Monitoring and predicting coastal dynamics for management, conservation and restoration: the MER Italian high-resolution modeling system

Querin S.[1], Bolzon G.[1], Brandino G. P.[2], Bruschi A.[3], Canu D.[1], Catini F.[3], Cossarini G.[1], De Giorgi F.[2], Di Biagio V.[1], Di Sante F.[4], Feudale L.[1], Gianni F.[1], Giordano F.[1,5], Giorgi G.[3], Gisonni M.[4], Ippoliti M.[4], Manizza M.[1], Marani A.[4], Marras G. F.[4], Nespolo J.[2], Petronio A.[1], Piani S.[1], Poggi M.[2], Salon S.[1], Scipione G.[4], Solidoro C.[1], Spada S.[1], Teruzzi A.[1]

[1] National Institute of Oceanography and Applied Geophysics - OGS, Italy

[2] eXact lab S.r.l., Italy

[3] Italian National Institute for Environmental Protection and Research - ISPRA, Italy

[4] CINECA (Consorzio Interuniversitario per il Calcolo Automatico dell'Italia Nord Orientale), Italy

[5] University of Trieste, Italy

COSS-TT meeting – Brest, 17-20 June 2025

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MARINE ECOSYSTEM RESTORATION

- **MER (Marine Ecosystem Restoration)** project, funded by the **NextGenerationEU** program (investment M2C4 - I3.5) is the largest project on the sea in the context of the National Recovery and Resilience Plan;
- **ISPRA** is the implementing body / contracting authority and the **Ministry for the Environment and Energy Security** is the administration holder of the financing of **400 M€** for **2022-2026**;
- **37 actions**: from oysterground restoration, to measurement networks, to the acquisition of a new oceanographic naval unit;
- **actions B32 (biogeochemical modelling)** and **B35 (impact of sewage discharges** – river / coastal outfalls)
- **coastal areas**: highly dynamic environments with **physical** and **biogeochemical** processes interacting over multiple spatial and temporal **scales**;
- **monitoring** and **predicting** these processes for effective management, conservation and restoration of marine ecosystems;
- high-resolution regional **downscaling tools** need careful integration of various **products** (and their **dependencies**): open sea boundary conditions, river discharge, high-resolution atmospheric forcing, satellite observations and in situ coastal data (including wastewater treatment plant inputs);
- modelling system designed for **operational purposes** (five-day short-term forecasts);
- **10-year reanalysis** (2011-2020) and **5-year hindcast** (2021-2025) for the assessment of both coastal-open ocean dynamics and temporal variability at fine scales.

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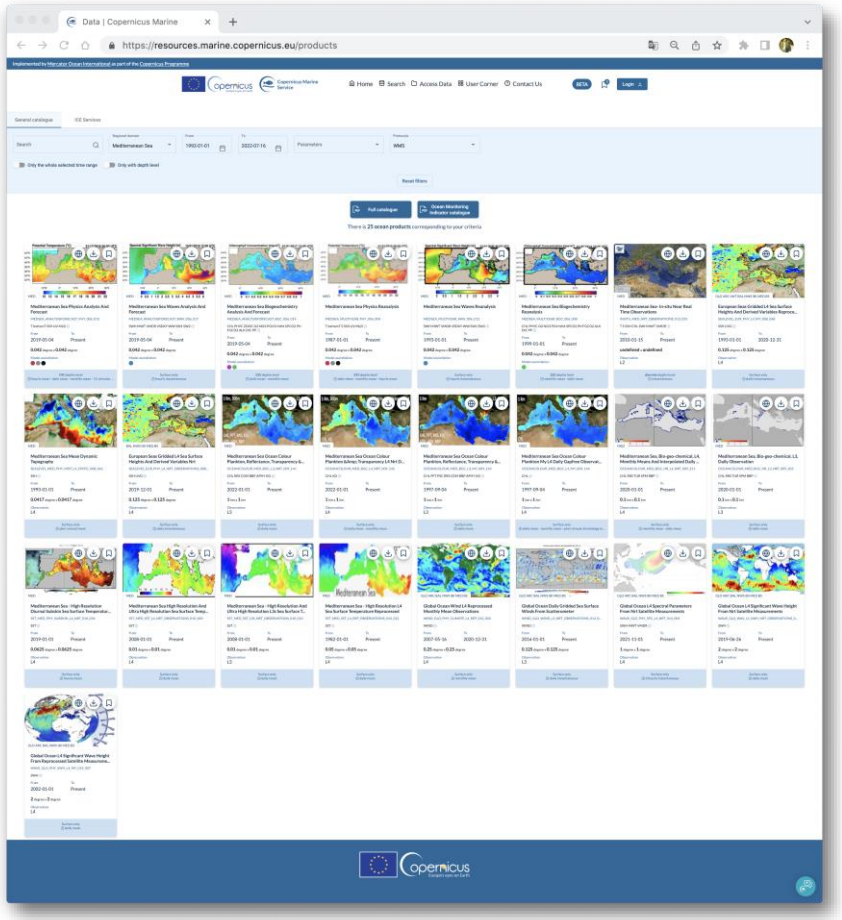
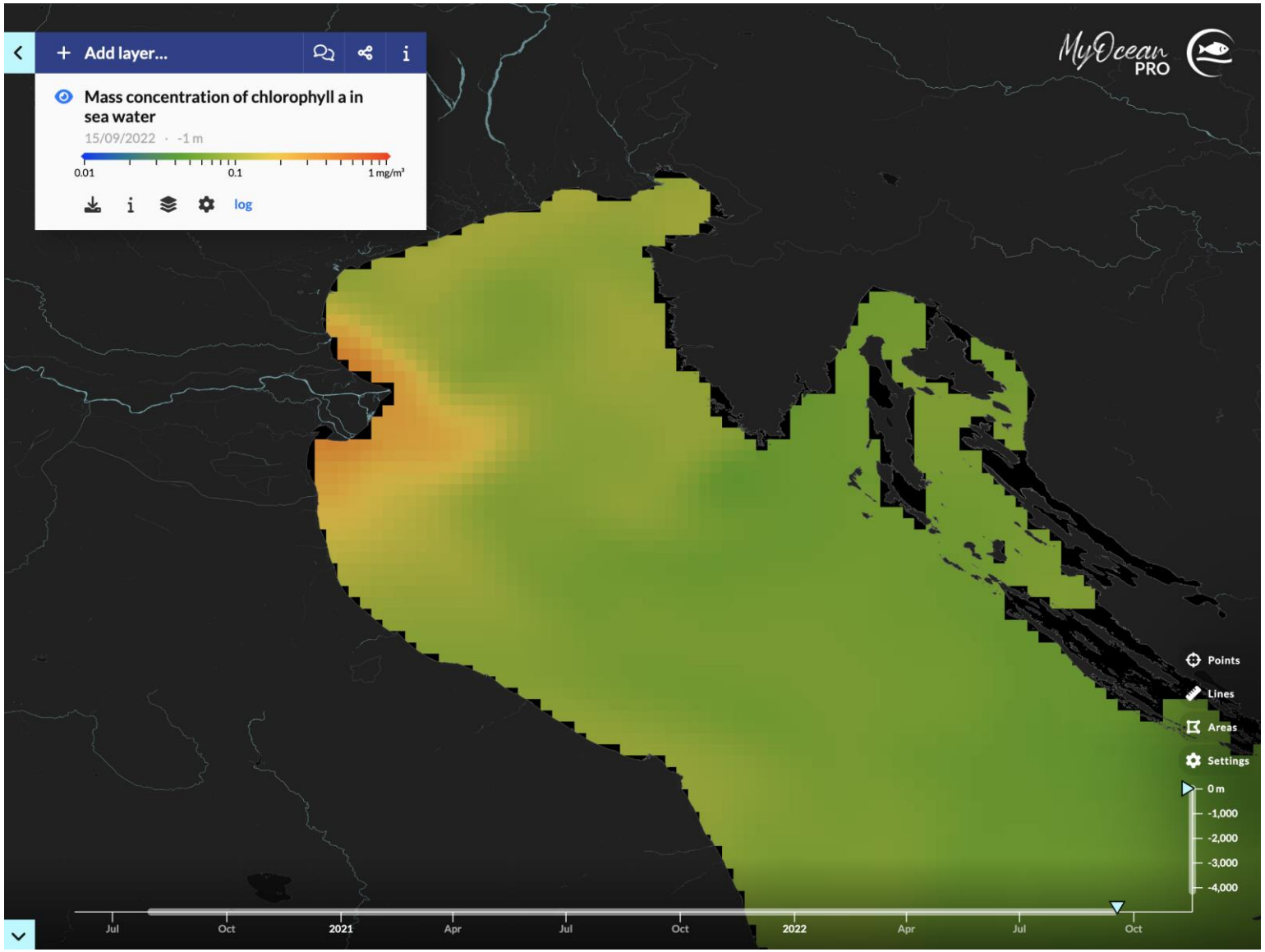
Need for higher resolution systems

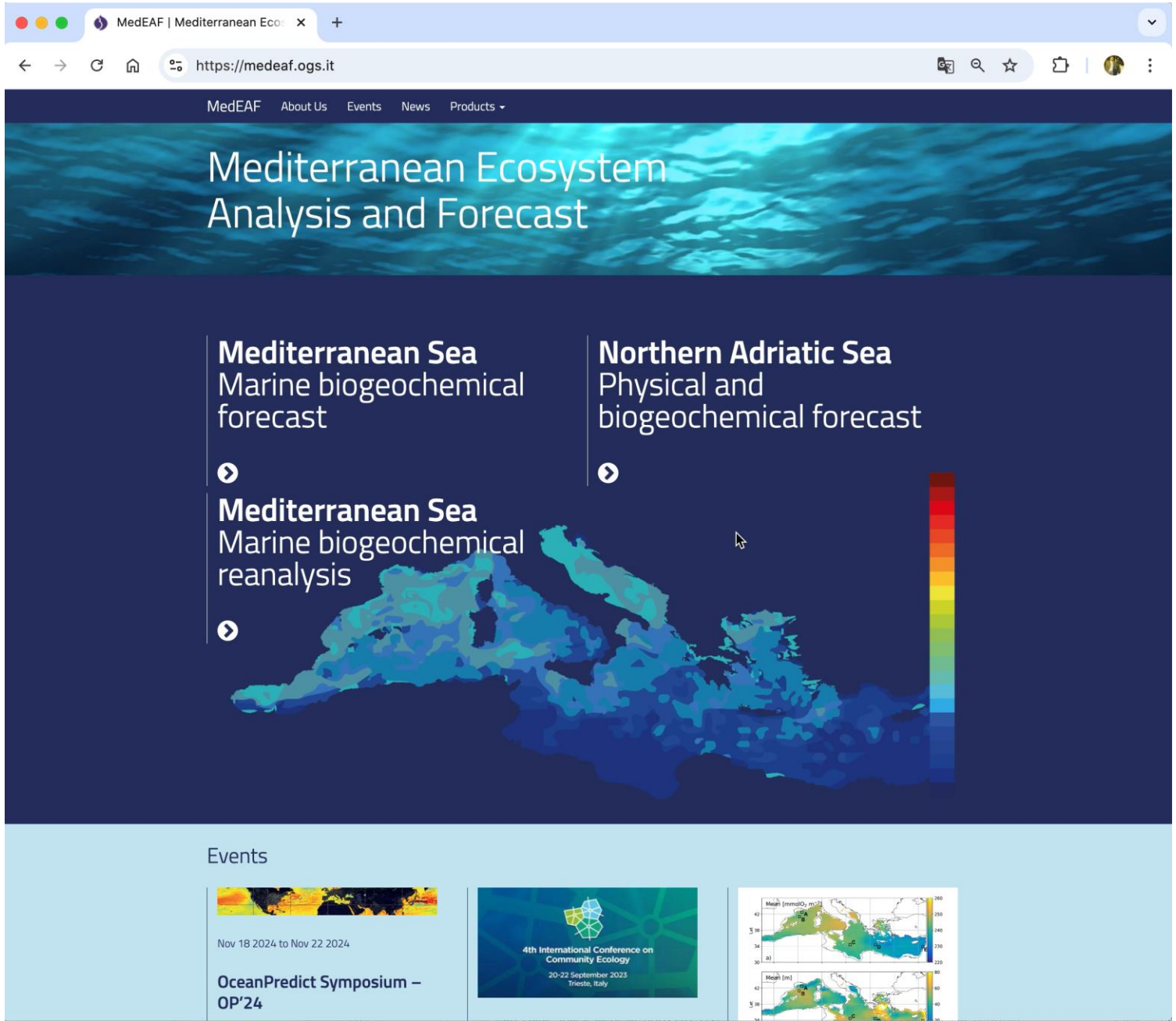
CMEMS online catalogue (**open** and **free**) of the products for the **physical** and **biogeochemical** variables and for **surface waves**

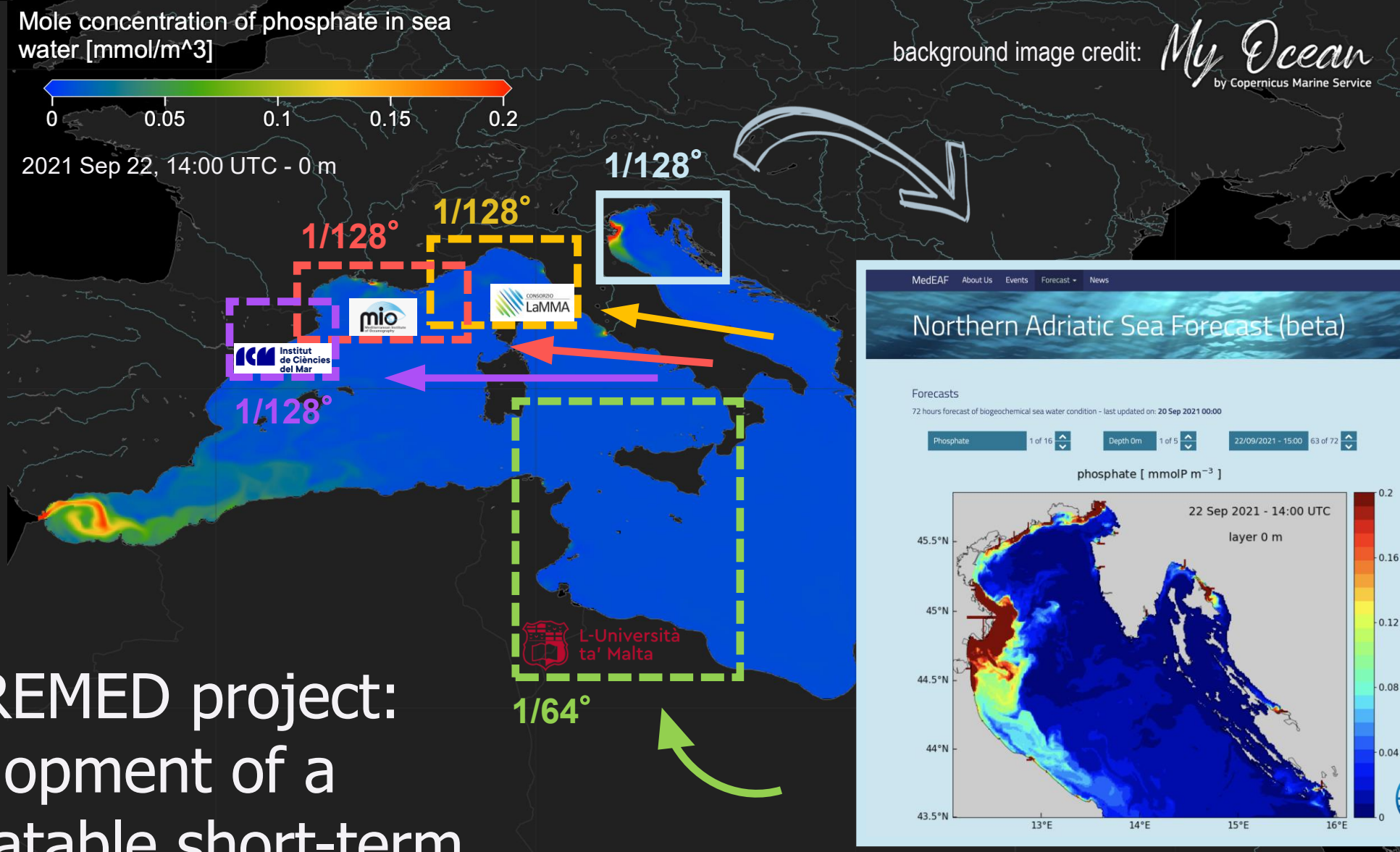




PROBLEM: for many coastal applications, the resolution (**1/24°**) is not enough...

MedEAF webpage: Med Sea products and downscaling on the northern Adriatic Sea



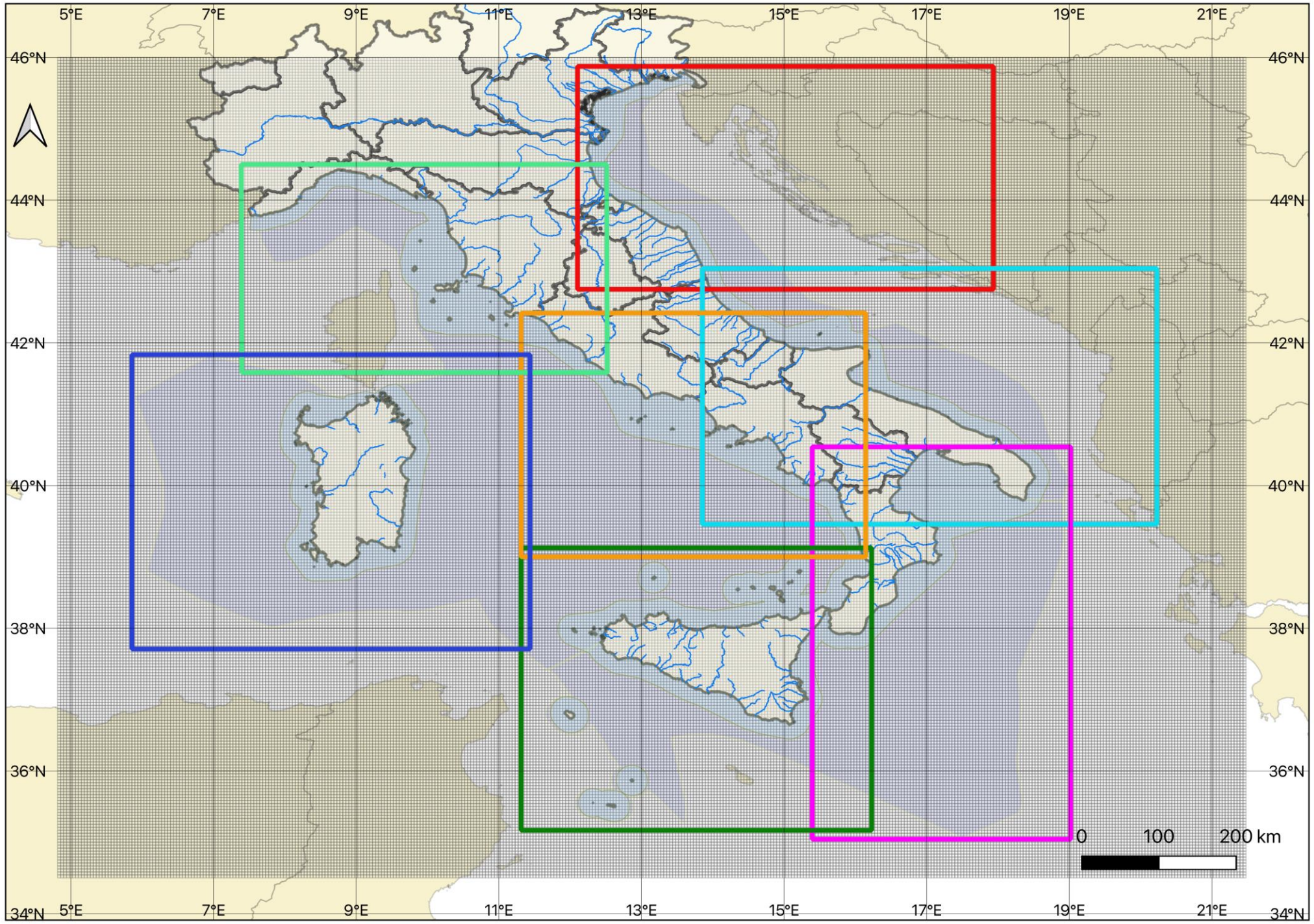


SHAREMED project: development of a relocatable short-term forecasting system for coastal areas

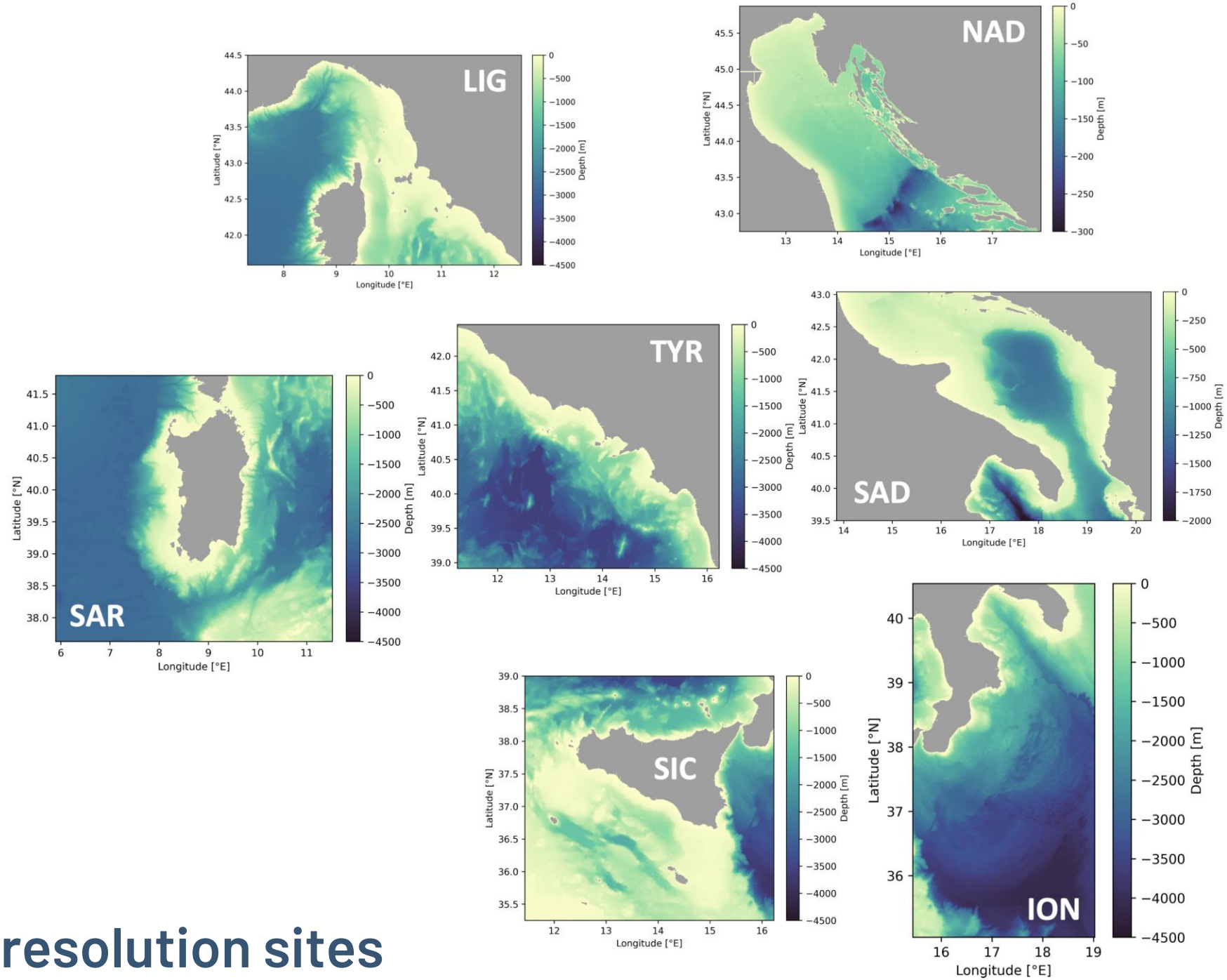
Interreg Mediterranean SHAREMED

OGS

Model domains (500 m res.)



Model domains (500 m res.)



+ 10 high-resolution sites

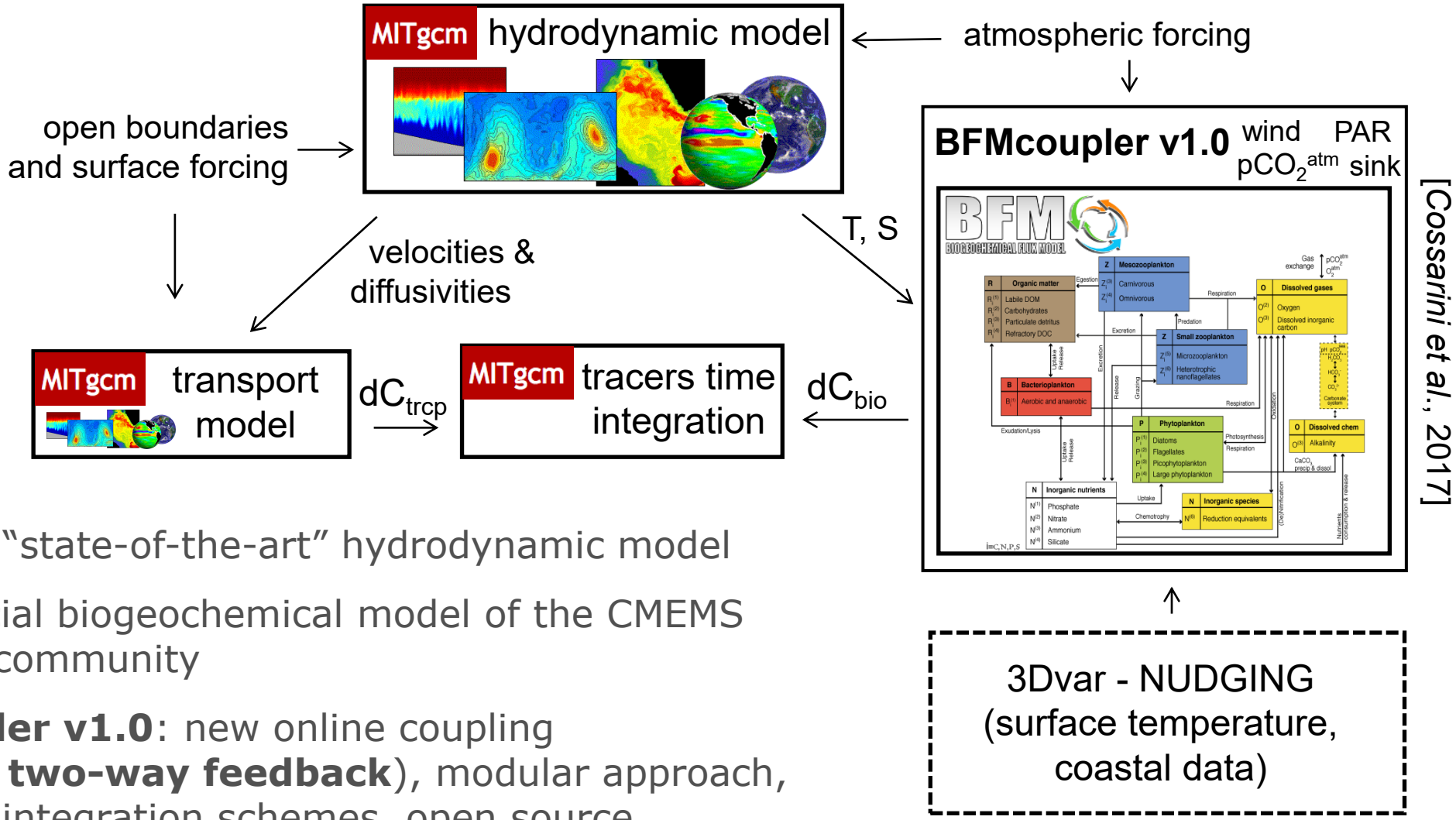
SUBCONTRACTS

Lot 1 - Adaptation and quality control of the **satellite products** of Ocean Color and Sea Surface Temperature of the Marine Copernicus service for the coastal strip of the Italian seas.

Lot 2 - Contribution to **optimization and validation** for the implementation of the biogeochemical modeling system at the national scale at a resolution of 500 m.

Lot 3 - Support for the implementation of the oceanographic modeling system at the scale of **high-resolution sites** (sites of extension not less than 400 km^2 with grid elements not greater than 100 m).

Modeling system based on the coupled MITgcm-BFM model



MITgcm: "state-of-the-art" hydrodynamic model

BFM: official biogeochemical model of the CMEMS Med-MFC community

BFMcoupler v1.0: new online coupling (**possible two-way feedback**), modular approach, optimized integration schemes, open source

3Dvar - NUDGING: assimilation of sea surface chl/temperature and coastal data of nutrients

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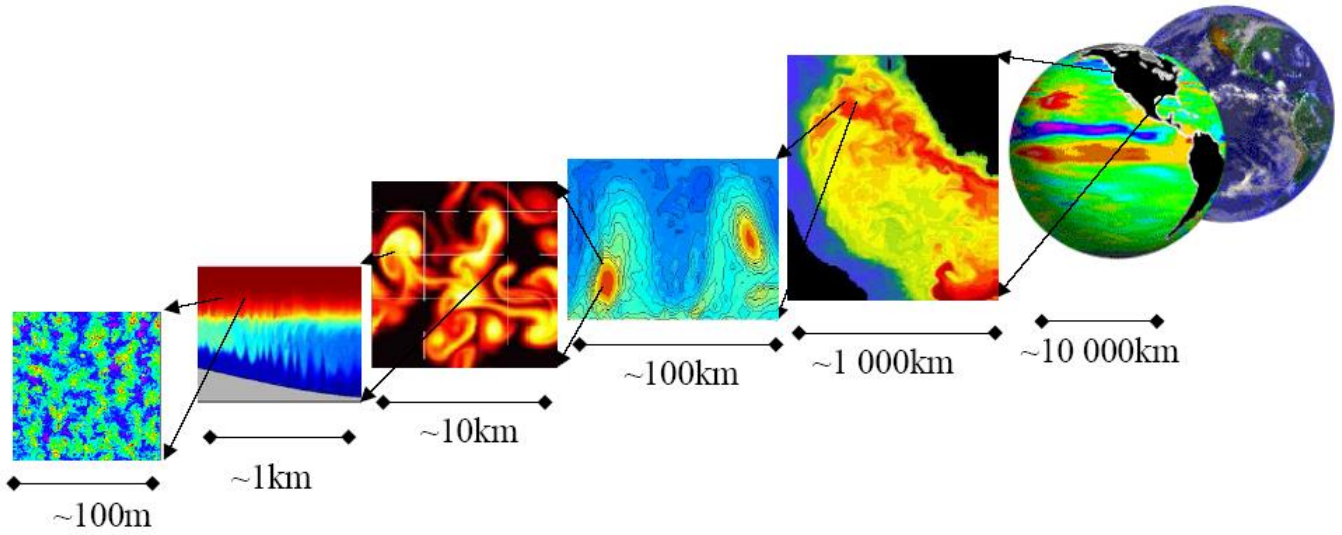
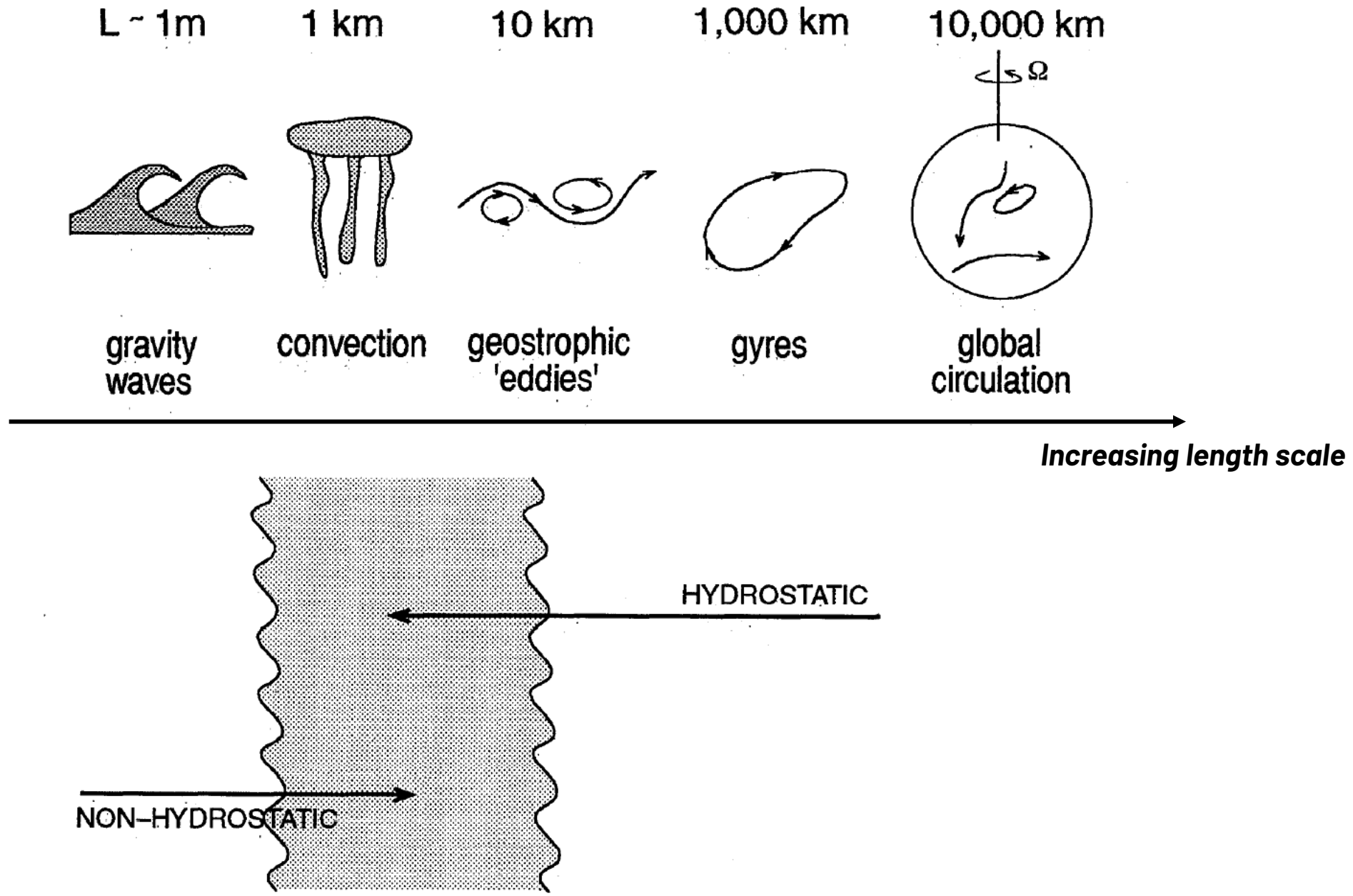
THE NUMERICAL MODEL

MITgcm Ocean General Circulation Model [*Marshall et al.*, 1997]

MITgcm main features:

- designed to study both atmospheric and oceanic phenomena
- includes non-hydrostatic capability
- adopts the KPP or GGL90 vertical turbulence parametrization
- adopts a finite volume technique
- developed to perform efficiently on a wide variety of computational platforms including MPI parallelizing directive





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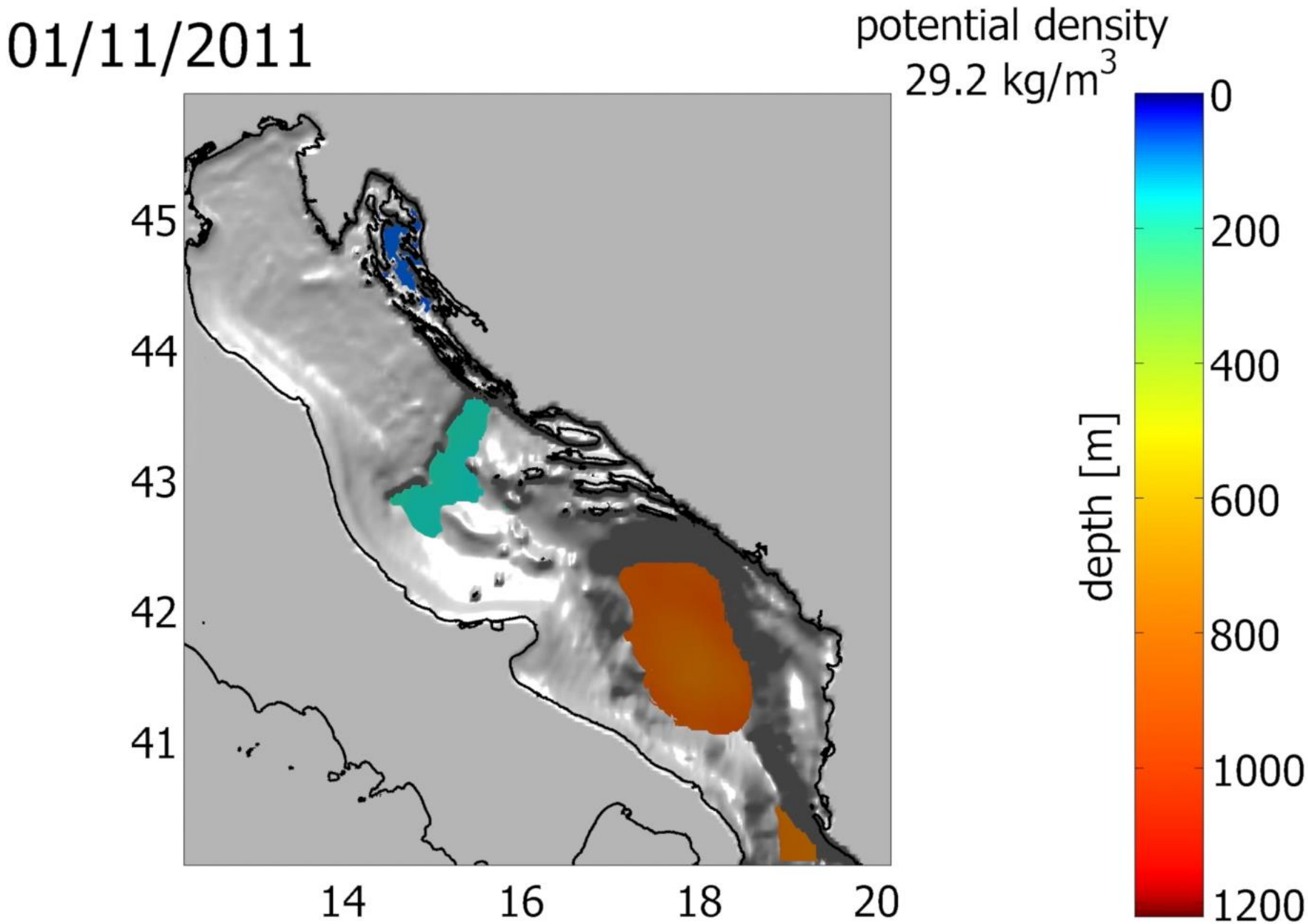

01/11/2011
potential density
29.2 kg/m3
45
44
43
42
41
14
16
18
20
depth [m]
0
200
400
600
800
1000
1200

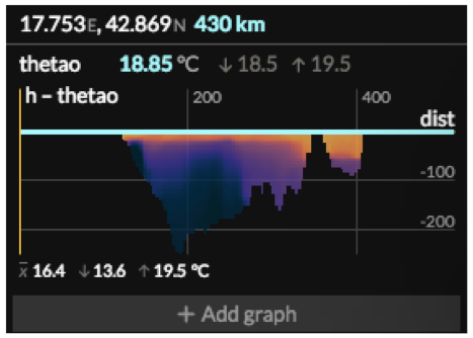
MER B32-B35 forecast and reanalysis components

Remote sensing data integration of **sea surface temperature** and **chlorophyll**

Copernicus Marine Service

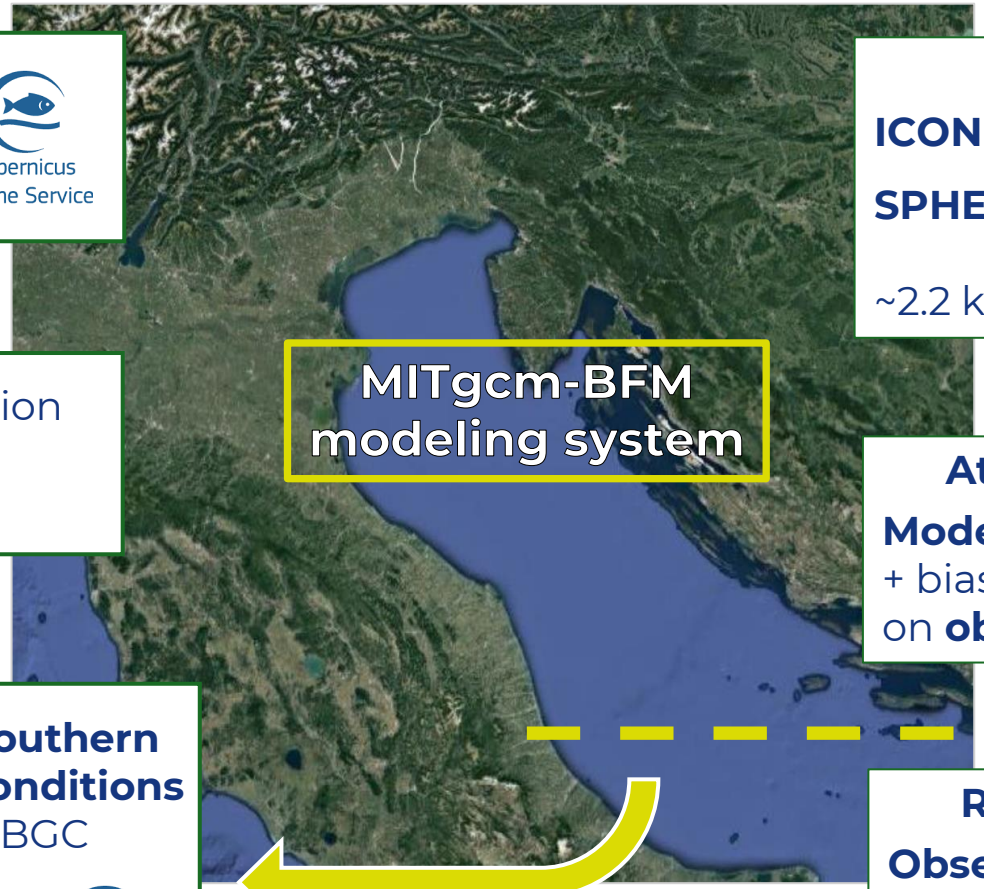
EIONET-SOE **in-situ** data integration

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale



Initial and southern boundary conditions for PHY and BGC variables

Copernicus Marine Service



Atmospheric forcing

ICON / COSMO forecasts

SPHERA reanalysis

~2.2 km horiz. res., 1 hour freq.

MISTRAL
Meteo Italian Supercomputing Portal

arpae emilia-romagna

Atmospheric nutrient deposition

Model results (~25 km horiz. resolution) + bias correction based on **observations**

Atmosphere Monitoring Service
atmosphere.copernicus.eu

River discharges and BGC loads

Observations and hydrological **model data** (~1.5 km horiz. res.)

ARPA FVG

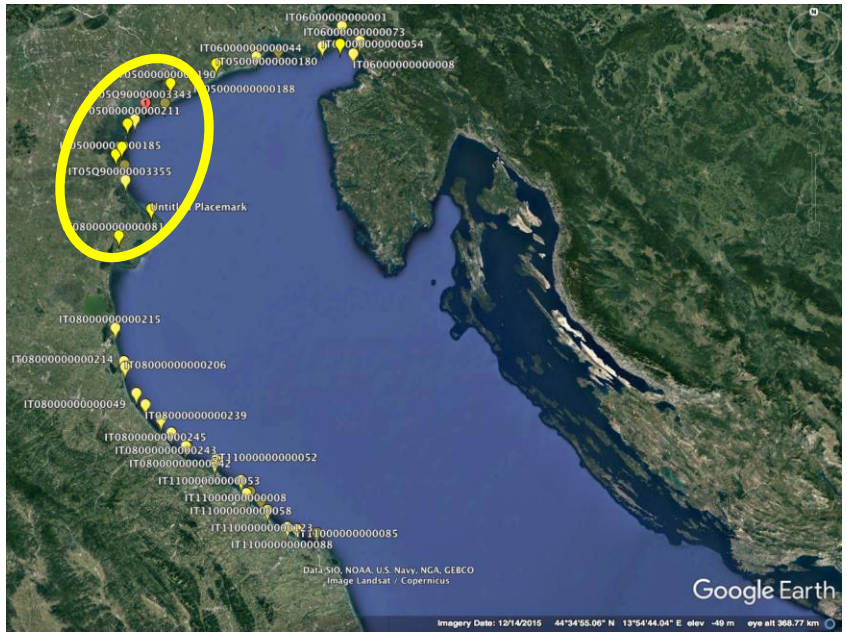
arpae emilia-romagna

Emergency Management

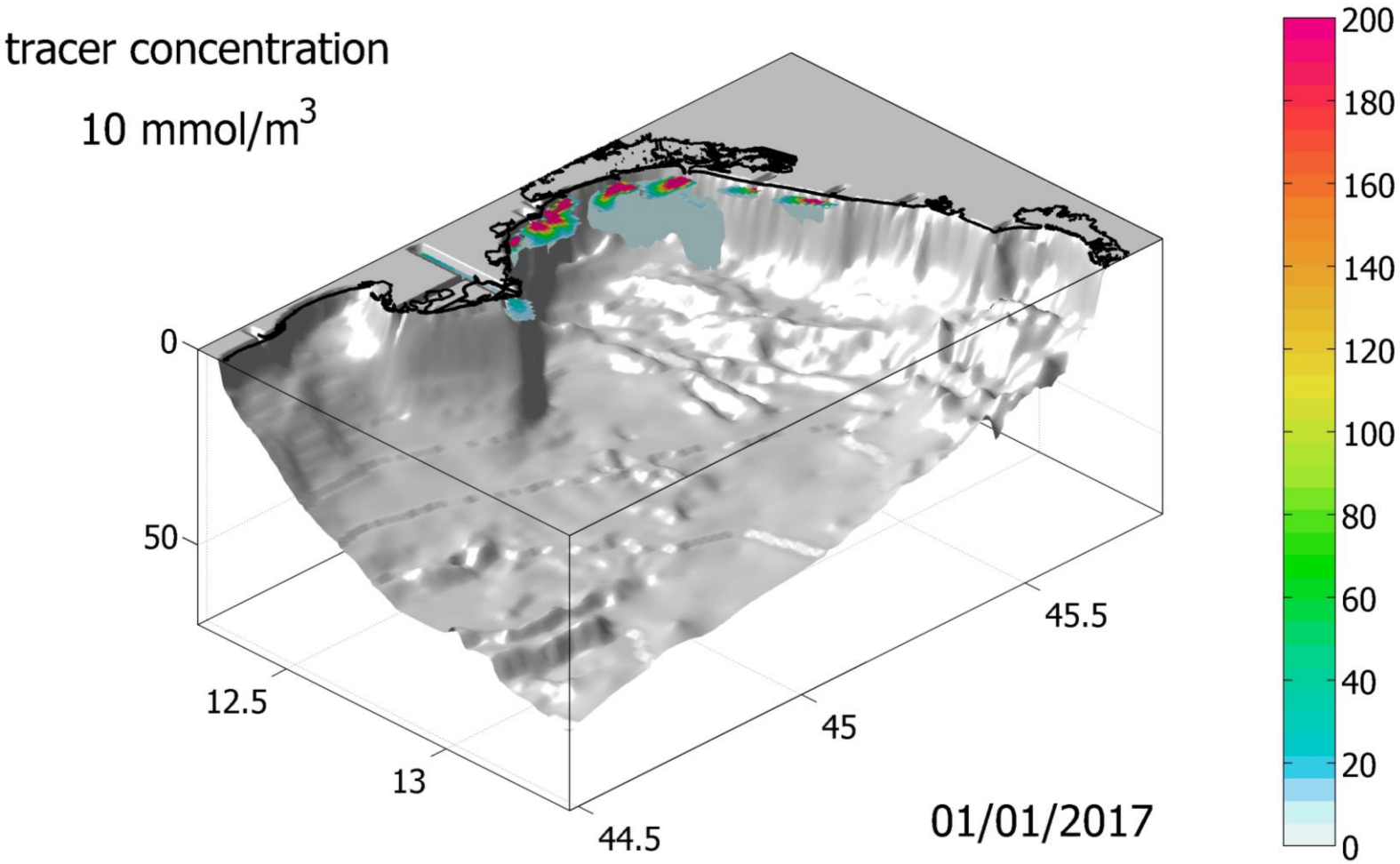
EFAS
European Flood Awareness System

Action B35: simulation of bottom sewage discharges

Bottom discharges, 3D case study (municipality of Chioggia):
12 sources of pollutant
(proxy of e. coli)



Coastal discharges (ISPRA dataset)



first order decay law [*Chan et al.*, 2013]

$$k(z,t) = \left(k_b + k_s S(z,t)\right)\theta^{T-20} + k_I I(t) e^{-e_t z}$$

z (depth), t (time), k_b=0.8, k_s=0.017, k_I=0.086, e_t=0.5 (higher transparency), θ=1.07

CADEAU OGS ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

exact lab

Solutions for the digital revolution

Client:

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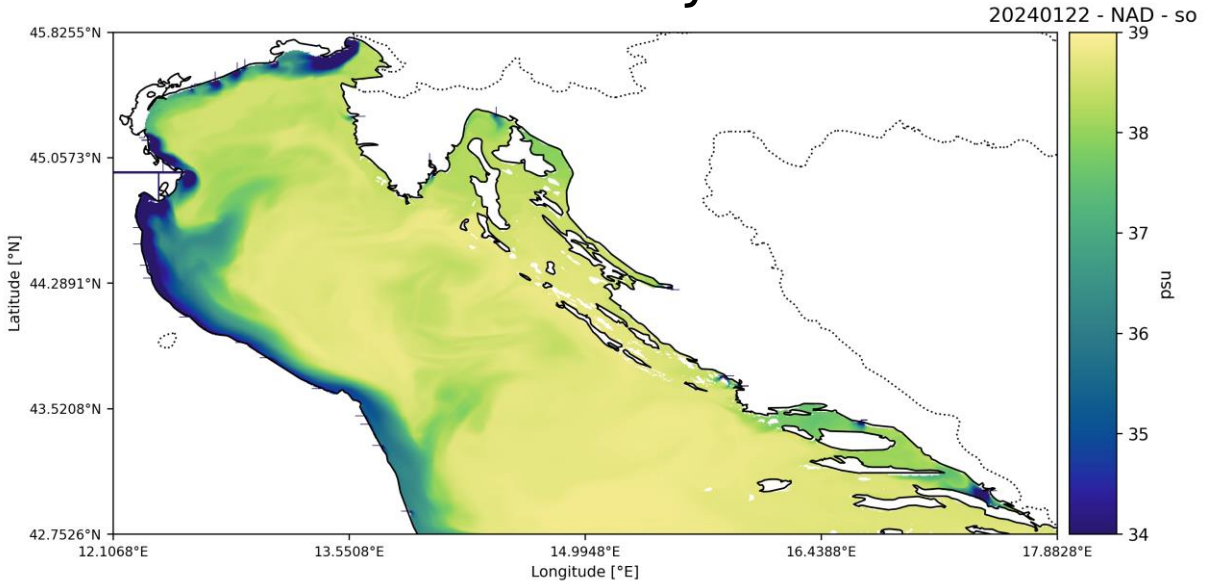
Case study: MER Biogeochemical operational chain engineering

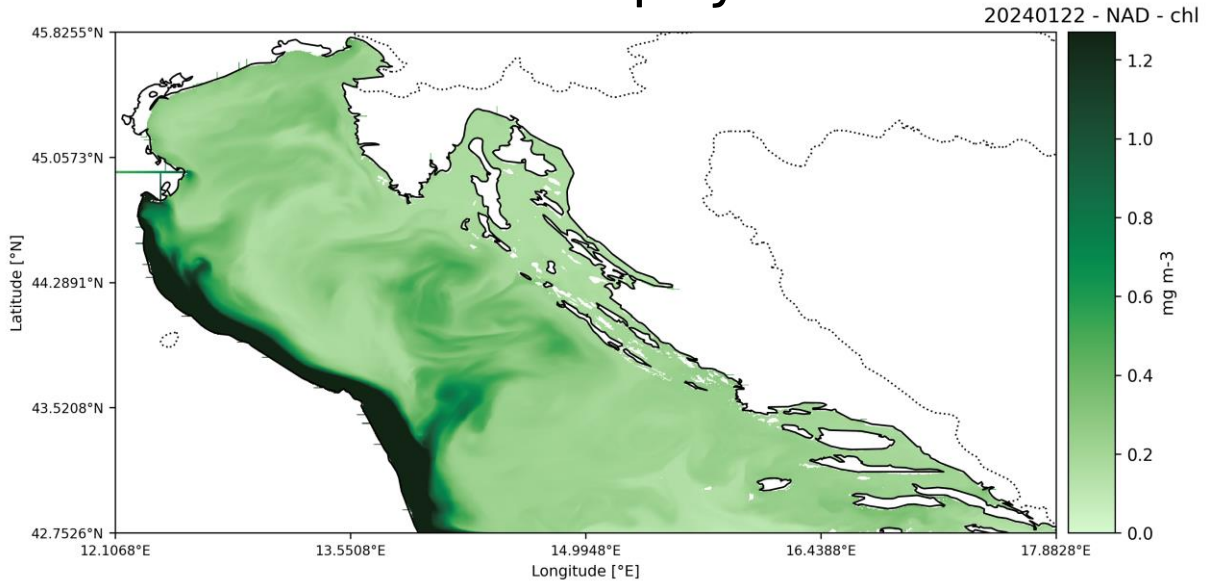
Model results – yearly run - NAD

WINTER 2024

salinity



chlorophyll



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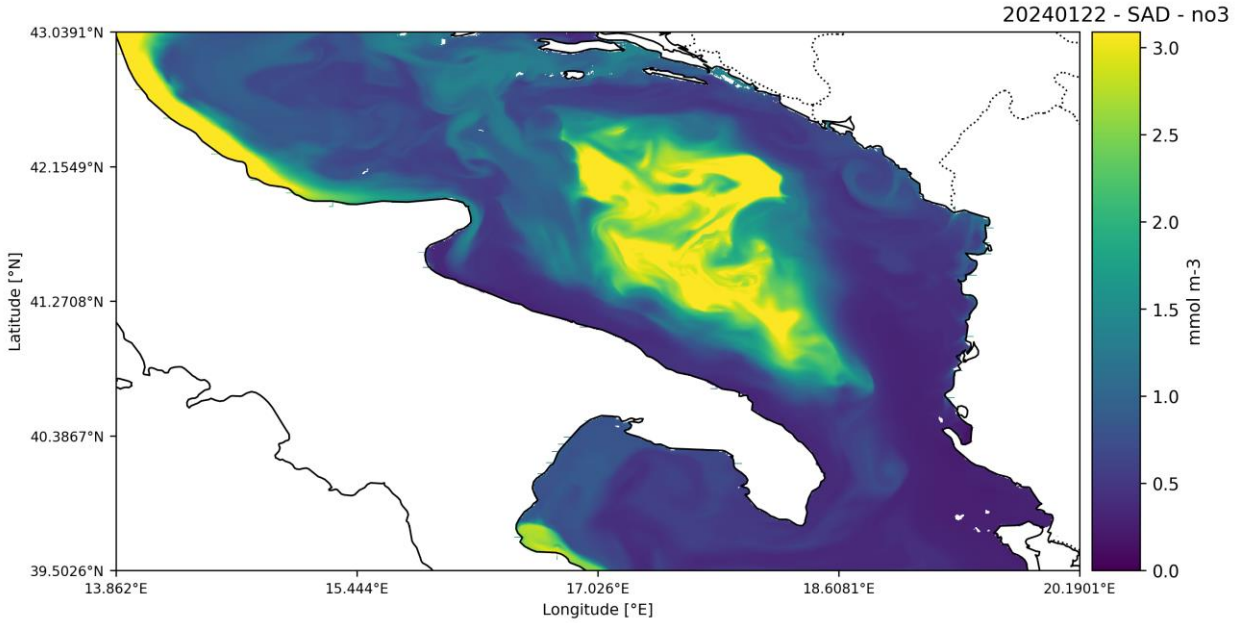
MARINE ECOSYSTEM RESTORATION

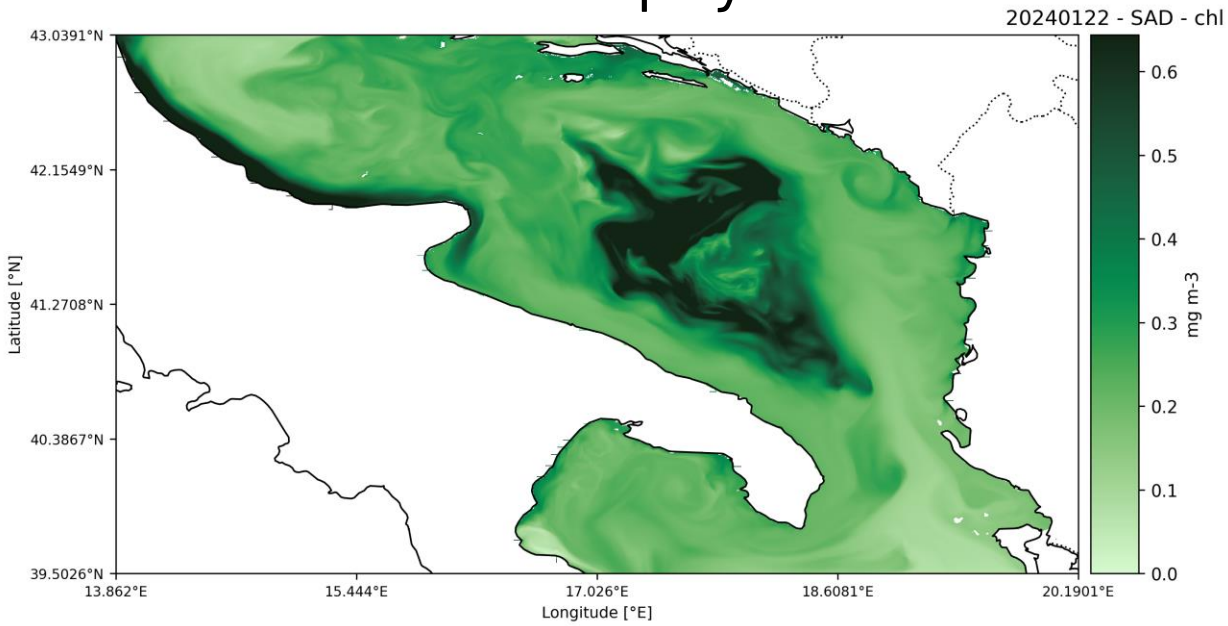
Model results – yearly run – SAD

WINTER 2024

nitrate



chlorophyll



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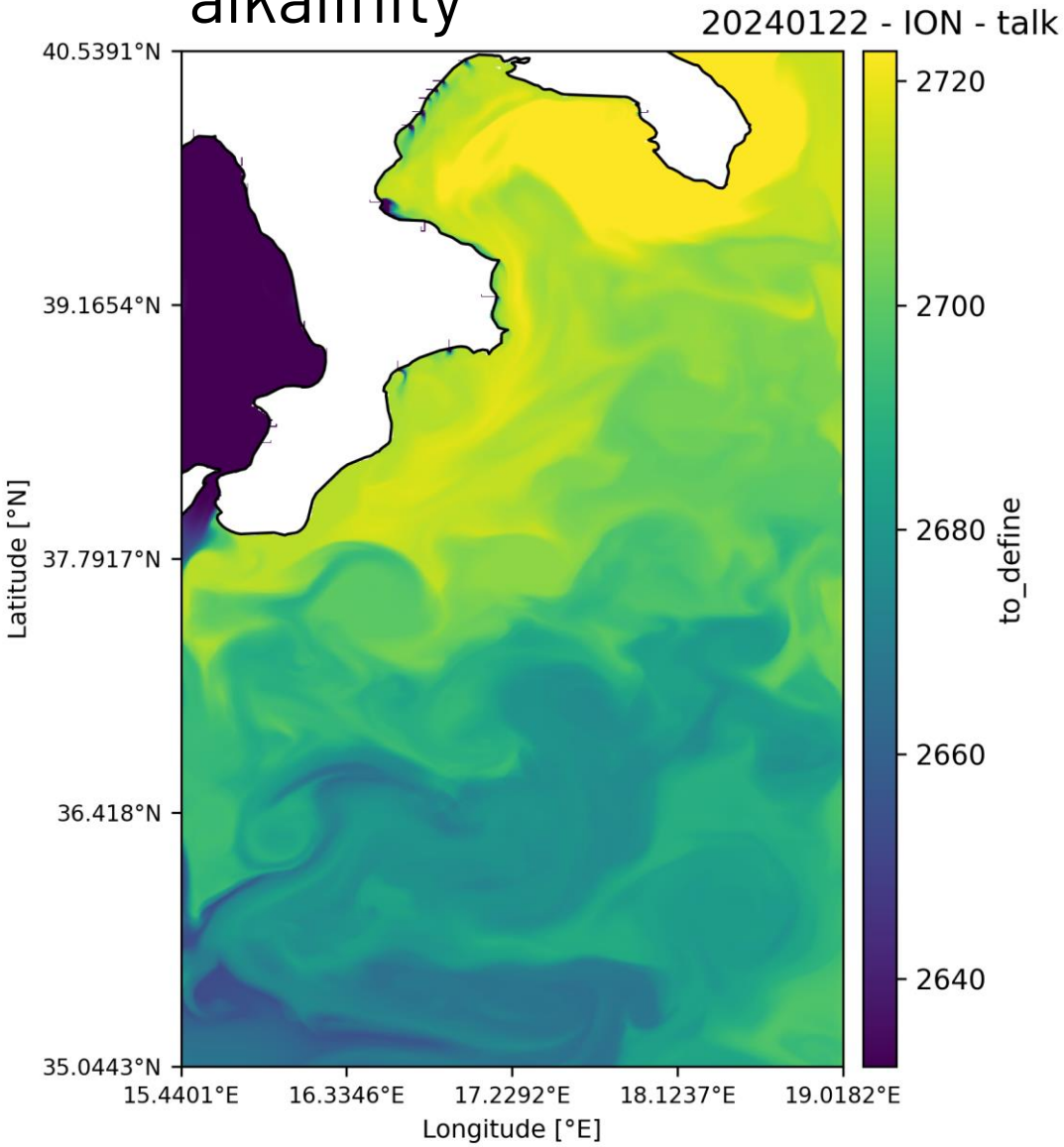
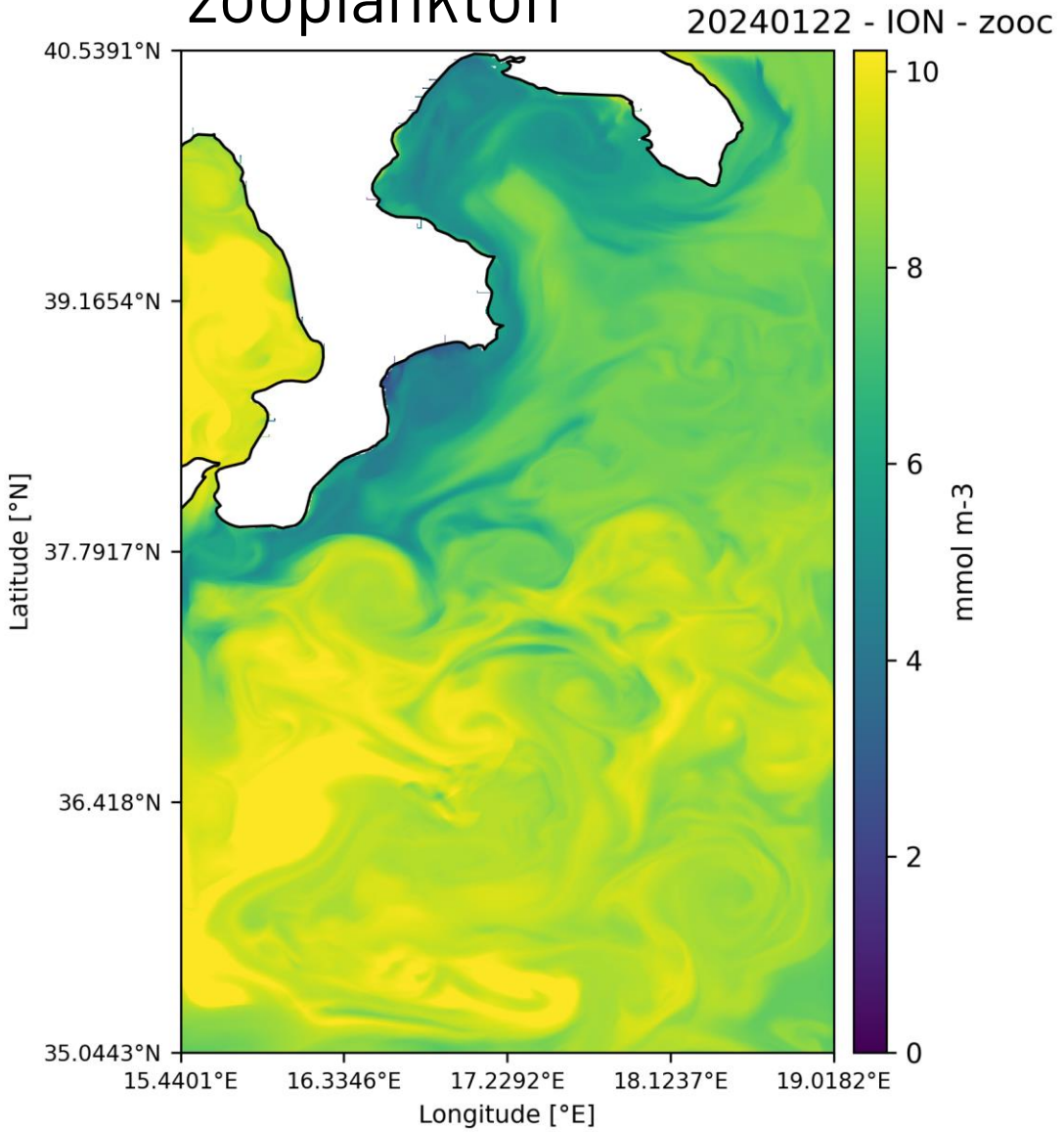
MARINE ECOSYSTEM RESTORATION

Model results – yearly run - ION

alkalinity



zooplankton



WINTER 2024

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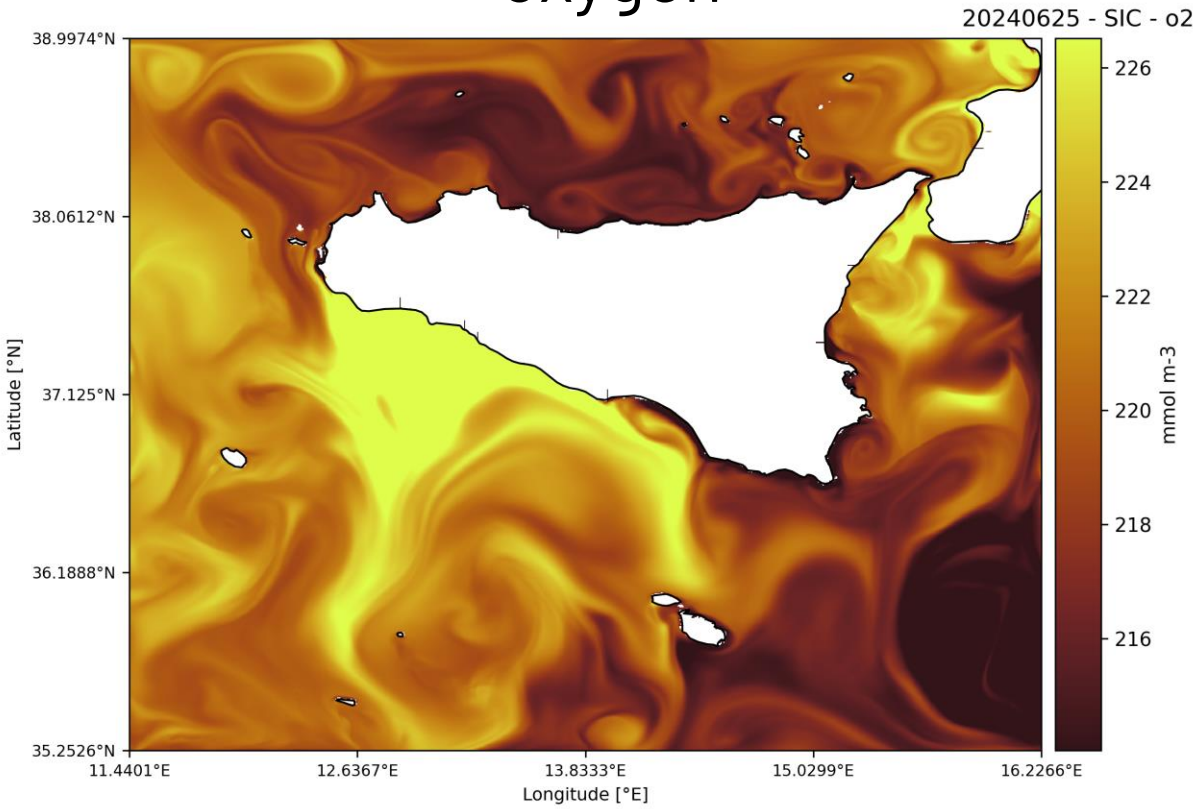
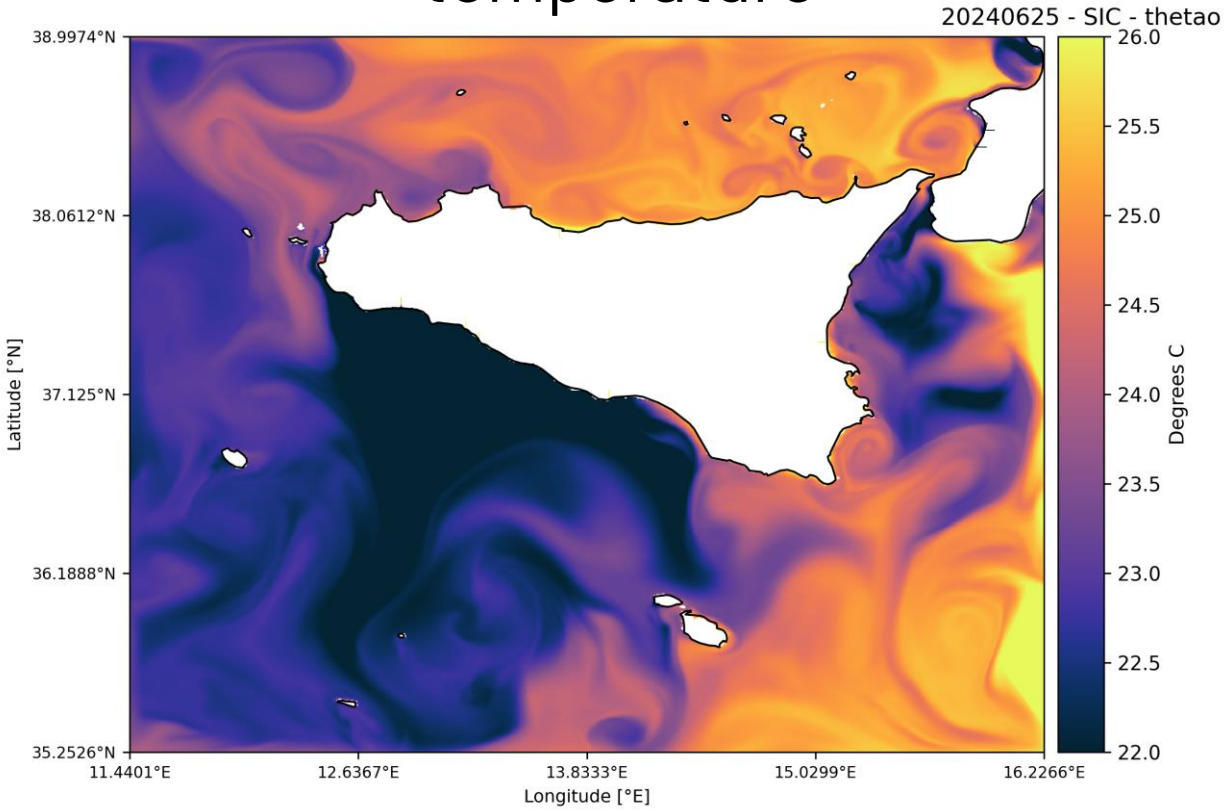
Model results – yearly run - SIC

SUMMER 2024

oxygen



temperature



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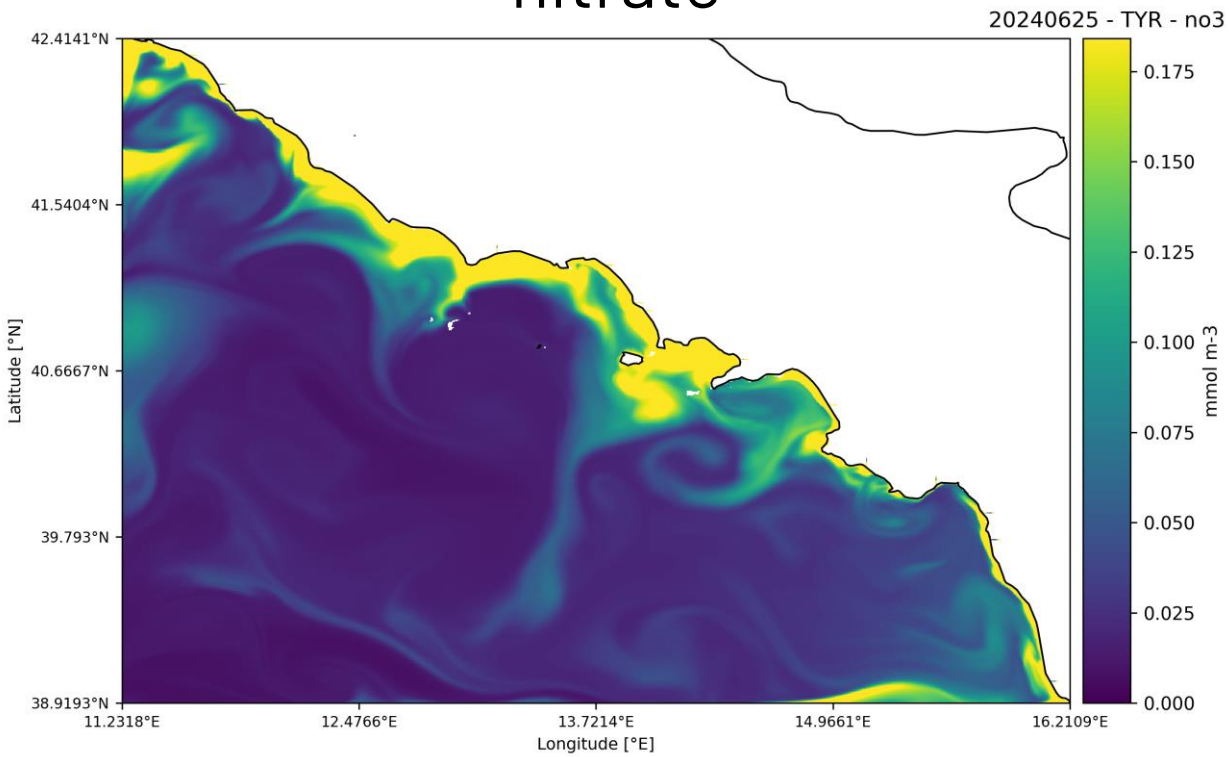
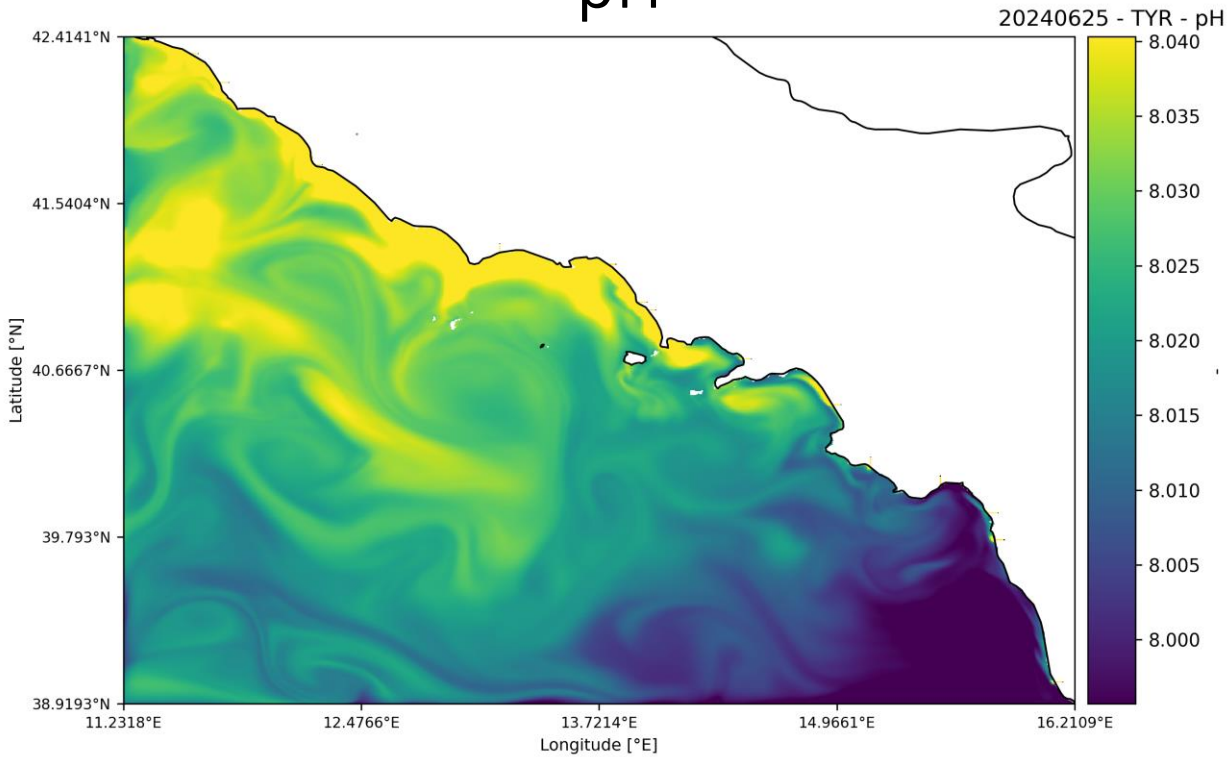
Model results – yearly run - TYR

SUMMER 2024

nitrate



pH



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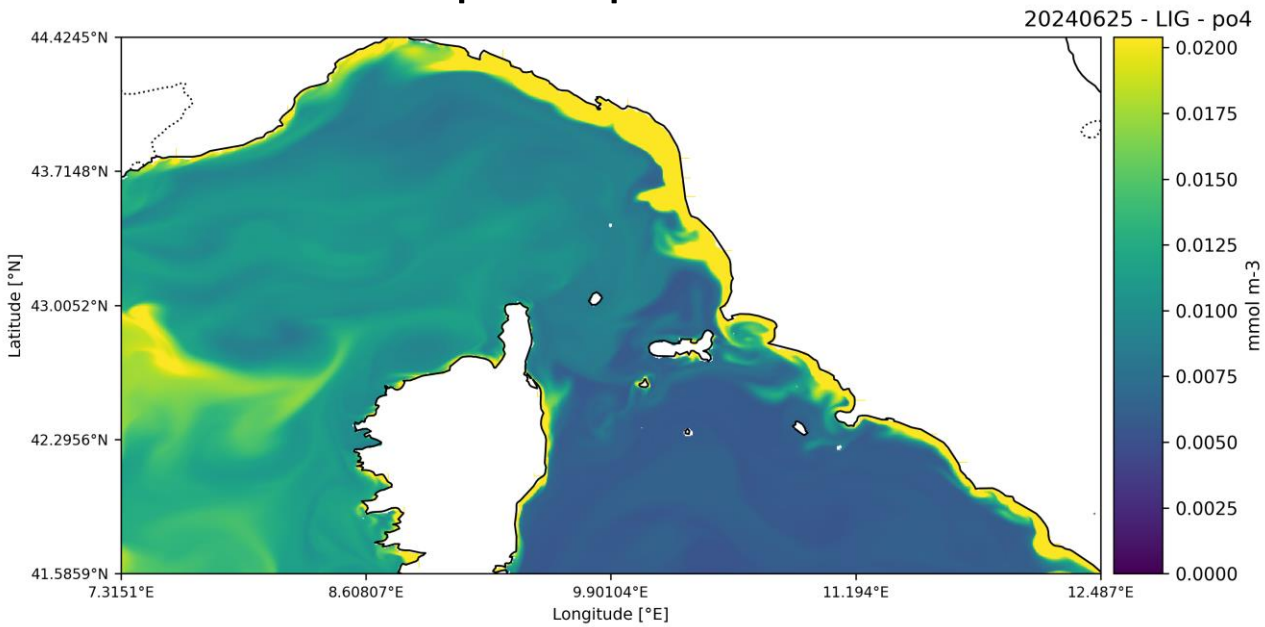
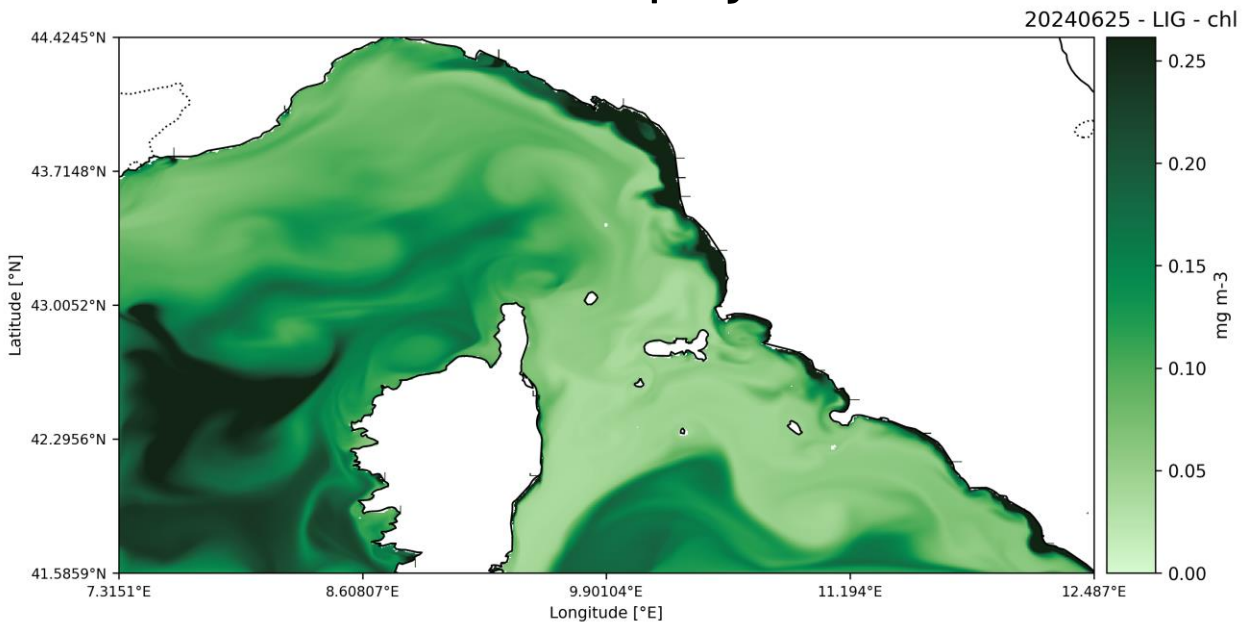
Model results – yearly run - LIG

SUMMER 2024

phosphate



chlorophyll



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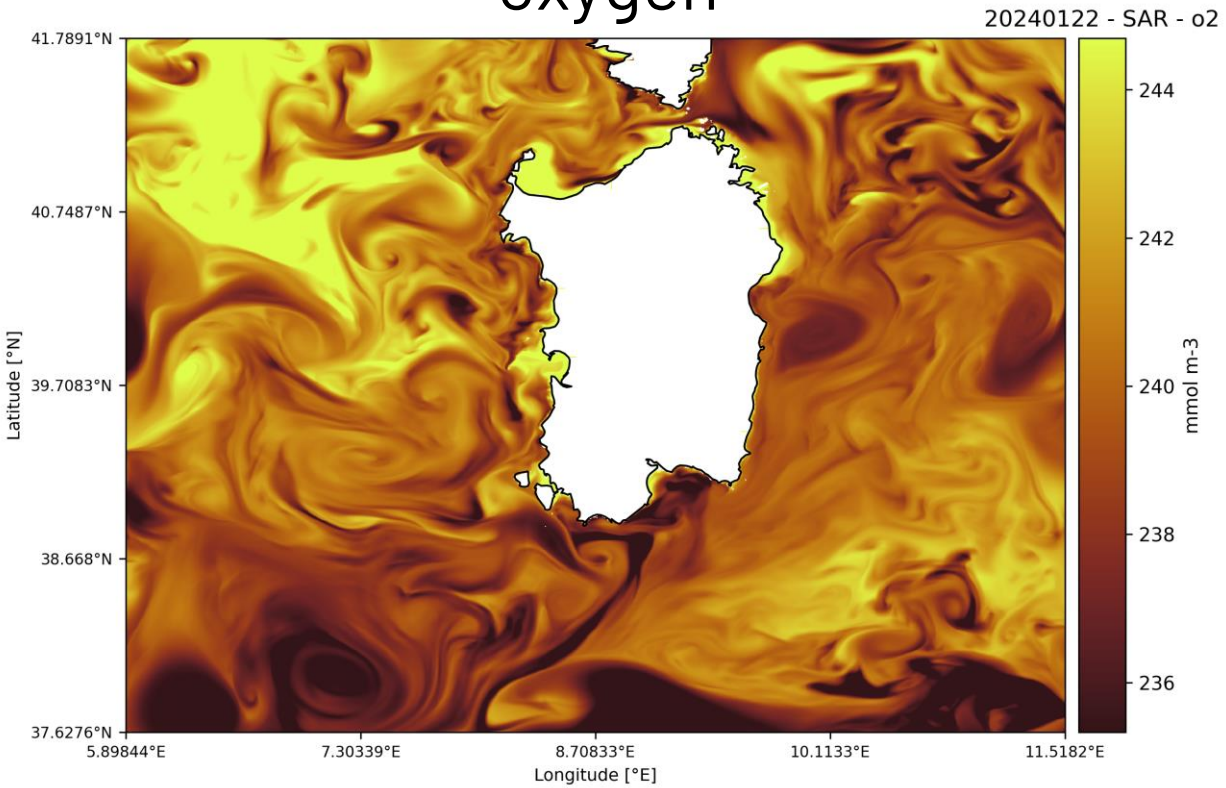
MARINE ECOSYSTEM RESTORATION

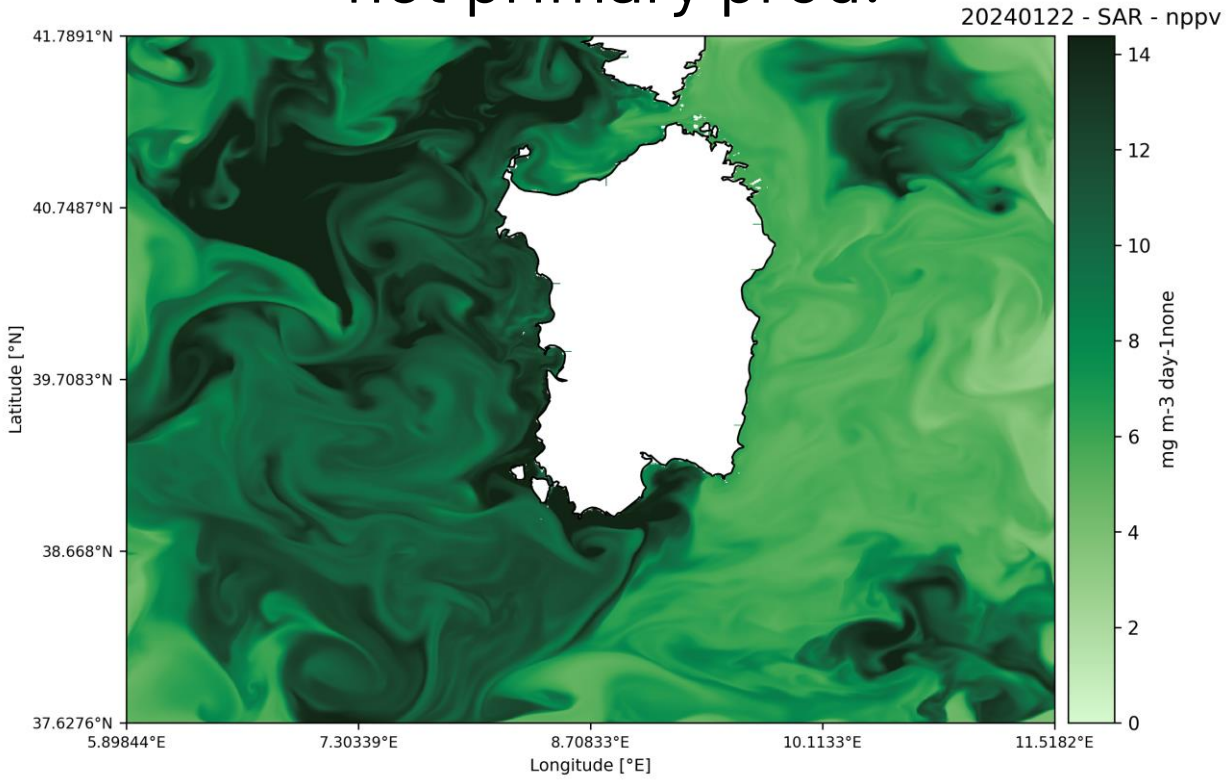
Model results – yearly run - SAR

WINTER 2024

oxygen



net primary prod.



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MARINE ECOSYSTEM RESTORATION

Wrap up...

- for coastal applications high **resolution** and high level of **detail** are needed
- **regional downscaling tools** need careful **integration** of various products (and their dependencies): open sea boundary conditions, river discharge, high-resolution atmospheric forcing, satellite observations and in situ coastal data;
- technological advancements and potential benefits of the **MER relocatable forecasting system**;
- preliminary results of the physical and biogeochemical hindcast simulations for the Italian coastal waters.

Thank you!

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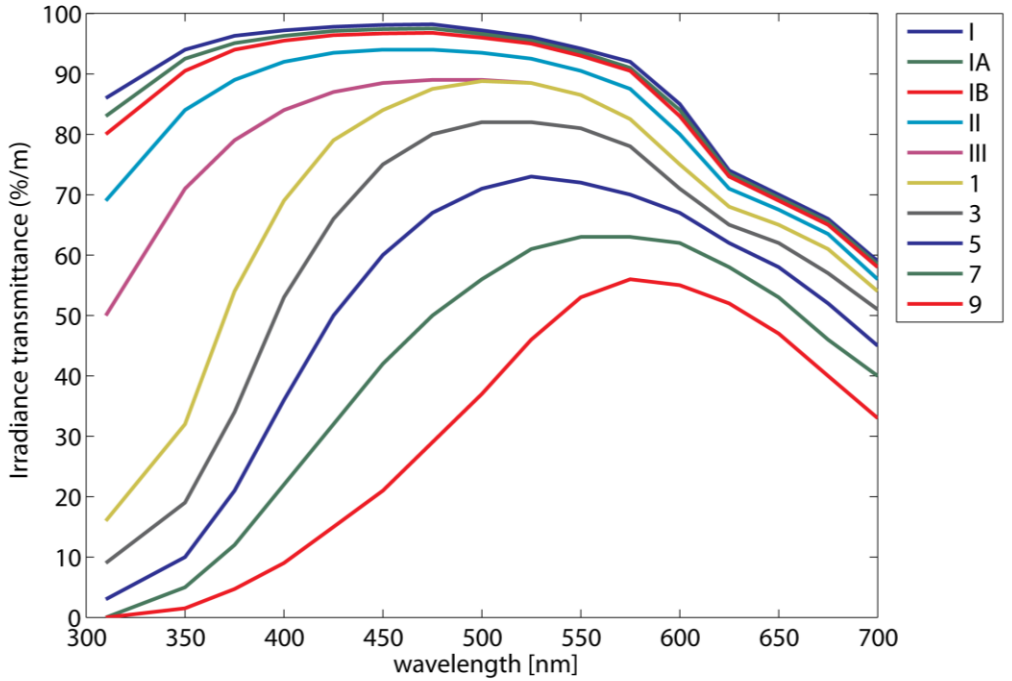
MER MARINE ECOSYSTEM RESTORATION

Importance of absorption of solar radiation

1. Jerlov water type

Jerlov [1976] discretized his observations into a set of five typical **oceanic** spectra and nine typical **coastal** spectra

Jerlov Water Type	Examples
I	Open Pacific
IA	Eastern Mediterranean, Indian Ocean
IB	Western Mediterranean, Open Atlantic
II	Coastal waters, Azores
III	Coastal waters, North Sea
1	Skagerrak Strait
3	Baltic
5	Black Sea
7	Coastal waters, dark



2. Choice of the **albedo**

3. Direct/diffuse short wave radiation from atmospheric models: **same standard**?

4. Spectral models of light absorption

5. Feedback from **biogeochemical models**

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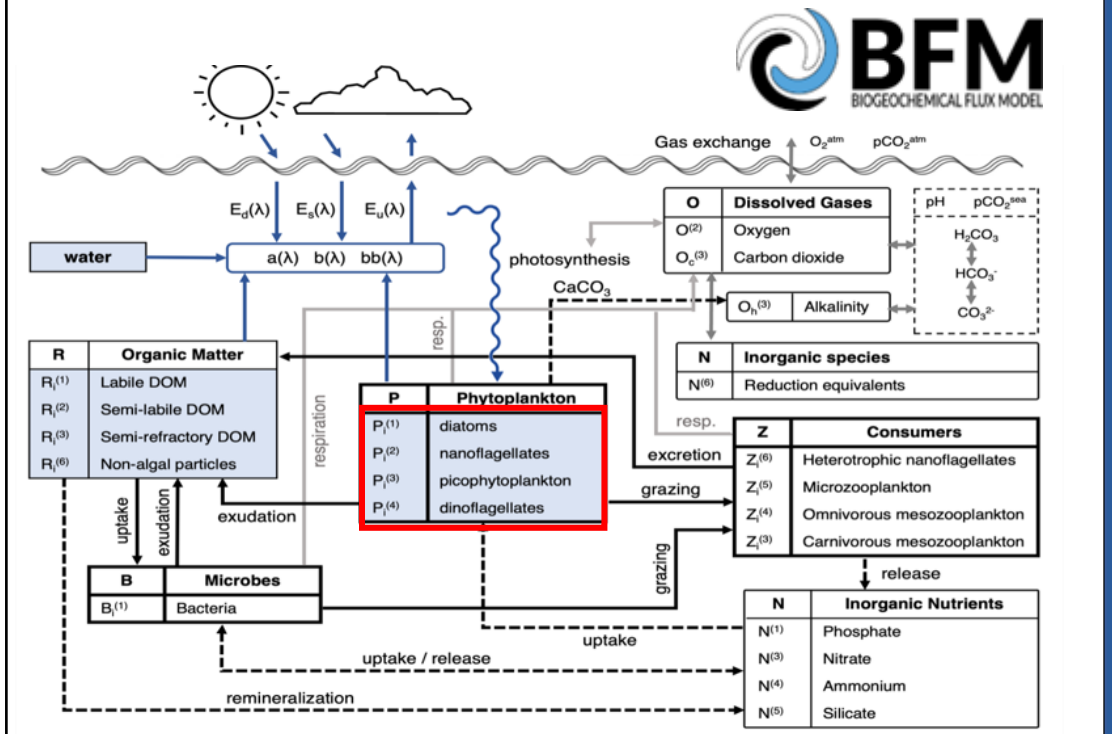
3DVAR assimilation in MITgcm-BFM system for chlorophyll

MITgcm-BFM 3D physical-biogeochemical model

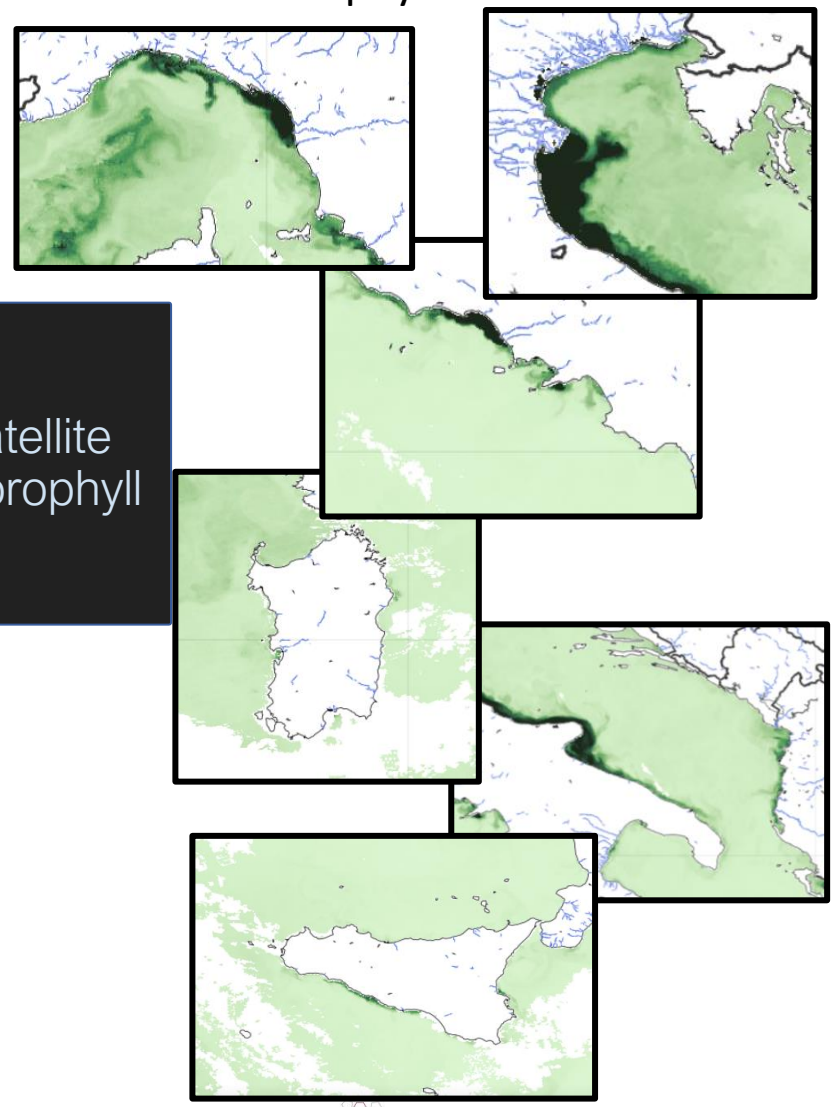
Biogeochemical Model



Variational data assimilation

Satellite chlorophyll

L3 OCTAC chlorophyll from CMEMS



Every week assimilation of 1 week of observations

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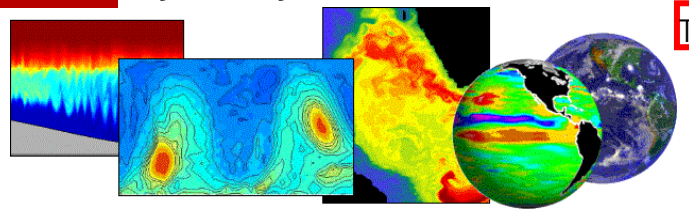
MARINE ECOSYSTEM RESTORATION

Assimilation in MITgcm-BFM of SST and in-situ nutrients

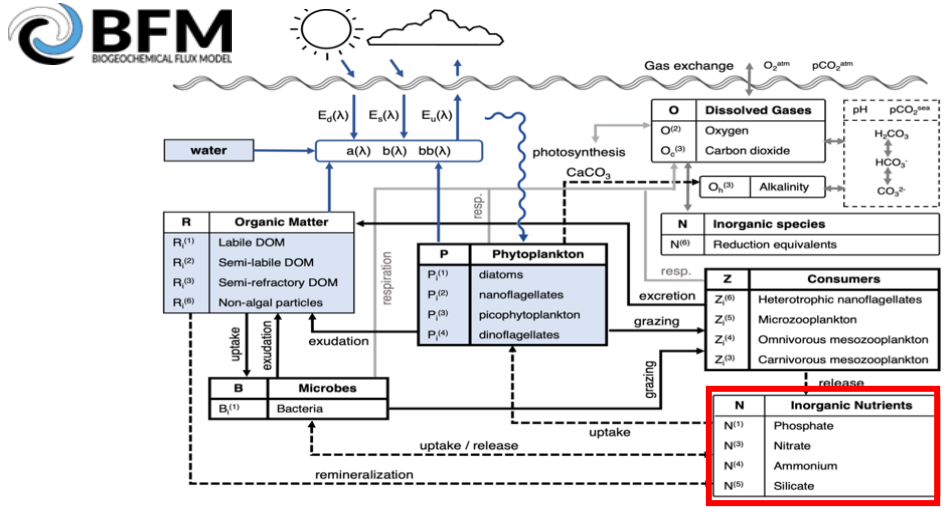
MITgcm-BFM 3D physical-biogeochemical model

MITgcm hydrodynamic model



Temperature
Salinity
u,v,w

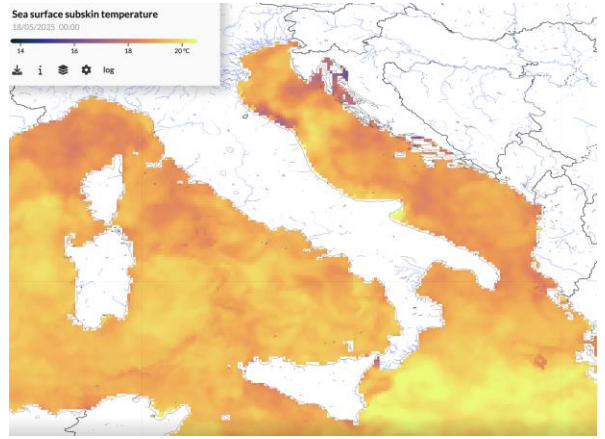
BFM BIOGEOCHEMICAL FLUX MODEL

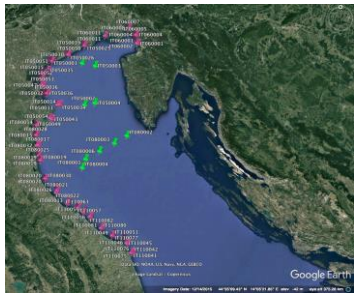


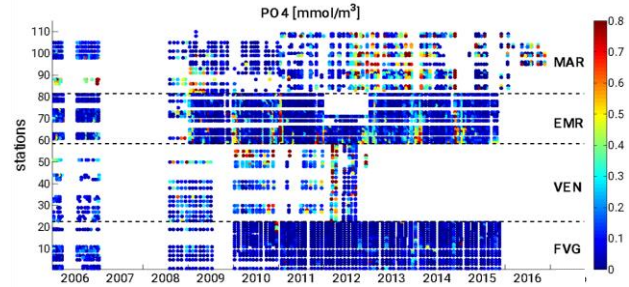
nudging scheme

$$\frac{N(st,r)_{x,y}}{\tau}\cdot(C(x,y,t)-C_{st})$$

SST and in situ data







Daily relaxation for SST and **monthly** relaxation for in-situ nutrient data

CMEMS SST and EIONET-SOE dataset

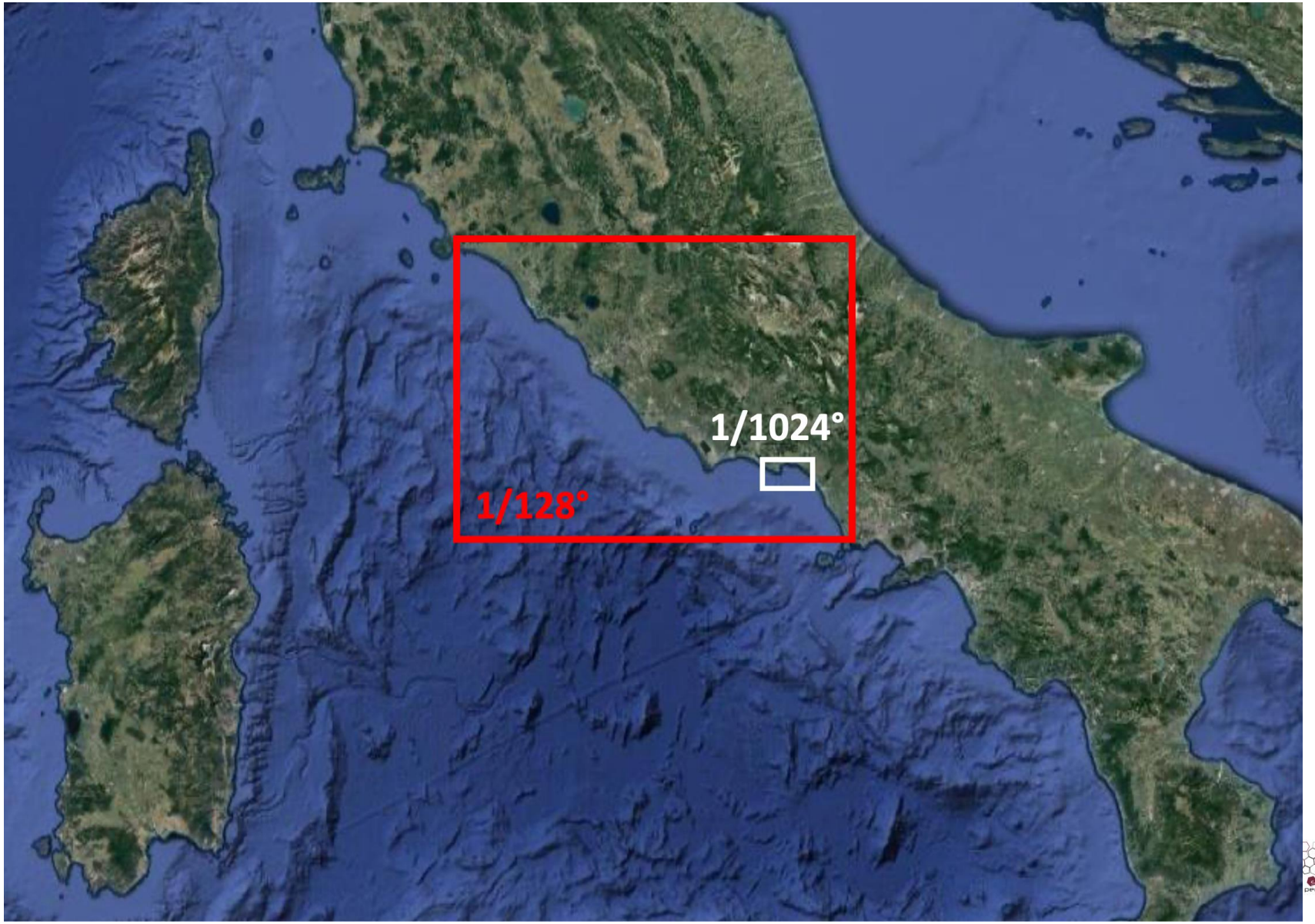
ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

MARINE ECOSYSTEM RESTORATION

Identification of allocated zones for aquaculture (AZA) – Lazio Region

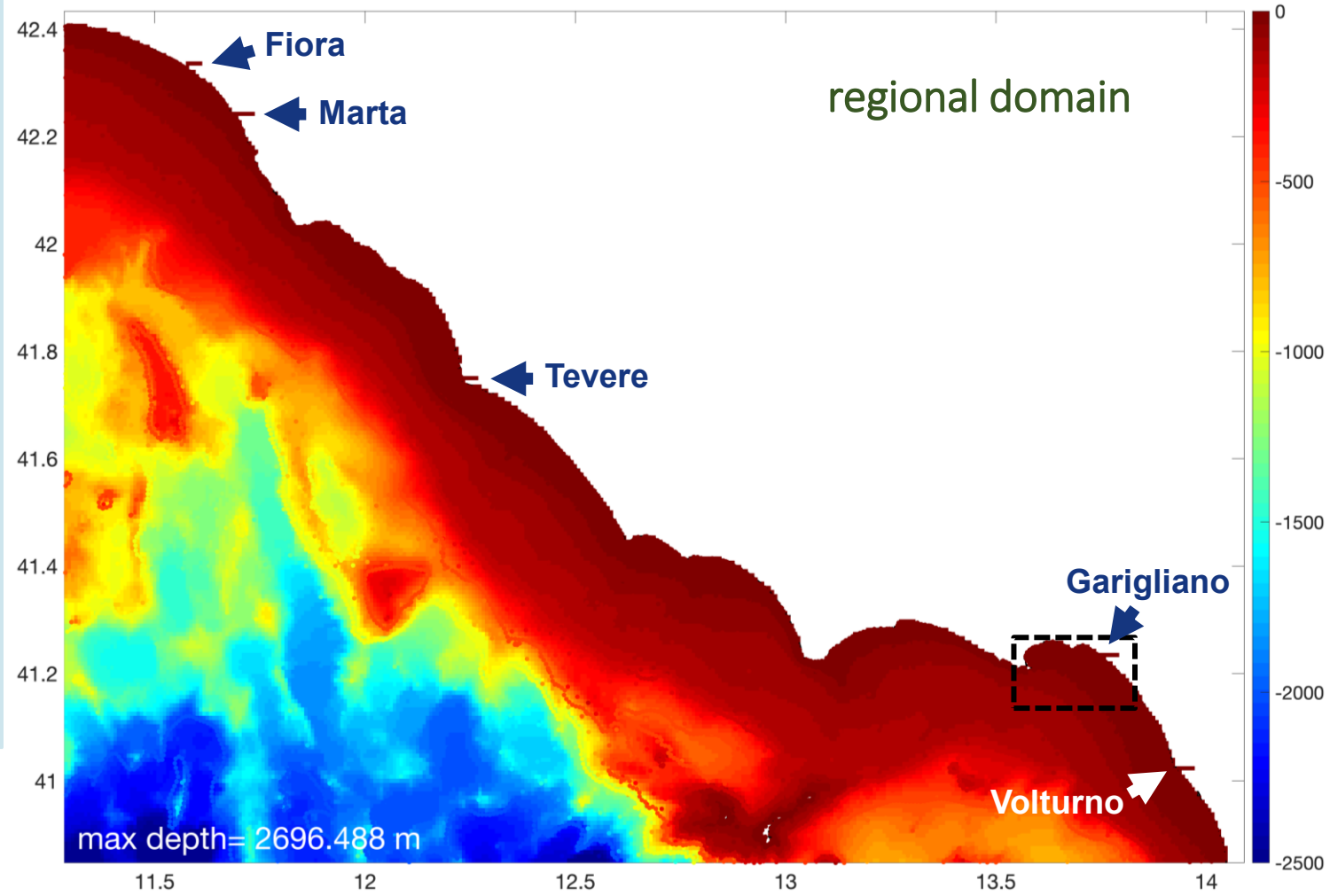
Model domains: regional and local scale



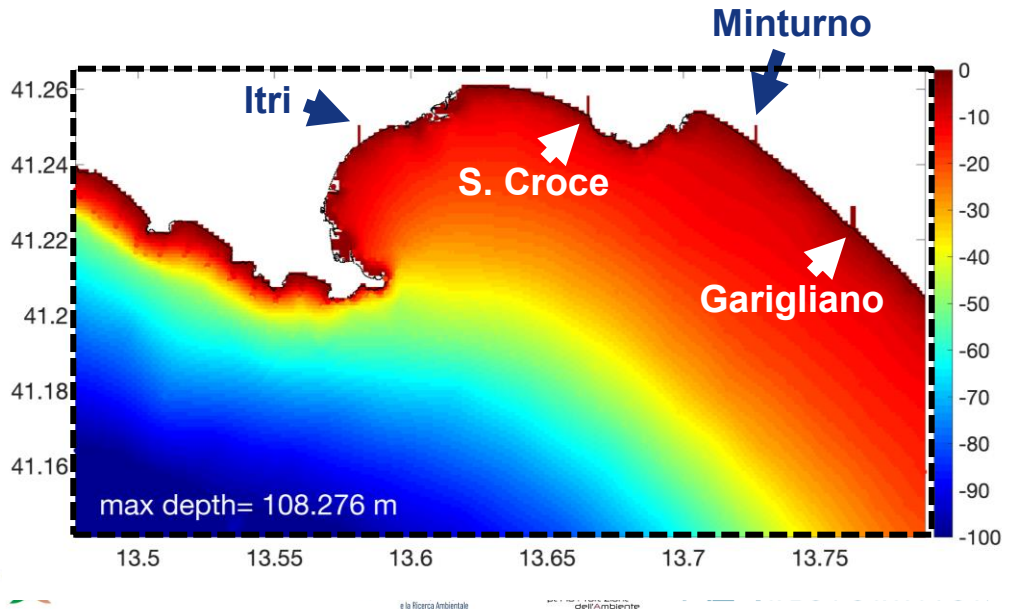
1/128° ≅ 750 m

1/1024° ≅ 95 m

Model domains: bathymetries



high resolution domain (from S. Agostino to Garigliano)



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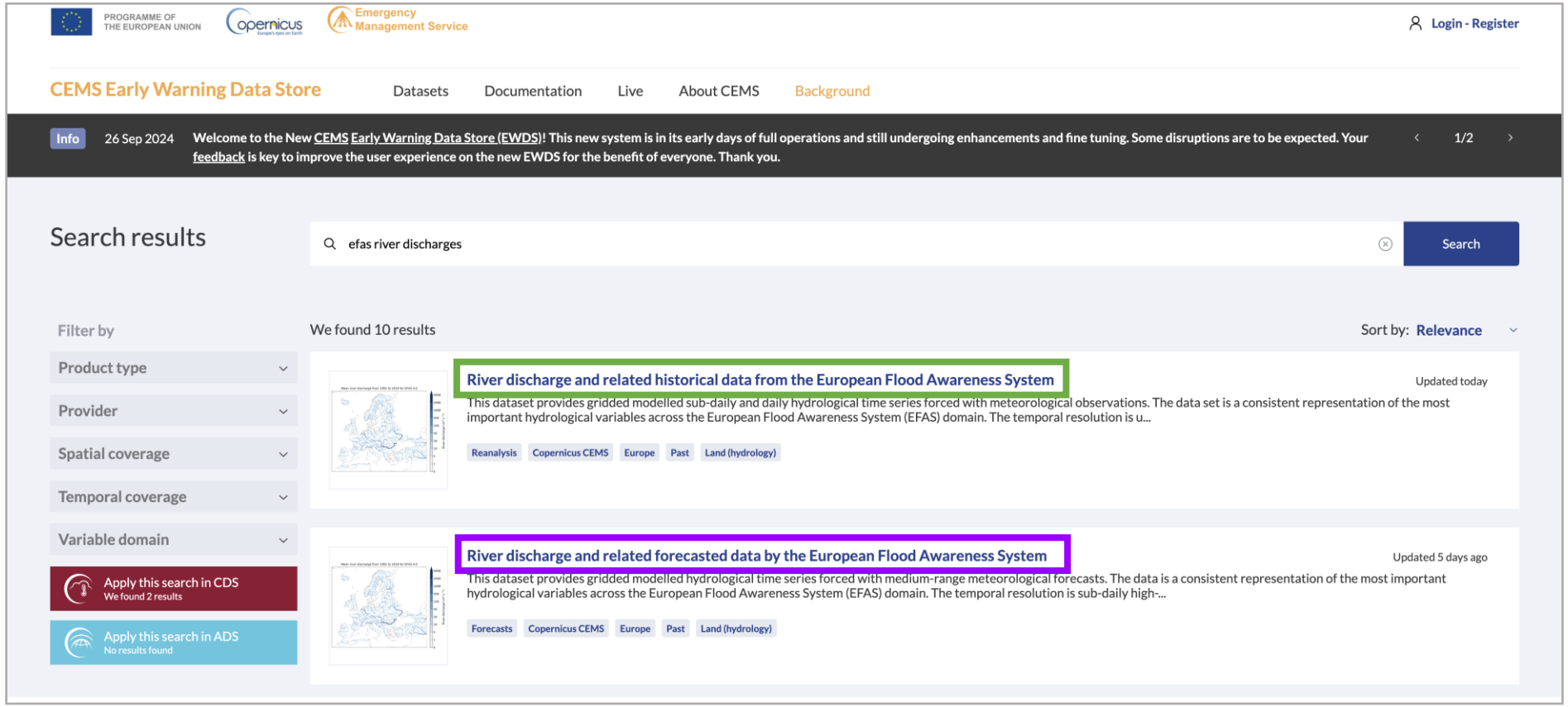
Copernicus EU EFAS river discharges



EFAS v5 products (hydrological model with 1.5 km resolution) consisting of **6-h 2D maps of river discharge**, divided in:

- **historical:** freely available, covering the **1992-present** time period;
- **forecast:** freely available, **since 2018-10-10** with 1 month delay, and **near-real-time** for **EFAS Third Party Partners** only.

OGS was appointed TPP by National Civil Protection Department and Copernicus Marine Service (one dataset on Med. scale), obtaining access to NRT data of high-resolution ECMWF and DWD forecasts (10 and 7 days) on a FTP server updated every 12h.

River modelling (1/3)

EFAS provides river discharge data within the **domain**:

longitude 25.2° W ÷ 50.2° E
latitude 22.8° N ÷ 72.2° N

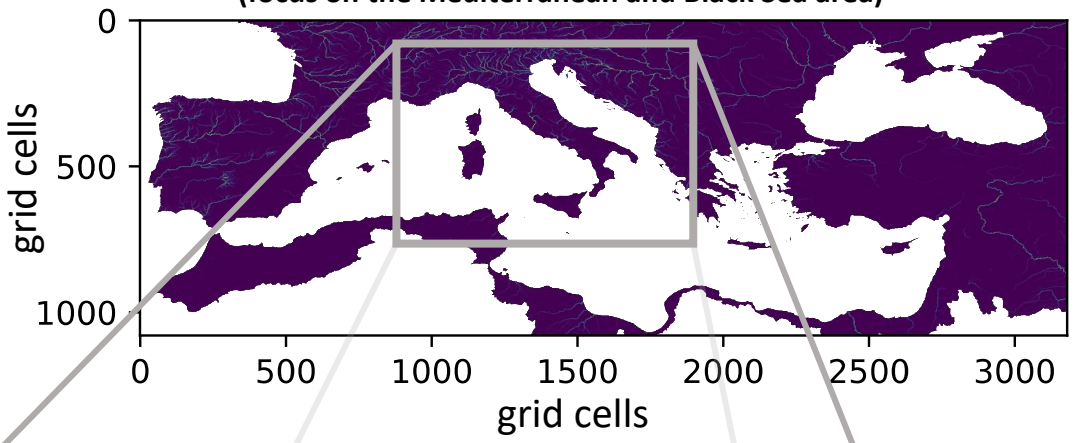
including the Mediterranean and Black Sea.

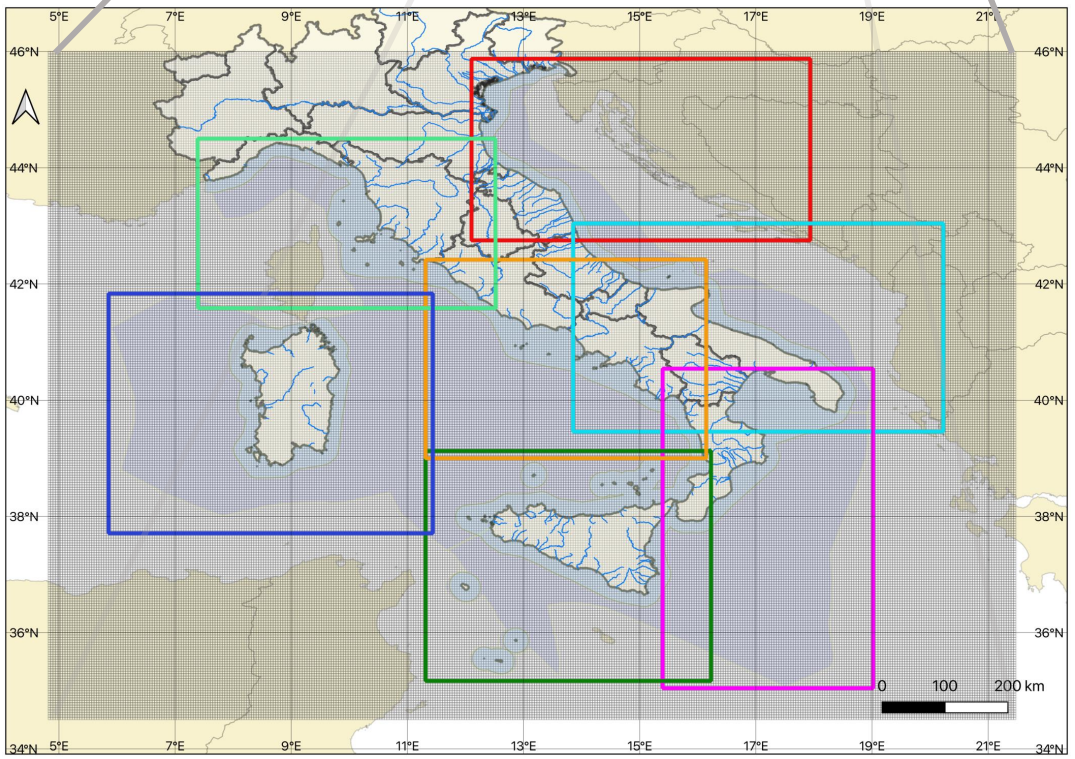
Rivers flowing into the **MER domains** were selected relying on:

- **spatial criteria** (correspondence between areas);
- a **threshold** imposed on the EFAS climatological annual **discharges**, computed in the time period 2011-2023 (to identify "**major rivers**").

EFAS DOMAIN

(focus on the Mediterranean and Black Sea area)



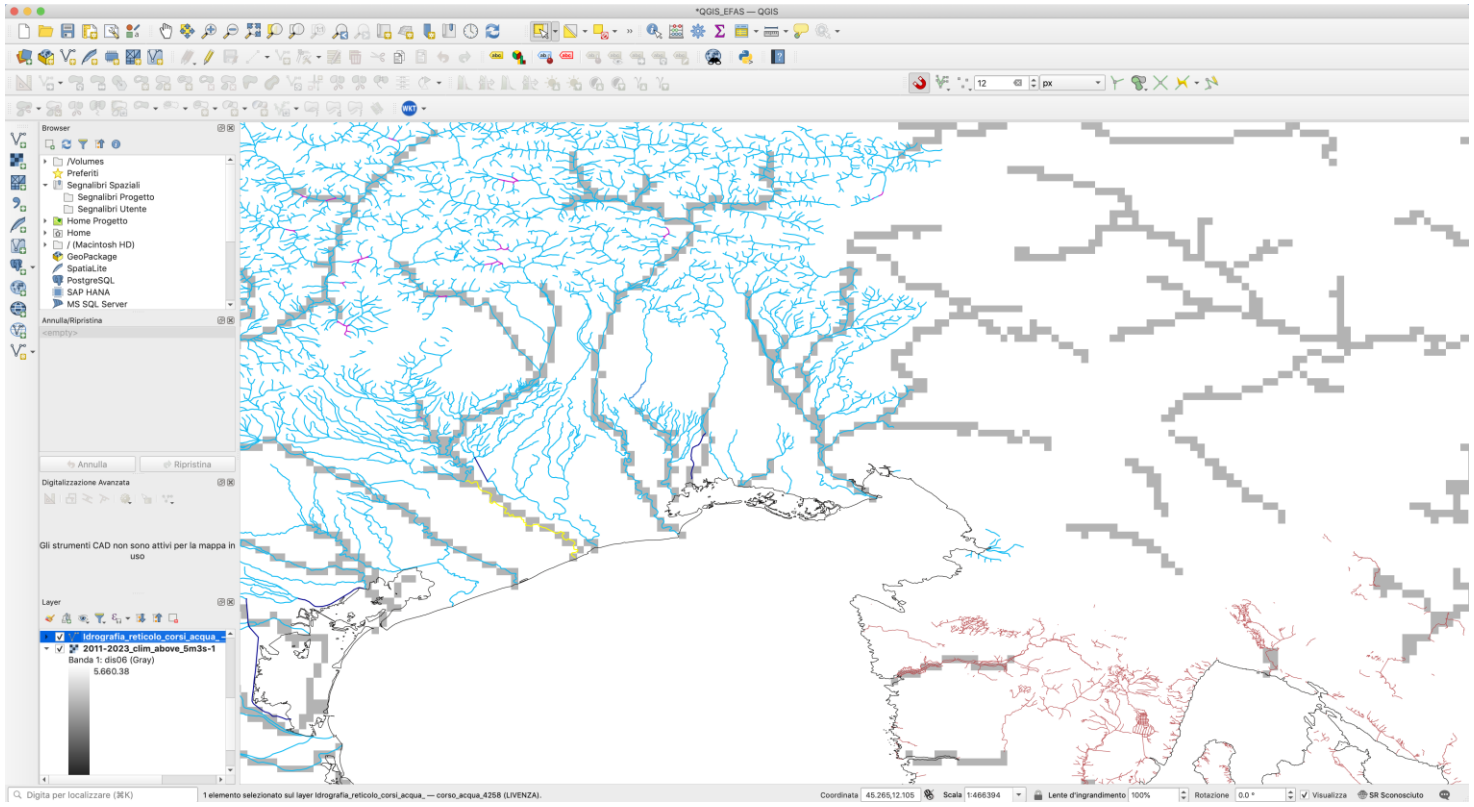


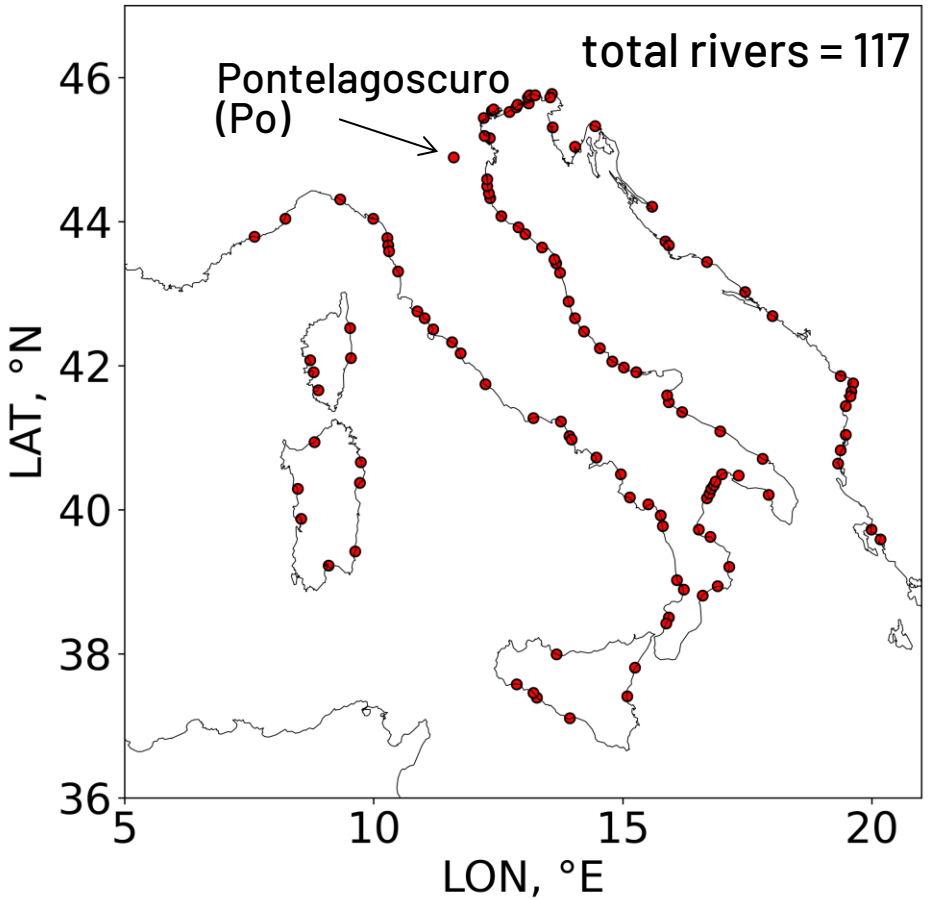
MER DOMAINS

River modelling (2/3)

1) IDENTIFICATION OF RIVERS

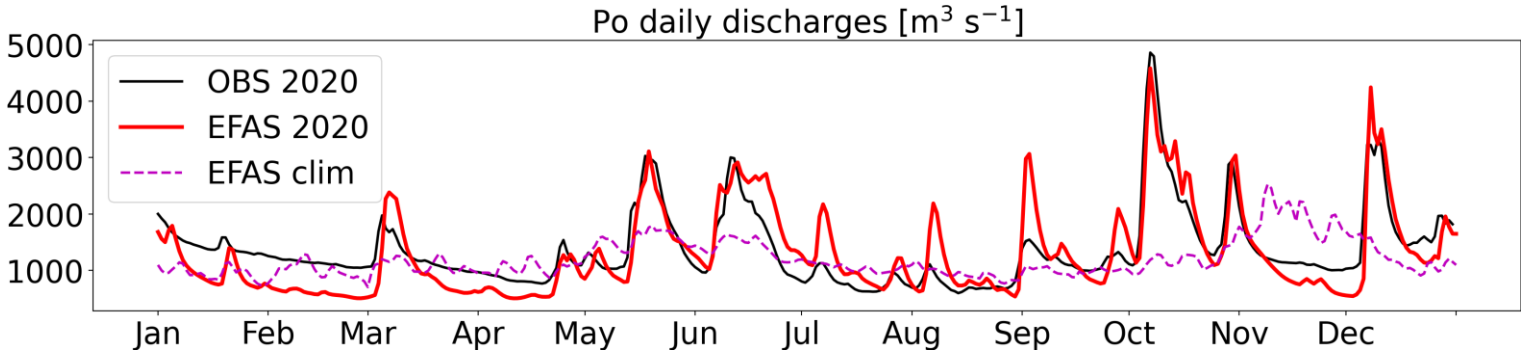
- We imposed a **threshold of 5 m^3s^{-1}** on climatological 2D EFAS maps of river discharge ➔ EFAS **river channels**;
- **QGIS overlapping** of EFAS channel network and shapefiles of **hydrographic networks** from independent datasets;
- identification of **nominal coordinates of river mouths** (to be inserted in the bathymetry) and **EFAS grid cells** (to extract flow data).





River modelling (3/3)

2) EXTRACTION OF DISCHARGES

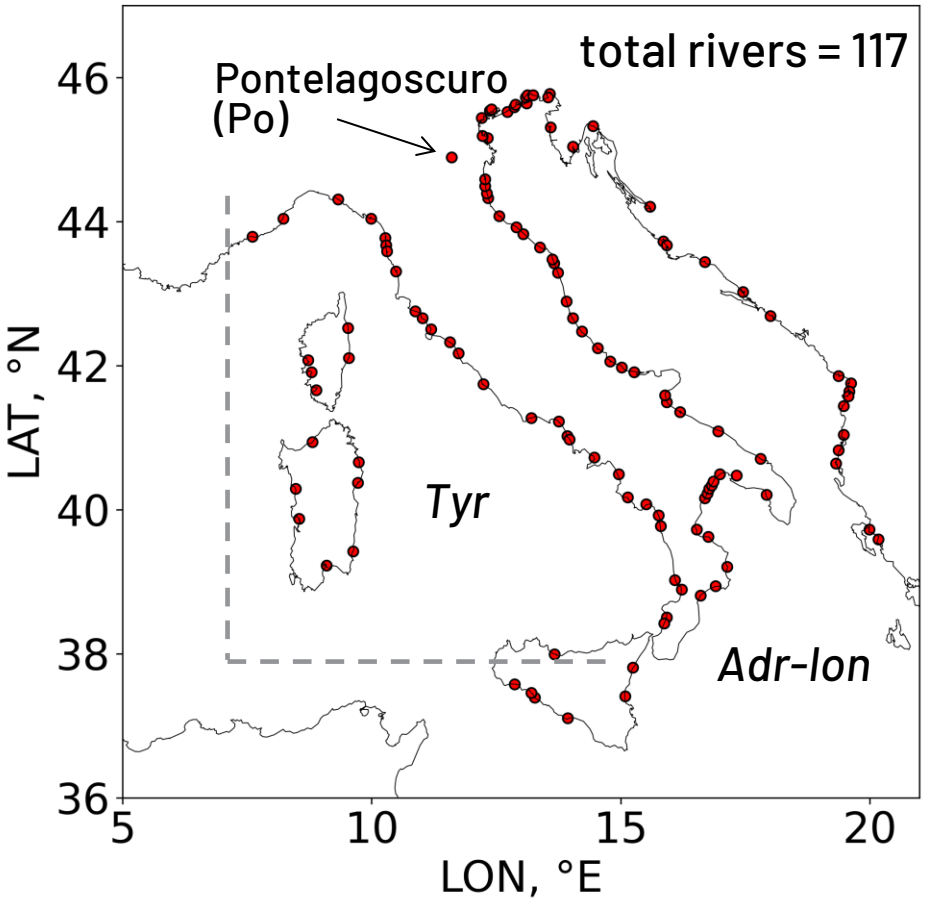


3) MODELLING OF BGC LOADS

load = daily discharge × conc. →

from up-to-date literature review

	Adr-Ion	Tyr
Nitrate [gN/m³]	1,74	2,23
Phosfate [gP/m³]	0,059	0,283
DIC [gC/m³]	36,08	52,96
POC [gC/m³]	1,52	1,68
DOC [gC/m³]	2,29	3,24
Alkalinity [mol/m³]	3,01	5,16

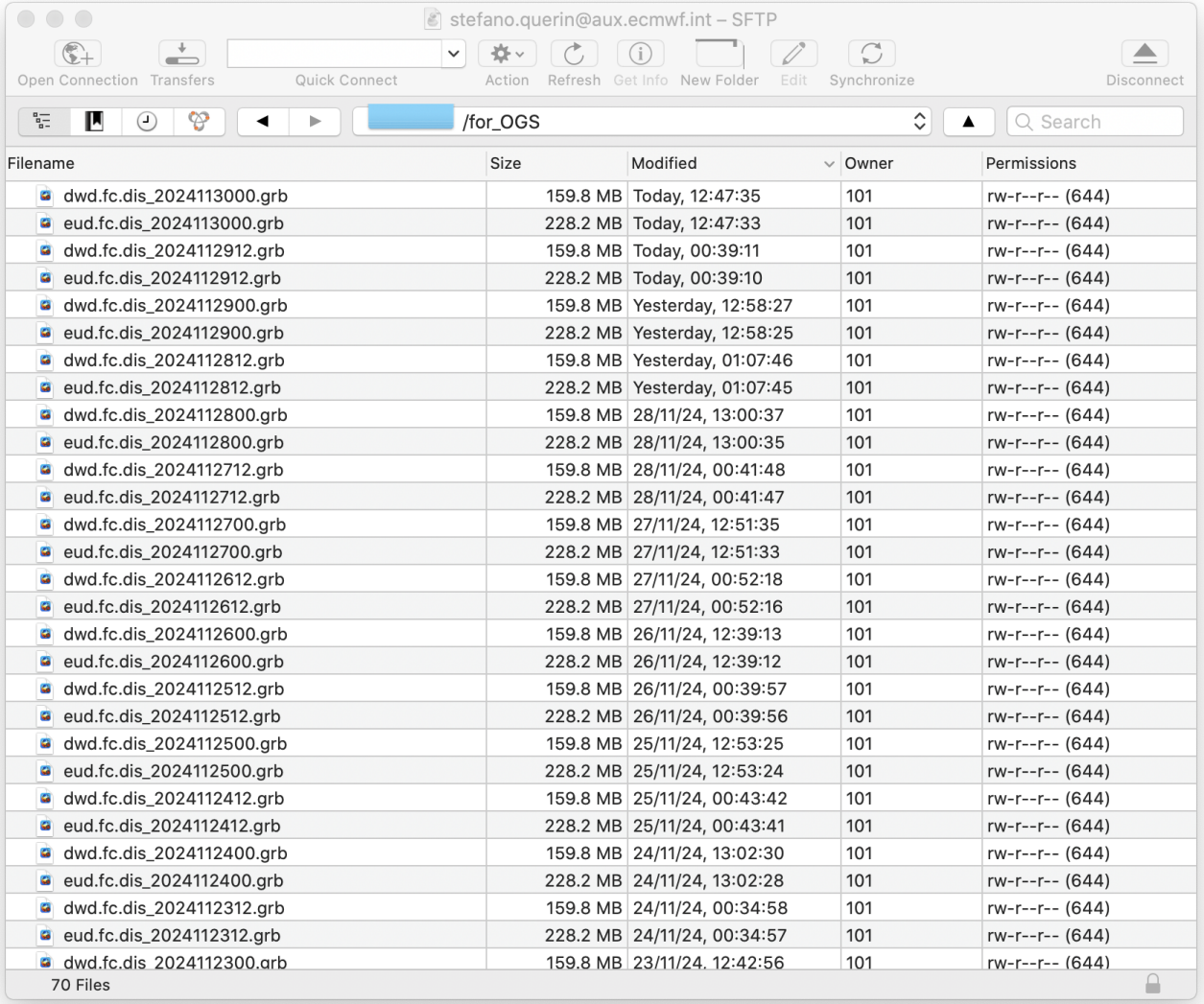


Recovery procedure of the **RT forecasts in absence of EFAS** forecast data

1) (*Base-level*) Use of daily river discharges from **EFAS daily climatology** [2011-2023];

2) (*Advanced*, if river daily observations are available) Discharges at point 1) **bias-corrected** by using daily observed discharges at measurement stations.

Example: for the **northern Adriatic** domain, we implement the recovery procedure 2) (*Advanced*) for a subset of EFAS rivers in the northern Adriatic area by using daily Po discharge rates measured at the Pontelagoscuro station.



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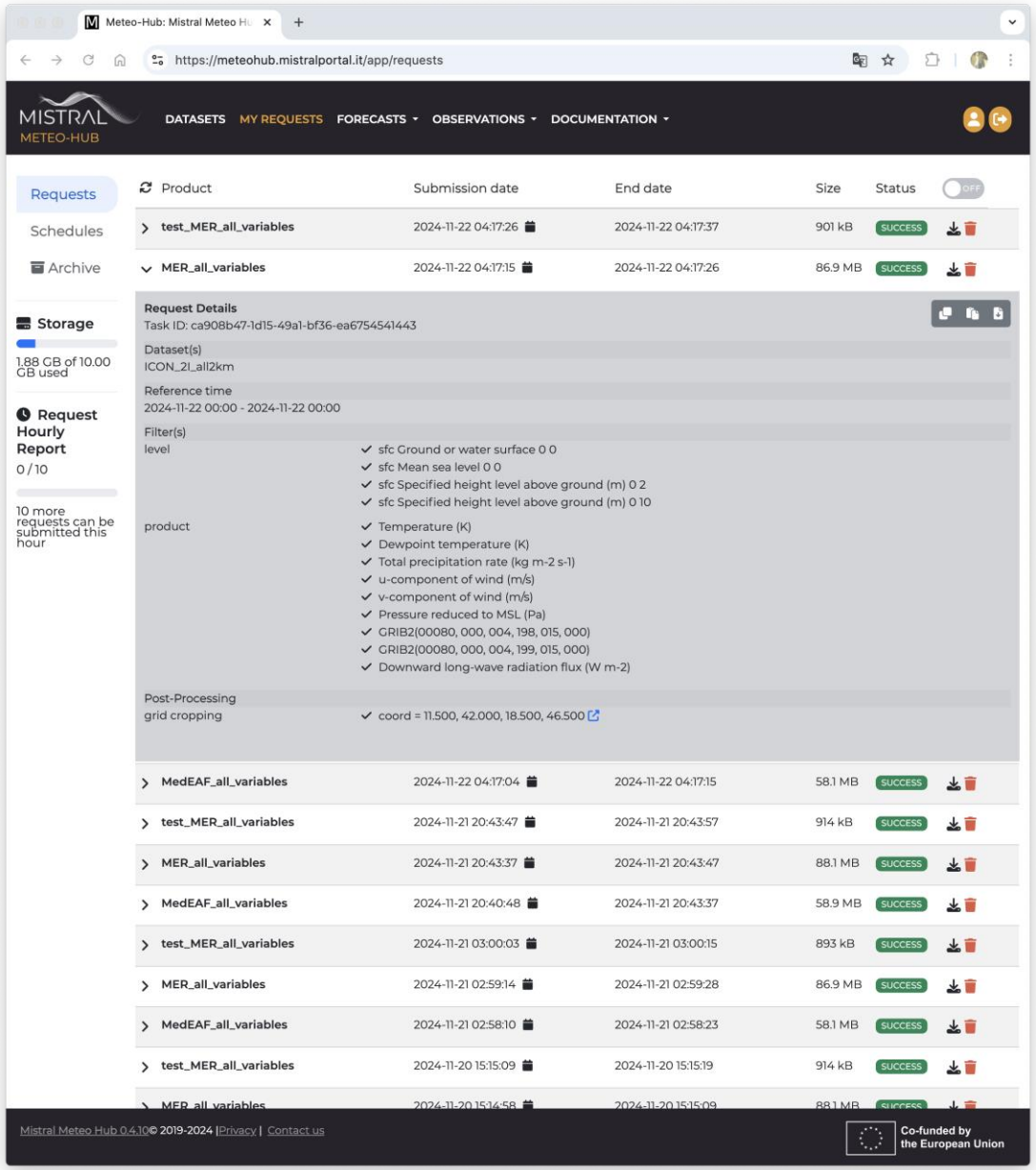
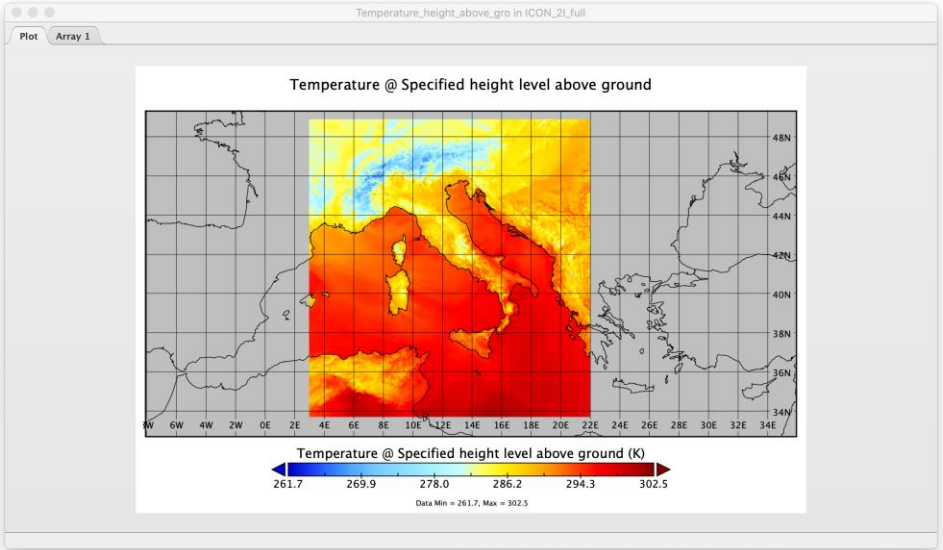
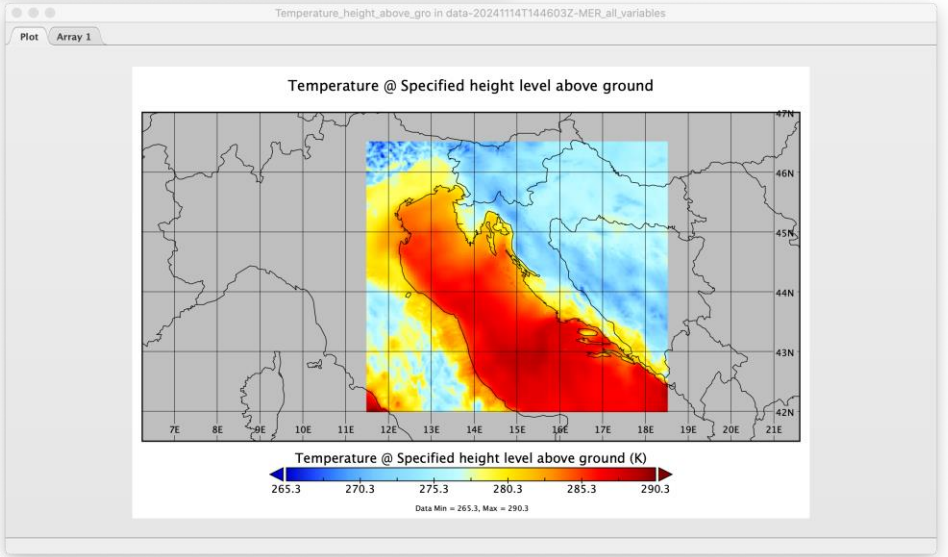
70 Files

Meteorological forecasts







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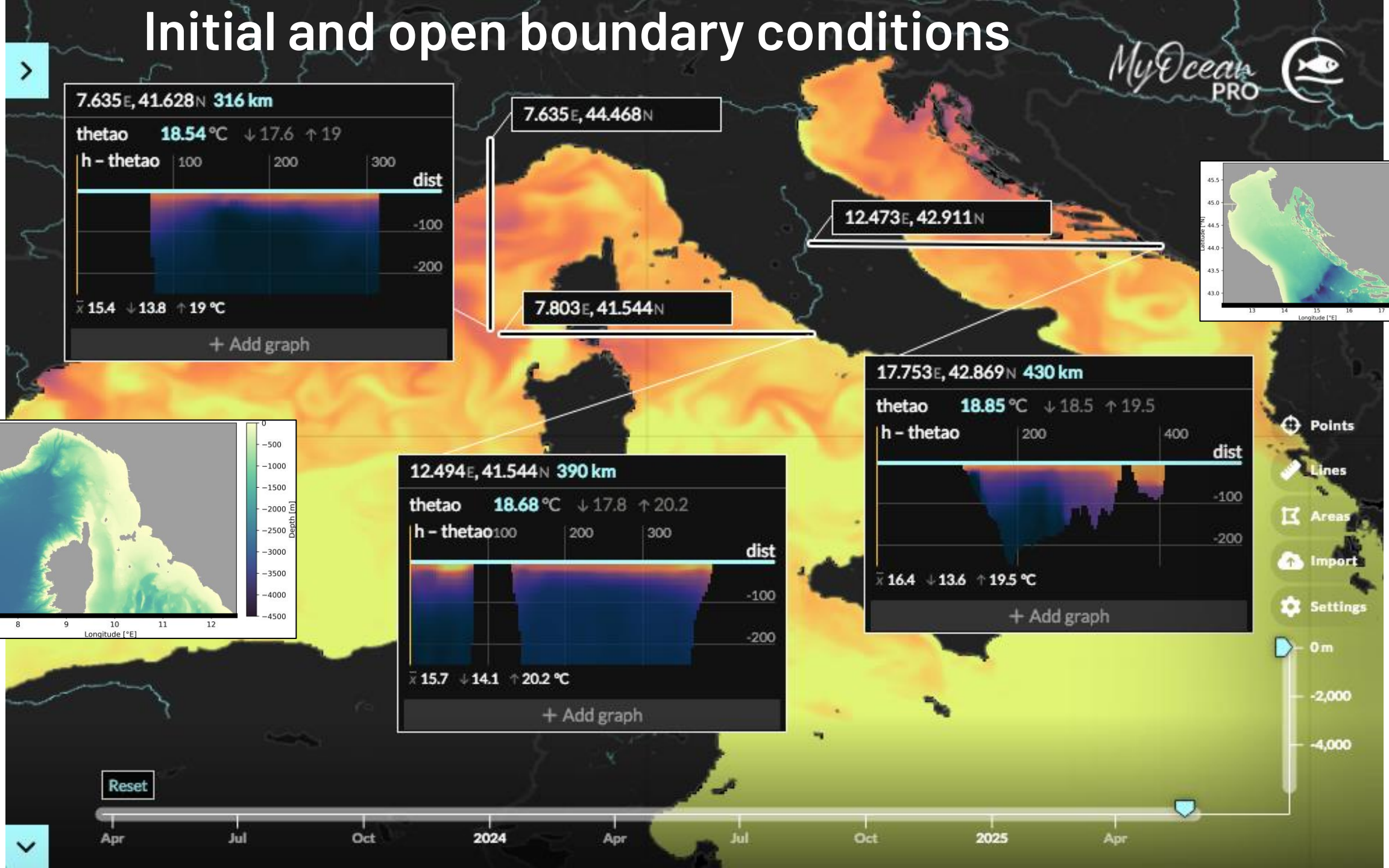
MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA
ISPRA
MARINE ECOSYSTEM RESTORATION

Initial and open boundary conditions



Other forcings

- **surface deposition** of nutrients (nitrate, phosphate)
- **bottom fluxes** of nutrients (nitrate, phosphate) and oxygen
- **sewage discharges** (from rivers and UWWTP outfalls)