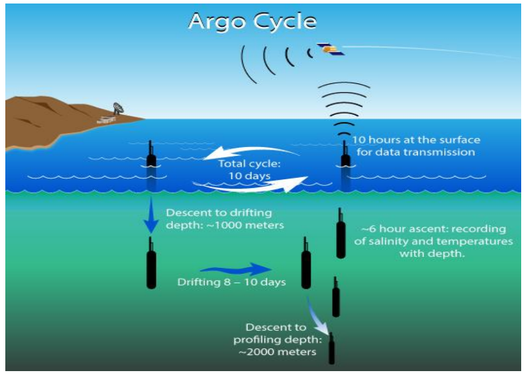
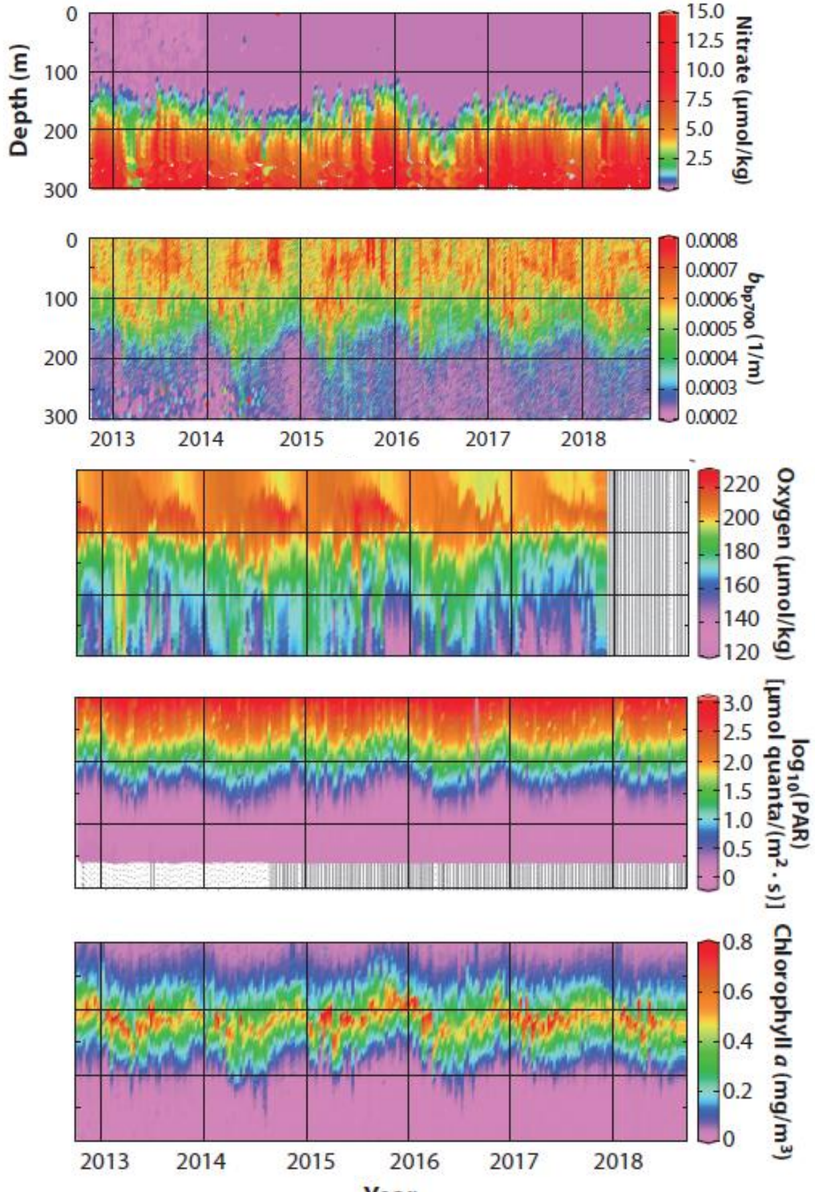
BIOGEOCHEMICAL ARGO





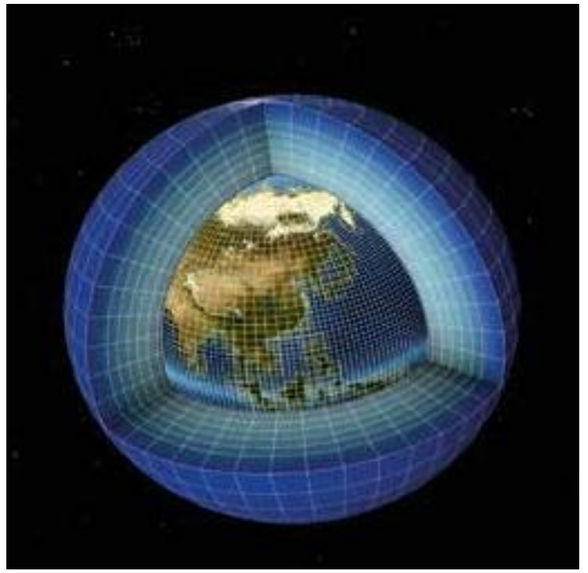
Target: 1000 BGC floats



Claustre et al., 2019

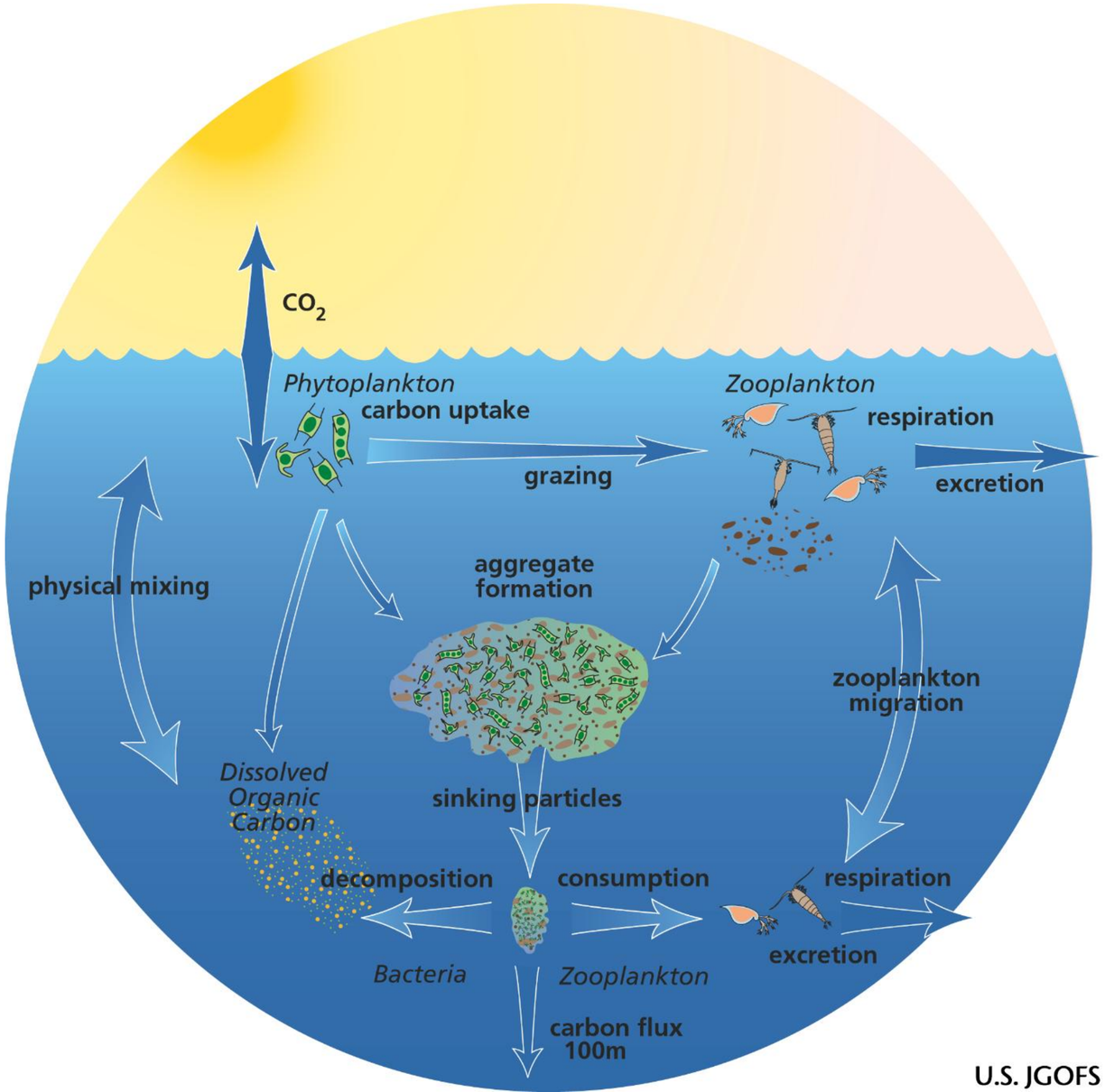
NUMERICAL OCEAN

- Mass balance equations
- No equivalent to Navier-Stokes equations for biogeochemistry
- Empirical representation of biogeochemical processes based on laboratory experiments.



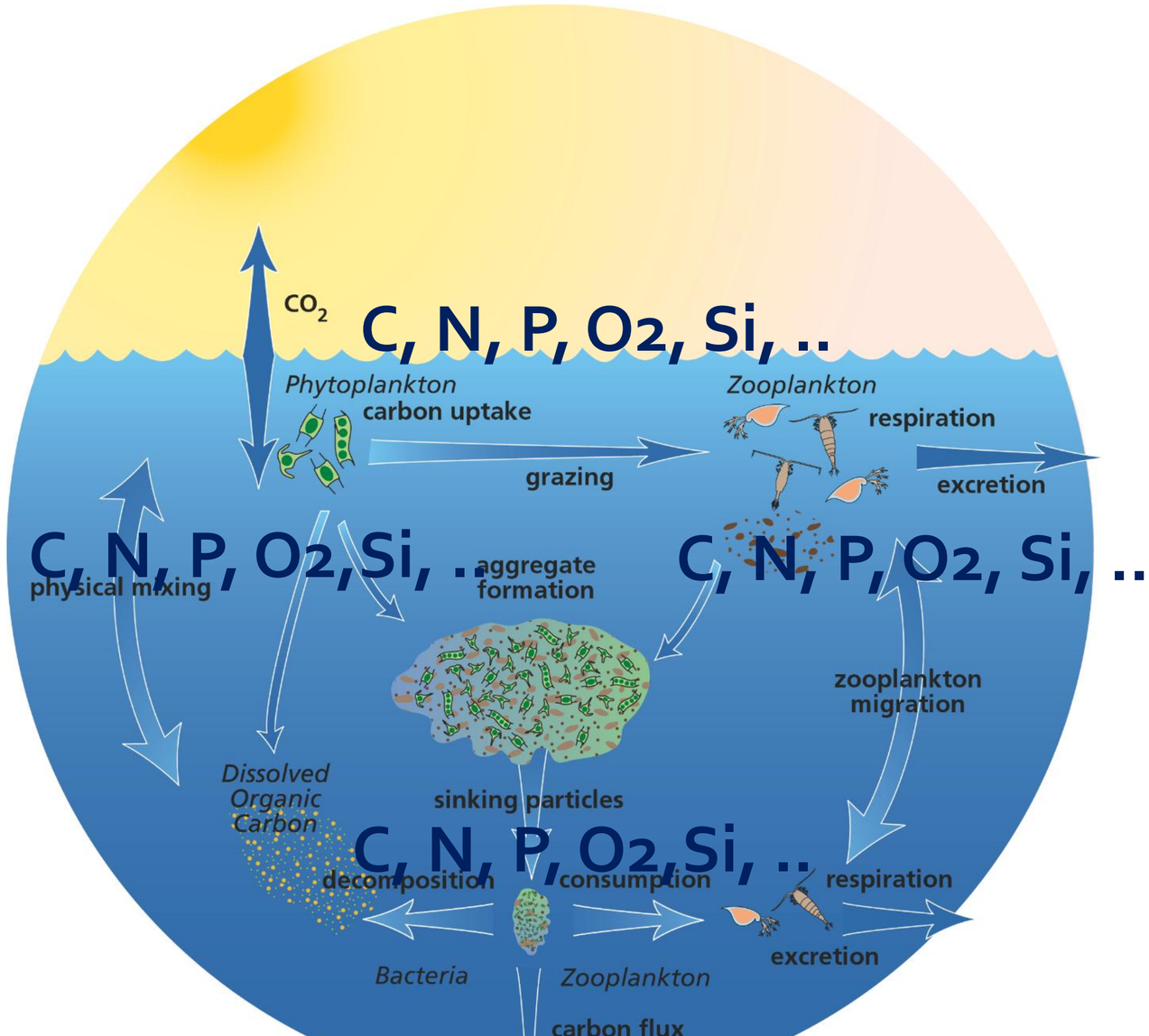
$$\frac{\partial y}{\partial t} + \underbrace{\underline{\nabla}_H.(\underline{u}y) + \frac{\partial}{\partial x_3}(wy)}_{\text{horizontal and vertical advection}} + \underbrace{\frac{\partial}{\partial x_3}(w_y^s y)}_{\text{sedimentation}} = \underbrace{\underline{Q}^y}_{\text{production / destruction}} + \underbrace{\frac{\partial}{\partial x_3}(\tilde{\lambda}\frac{\partial y}{\partial x_3}) + \lambda_H \nabla_H^2 y}_{\text{horizontal and vertical diffusion}}$$

BIOGEOCHEMICAL MODELLING



U.S. JGOFS

BIOGEOCHEMICAL MODELLING



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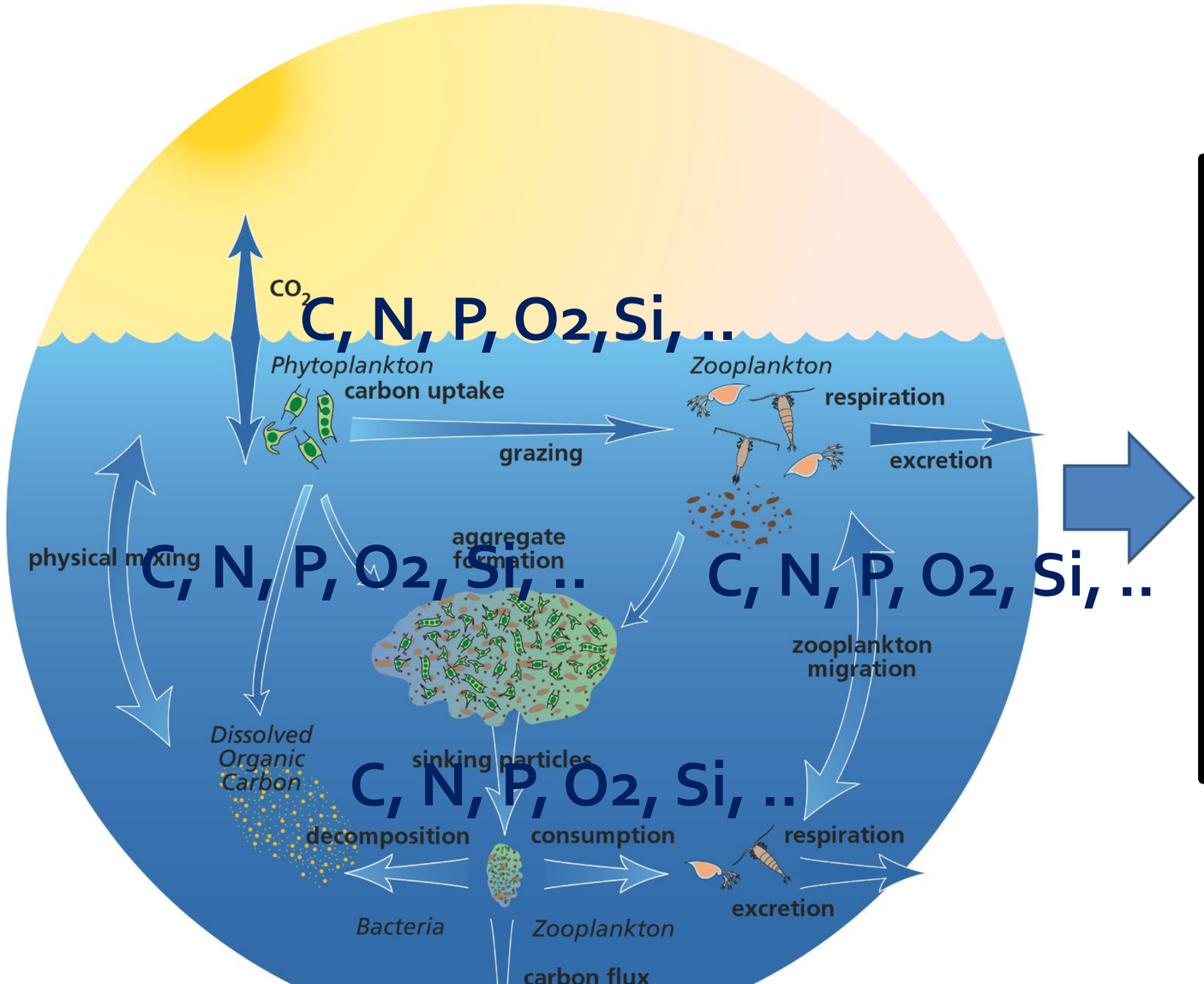
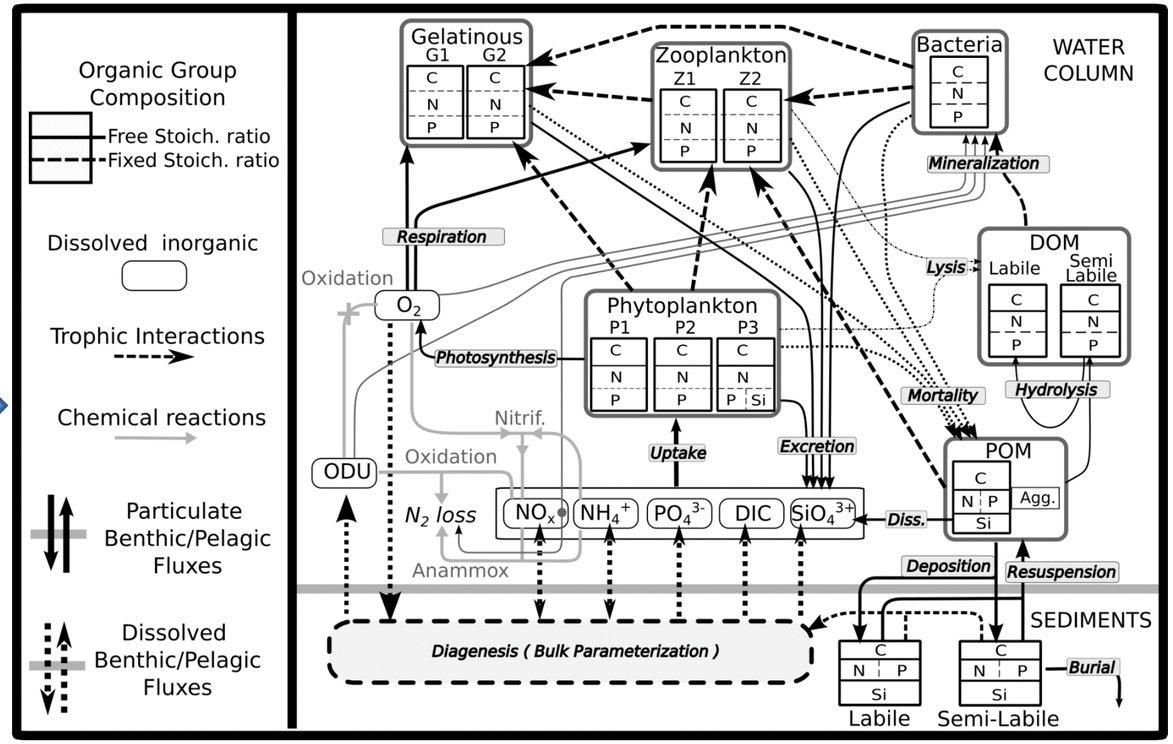
BIOGEOCHEMICAL MODELLING





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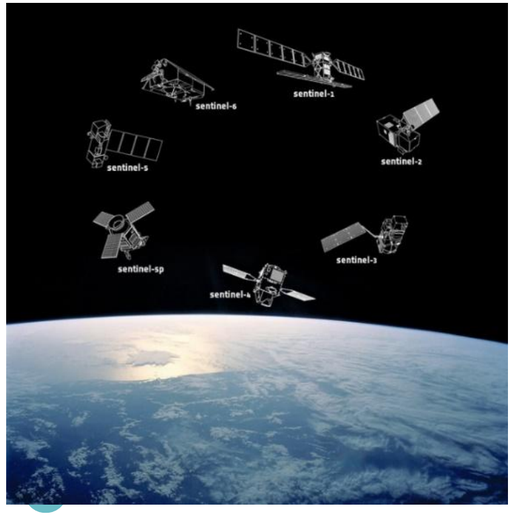
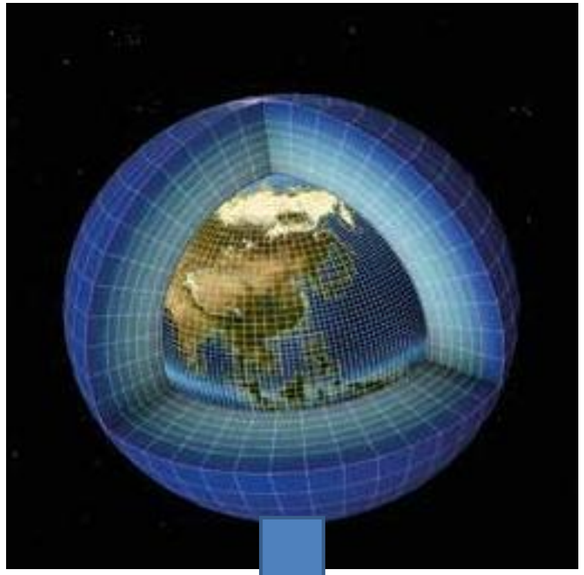
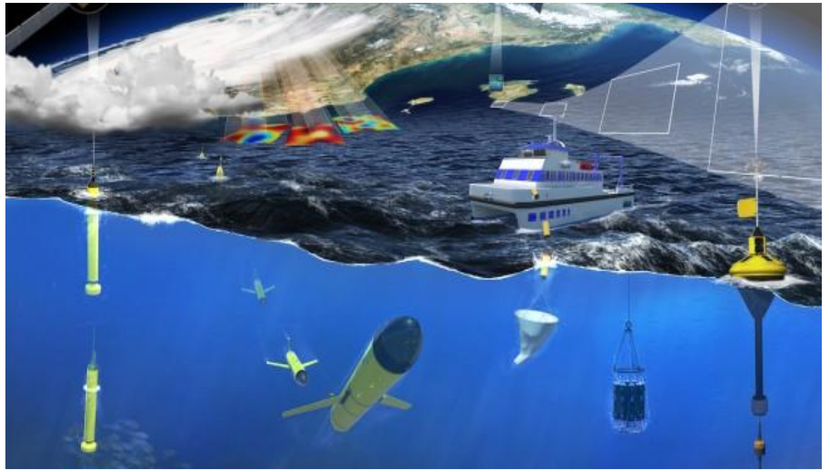
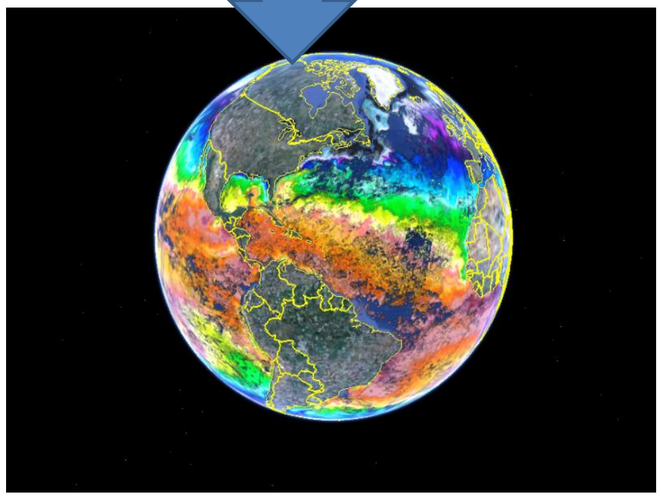
MODEL INTEGRATION









- Initial State
- Evolution equations
- Boundary conditions
- Data Assimilation

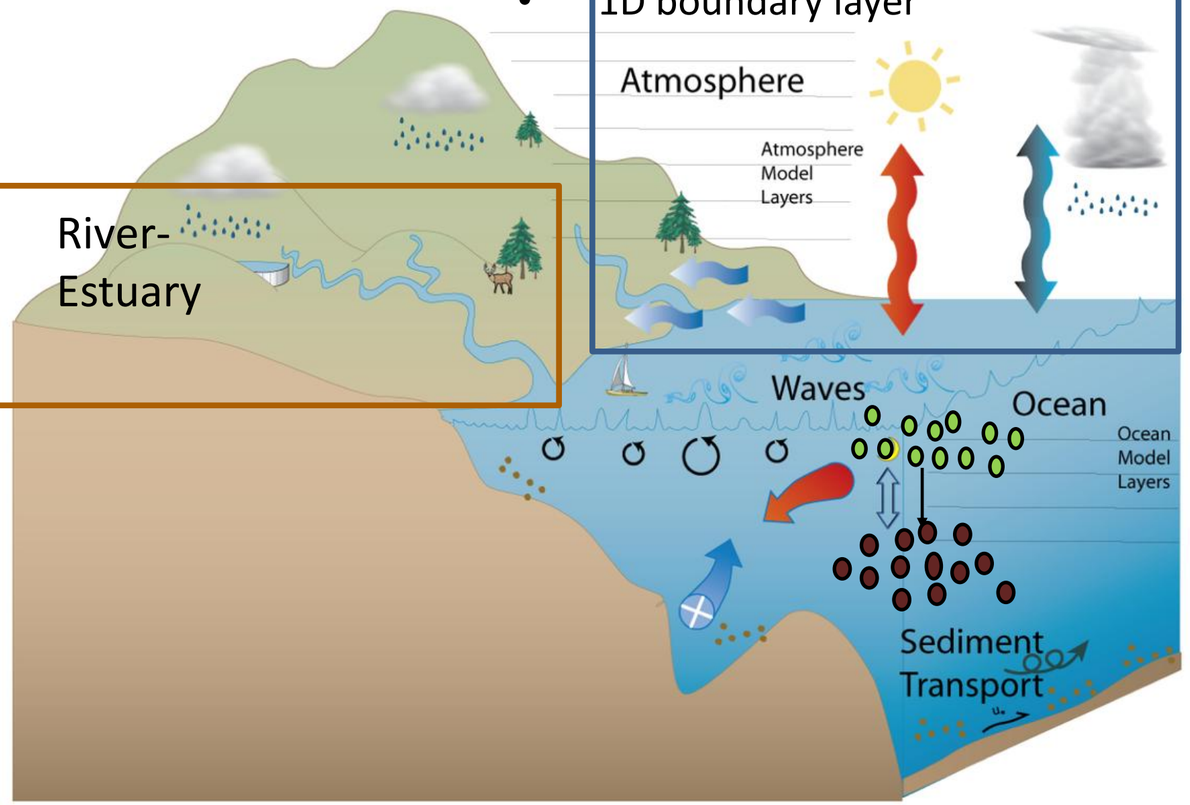
OCEAN –INTERFACES

Atmosphere

- Nutrients deposition
- pCO2
- Radiative information
- 1D boundary layer

Rivers

- Nutrients fluxes
- Suspended materials



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FORECASTING –REANALYSIS

7 regions

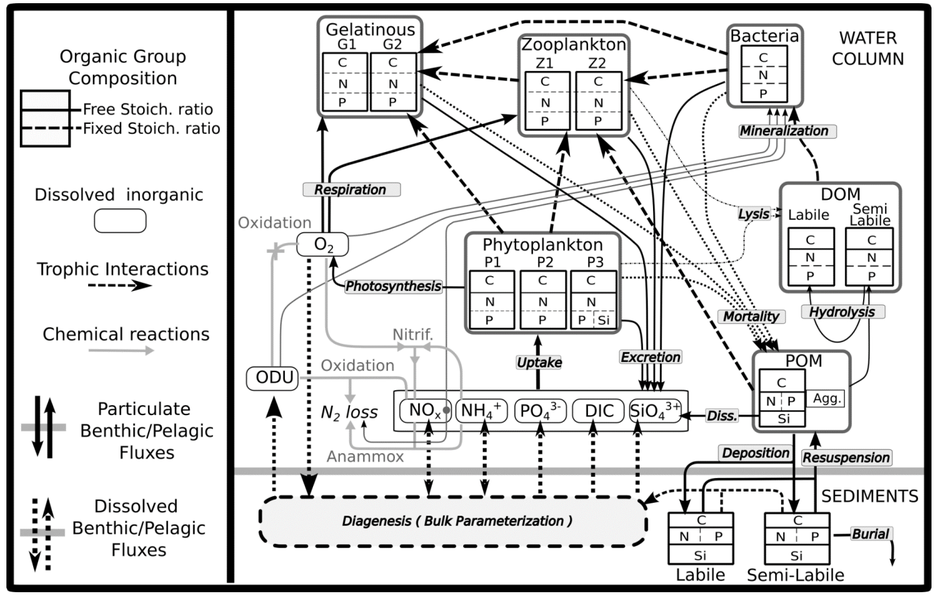
- 1. Global
- 2. Arctic
- 3. Baltic
- 4. NWS
- 5. IBI
- 6. Med Sea
- 7. Black Sea

Simulations

REANALYSES

~25 years

Plankton Functional Types models



FORECAST

5 to 10 days

Environmental variables

Distributed products :

- Nutrients (NO3, PO4),
- Oxygen
- Plankton: Chla, Phyto in carbon (total and functional groups), Primary Production
- biomass of Zoo in carbon
- Carbonate: pH, DIC, spCO2, fCO2
- Optics (Kd)

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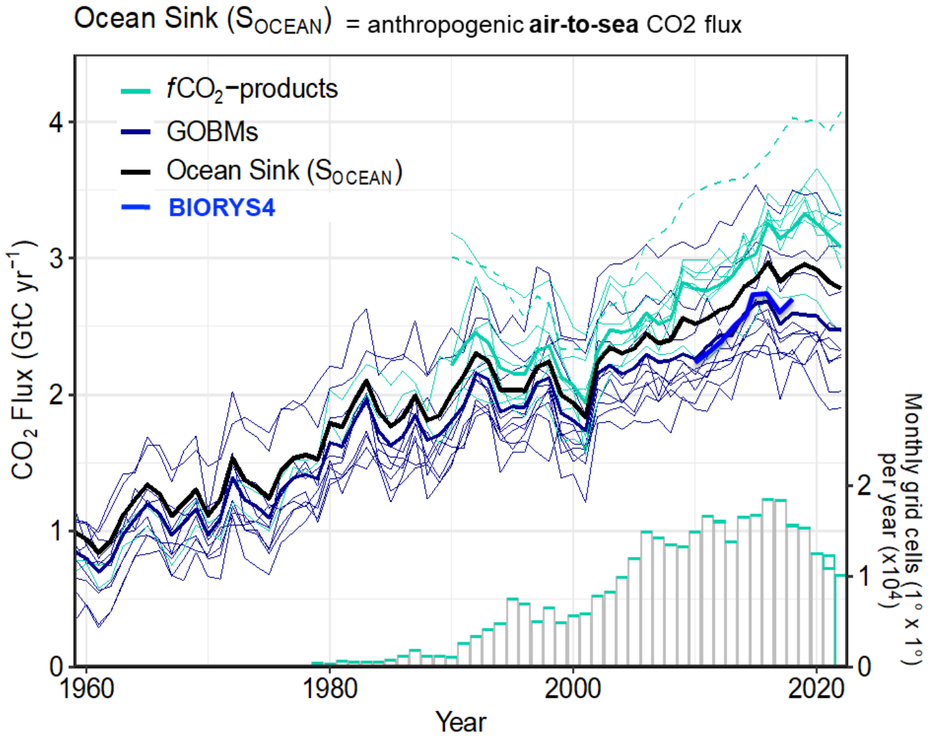
GLOBAL OCEAN CARBON SEQUESTRATION

Preliminary results:
- ✓ Efficient control of CHL and nutrients
- ✓ Significant improvements in carbonate chemistry variables
- ✓ Encouraging results on air-to-sea CO2 flux estimation

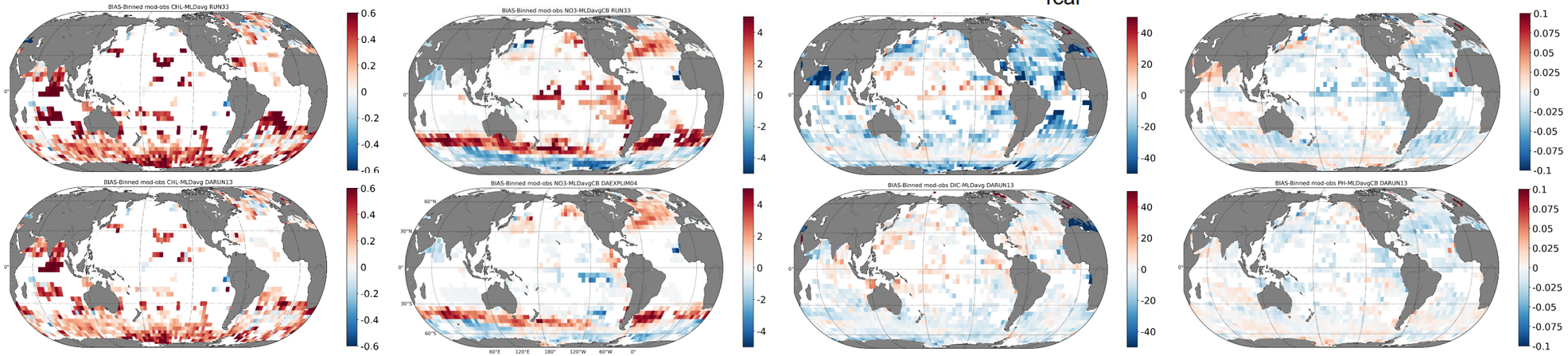


Chl | **NO3**

CONTROL (assimilated dynamics, no BGC/carbonates data assimilation, no relaxation)

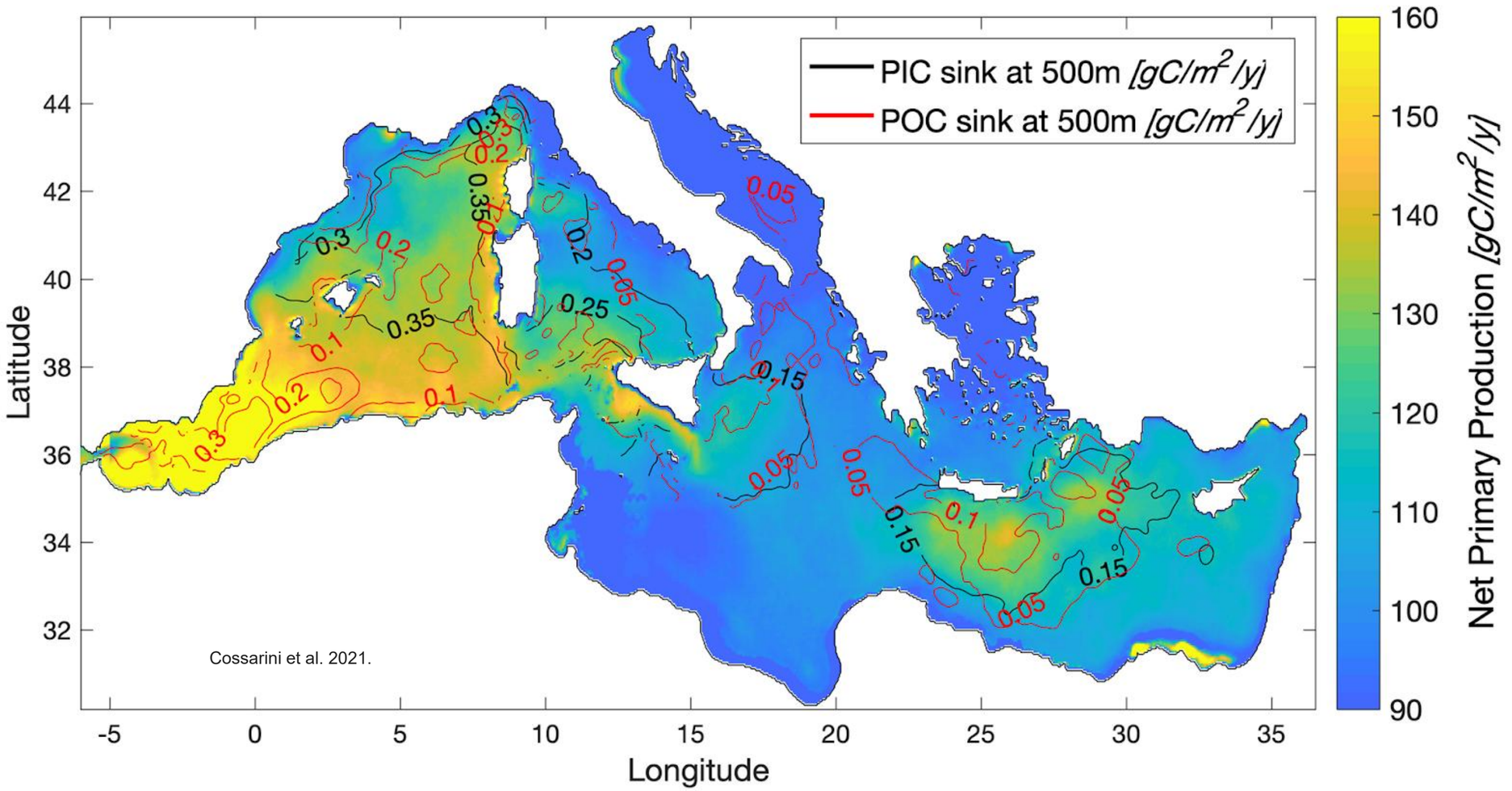
BIORYS4

Bias (model vs BGCArgo database) 2009-2018



MEDITERRANEAN SEA PRODUCTIVITY

Marine productivity and contribution of the biological (POC) and carbonate (PIC) pumps to the sink of organic carbon into the Mediterranean interior



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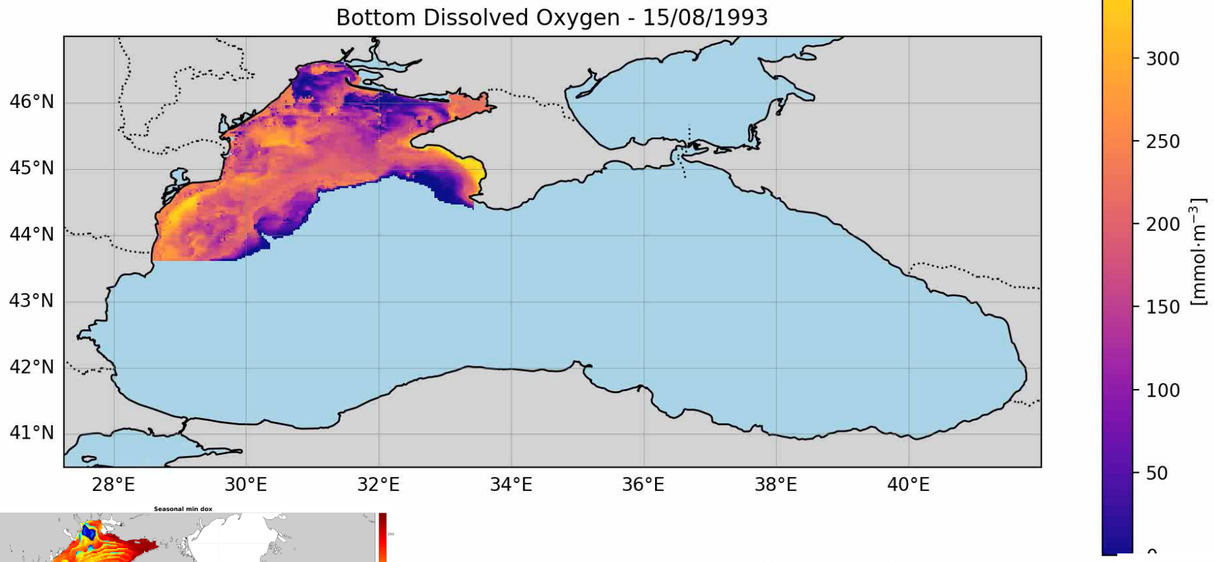
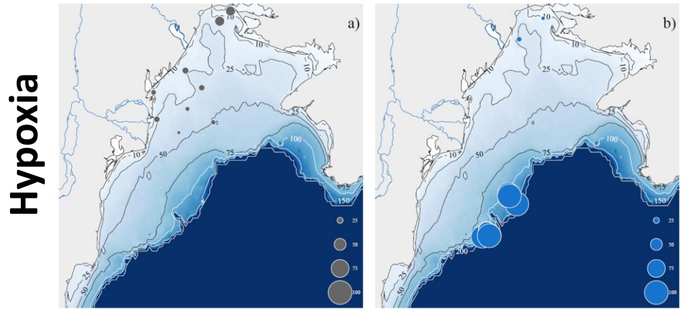
BLACK SEA OXYGEN and BIODIVERSITY

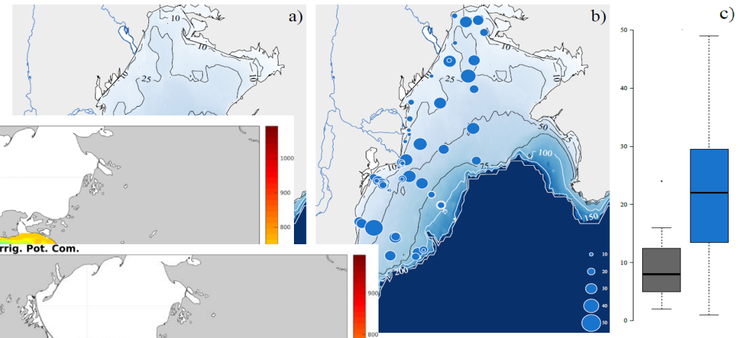
Marine Hypoxia (O2<63 µmol/l) on the Black Sea's northwestern shelf in summer

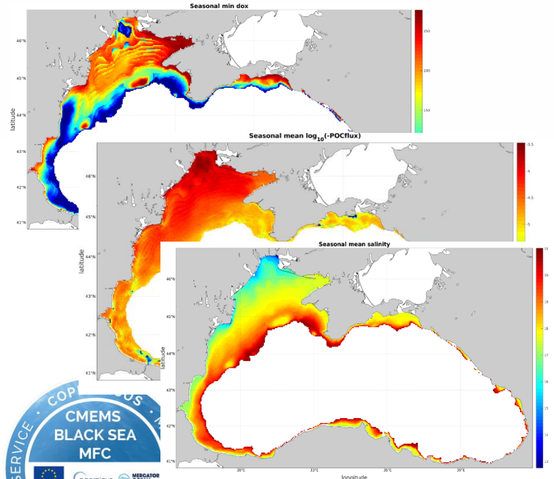


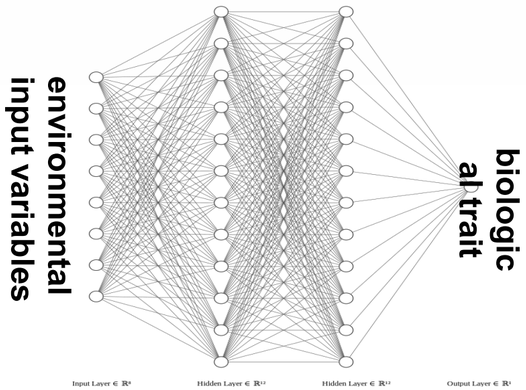
Days with hypoxic conditions in the 90s (left) and 2010s (right) (CMEMS REANALYSIS)

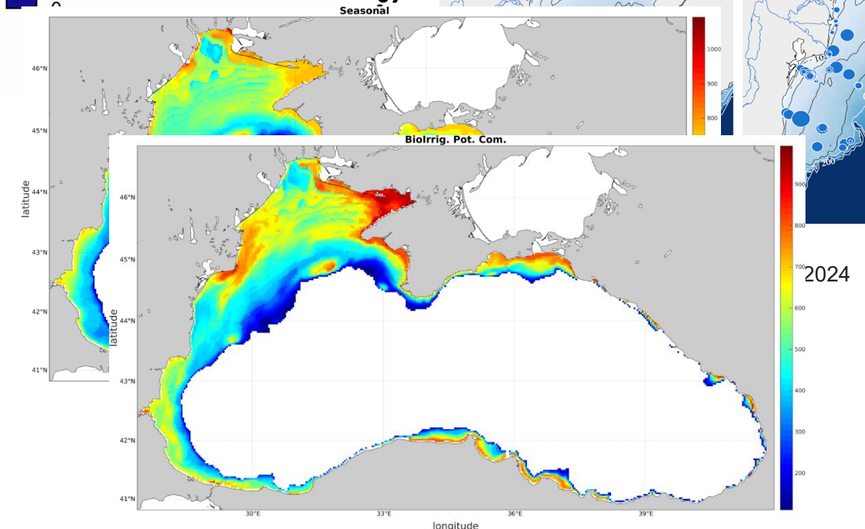


Species richness in the 90s (left) and 2010s (right)









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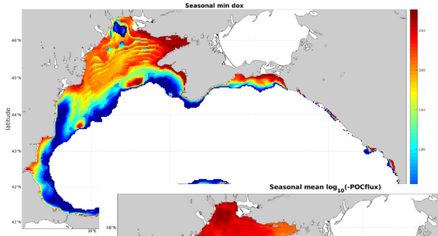
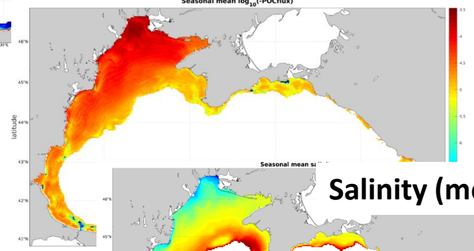
BLACK SEA ENVIRONMENT and BIOLOGY

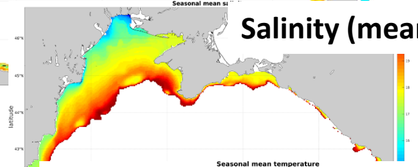
Oxygen (min)

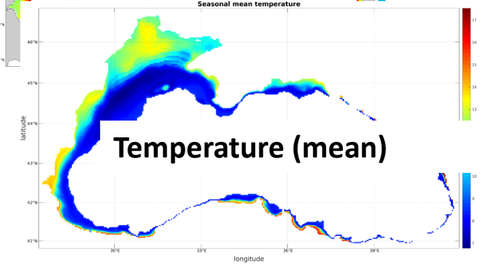


POC (log (mean))



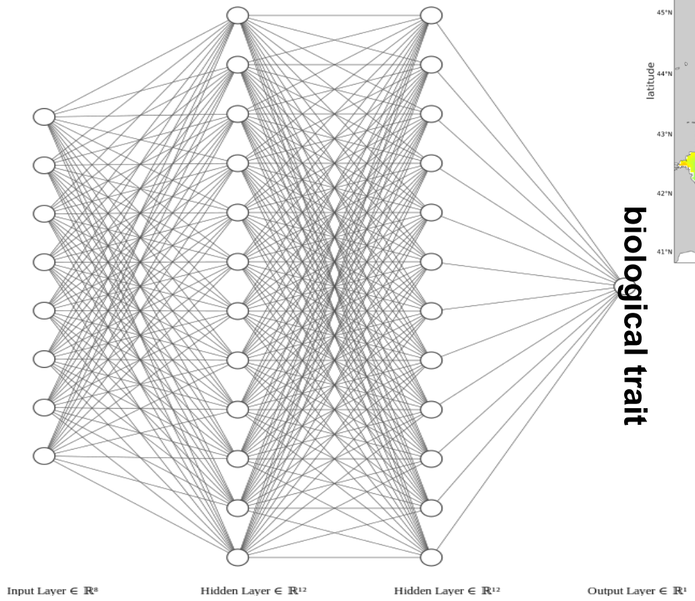
Salinity (mean)





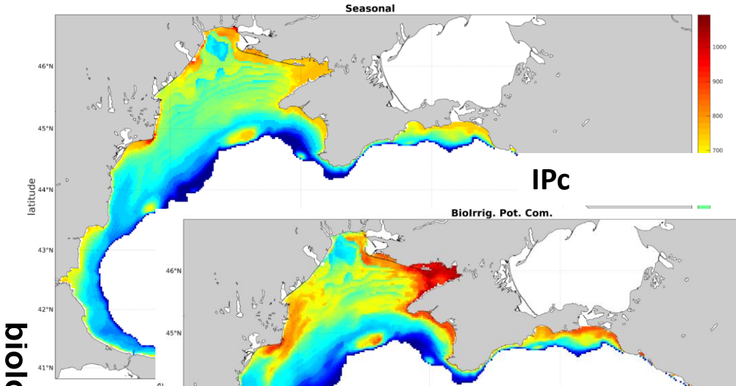
Temperature (mean)

environmental input variables

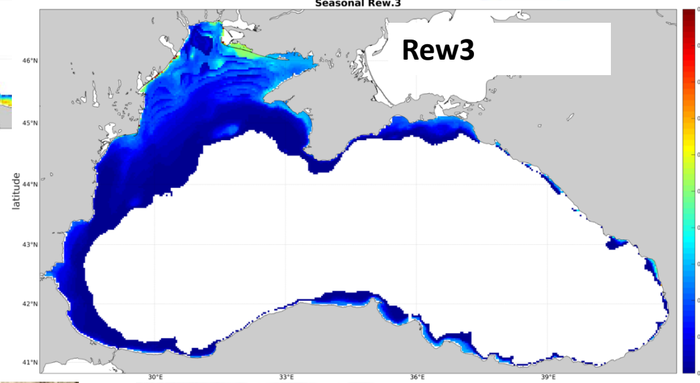


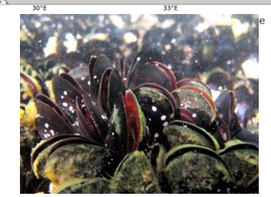
biological trait

BPc



IPc





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COPERNICUS · MARINE ENVIRONMENT MONITORING SERVICE

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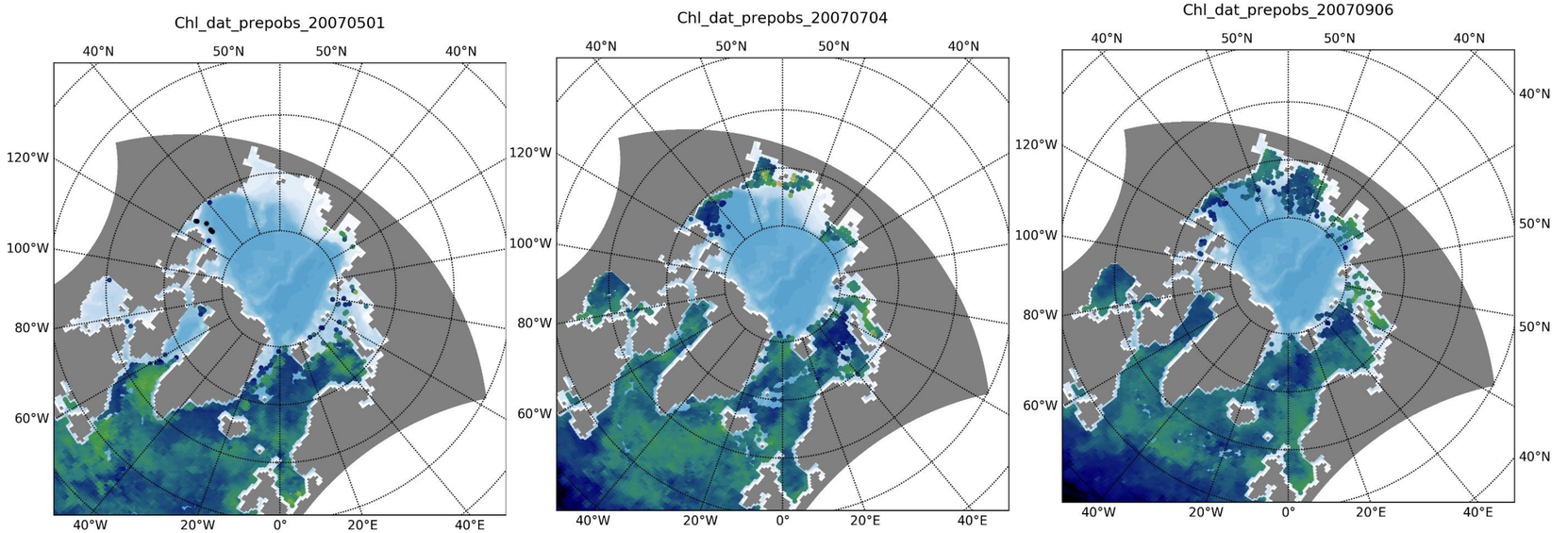
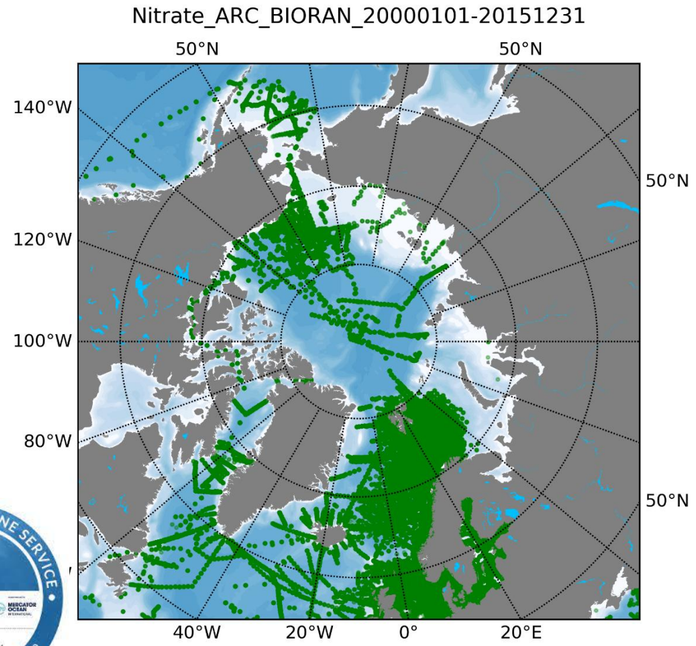
ARCTIC OCEAN CHLOROPHYLL

BIORAN System:

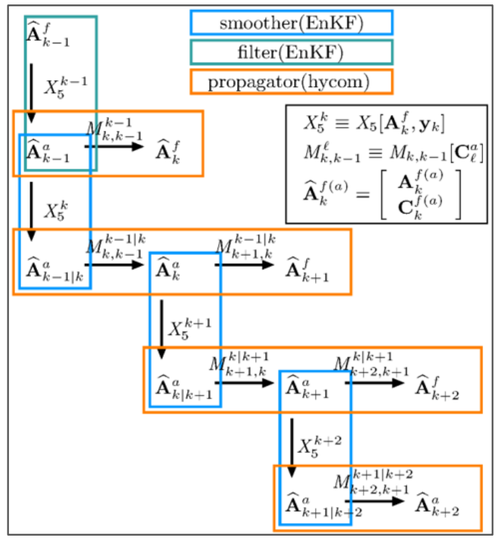
HYCOM-FABM-ECOSMO
Fixed lag EnKS (smoother)
BGC State-Parameter joint estimation
Gaussian Anamorphosis in Chl-a observation

Assimilated Data:
Satellite Chl-a (ESA OC CCI 8 daily)
In-situ nutrients (Nitrate,Silicate,Phosphate)
Source: GLODAPv2, ICES, NMDC, Clivar



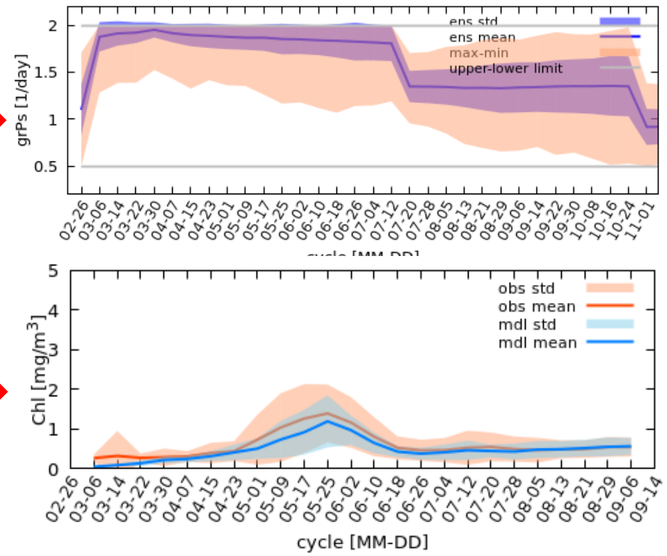


in-situ nutrients



parameter

state



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