Ocean Predict

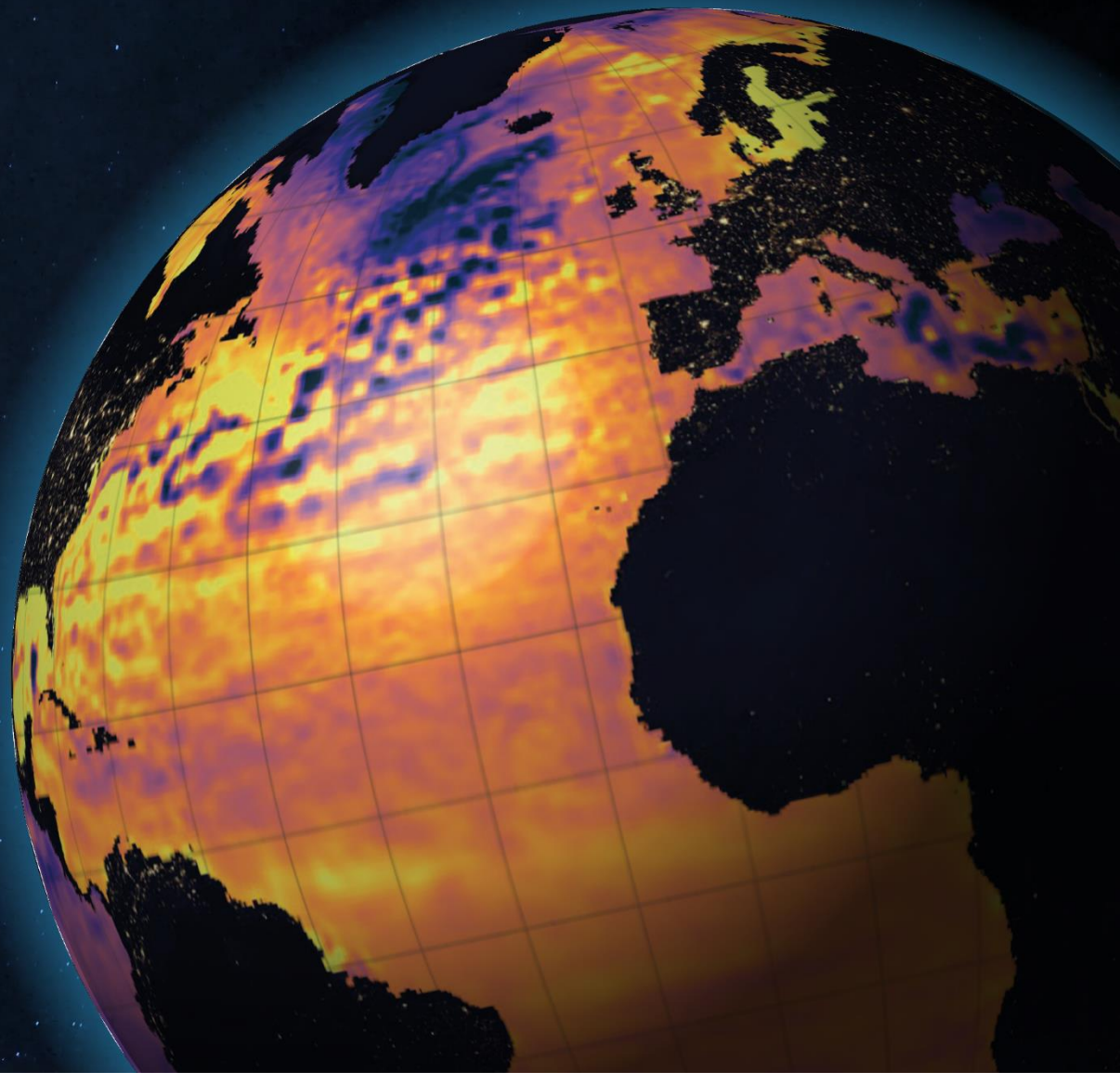
SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Predicting the green ocean: main achievements from the CMEMS biogeochemical models and perspectives.

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



Outlines

Overview of system évolutions over 2015-2024:

- Model structure
- Coupling with the physics
- Model resolution
- Boundary conditions
- Products delivery
- Products quality
- Data Assimilation
- Products use

SWOT anlysis

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Ocean Predict

Ocean Predict Copernicus Marine Forecasting Centers

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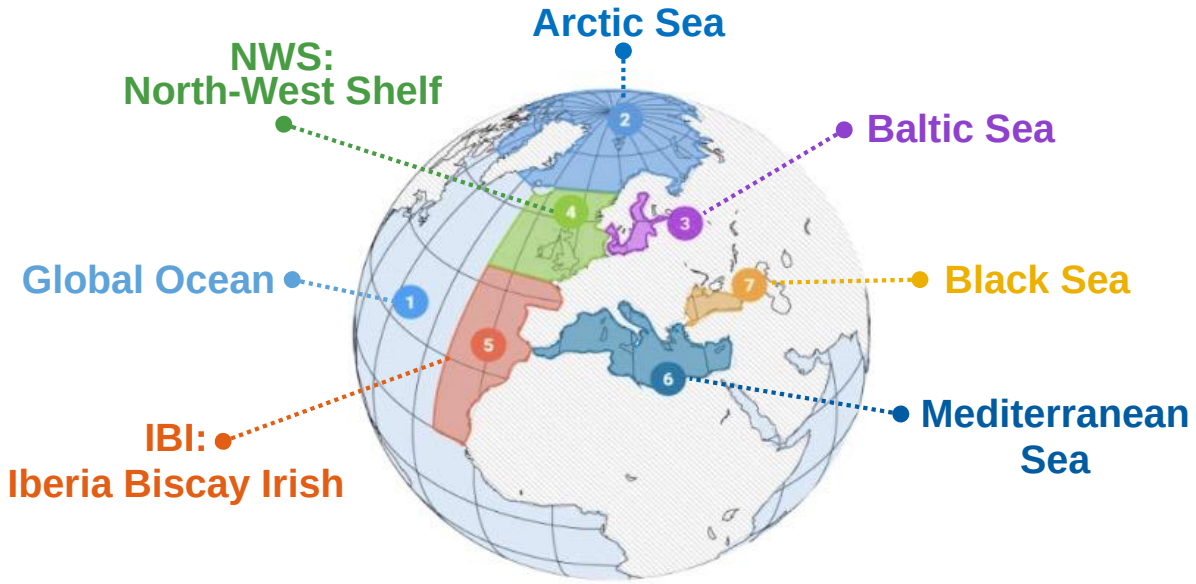
The Copernicus Marine Forecasting Centers (7) cover the global ocean and 6 marginal seas.

--> specific biogeochemical characteristics

--> need of specialized BGC models tailored to these distinct environments



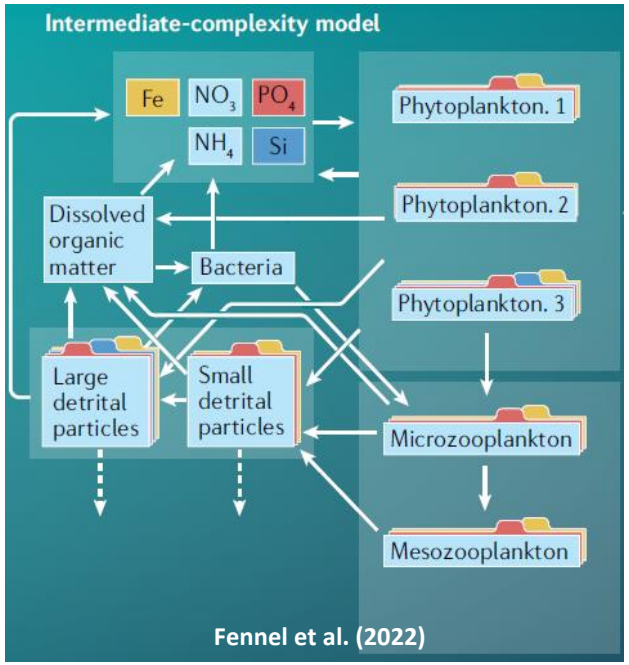
Six BGC models (ECOSMO, ERGOM, BAMBHI, PISCES, BFM, ERSEM)

System evolution- Model structure

From the beginning of Copernicus (2015):

Six BGC models (ECOSMO, ERGOM, BAMBHI, PISCES, BFM, ERSEM) with:

- intermediate to high complexity model (~20-40 state variables)
- nutrients: NO3, NH4, PO4, SiO4
- oxygen cycle
- Plankton functional types approach:
  - at least diatoms and non-diatoms groups
  - 2 or more zooplankton size classes



Fennel et al. (2022)

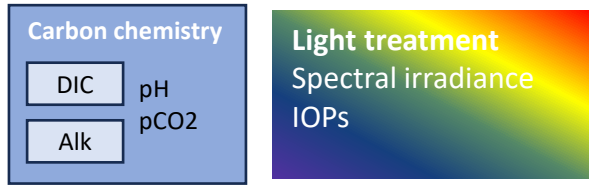
System evolution- Model structure

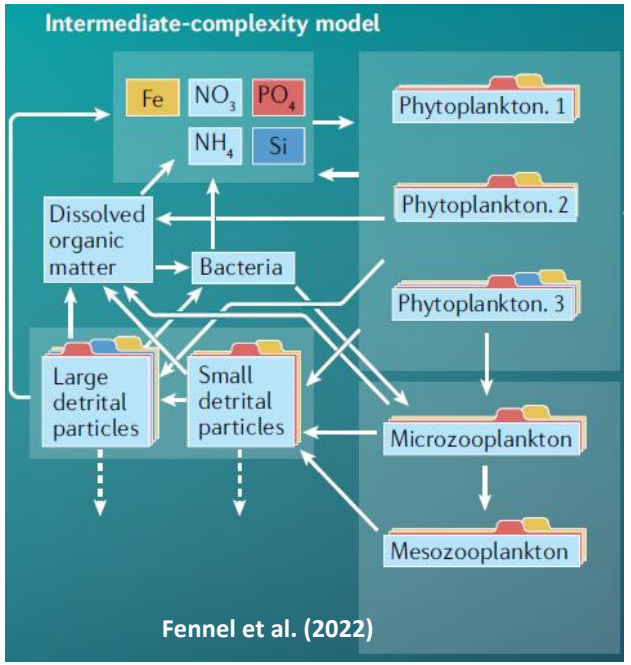
From the beginning of Copernicus (2015) to the end of the Copernicus phase 2 (2024) : :

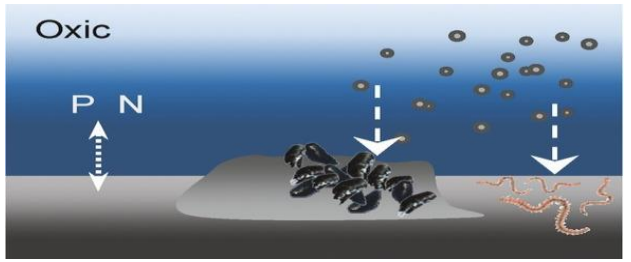
Six BGC models (ECOSMO, ERGOM, BAMBHI, PISCES, BFM, ERSEM) with:

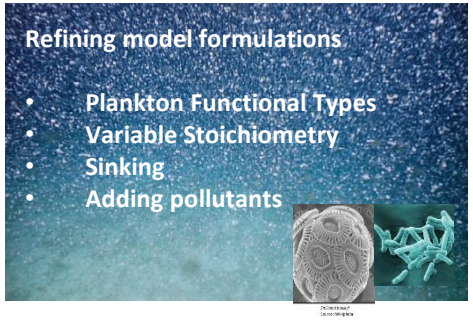
- intermediate to high complexity model (~20-40 state variables)
- nutrients: NO3, NH4, PO4, SiO4
- oxygen cycle
- Plankton functional types approach:
  - at least diatoms and non-diatoms groups
  - 2 or more zooplankton size classes

- variable stoichiometry
- carbon chemistry
- better light treatment and optics
- coupling with benthos
- adding PFTs









Physical models

- homogenization of model systems with more use of NEMO and FABM
- Online coupling (5), offline coupling (2)

2015
5 models
(HYCOM, HBM, GHER, RCO, NEMO3.1/3.4)

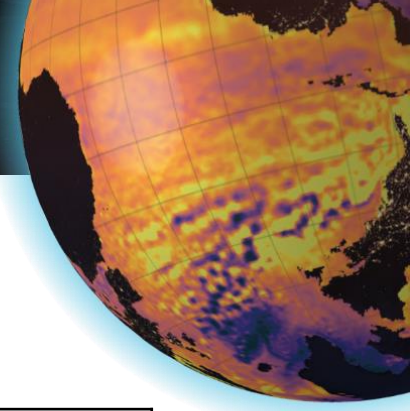
→

2024
2 models
(HYCOM, NEMO3.6-4.2)

2015
none

→

2024
5 coupled with FABM
(3 NRT, 2 MYP)



Resolution

NRT	horizontal resolution (km)		vertical levels	
	2015	2024	2015	2024
ARC	12 km	6.25 km	12	40
BAL	2 km	2 km	25	56
BLK	5 km	2.5 km	31	59
GLO	27.5 km	27.5 km	50	50
IBI	3.1 km	3.1 km	50	50
MED	6.9 km	4.6 km	73	125
NWS	7 km	2.9 km	24	50

MYP	horizontal resolution (km)		vertical levels	
	2015	2024	2015	2024
ARC	25	25	12	40
BAL	3.7	2	56	56
BLK	15	2.5	31	59
GLO	27.5	27.5	75	75
IBI	9.25	3.1	50	50
MED	6.9	4.6	73	125
NWS	12.3x7.4	12.3x7.4	24	24

- increase in horizontal (submesoscale in NRT) and/or vertical resolution for 5 out of 7 MFC in NRT and MYP systems
- Increased alignement between NRT, MYP

System evolution – boundary conditions

Atmosphere

	2015	2024
NRT	ECMWF: 1.125°, 6 hours	ECMWF: 0.1°, 1-6 h
MYP	ERA-interim/ERA-40 1.125°, 6 hours	ERA-5 0.1°, 1 hour
		Climatologies of Nutrients, pCO2, Spectral radiation

- Higher resolution in space (10), and time (1-6)
- Nutrients inputs

Rivers

river water input

2015 NRT	2015 MYP	2024 NRT	2024 MYP
Arctic-HYPE E-HYPE HBV model rec. timeseries climatologies (3x)	Arctic-HYPE rec. timeseries Sesame climatologies (4x)	Arctic-HYPE E-HYPE (2x) rec. timeseries EFAS climatologies (2x)	Arctic-HYPE E-HYPE Sesame PERSEUS rec. timeseries climatologies (1x)

river nutrient input

2015 NRT	2015 MYP	2024 NRT	2024 MYP
GlobalNEWS HBV model rec. timeseries climatologies (3x) E-HYPE	GlobalNEWS PERSEUS rec. timeseries climatologies (4x)	GlobalNEWS(2x) E-HYPE rec. timeseries PERSEUS climatologies (2x)	GlobalNEWS(2x) E-HYPE PERSEUS rec. timeseries climatologies (1x)

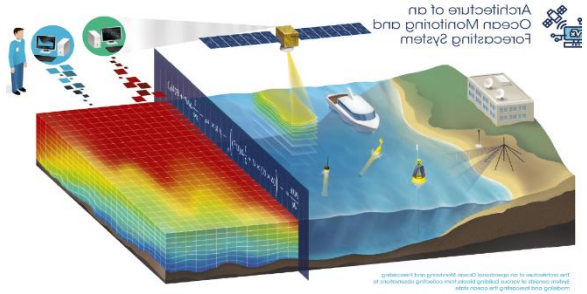
- less use of climatologies

Ocean Predict System evolution- Products

From the beginning of Copernicus (2015) :

Distributed products :

- Plankton: Chla, Phyto in carbon, Primary Production
- Nutrients (NO3, PO4),
- Oxygen



Near Real Time

Analysis: - 2 years

Forecast: 10 days

- Daily Mean
- Monthly mean

Multi Year

Reanalysis: last decades (at least 2007-2010)

Ocean Predict System evolution- Products

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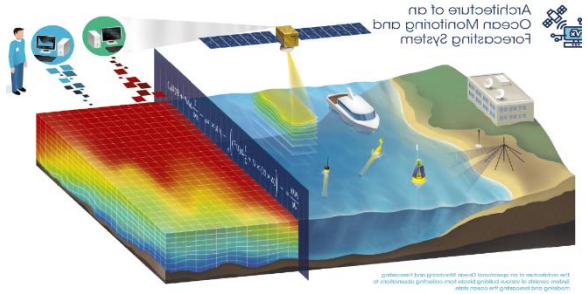
From the beginning of Copernicus (2015) to the end of the Copernicus phase 2 (2024) :

Distributed products :

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



Near Real Time

Analysis: - 2 years

Forecast: 10 days

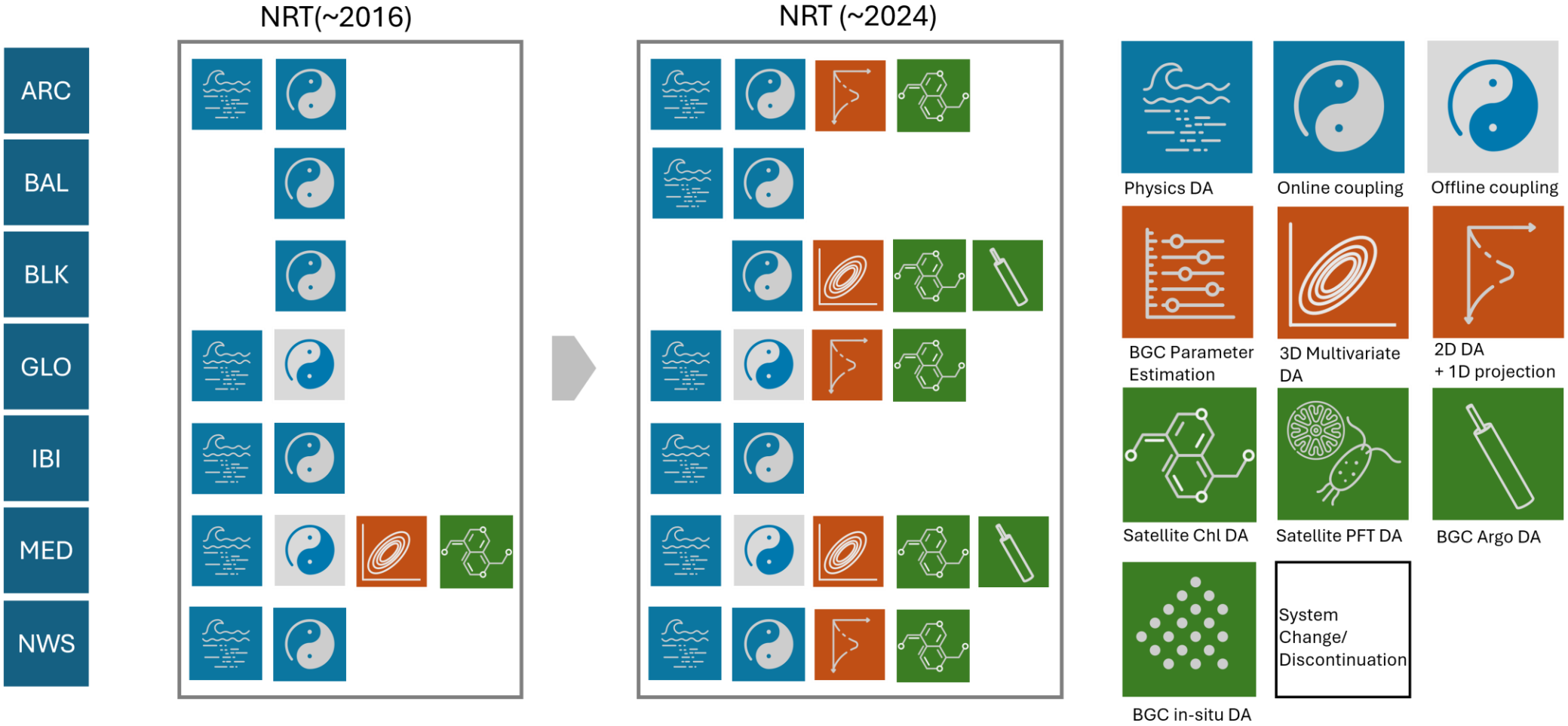
Multi Year

Reanalysis: last decades (at least 2007-2021)

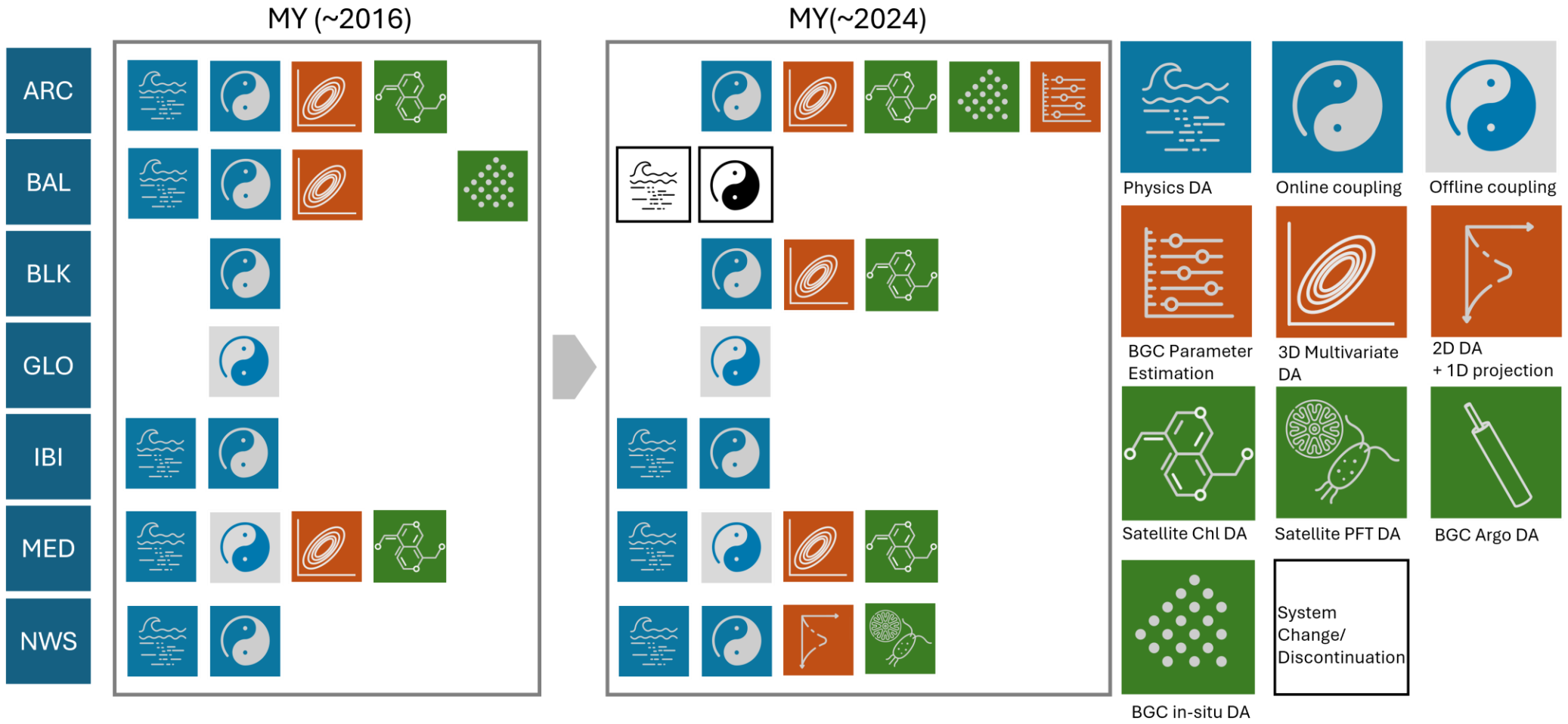
Interim: up to m-1

- Monthly mean
  - Daily Mean **(MYP)**
    - **Hourly Mean**
    - **(air-sea fluxes)**

System evolution – Data Assimilation



System evolution – Data Assimilation

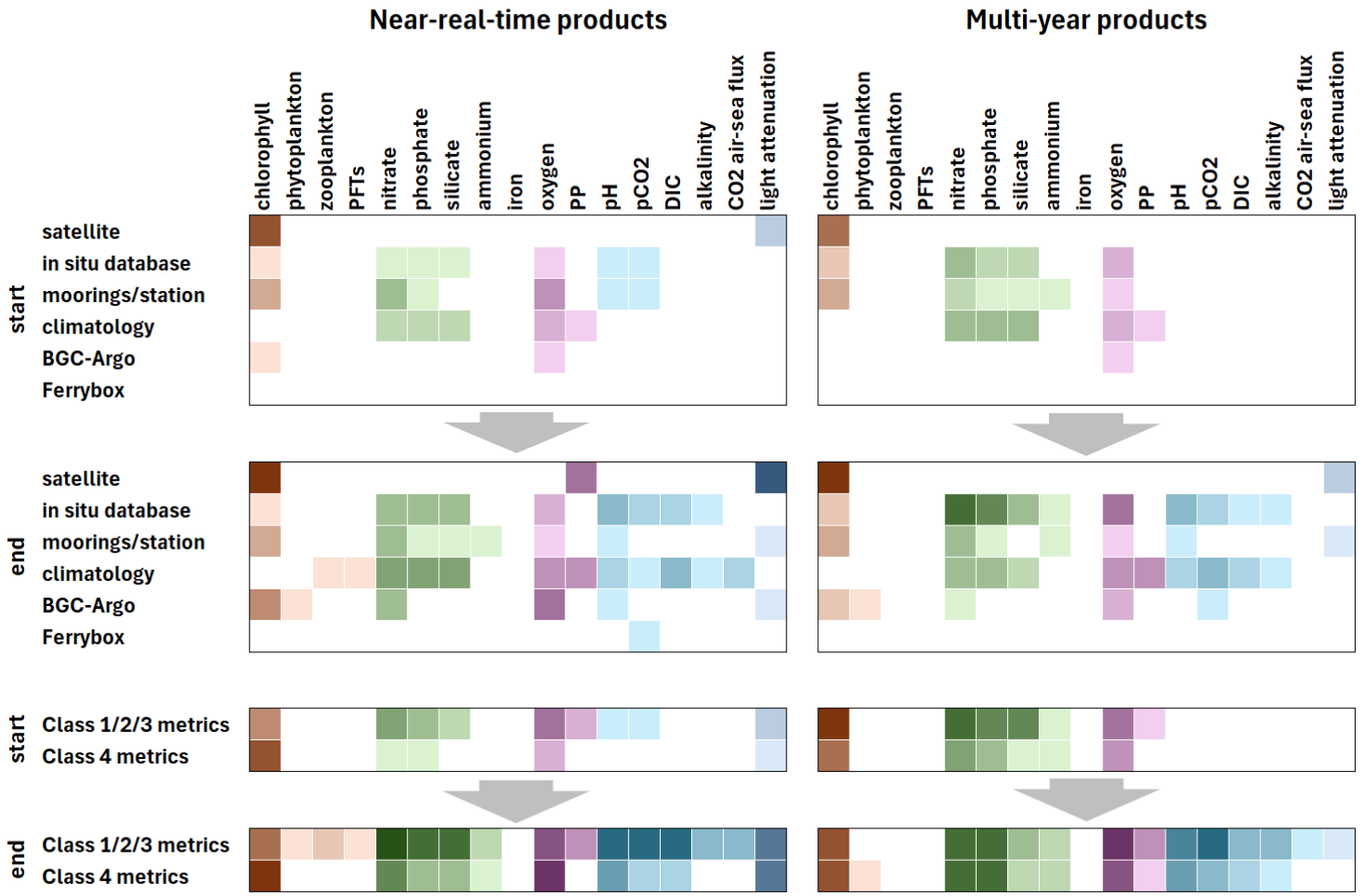


System evolution – Products Quality

Observations and metrics used in product quality documents.

Darker colour show more PUs using it.

More use of quantitative metrics using model-observation match-ups (GODAE Class 4)



PUs are using a wider range of data sources

More variables are assessed

System evolution – DA and Products quality

In 2015 very few systems had DA especially in NRT

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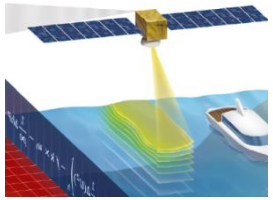
Nearly at 2020 most of the systems with assimilation of satellite chlorophyll



Variable	Improvements in most of MFCs (specific MFC)
Chlorophyll	Horizontal gradients and seasonal patterns
Primary production	Horizontal gradients and seasonal patterns
Phytoplankton functional types	(Basin wide estimation, MED; Seasonal patterns, NWS)

System evolution – DA and Products quality

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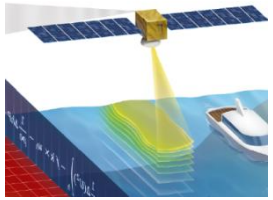

In 2023 assimilation of profiles more widely adopted

Variable	**Improvements in most of MFCs (specific MFC)**	**Improvements in most of MFCs (specific MFC)**
Chlorophyll	Horizontal gradients and seasonal patterns	Vertical distribution (deep chlorophyll maximum, MED)
Primary production	Horizontal gradients and seasonal patterns	
Phytoplankton functional types	(Basin wide estimation, MED; Seasonal patterns, NWS)	
Nutrient		Vertical distribution
Oxygen		Vertical distribution (oxygen penetration depth, BLK)

Mapping BGC products to indicators

GOOS list of BGC-related EOVs

Biogeochemistry	Biology and Ecosystems
Oxygen	**Phytoplankton biomass and diversity**
Nutrients	**Zooplankton biomass and diversity**
Inorganic carbon	*Fish abundance and distribution*
Transient tracers	*Marine turtles*, birds, mammals abundance and distribution
Particulate matter	Hard coral cover and composition
Nitrous oxide	Seagrass cover and composition
Stable carbon isotopes	Macroalgal canopy cover and composition
Dissolved organic carbon	Mangrove cover and composition
	Microbe biomass and diversity (*pilot)
	Invertebrate abundance and distribution (*pilot)

Available from Copernicus Marine Service
EOVs under development or capable of development

Mapping BGC products to indicators

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NECCTON (see S. Ciavatta talk).
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Products Use– Indicators

Mapping BGC products to indicators

VARIABLES

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EOVs under development or capable of development

PROCESS RATES

Ocean Monitoring Indicators OMIs

- **23 OMIs** for monitoring changes in the BGC ocean state and ocean health
- **Mostly based on observations** (for now) but BGC models are improving (e.g. version refinement, new parameterizations, data assimilation, etc.)

Indicator framework	Indicator type
Copernicus Ocean Monitoring Indicators *Specificity: dissemination of numerical value **in operational mode***	Chlorophyll & primary production (14) Eutrophication & bloom (1) Ocean acidification (2) Ocean deoxygenation (2) Oligotrophication (4)
GCOS-WMO Global Climate Indicator framework	Ocean acidification
GOOS Ocean Indicator framework	Ocean acidification Ocean deoxygenation Net community Production

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Colors denote common indicators to frameworks

SWOT

Strengths

- Coordinated
- Common best practices and high quality standards for system development and evolution.
- Increased quality, resolution, extension, ..
- Diversified number of BGC products

Weaknesses

- Boundary conditions for bgc variables
- Lack of bgc data
- Uncertainty quantifications
- Benefit of increased resolution difficult to demonstrate
- Contribution to decision making process and indictaors definition still limited

SWOT Analysis

Opportunities

- Novel bgc data : type, resolution, quality
- High requirements for bgc products
- Use of ML as model emulator
- Stochastic approaches
- Coupling with other Copernicus services to improve boundary conditions
- Transition towards a DTO that includes bgc products an emulators
- Connexion with biology and users applications

Threats

- Computing resources very huge of ensemble system with increased resolution
- Funding support to bgc observation
- No improvement of boundary conditions
- Mismatch of users needs and products/service delivery
- Huge amount of information in the digital twin ocean

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European Commission

Copernicus Marine Service

EU4oceanobs
INTERNATIONAL OCEAN GOVERNANCE
EU COMPONENT TO GLOBAL OCEAN OBSERVATIONS

MERCATOR OCEAN INTERNATIONAL

esa

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

Met Office

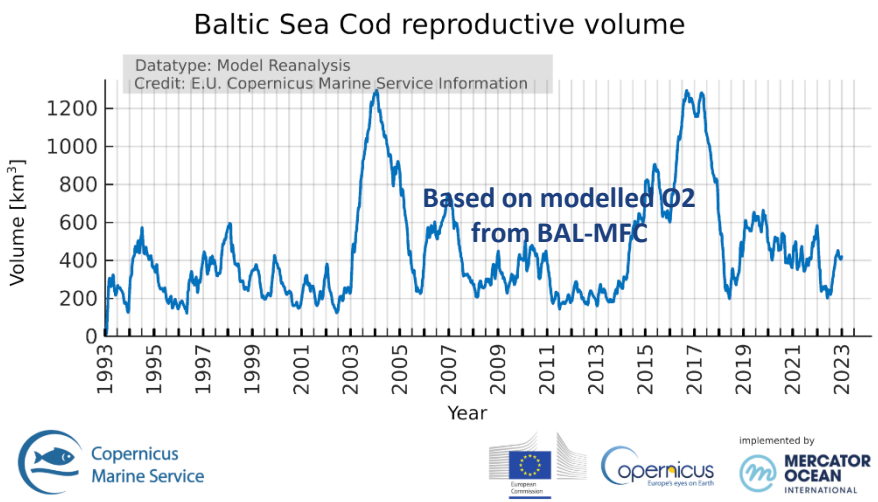
NERSC

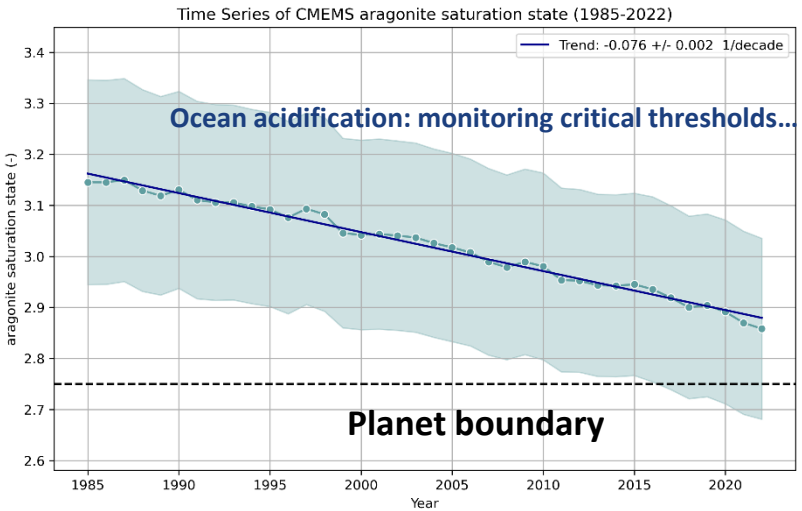
Australian Government
Bureau of Meteorology

Canada

Products Use– Indicators & users services

Example of OMIs





From model outputs to services and "what-if" scenarios

- The service supports policymakers and agencies in water quality management, flood risk mitigation and sustainable use of resources.
- BGC models remain critical tools for setting up what-if scenarios (e.g. hindcasts/projections)

	ARC NRT/MY	BAL NRT 003_007	BAL MY 003_012	BLK NRT 007_010	BLK MY 007_005	GLO NRT 001_028	GLO MY 001_029	GLO MY Nekton 001_033	IBI NRT 005_004	IBI MY 005_003	MED NRT 006_014	MED MY 006_008	NWS NRT 004_002	NWS MY 004_011
Monitoring porpoise in Kattegat Natura 2000 protected area		■												
Warning system for land-based pollution in the Romanian coastal area				■										
ForCOAST				■										
Metocean analysis to support Maritime Spatial Planning in the western Black Sea Basin					■									
Supporting the MSFD directive in the Black Sea					■									
Mapping marine biodiversity issues to better plan the deployment of offshore wind farms						■	■							
Monitoring coastal waters of the Lisbon Area (Portugal) in support of EU directive implementation						■								
Marine Data Viewer: Uniting In-Situ Measurements, Models, and Satellites for Essential Ocean Variables						■								
Modelling Reveals New Insights on Phytoplankton Blooms in NW Iberian Upwelling						■								
Real-time assessment of MPAs with marine megafauna movements and bio-physical ocean variables						■								
A model to support sea turtle protection at sea						■	■							
COASTSERV: Downscaled CMEMS products for high-resolution coastal models						■	■							
The Brazilian Sea Observatory - Coastal Service						■								
LAMBDA PROJECT – Land-Marine Boundary Development & Analysis						■								
UMITRON PULSE: high-resolution ocean data map for aquaculture farmers						■								
EMERGE: Modeling ocean pollution from ship emissions						■								
Copernicus Marine for Maritime Spatial Planning: The PLASMAR Project						■								
Predicting the habitat and distribution of giant squid						■								
Support to exploration activities for Deep Sea Mining						■				■				
Modelled prey fields predict predator foraging success							■	■						
Tracking whales in the North-Atlantic								■						
Early warning in the Mediterranean Sea								■						
CONNECT Tagus – water quality and extreme water levels in the Tagus Estuary									■					
Offshore aquaculture systems for salmon farming									■	■				
Teaching Marine Biogeochemistry at the Shelf Edge										■				
OCEANA Marine expeditions to fill key gaps in biodiversity data										■	■		■	
Sustainable monitoring of transparent coastal waters by high-resolution satellites											■			
Enhancing traceability and tracking in Aquaculture and fisheries supply chain through the use of blockchain and earth observation											■			
Map2Fish – A fish stock service for tourism											■	■		
JellyX: A Monitoring tool to detect jellyfish swarms											■			
Web Service Platform for Maltese coastal waters											■			
Met-Ocean studies and key environmental parameters for floating offshore wind technology											■			
Northern Adriatic sea water quality for aquaculture and tourism sectors - Cadeau project												■		
Support to Maritime Spatial Planning European Directive												■		
OCEan Biological Information Service: OCEBIS													■	
Eutrophication and acidification in marine ecosystems: North Sea use case														■
Marine Assessments in support to MSFD														■

Cartography of Copernicus Marine use-cases using BGC MFC systems

Ocean Monitoring Indicators OMIs related to biogeochemistry

Indicator framework	Indicators
Copernicus Ocean Monitoring Indicators *Specificity: dissemination of numerical value **in operational mode***	Chlorophyll & primary production (14) Eutrophication & bloom (1) Ocean acidification (2) Ocean deoxygenation (2) Oligotrophication (4)
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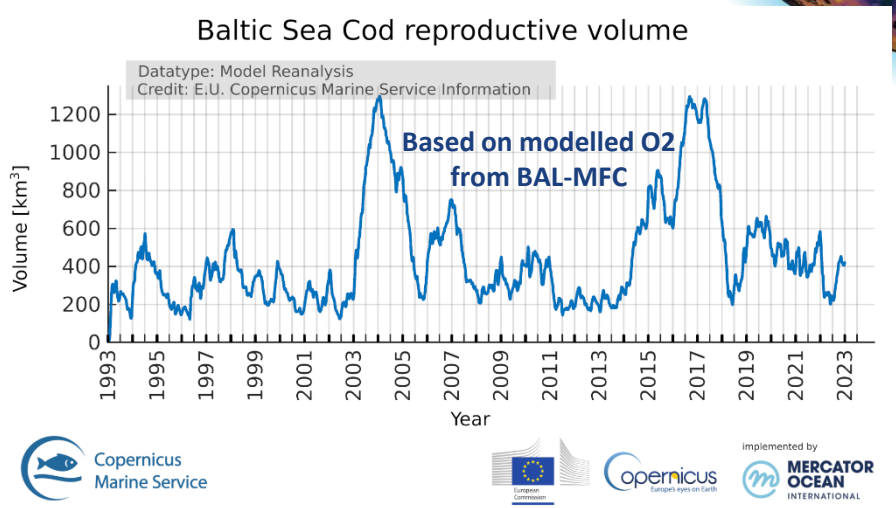

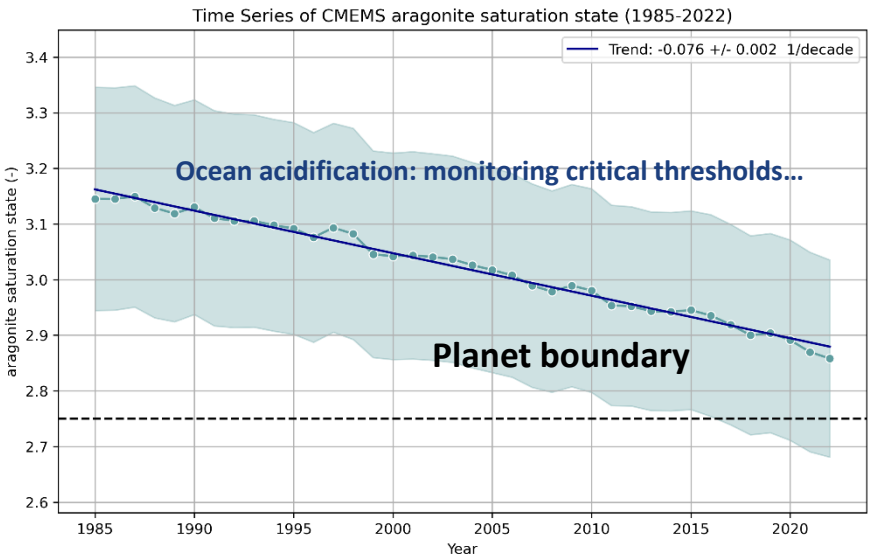

Products Use– Downstream services

	ARC NRT/MY	BAL NRT 003_007	BAL MY 003_012	BLK NRT 007_010	BLK MY 007_005	GLO NRT 001_028	GLO MY 001_029	GLO MY Nekton 001_033	IBI NRT 005_004	IBI MY 005_003	MED NRT 006_014	MED MY 006_008	NWS NRT 004_002	NWS MY 004_011
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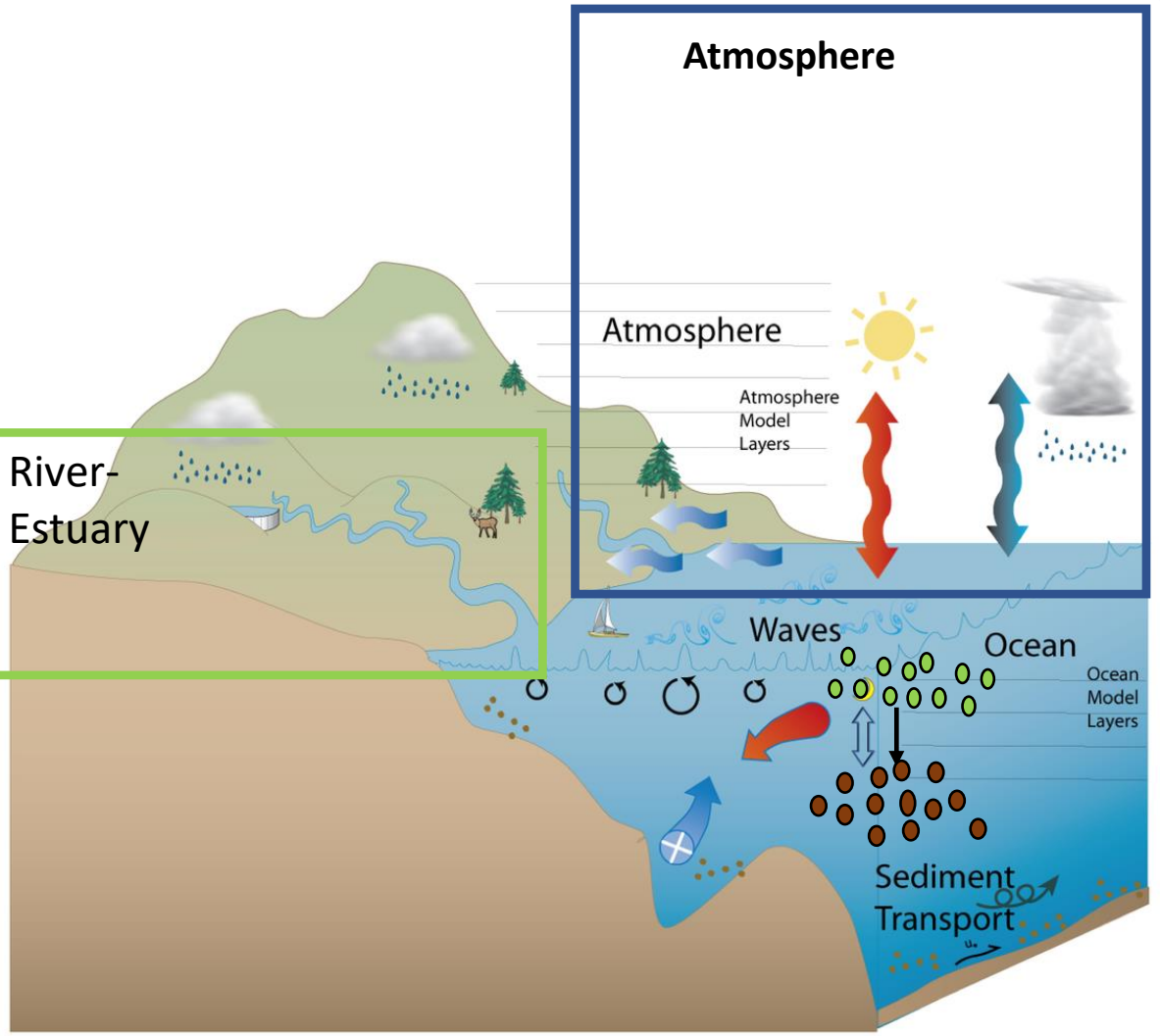
Cartography of Copernicus Marine use-cases using BGC MFC systems

Coupling at the Interfaces: 2015

Rivers
- Nutrients fluxes
- Suspended materials

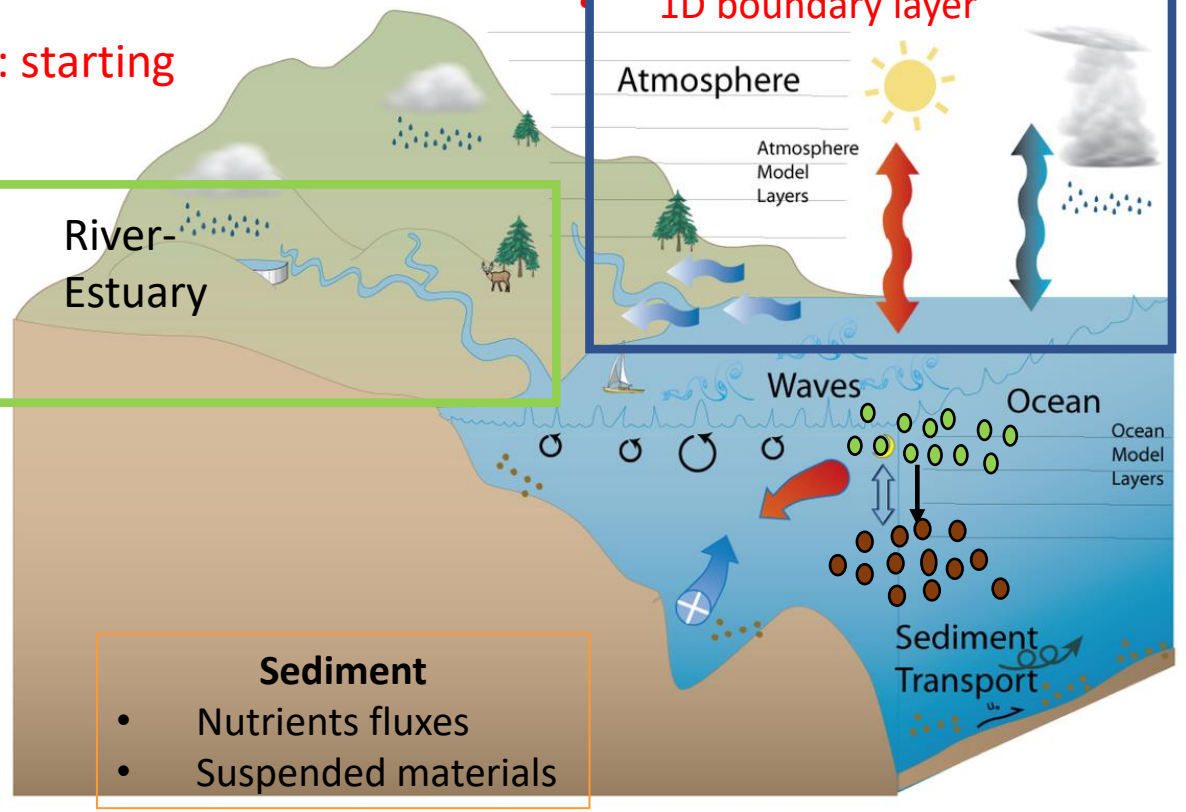


Coupling at the Interfaces: **2024**
Make the link with:

- PU-WAV: **ongoing**
- Other CMEMS domains: **ongoing**
- Other Copernicus Services (Atmosphere, Land): starting

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

Rivers
- Nutrients fluxes
- Suspended materials



Sediment
- Nutrients fluxes
- Suspended materials