Consiglio Nazionale delle Ricerche

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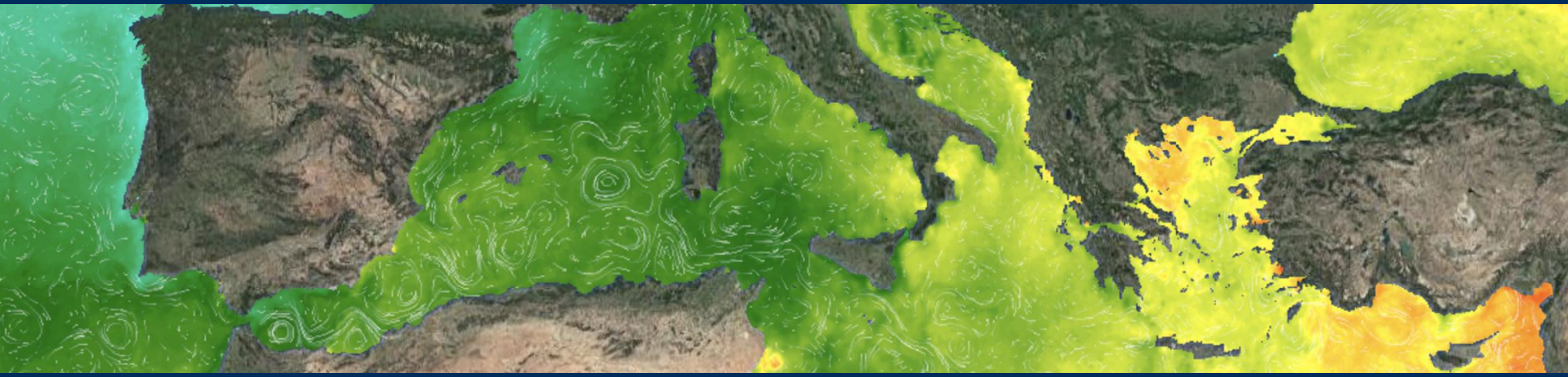
esa



4DMED-sea

4DMED-SEA project: data-driven reconstruction of Mediterranean seascape for the study of upper ocean biophysical interactions

Bruno Buongiorno Nardelli (on behalf of the 4DMED-Sea team)

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core partners

extended team

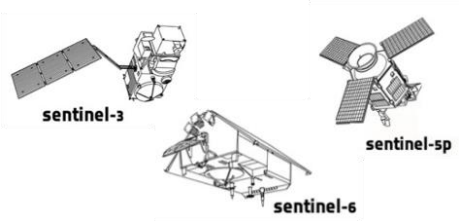
4DMED-Sea

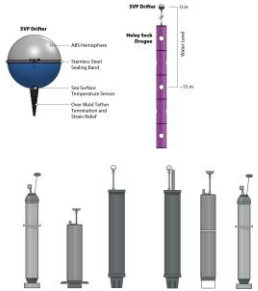
Bruno Buongiorno Nardelli[1], Claudia Cesarini[2], Vincent Rossi[3], Marina Levy[4], Nathalie Verbrugge[5], Ismael Hernandez-Carrasco[6], Astrid Bracher[7], Federico Falcini[1], Alain Arnaud[8], Simone Colella[1], Daniele Iudicone[1], Emanuele Organelli[1], Michela Sammartino[1], Rosalia Santoleri[1], Leo Berline[3], David Nerini[3], Francesco D'Ovidio[4], Roy El Hourany[4], Clement Haeck[4], Sandrine Mulet[5], Eric Greiner[5], Yannice Faugere[5], Marie Isabelle Pujol[5], Anaelle Treboutte[5], Maxime Ballarotta[5], Jeremy Augot[5], Ananda Pascual[6], Hongyan Xi[7], Marina Tonani[8], Ronan Fablet[9], Clement Ubelmann[10]

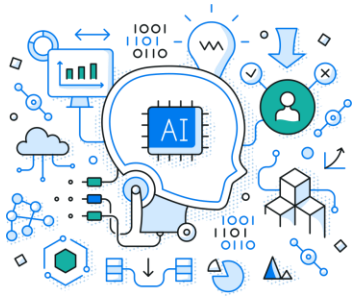
[1]Consiglio Nazionale delle Ricerche - Istituto di Scienze Marine, Italy; [2]Innuere Consulting, Italy; [3]Aix-Marseille Université, France; [4]Centre National de la Recherche Scientifique, France; [5]Collecte Localisation Satellites, France; [6]Consejo Superior de Investigaciones Científicas, Spain; [7]Alfred Wegener Institute, Germany; [8]Mercator Ocean International, France; [9]IMT Atlantique, France; [10]Datlas, France

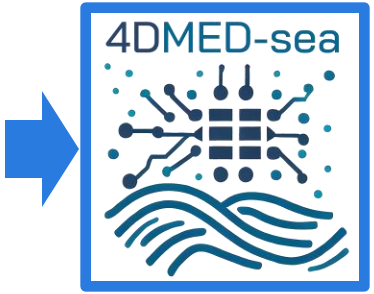
Project objectives

- to advance our understanding of the complex interactions between physical/biological/biogeochemical, **multi-scale processes** occurring in the **Mediterranean Sea**
- to exploit the European Earth Observation (EO) capacity (primarily **Sentinel** and **Earth Explorer missions**)
- to develop **advanced tools** to combine and analyse satellite and in situ data, based on Artificial Intelligence/Machine Learning (AI/ML)
- to generate and validate **consistent high-resolution 4D reconstruction(s)** of the **Mediterranean Sea** physical and biogeochemical state
- to demonstrate the **potential** of the project outcomes as **advanced monitoring solutions** for the management, restoration and preservation of the Mediterranean Sea Health









Project activities (1/3)

- the **development and generation** of **novel gap-free level 4 (L4)** **surface products** covering the Mediterranean Sea (2DMED): increased resolution surface **dynamic topography**, and **sea surface salinity** (SSS) estimates

- the **development and generation** of **novel** **4D reconstructions** of both **physical** and **physical-biological ocean state** covering the Mediterranean (4DMED). 4D Bio-phys. reconstruction includes estimations of the marine primary production with an upgraded version of the Morel (1991) model

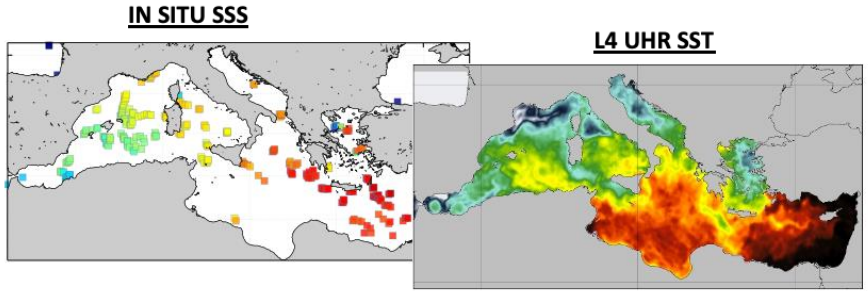
- the **development and generation** of **a novel Kd product (diffuse attenuation coefficients)** at the UV-AB, UV-A and short blue derived from **Sentinel 5P** (aligned with ESA project S5POC-PAL2)

4DMED-sea

4DMED products: Sea Surface Salinity L4

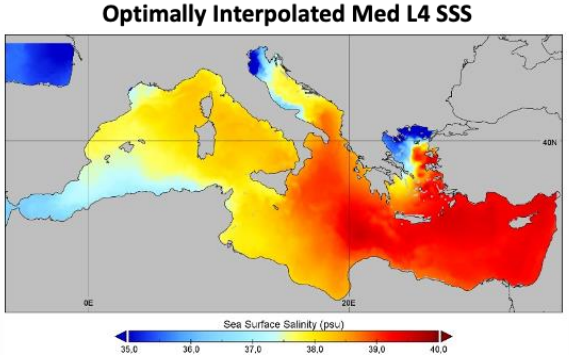
New 2D Sea Surface Salinity (SSS) product over a 6-year period [2016-2021] with a refined grid (1/24°) and improved effective resolution

→based on multivariate optimal interpolation algorithm used operationally within Copernicus Marine Service



$$C(\Delta r, \Delta t, \Delta SST) = e^{-\left(\frac{\Delta r}{L}\right)^2} e^{-\left(\frac{\Delta t}{\tau}\right)^2} e^{-\left(\frac{\Delta SST_{filtered}}{T}\right)^2}$$

→multidimensional covariance function



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Buongiorno Nardelli (2012, 2016)
Sammartino et al. (2022)

4DMED products: Sea Surface Level L4

New 2D Sea Level products over a 6-year period [2016-2021] with a refined grid (1/24°) and improved effective resolution

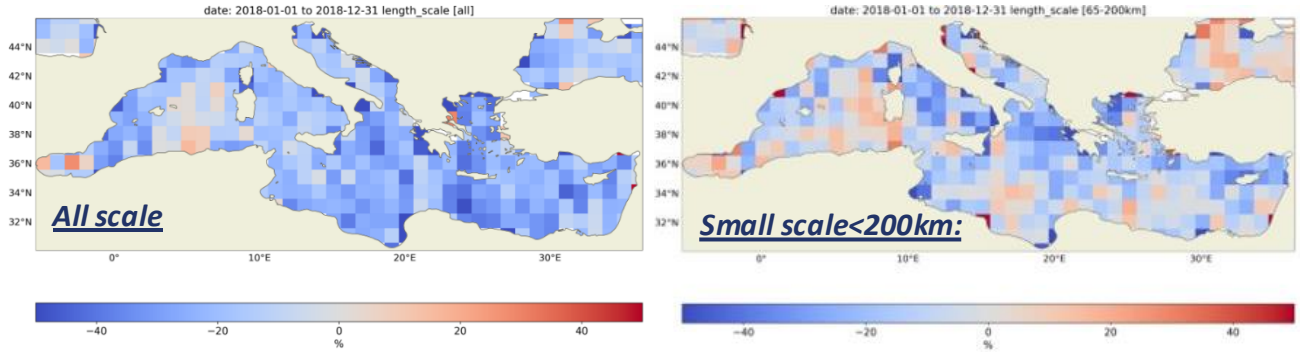
→development of novel/improved mapping algorithms considering **MIOST** and **4Dvarnet** Level-4 methods as an alternative to DUACS mapping (Optimal Interpolation)

MIOST (Multi-scale Inversion for Ocean Surface Topography)

→extends the OI mapping framework, using a wavelet decomposition to allow the construction of multiple independent components of the assumed covariance model

→refined mapping parameters for the Mediterranean Sea, *Ubelmann et al.*, 2021)

Validation based on the **SSHA comparison** between gridded reconstruction and independent **altimeter** data



Blue: MIOST better than DUACS
Red: DUACS better than MIOST

Difference in the variance of the mapping error between the MIOST and the DUACS (H2A altimeter excluded and used as reference)

4DMED products: Sea Surface Level L4

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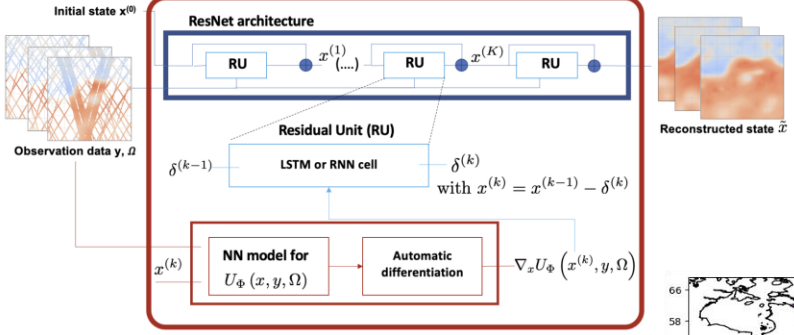
4DVarNet framework developed by IMT Atlantique

→deep learning scheme backed on a variational a trainable variational data assimilation formulation

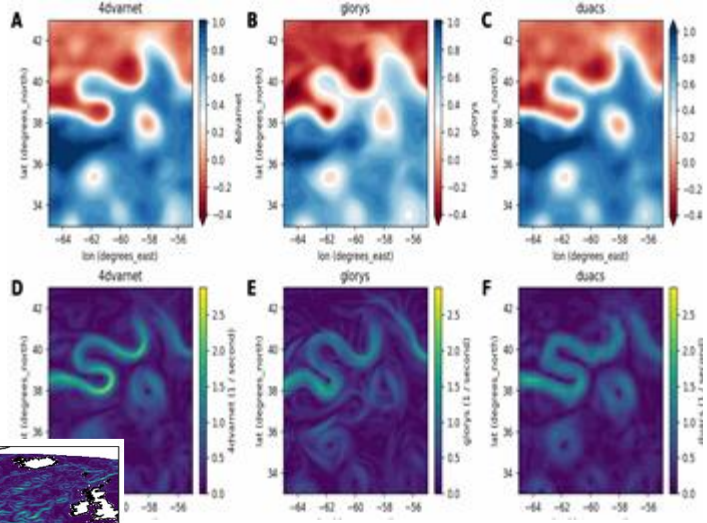
→originally developed and trained on the Gulf Stream area (eNATL60 model)

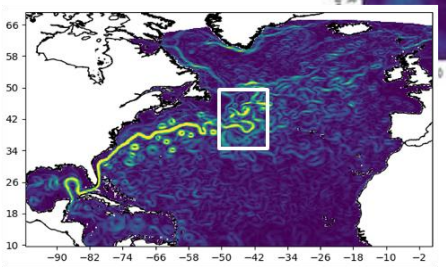


Fablet et al. Learning Variational Data Assimilation Models and Solvers. JAMES, 2021

Beauchamp, et al.: 4DVarNet-SSH: end-to-end learning of variational interpolation schemes for nadir and wide-swath satellite altimetry, Geosci. Model Dev., 2023.

4DVarNet, Glorys & DUACS SSH (and gradient) reconstructions 6 along-track real nadir datasets





4DMED-sea

IMT Atlantique

CLS
COLLECTE LOCALISATION SATELLITES

4DMED products: Sea Surface Level L4

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→several different **Observing System Simulation Experiments** (OSSE) and **Observing Systems Experiments** based on different models (**CMCC MEDSEA model**)

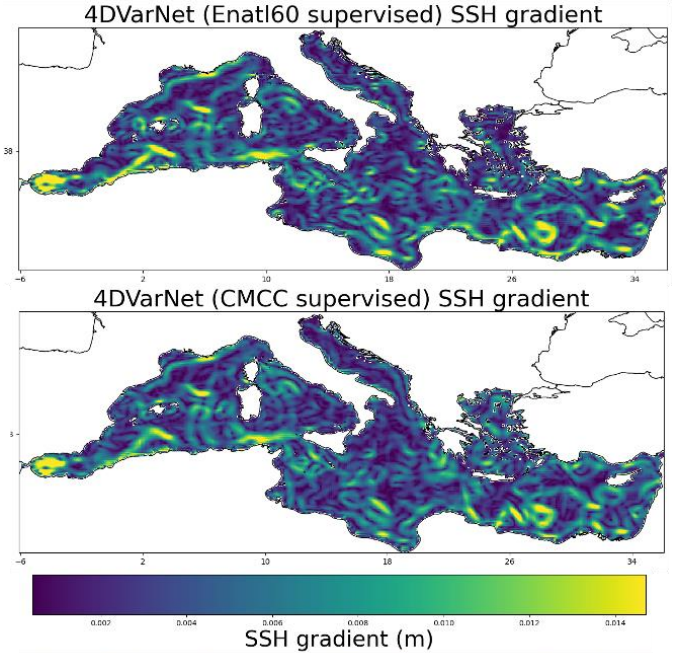

Figure : Daily snapshots of the SSH gradient reconstructions for day 2016-01-21. SSH fields are reconstructed from: 4DVarNet trained on Enatl60 (top), or MEDSEA CMCC model (bottom).

4DMED-sea

4DMED products: Sea Surface Level L4

New 2D Sea Level products over a 6-year period [2016-2021] with a refined grid (1/24°) and improved effective resolution
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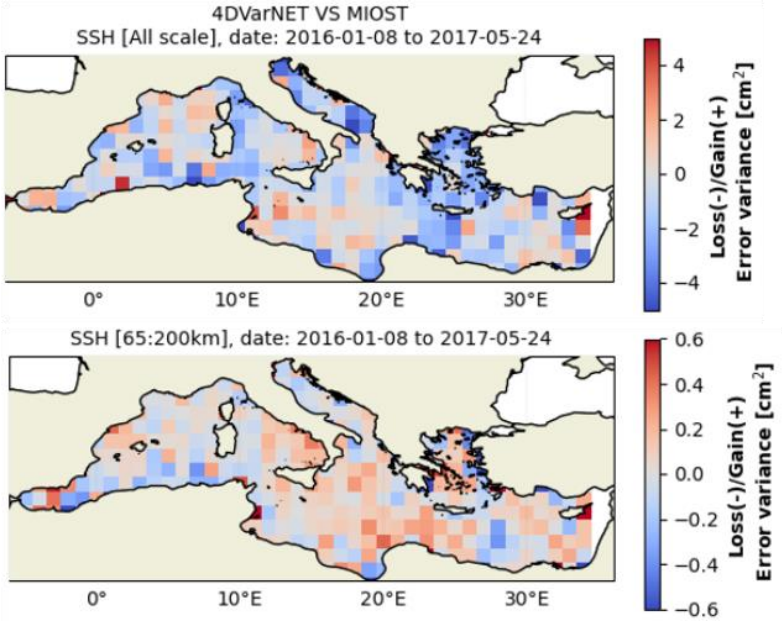
Scale	Method	$RMSE - cm$	$\sigma(RMSE) - cm$
All Scale	4DvarNET	4.402	1.254
	MIOST	4.464	1.275
65 - 200 km	4DvarNET	1.091	0.241
	MIOST	1.075	0.239



Blue: 4DVarNet better than MIOST
Red: MIOST better than 4DVARNET

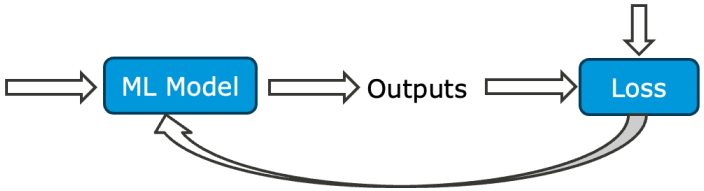
4DMED products: Experimental 4D physical variables

Novel **4D reconstructions** of **physical ocean state** covering the Mediterranean (4DMED) through the synergic combination of HR L4 surface data, vertical profiles from in situ data and numerical model output

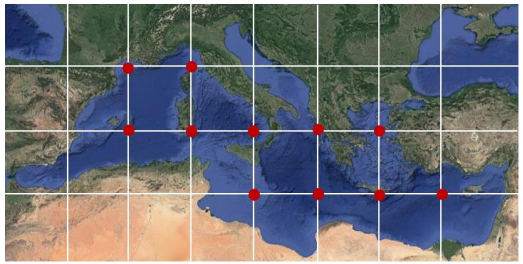
Learning on model numerical data using Mediterranean CMCC (1/24°) reanalysis (MEDSEA)

Targets
MEDSEA T(z), S(z) [0-150m]

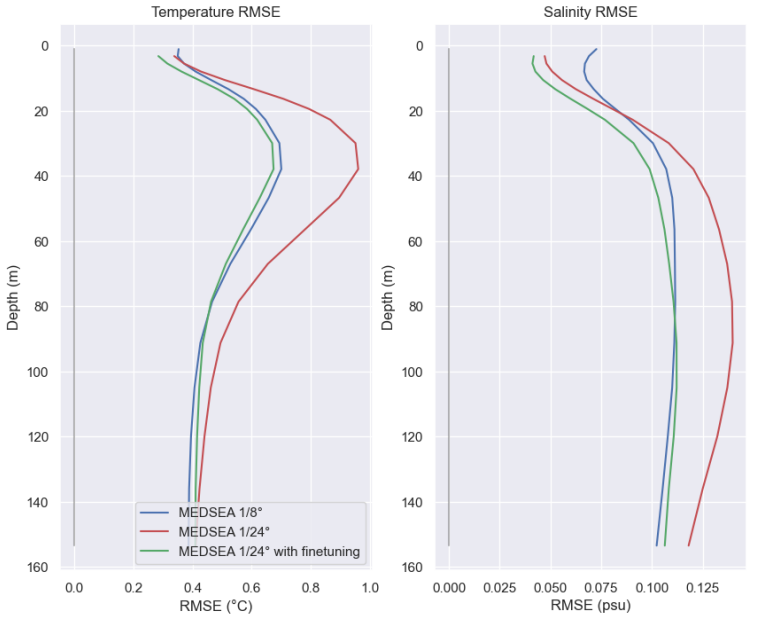
Inputs
MEDSEA SST, SSS, HDYN



Local approach - 1 model every 1/4°
Models:
FFNN with 1 hidden layer (100 neurons)



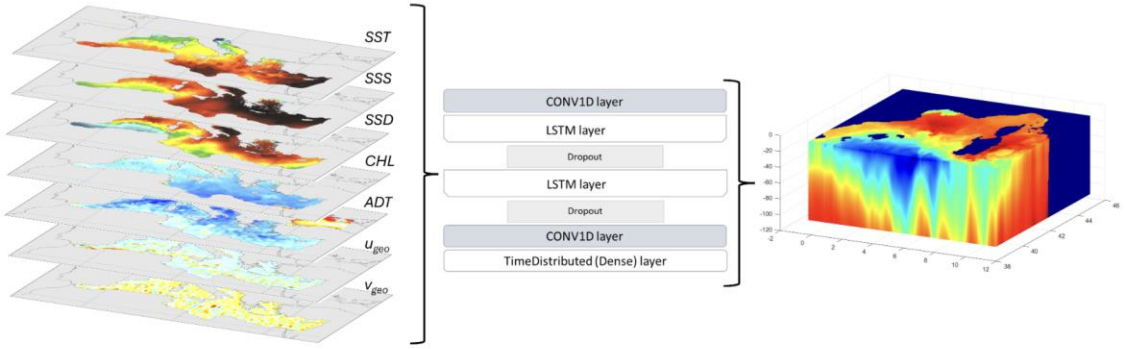
Global approach - 1 model for the whole ROI
Model:
U-Net like architecture (3.1M parameters), trained at 1/8° resolution



4DMED products: Experimental 4D combined physical-biological variables

Novel **4D reconstructions** of **physical-biological ocean state** covering the Mediterranean (4DMED) through the synergic combination of HR L4 surface data and vertical profiles from in situ data

→key **physical** and **biological** variables (T, S, U_g, V_g, Chl-a, PP)



[Lat, Lon, doy + Surface satellite and multi-obs data] → *Physically-informed Neural Network model* → *3D Reconstruction of bio-physical fields*

Physically-informed DNN

1. $$Loss_{depth} = w_{profile} \frac{1}{N} \sum_{n=1}^{N} (y_{true\_profile} - y_{predicted\_profile})^2$$

2. $$Loss_{dens} = \frac{1}{N} \sum_{n=1}^{N} (\sigma_{true} - \sigma_{predicted})^2$$
   - enforcing consitency between density estimated from predicted T/S (through the **equation of state**) and true density profiles

3. $$Loss_{phy} = \frac{1}{N} \sum_{n=1}^{N} RELU\left(\frac{\Delta\sigma}{\Delta z}\right)$$
   - constraining the profile to be statically stable by penalizing the predictions that contain **density inversions**

$$Loss_{TOT} = Loss_{depth} + Loss_{dens} + Loss_{phy}$$

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4DMED products: Experimental 4D combined physical-biological variables

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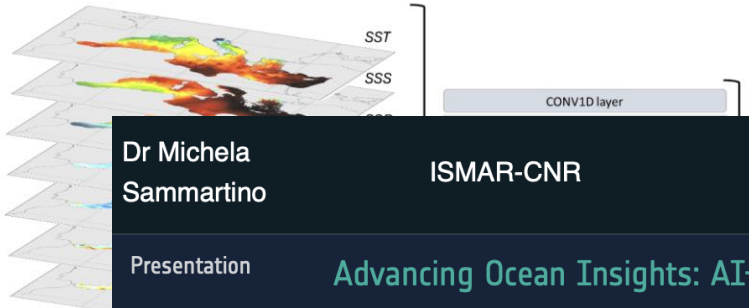
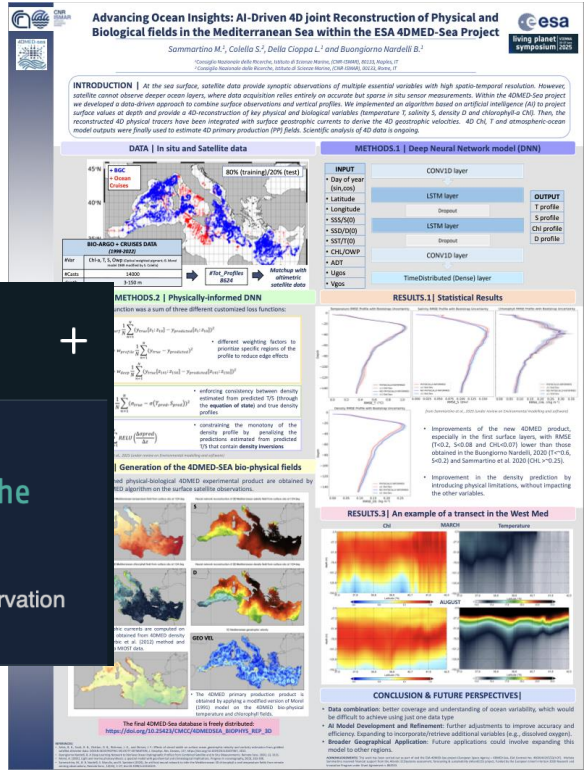


Dr Michela Sammartino
ISMAR-CNR

Presentation

Advancing Ocean Insights: AI-Driven 4D Joint Reconstruction of Physical and Biological Fields in the Mediterranean Sea Within the ESA 4DMED-Sea Project **Presenter**

Date: June 25 | Session: D.02.04 - POSTER - Machine Learning for Earth System Observation and Prediction



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- the **development and application** of **advanced Lagrangian analysis and validation tools** including:

  -**Lagrangian models** incorporating inertial effects to compute trajectories of particles and tracers with different size, density, and behaviour (neural network approach, Hernandez-Carrasco and Orfila, 2018; kinematic approach, Lacorata et al., 2008; Falcini et al., 2015);

  -a suite of **Lagrangian metrics**

- an **intensive validation of experimental 2D/4DMED products** on the **western Mediterranean Sea** using physical and biological in situ observations collected from different experiments

4DMED tools: Lagrangian analysis

Lagrangian analysis tools:

- Rotationally Coherent Lagrangian Vortices based on *Haller et al*. (2016) and *Tarshish et al*. (2018)
- Lagrangian kinematic variables: Finite-Size Lyapunov Exponents, Finite-Time Lagrangian EKE

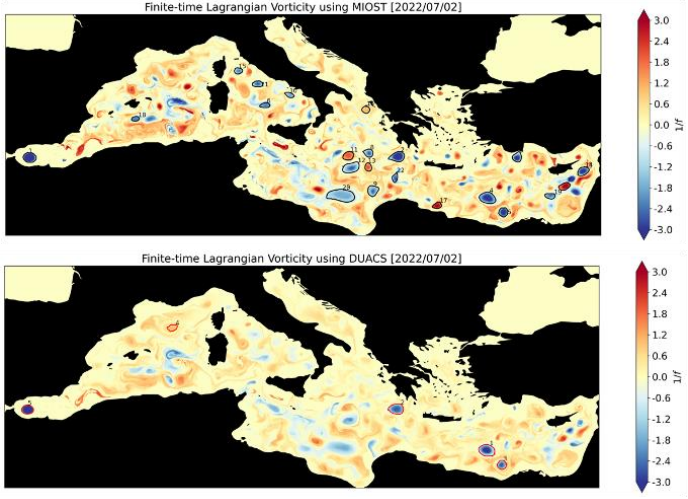
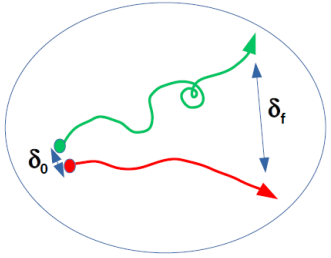


Figure. *(coloured contours) FTLV (40 days) maps for δ_0 = 1/24° obtained using velocity fields derived from MIOST (top) and DUACS (bottom) on July 22nd, 2022. (contours) Identified RCLV for MIOST (top) and DUACS (bottom).*

Applying the same parameters **MIOST** identifies more **RCLV** than **DUACS**



$$\lambda(x, t_0, \delta_0, \delta_f) = \frac{1}{|\tau|} \ln \frac{\delta_0}{\delta_f}$$

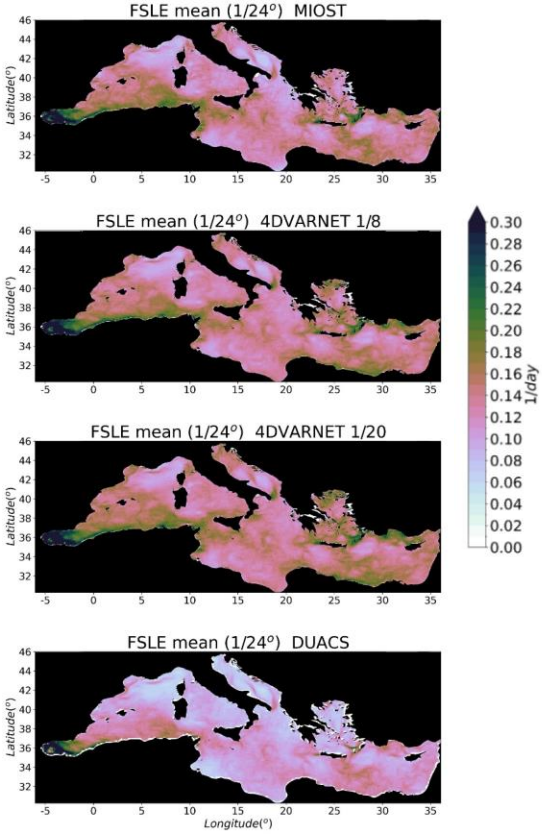


Figure. Mean FSLE maps for δ_0 = 1/24 obtained using velocity fields derived from the MIOST, 4DVARNET1/8, 4DVARNET1/20 and DUACS altimeter product.

MIOST and **4DVARNET** velocity fields are more energetic than **DUACS**

project activities (3/3)

- **three scientific case studies** aimed to:

1) improve our understanding of the **impact of mesoscale-to-submesoscale fronts on phytoplankton** organisms

2) describe **Mediterranean seascape** and related variability in terms of **hydrodynamic provinces and biogeochemical/ecological regions**

3) investigate **role of Lagrangian transport on the recruitment** of selected Mediterranean fish species

- **one test case** dedicated to:

assess how 4DMED products and scientific results would fit into a **Digital Twin of the Ocean**, specifically targeting marine spatial planning/MPAs and fisheries management.

- **one additional activity** dedicated to investigate **Lagrangian particles grounding issues**

4DMED-sea

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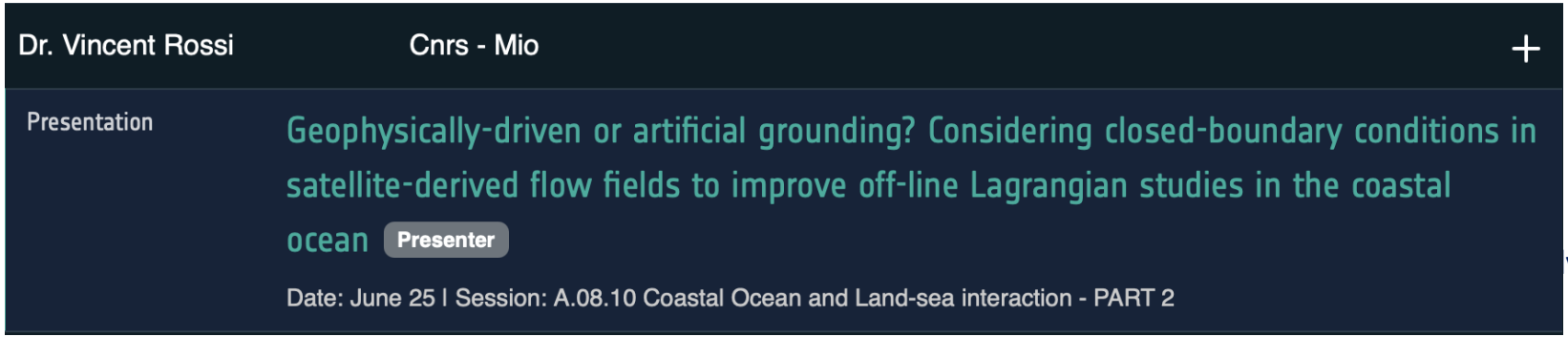
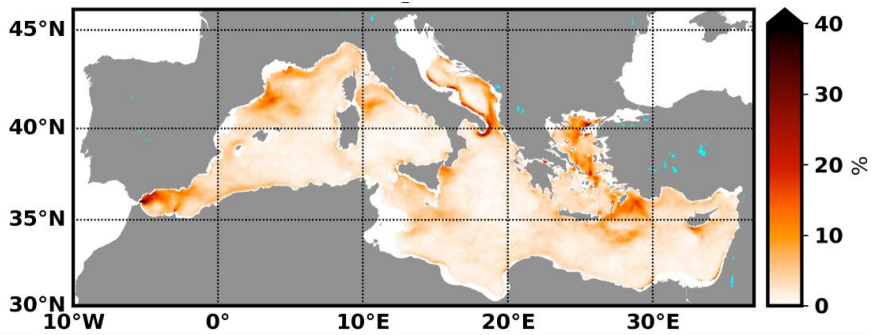


- **one additional activity** dedicated to investigate **Lagrangian particles grounding issues**

4DMED-sea

Are fronts oasis of life in the Mediterranean Sea ?

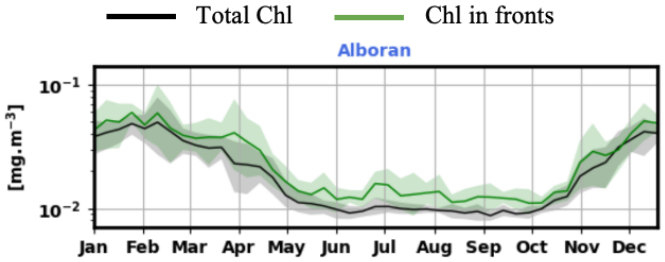
- Detection of fronts with the **Heterogeneity Index** algorithm (*Haëck et al.*, 2023)*
- Seasonal variations of frontal activity in bioregions of the Mediterranean Sea
- Quantify impact of these fronts on phytoplankton distribution and diversity



Occurence of thermal over 2016-2021 in %

	Winter	Spring	Summer	Autumn
Alboran	14.3±21.8	29.2±25.3	31.9±26.9	20.1±24.1
Gulf of Lion	13.9±18.6	-2.3±13.6	10.6±10.0	19.3±10.4
Alg-Tyr	11.3±11.7	8.3±7.3	8.3±4.5	10.7±6.1
Ion-Lev	7.7±6.1	3.5±4.2	9.7±5.1	6.7±4.5

Surplus (%) of Chl over fronts in different regions of the Med Sea



Chl median over fronts in the Alboran region

*Haëck, C., et al., Biogeosciences, 2023

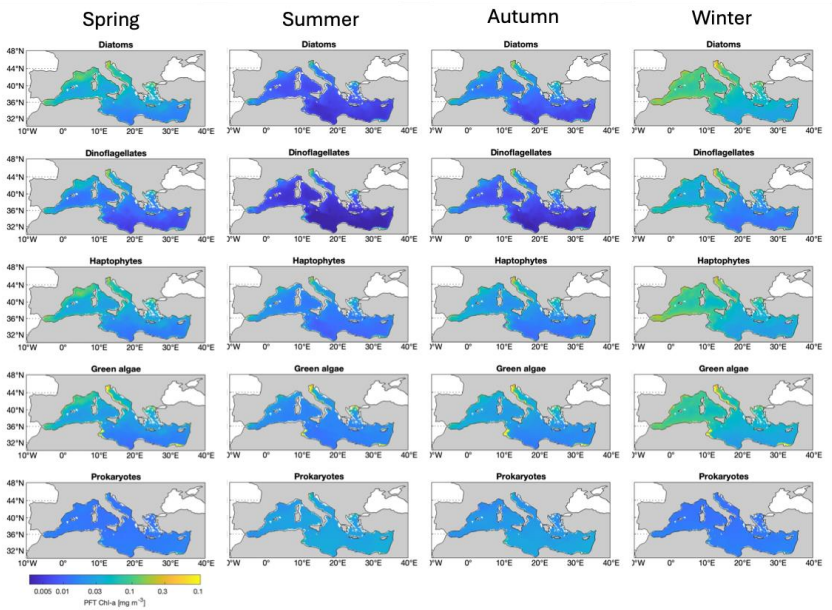
Scientific studies: **Mediterranean seascape, hydrodynamic provinces & ecoregions identification**

Partitioning the Mediterranean Sea in **ecoregions based on phytoplankton phenology and production**

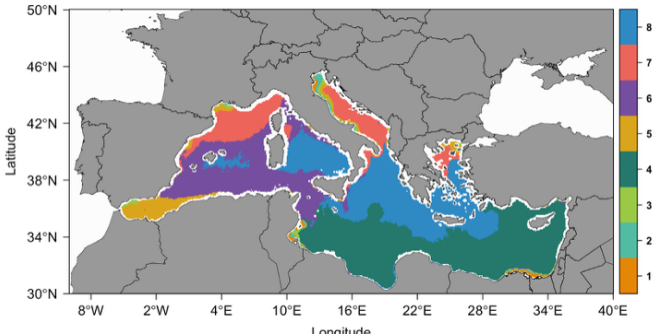
→exploiting information on the composition of phytoplankton and organic carbon dynamics

Biomass of five phytoplankton groups derived from Sentinel 3 OLCI data

Xi et al. 2021



Ecoregion clustering of the Med Sea using self-organising mapping (SOM) based on Kd, Diatoms, Prokaryotes and PP (2019-2021)



The Mediterranean seascape is complex and underlines regions characterized by different interplay between phytoplankton groups and dissolved organic matter. Cluster 1 is only present in front of Po and Nile rivers. While the most productive regions are described by Cluster 7, Clusters 4, 6, 8 are widespread across the basin within well-known oligotrophic regions.

Contact: hongyan.xi@awi.de; emanuele.organelle@artov.ismar.cnr.it

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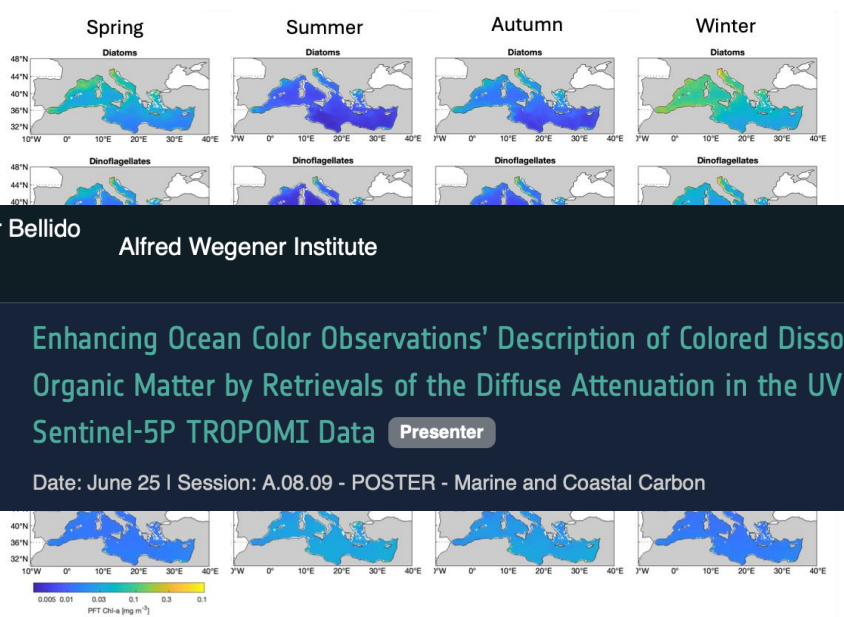

Alfredo Joswar Bellido Rosas — Alfred Wegener Institute

Presentation

Enhancing Ocean Color Observations' Description of Colored Dissolved Organic Matter by Retrievals of the Diffuse Attenuation in the UV from Sentinel-5P TROPOMI Data — Presenter

Date: June 25 I Session: A.08.09 - POSTER - Marine and Coastal Carbon

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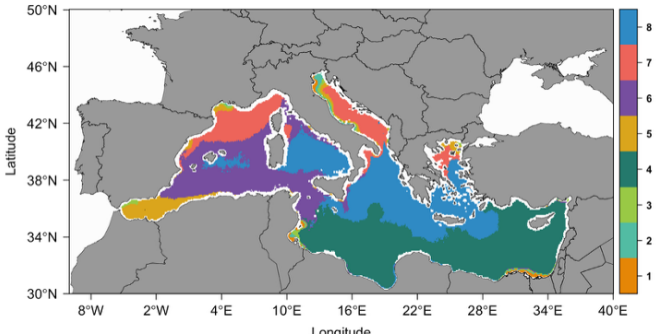

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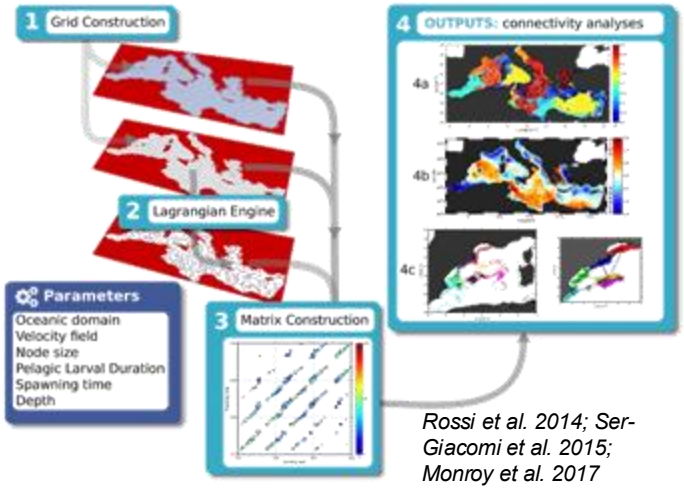
4DMED-sea

PHYTOPTICS Helmholtz Young Investigators Group

AWI

Partitioning the Mediterranean Sea in **ecoregions based on Lagrangian connectivity**



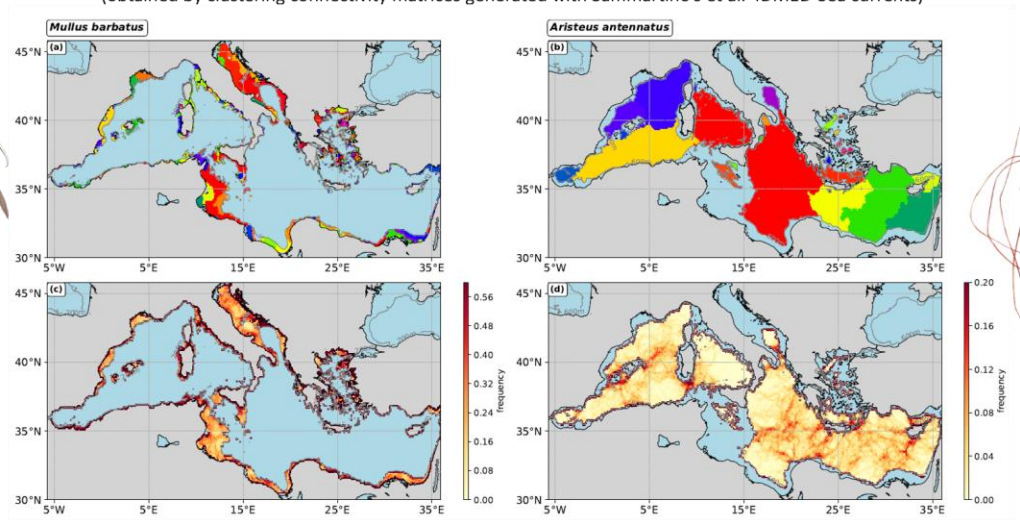
Rossi et al. 2014; Ser-Giacomi et al. 2015; Monroy et al. 2017

→ Community detection with **Infomap**: finds the sets of nodes strongly connected among them and weakly connected with the rest

→ **Hydrodynamical provinces** in which larvae are more likely to disperse within each other than among them for a given time-scale

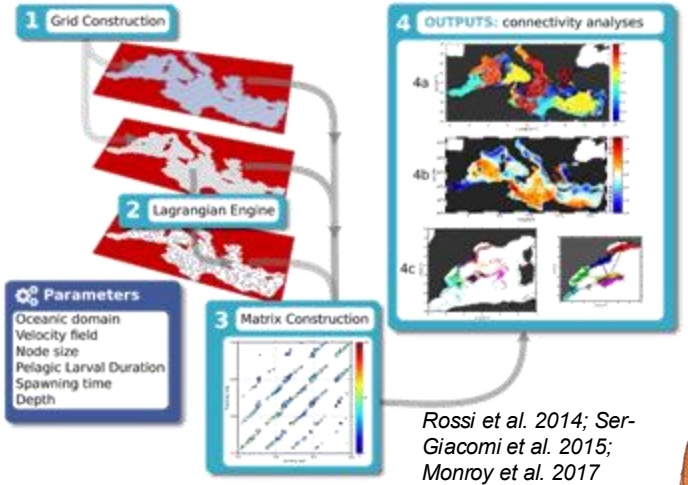
Hydrodynamical provinces inform on early-life dispersal patterns

(obtained by clustering connectivity matrices generated with Sammartino's et al. 4DMED-Sea currents)



Scientific studies: **Mediterranean seascape, hydrodynamic provinces & ecoregions identification**

Partitioning the Mediterranean Sea in **ecoregions based on Lagrangian connectivity**



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→ Community detection with **Infomap**: finds the sets of nodes strongly connected among them and weakly connected with the rest

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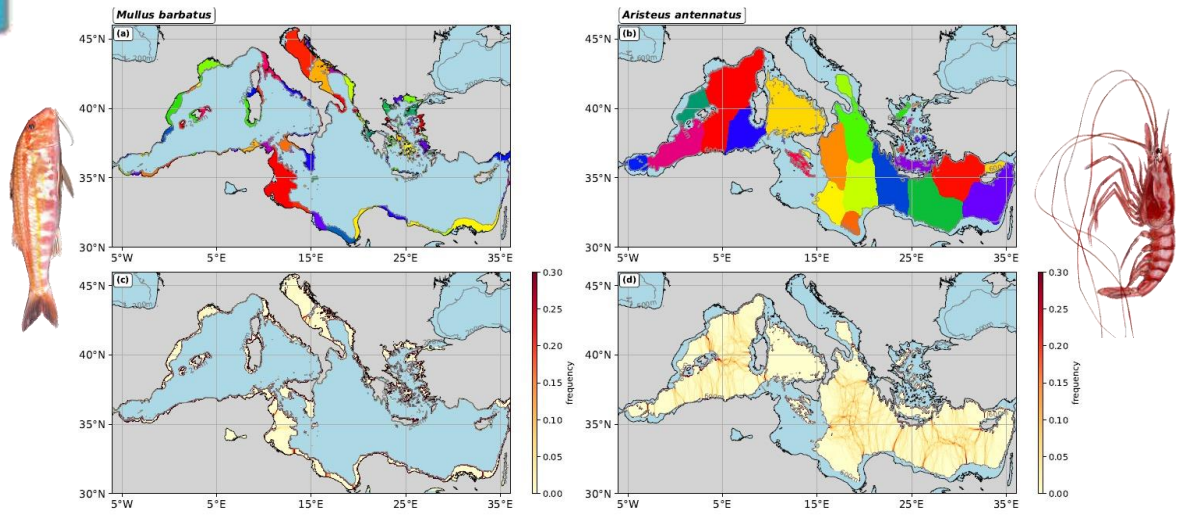
Thermal clusters inform on adults' adaptation

(obtained by clustering graph built based on spatial proximity and temperature similarity extracted from Sammartino's et al. 4DMED-Sea temperatures)



Explaining intraspecific biogeography through ocean circulation and temperature variability

Rwawi Chaimaa[1], Molto Vicenç[2], Berline Léo[1], and Rossi Vincent[1]

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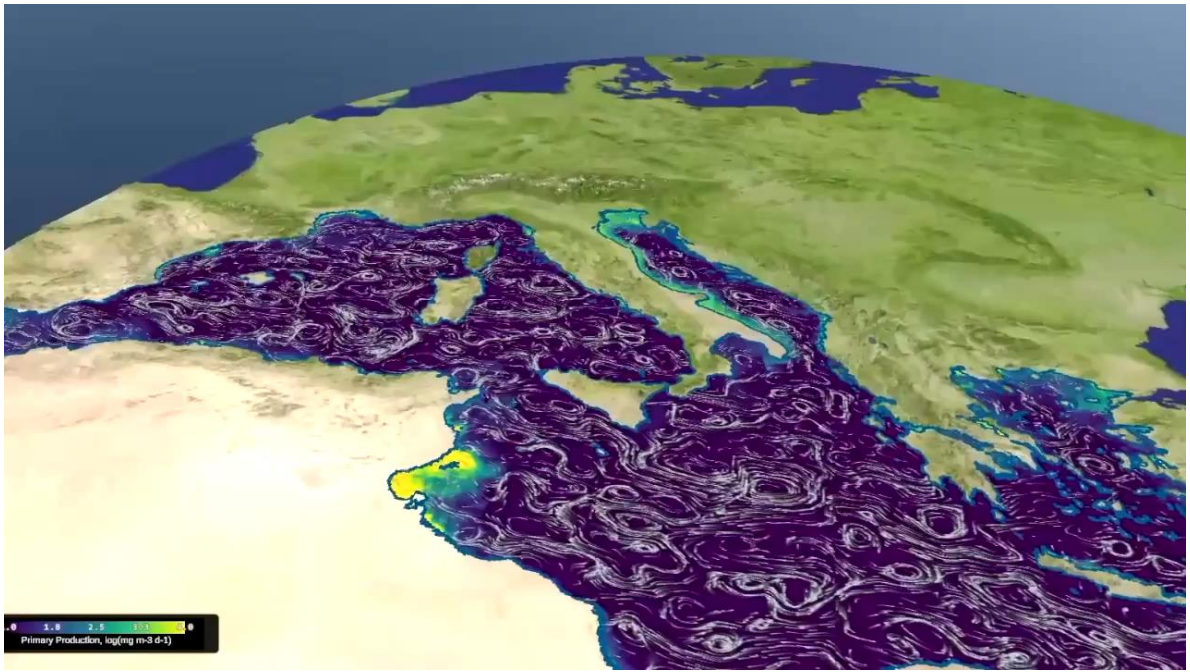


4DMED-SEA **Virtual Reality experience** at the ESA **Science for Society booth**

TODAY 17:40-18:00, Friday 10:00-11:30

"Living" Planet Symposium...

- we need to protect our ecosystem
- we need to understand and adapt to climate change
- we must stand for humanity and refuse to turn a blind eye to war crimes

UNRWA situation and response to the escalation in the Gaza Strip

Over 680,000 people estimated to have been forcibly displaced since 18 March.

At least **809*** people sheltering in UNRWA premises have been killed and **2,500*** injured since 7 October 2023.

UNRWA fatalities and damage to installations

317 UNRWA team members **killed**

311* UNRWA installations damaged

863* incidents

*Numbers are subject to change once verifications are concluded.

UNRWA response – Food assistance

Due to the 11-week-long siege imposed by the Israeli authorities between 2 March and 18 May, UNRWA flour and food parcels ran out several weeks ago.

UNRWA response – Health

Update for 9-15 June 2025

Only 7 UNRWA health centres operational on 15 June

81,169 medical consultations were provided in **5** UNRWA health centres, **2** temporary health centres and **25** medical points inside and outside shelters.

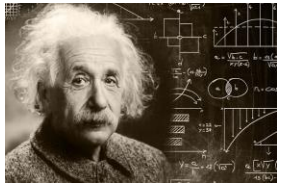
Up to **125** mobile medical teams covered the medical points.

UNRWA response – Psychosocial Support

Since the onset of the conflict, around **730,000** displaced people, including over **520,000 children**, have benefitted from psychosocial support sessions and activities.

171,839 displaced people received awareness raising sessions and internal community social network support.

8,500 persons with disabilities and injuries received assistive devices and rehabilitation services.



"***Peace cannot be kept by force; it can only be achieved by understanding.***"
A.Einstein