SYMPOSIUM OP'24

19 Nov. 2024

Ocean Predict

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

THEME #2

Coastal/Regional

ocean prediction across scales, processes and applications

Joanna STANEVA
HEREON

Anna TERUZZI
OGS

9:15 AM ROOM II

PLENARY SESSION

Why is coastal modeling vital?

Coastal zones are:

- heavily used and impacted areas of the global ocean
- a diverse array of resulting human pressures and anthropogenic stressors
- particularly vulnerable

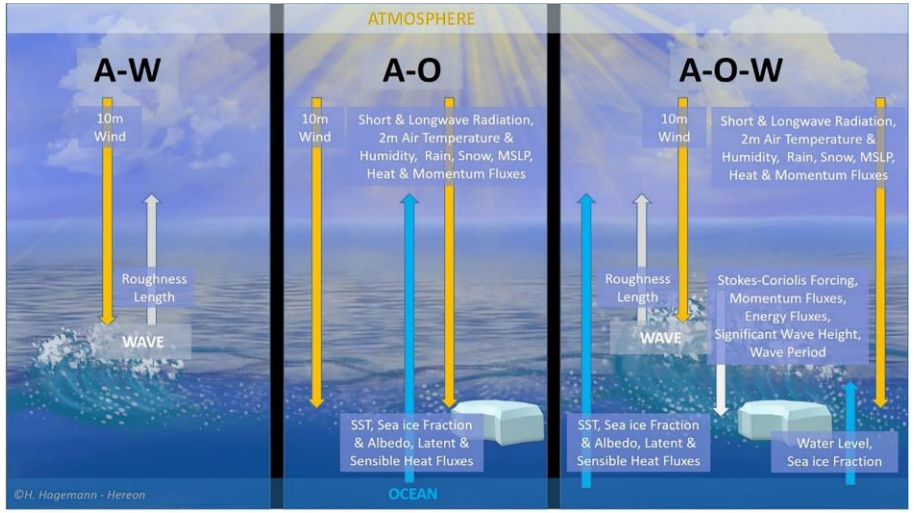
(adapted from Melet et al., 2020)

➔ **Efforts are ongoing to reinforce coastal modeling capabilities to increase marine knowledge and meet societal needs.**

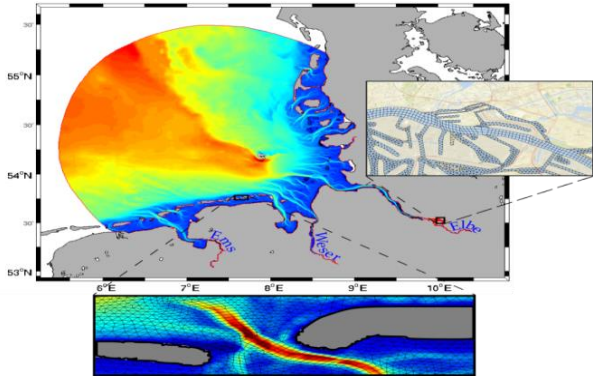
End-to-End Coastal Predicting Systems

- Interaction between different models is important
- Not much interest if not well linked to:
  - a) Larger-scale models
  - b) Atmosphere-wave models, hydrology, land use models

Diversity of model components/scales (time and space)



Near-Coastal models/applications



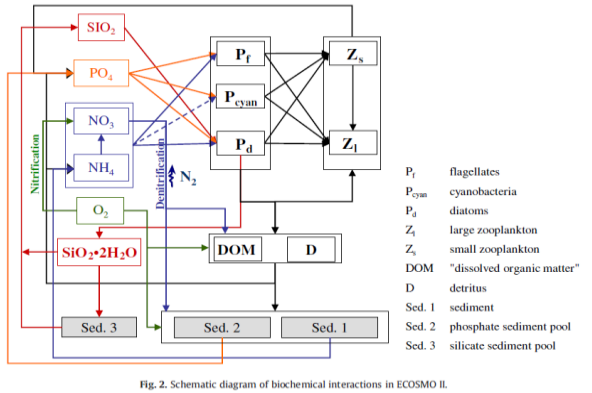
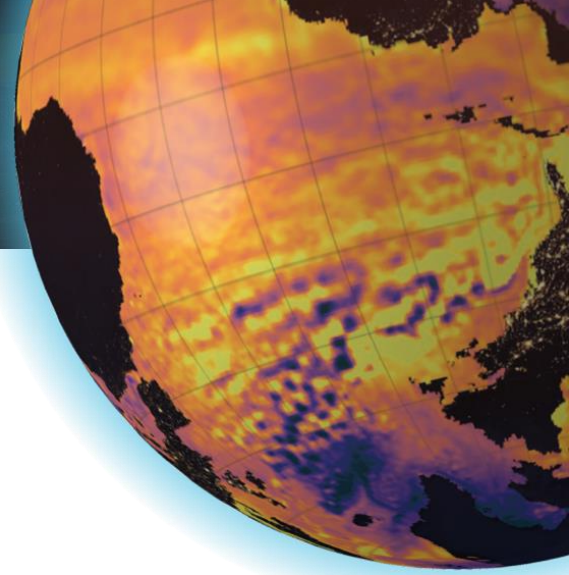


Fig. 2. Schematic diagram of biochemical interactions in ECOSMO II.

- Synergy between newly available observational data and coastal models
- Solve practical problems
- Operational design/Demonstration/Climate change
- End-users/Society demands



Regional and Coastal Ocean Forecasting

Multidisciplinary, multi-platform coastal observing system (Open access/ permanent & relocatable)

Numerical models of waves-hydrodynamics and ecosystem, coupled to atmospheric and hydrology forecasts

Data assimilation/AI, ensembles for optimal field estimates and uncertainty estimates

Continuous (robust) production of nowcasts/forecasts of relevant environmental state variables

The operational approach:
from large to coastal/estuary space scales
weekly to monthly time scales

Society based products

Regional and Coastal Operational Oceanography science should be **data explorative**, unifying theory, experiments, and multi-scale, multi-compartments simulations and society based.

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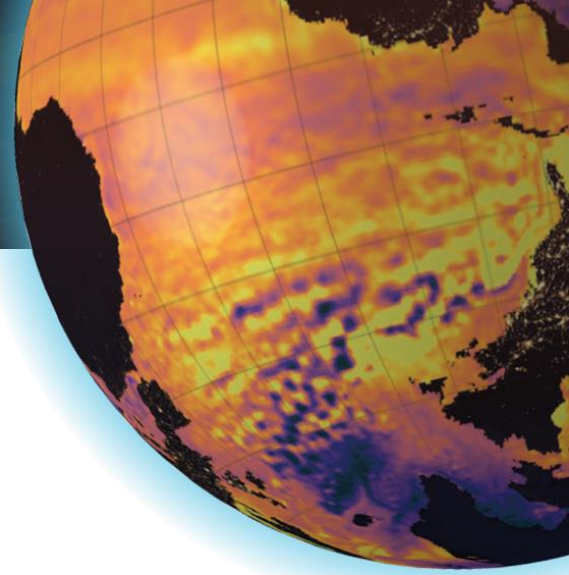


Impacts and Design

See our poster!
Tues. 19th
Observational
Systems

The FOCCUS project specifically addresses and enhances the coastal extension of **Copernicus Marine Environment Monitoring Service** to better serve coastal users and EU Member States.

FOCCUS

Forecasting and observing the open-to-coastal ocean for Copernicus users

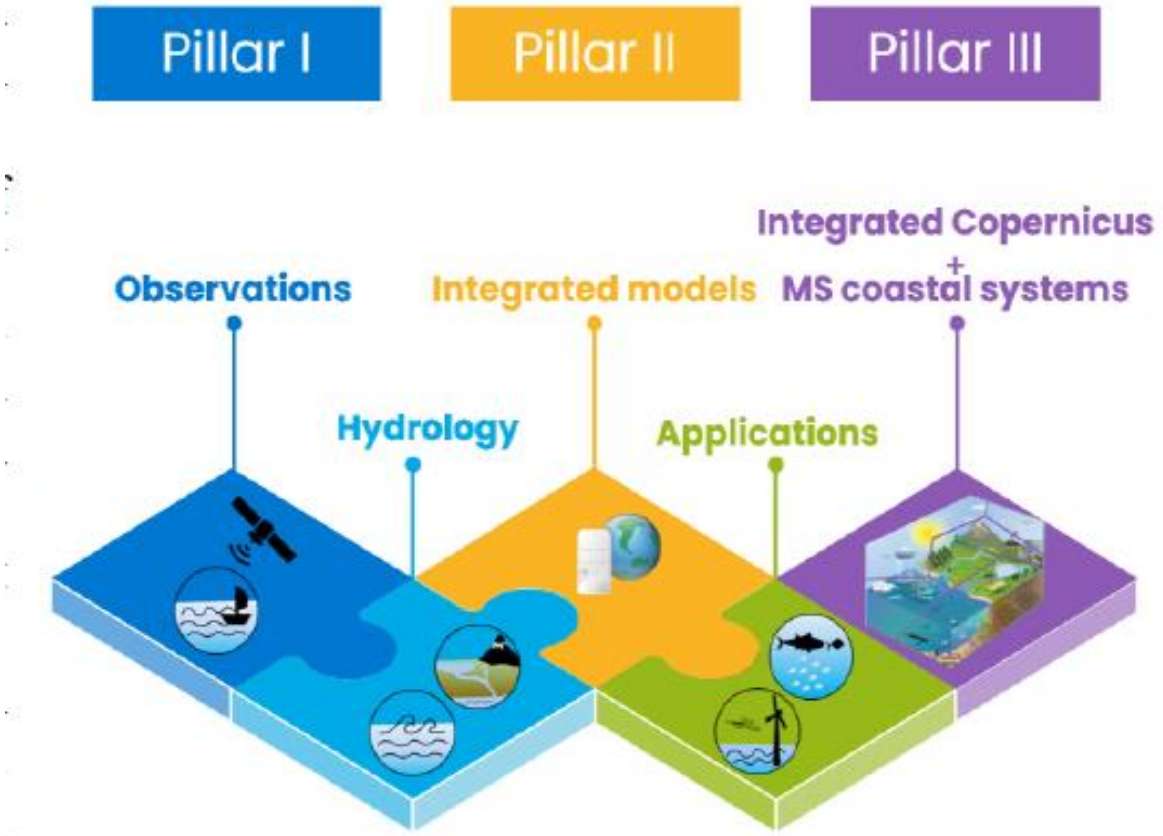
FOCCUS

Endorsed by UN Ocean Decade (CoastPredict)

1.	HEREON	Germany
2.	MOi	France
3.	CMCC	Italy
4.	SHOM	France
5.	CLS	France
6.	SOCIB	Spain
7.	CNR	Italy
8.	Deltares	Netherlands
9.	NERSC	Norway
10.	MET.NO	Norway
11.	SMHI	Sweden
12.	+ATLANTIC	Portugal
13.	RBINS	Belgium
14.	MHD	Romania
15.	EUROGOOS	Belgium
16.	BC	Germany
17.	DMI	Denmark
18.	Ifremer	France
19.	SSBE	Belgium

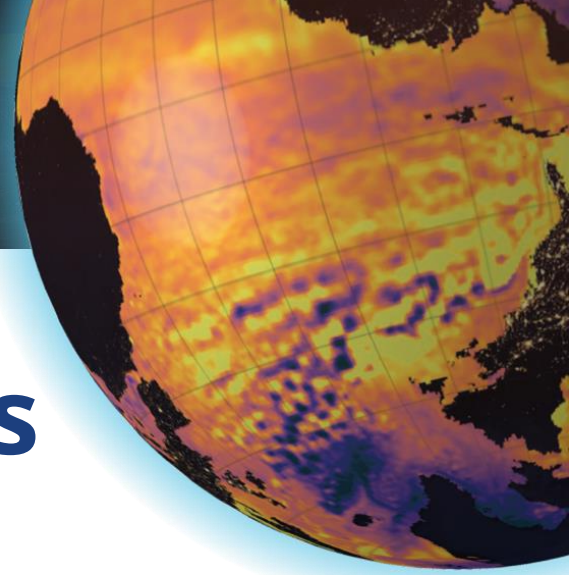
Aim:

achieve a seamless monitoring and forecasting of the ocean



- applying and improving methods
- development of new coastal products

→ **Operational, fit-for-use coastal information service for the society.**



Novel High-Resolution Observations

➔ Ongoing improvements to innovative coastal observations in response to society and policy needs.

- Enhancement of required Essential Ocean Variables (**EOV) retrieval** in the coastal areas.
- Use of **data fusion** to create new coastal products.
- **AI methods** to enhance coastal observations.
- New approaches for improving **access, processing and data tracking.**

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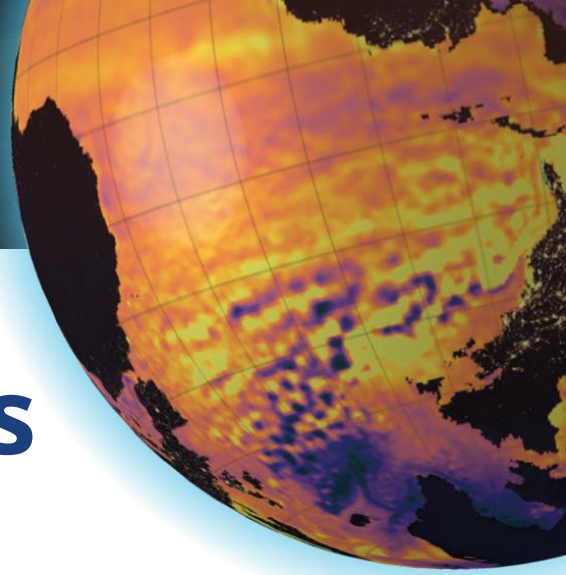
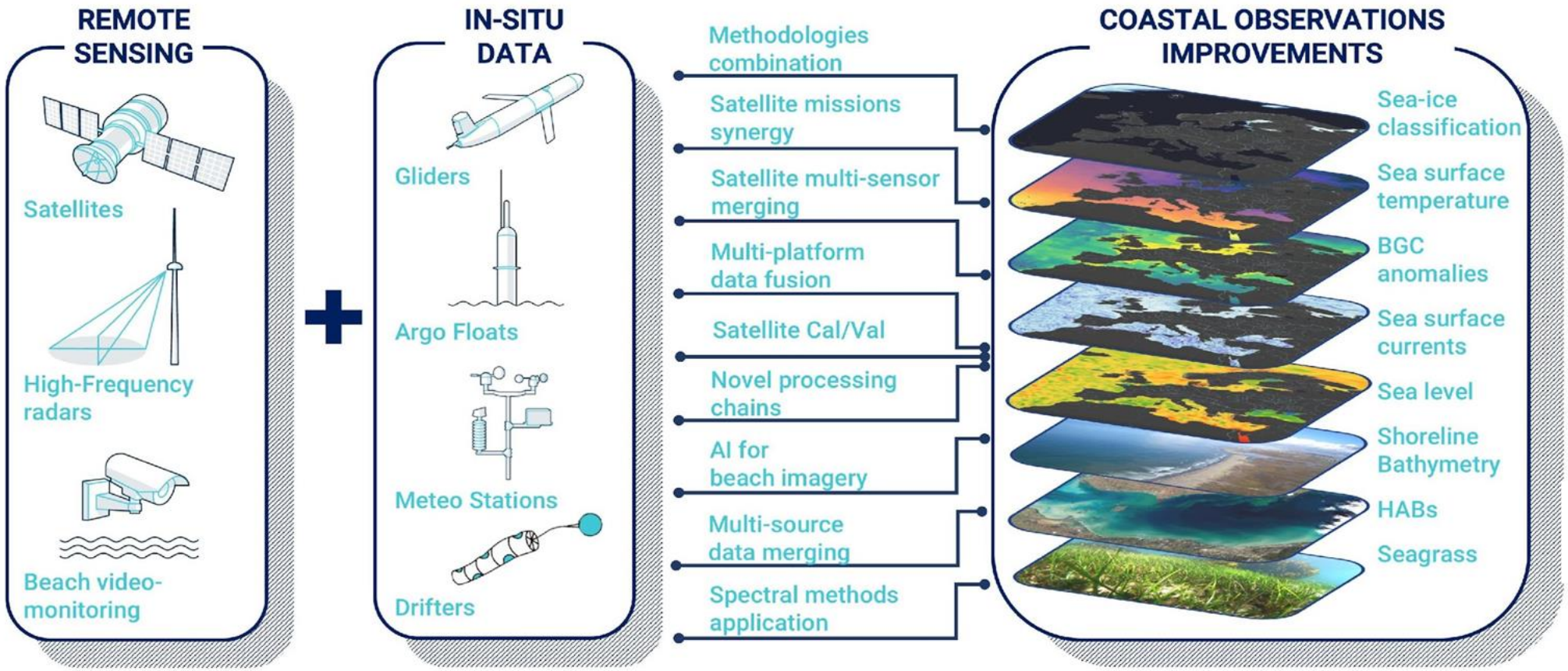
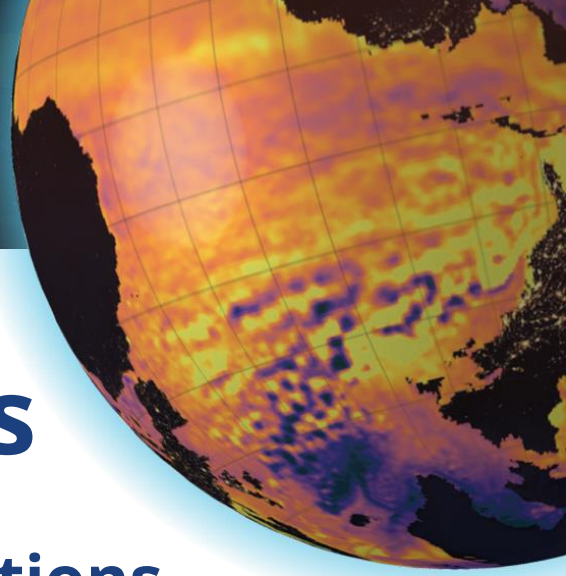


Novel High-Resolution Observations



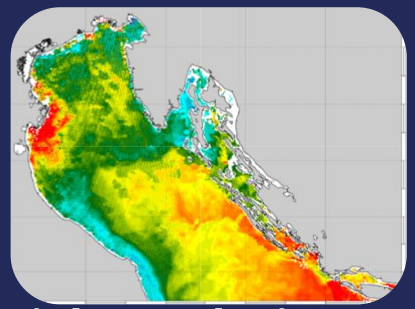
See our poster!
Tues. 19th
Observational Systems



Novel High-Resolution Observations

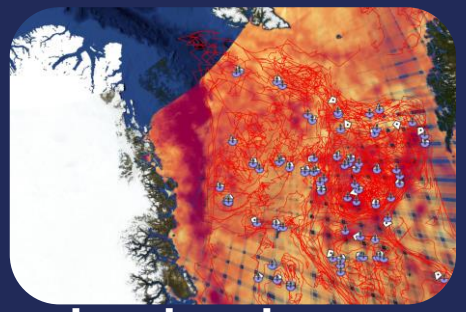
→ Ongoing improvements to innovative coastal observations in response to society and policy needs.

Enhanced coastal observations



High-resolution SST

Remote-sensing data fusion



Sea level and currents

AI applied to beach imagery

AI-derived shorelines

Coastal and river data tracking

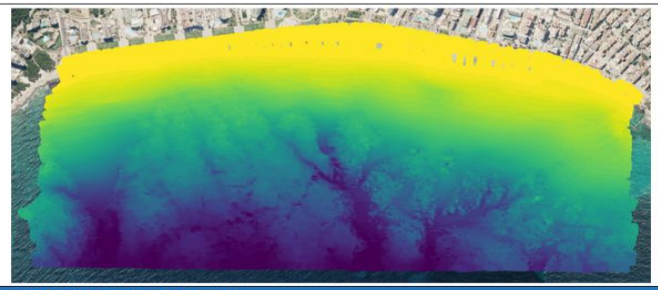
EU river dataflow

Novel remote sensing for coastal change

- Data formats definition
- Metadata standards

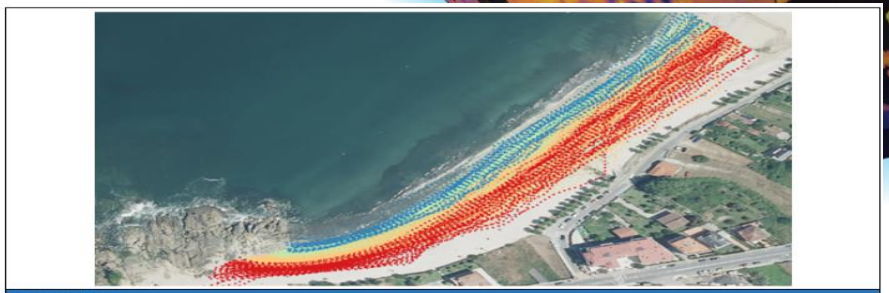
Morphology

Topobathymetry



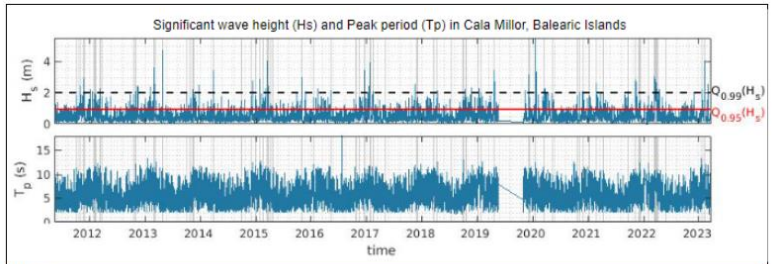
HIGH-RESOLUTION TOPOBATHYMETRIES	
DATA PRODUCT INFORMATION	
Full Name	High-resolution topobathymetries
Description/Overview *[max 50 words]*	Sand level measurements covering the entire beach system (ranging from approximately +2 m to -15 m) are conducted semi-annually to capture the beach morphology during both summer and winter seasons.
Source	In-situ observations
Area or Geographical coverage	Balearic Islands ; Black Sea

Shorelines



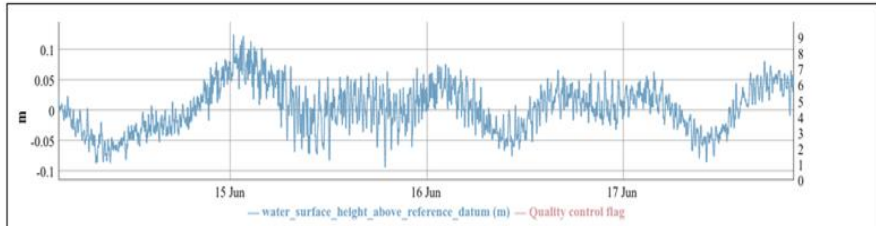
SHORELINES	
DATA PRODUCT INFORMATION	
Full Name	Shorelines
Description/Overview *[max 50 words]*	In-situ measured shoreline positions (RTK) and image derived ones from beach imaging systems georectified products (manually digitised by a human).
Source	In-situ observations
Area or Geographical coverage	Balearic Islands ; Black Sea

Waves



WAVES	
DATA PRODUCT INFORMATION	
Full Name	Wave parameters
Description/Overview *[max 50 words]*	Hourly wave data are provided in ASCII files. Each ASCII '*.wap' file is accompanied by the corresponding data header file ('*.hdr' extension) that contains all the information related to the instrument deployment

Sea Level

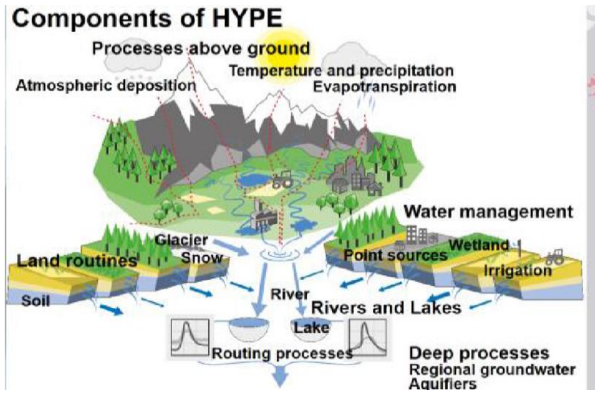


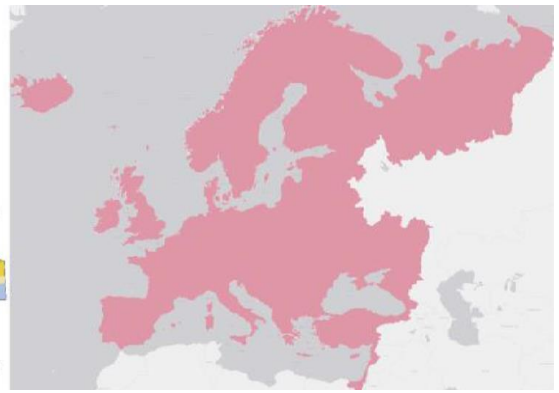
SEA LEVEL	
DATA PRODUCT INFORMATION	
Full Name	Sea Level - Real-Time / Near Real Time Values
Description/Overview *[max 50 words]*	Hourly wave and water depth measurements are available in ASCII. Each ASCII '*.wap' file is accompanied with the corresponding data header file

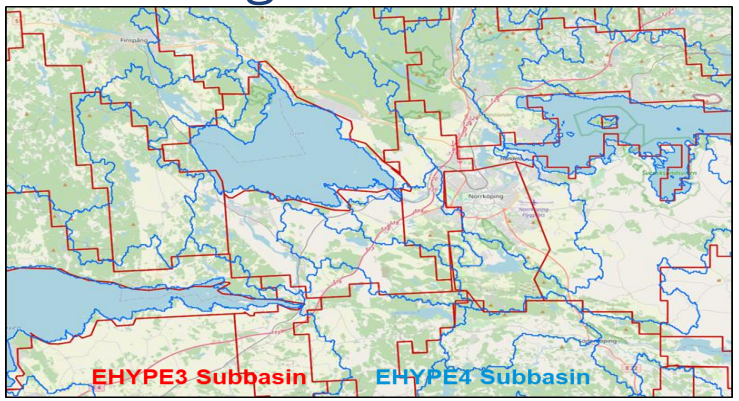
Improved Model Interfaces in the Land-Ocean Continuum

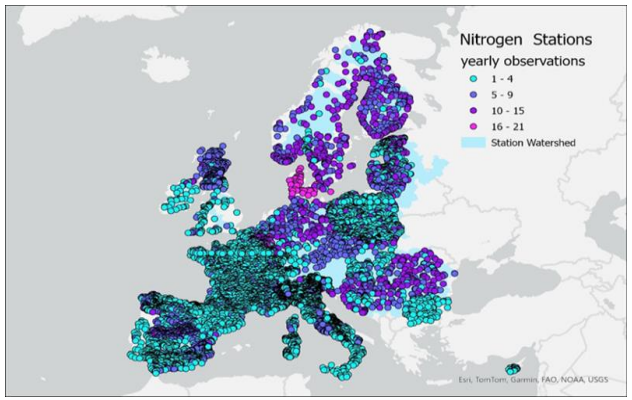
➔ Optimization of approaches for river runoff estimations based on a **combination of hydrological models and observations** and **integration with coastal models**.

- Improvements in producing hydrological hindcasts and river representation.
- Use of Pan-European hydrological models.
- Revised and recalibrated runoff, nutrients, and sediments.
- Updated calibration routines and nutrient integration.



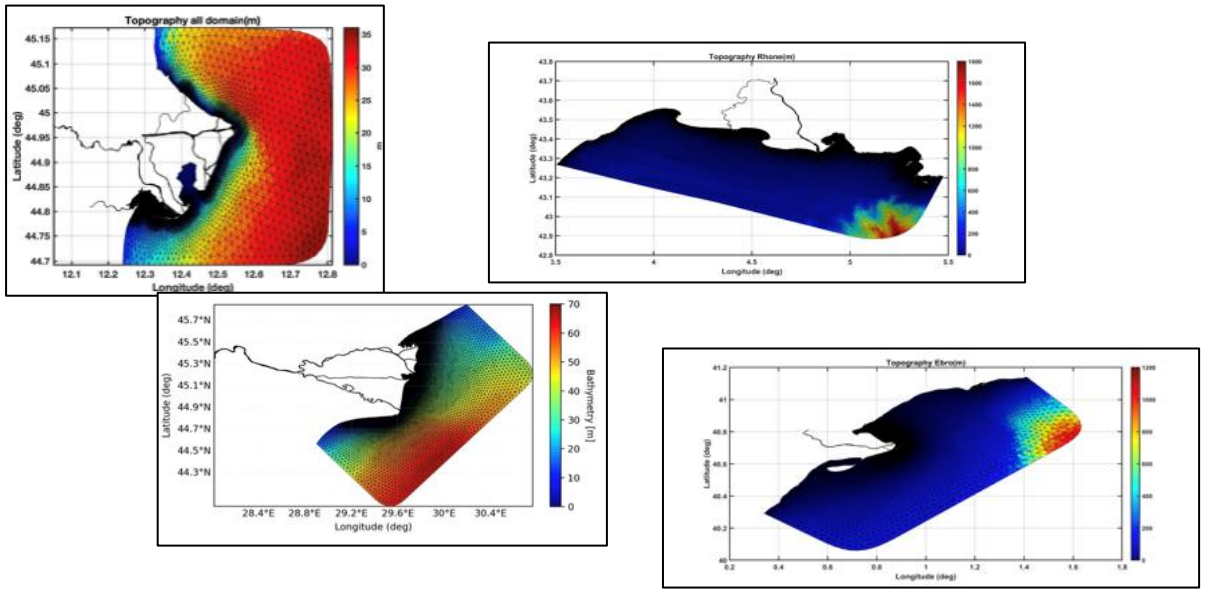


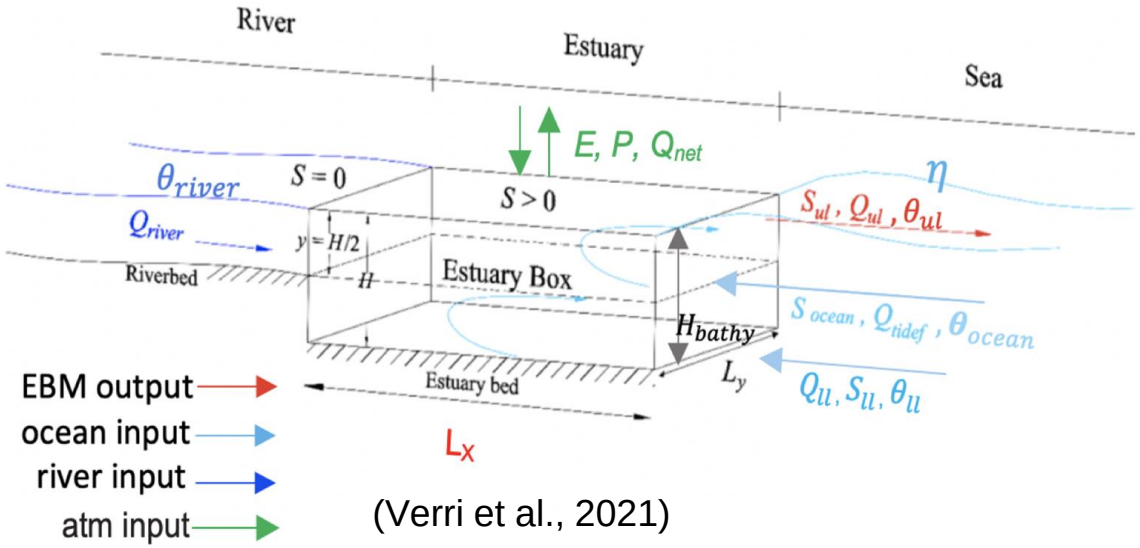




Estuary Box Models (EBMs) and Interfaces

- Use of AI techniques to improve EBMs.
- Exploitation of unstructured grid models.
- Testing improvements using connections with observations.



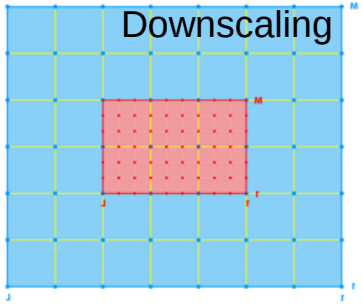


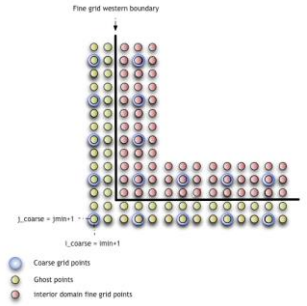
(Verri et al., 2021)

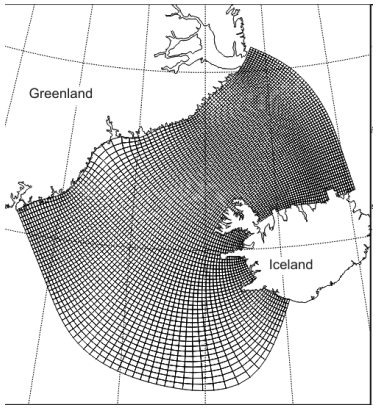
Interfaces Between Hydrology/ Coastal and Regional/Ocean Models

- Implementation of new **nesting** capabilities.
- New ability to map **coastal system parameters** regarding biogeochemical models and regions with many state variable requirements.

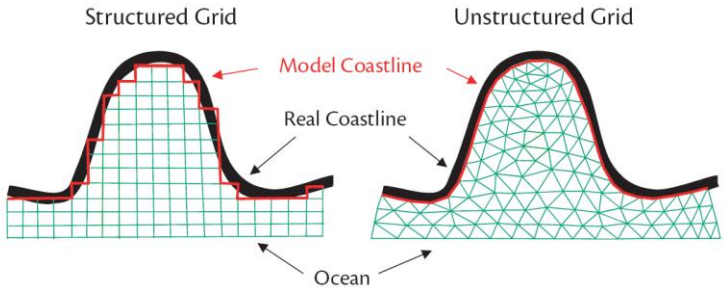
Nested Grids







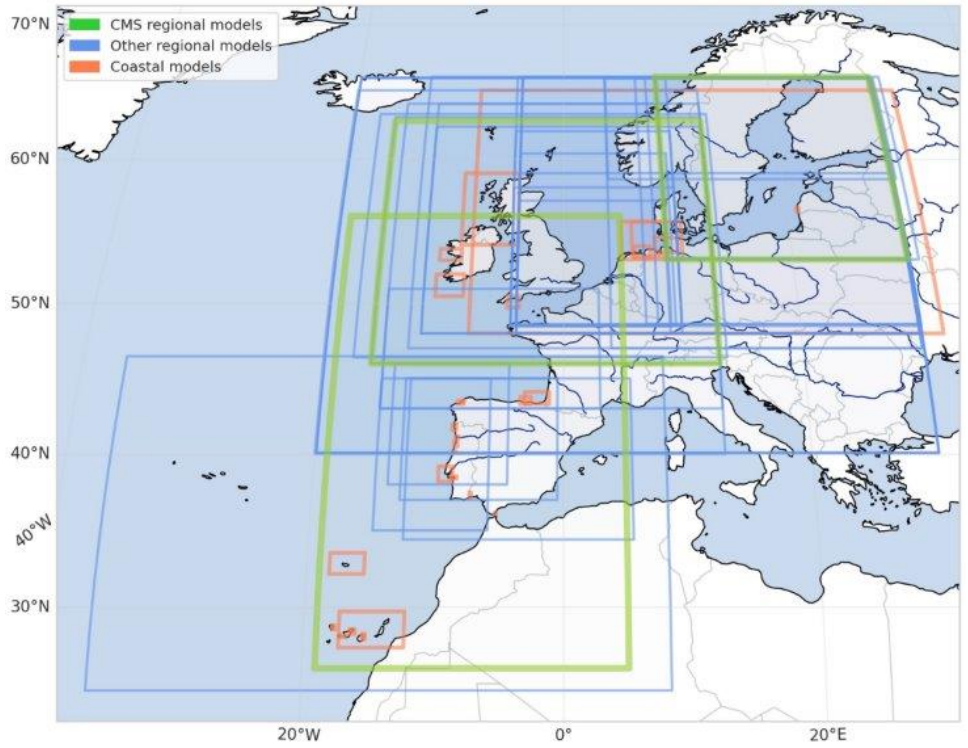
Unstructured Grids



http://www.ocean-modeling.org/docs.php?page=s-coordinate

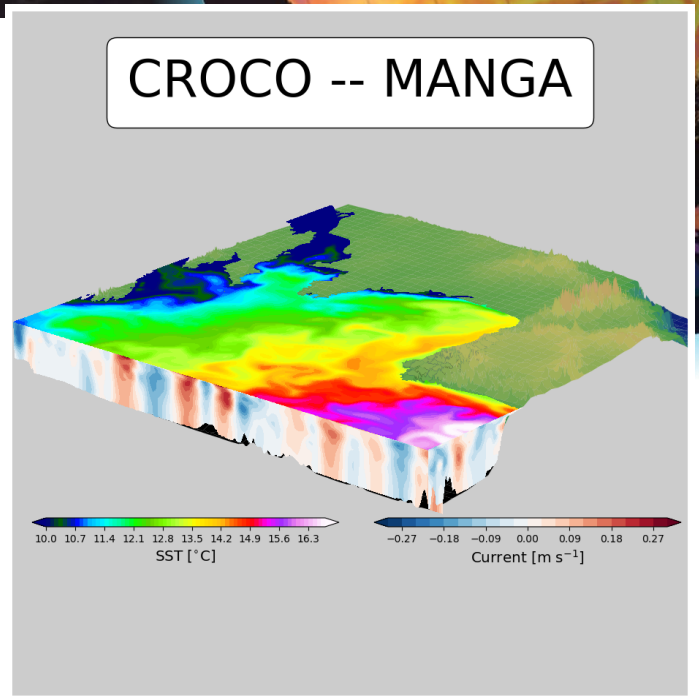
Interfaces Between Coastal and Regional Ocean Models

- **Enhancing their coherency by upgrading its coastal systems for improved coupling and downscaling.**
- Processing chains are set up and tested to exploit new coastal ocean observations and new and improved algorithms.
- Securing continuity of robust coastal services from global and regional to local levels.



Coastal interfaces

SHOM – CROCO
Coastal and Regional Ocean Community model

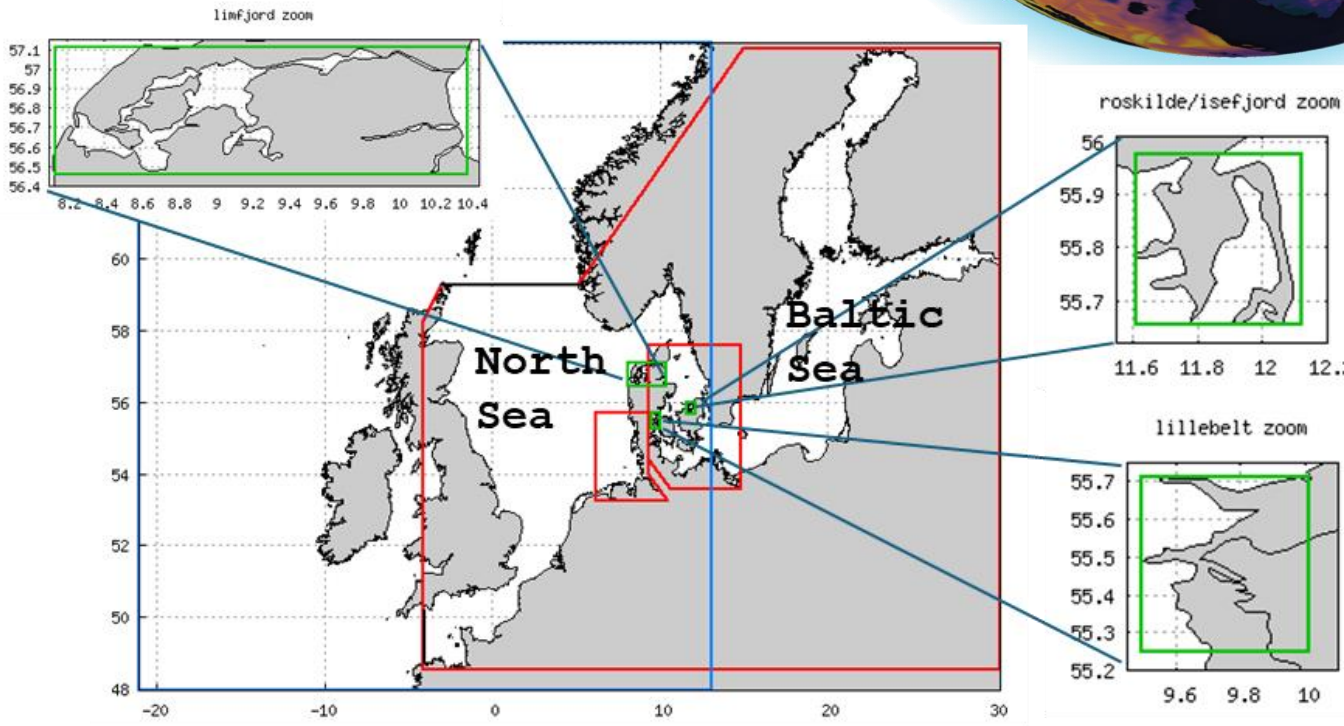


External data – Copernicus interfacing

- Hydrology and currents:
  - **GLORYS12V1:** 1/12°, global, daily, ERA-forced
  - **MFC-IBI:** 1/36°, ERA-forced
  - **Single model ensemble reanalysis:** 1/4°, global, ERA-forced
- Tidal forcing: **AVISO** - **FES2014**
  - 1/16°, global, 10 main tidal harmonics
- Runoff: - **Copernicus - GLOFAS**
  - Global, daily
  - Hydrological reanalysis

DMI – DKSS
Danish Coastal system

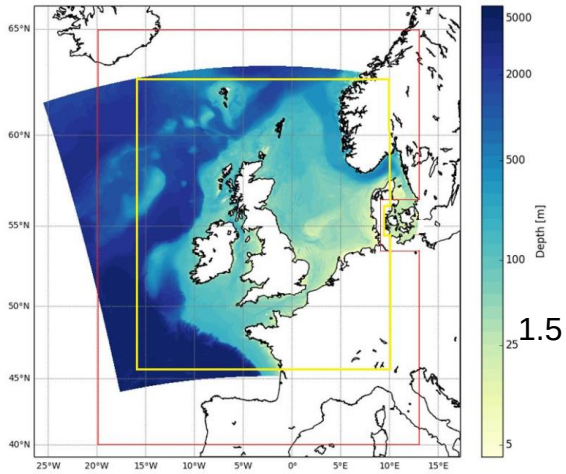
- OBCs: COPERNICUS Marine
  North West Shelf and Baltic MFCs
  - Sea level, hourly
  - T/S, daily or hourly
- Initial conditions**: BAL+NWS MFC**
  - nudging (subsurface T/S, monthly)



0.1-3 n.m. resolution, 7 two-way nested domains

North Sea / Baltic Sea

HEREON: German Bight - GCOAST

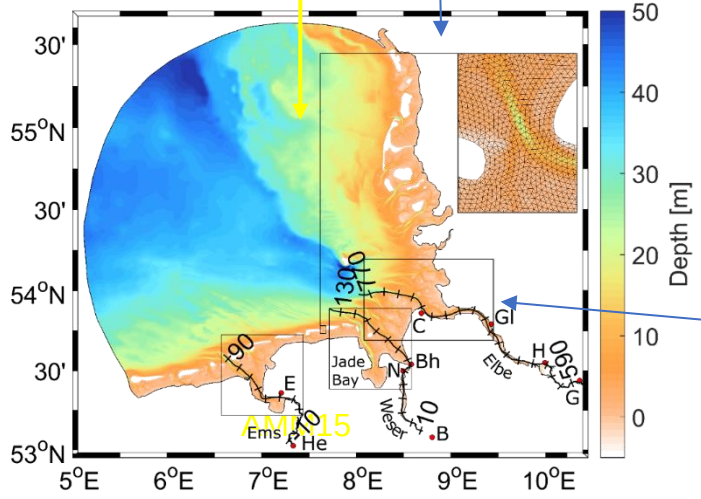


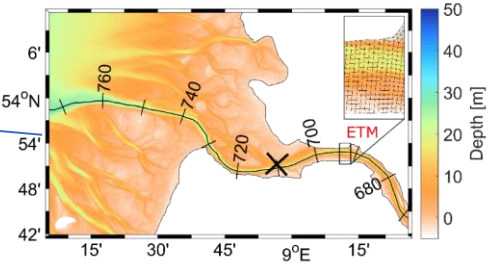
1.5 km

NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_001

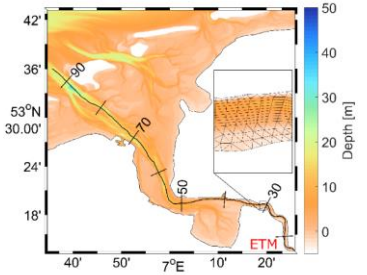
One way nest

COSMO-EU





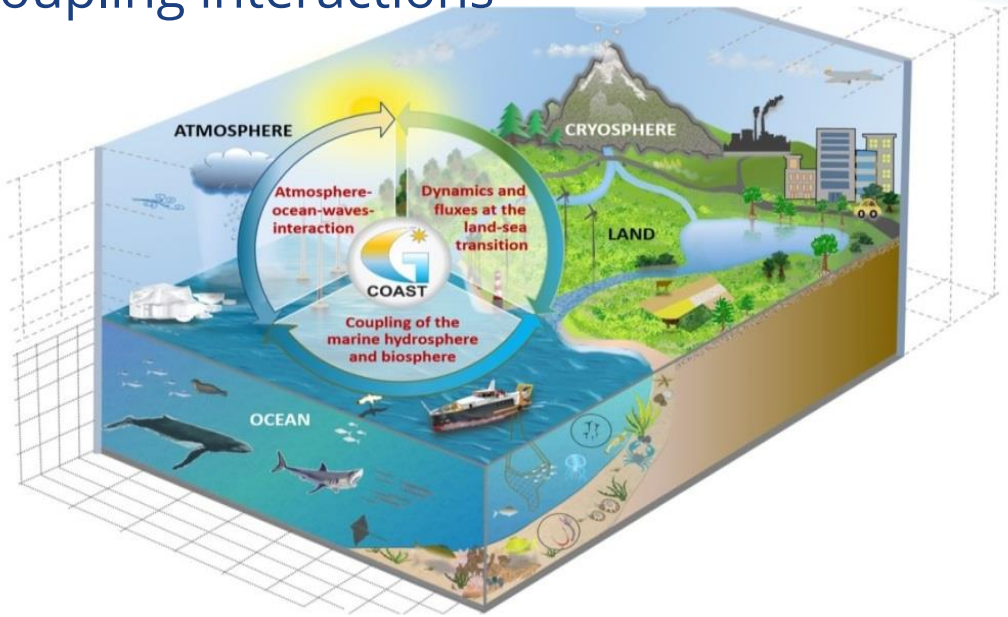
River discharge at weirs



- The Dynamics of the regional NWS COPERNICUS Marine Service (1.5 km) product are interpolated as boundary forcing in a one way nesting approach using flexible routines.
- The resolution of the nested German Bight model´s unstructured grid seamlessly refines from 1.5km towards 50m across estuaries to resolve coastal and estuarine baroclinic processes.

Integrated COAstal model SysTem (GCOAST)

- Integrate Observations and multi - disciplinary Models
- Dynamics and fluxes at the land-sea transition
- Coupling of the marine hydrosphere and biosphere
- Cross-scale interactions, atmosphere-ocean-wave coupling interactions

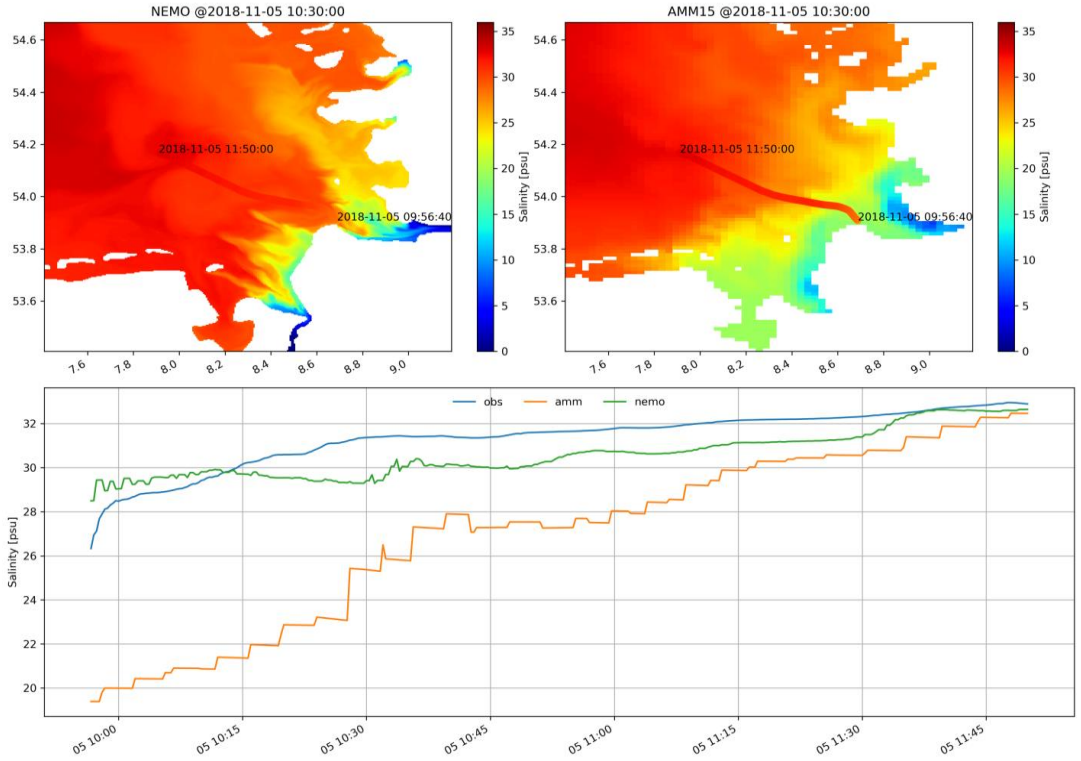


- Dynamical downscaling - regular grid and
- Unstructured grid

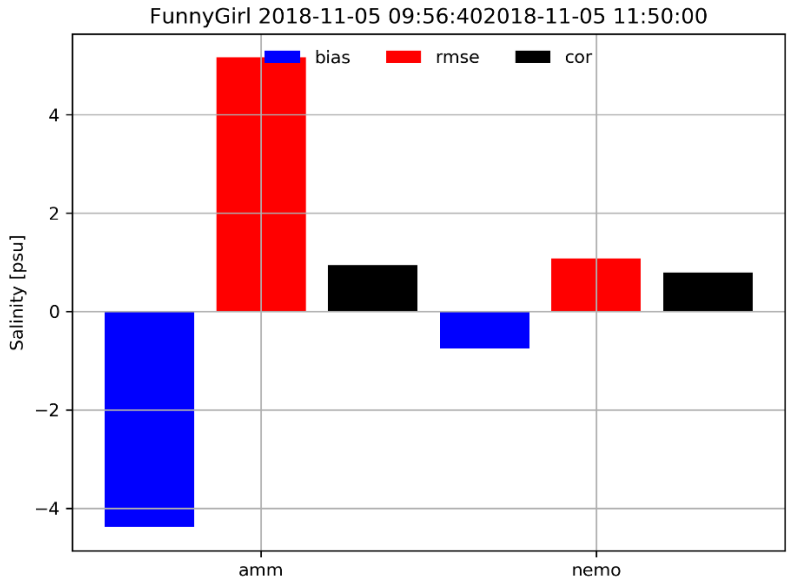
Salinity Fronts

Copernicus Marine versus GCOAST coastal forecasting FerryBox tracks

GCOAST



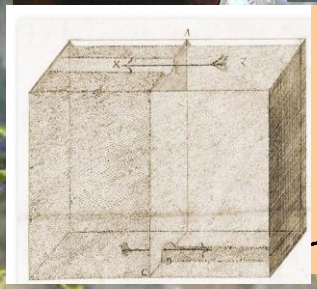
Copernicus Marine - NWS-1.5km

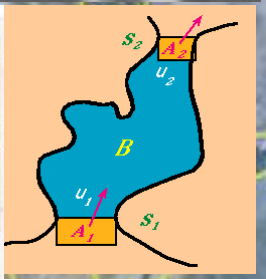


Dynamics of Ocean Straits

From Marsigli (1681) to (Knudsen (1900) and beyond)

Water cycle and the challenge of basin inter-connections





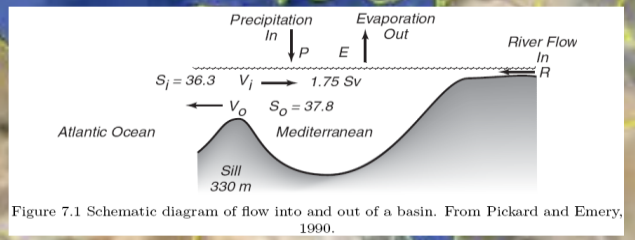


Figure 7.1 Schematic diagram of flow into and out of a basin. From Pickard and Emery, 1990.

$Q1+R=Q2$

$Q1S1=Q2S2$

$Q1=R/(S1/S2-1)$

$Q2=R/(1-S2/S1)$

SYMPOSIUM OP'24

Ocean Predict

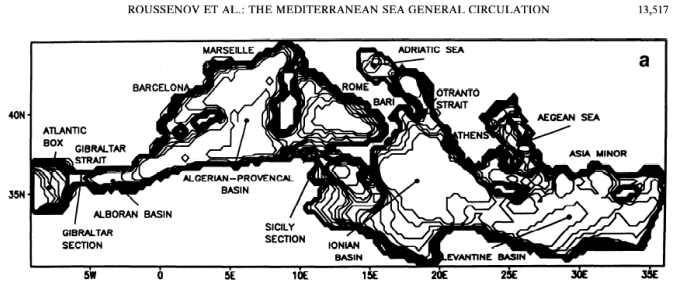
In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Ocean and Estuarine Basins

Well-known (ocean) cases:

- **Denmark Strait** (~190 m deep and ~300 km wide)
- **Strait of Gibraltar** (~300-900 m deep and ~15 km wide)

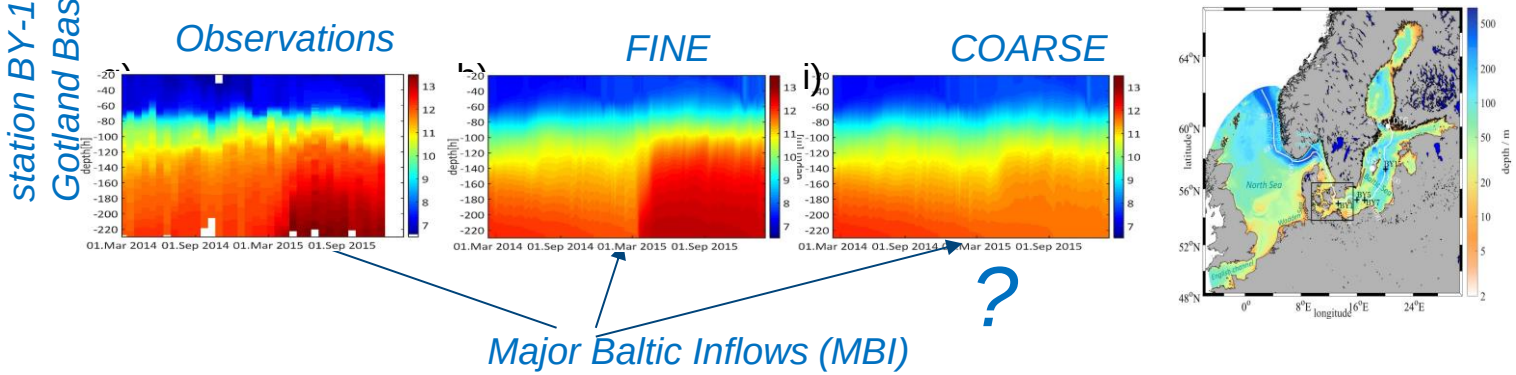


1995: ~30 km grid

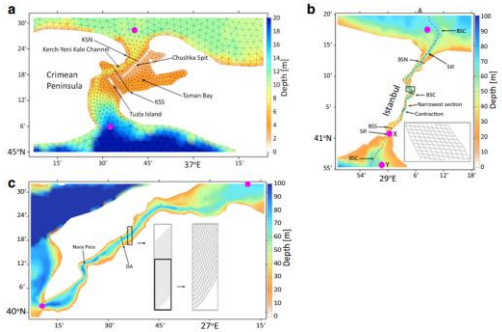
Zhang et al. (2015 OMOD); Stanev et al. (2018, OMOD), etc

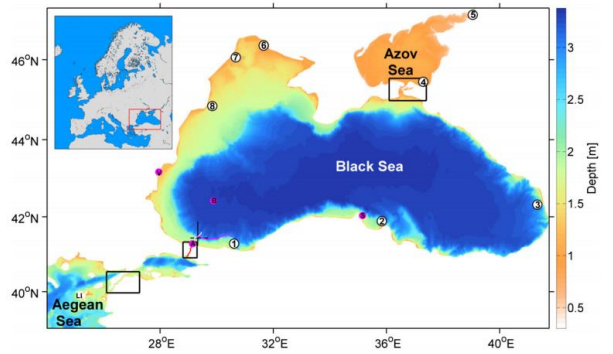
Less well-known cases of inland estuarine basins:

- **The North Sea - Baltic Sea ~80m**

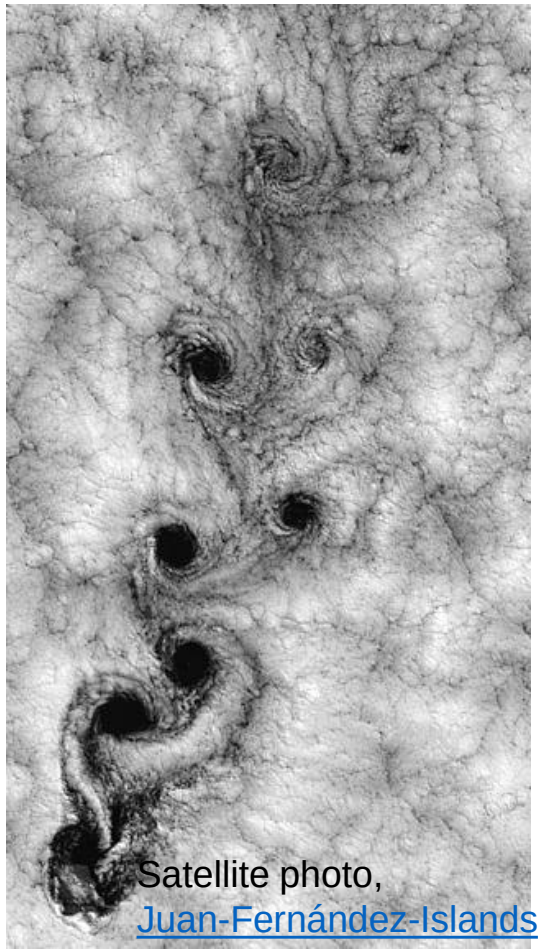


- **The Black Sea**



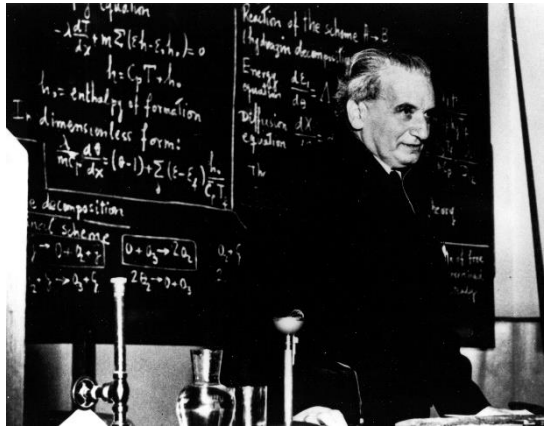


Down to meter scales:
Karman vortices

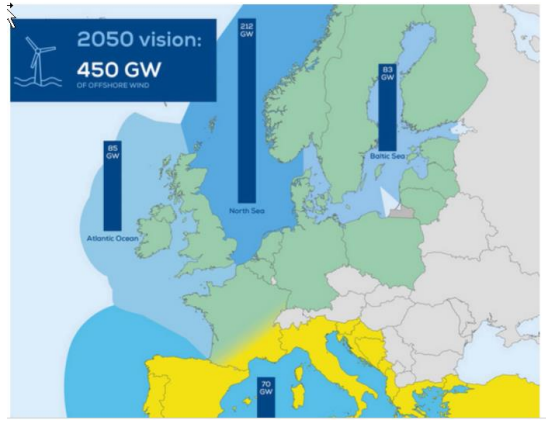


Satellite photo, [Juan-Fernández-Islands]

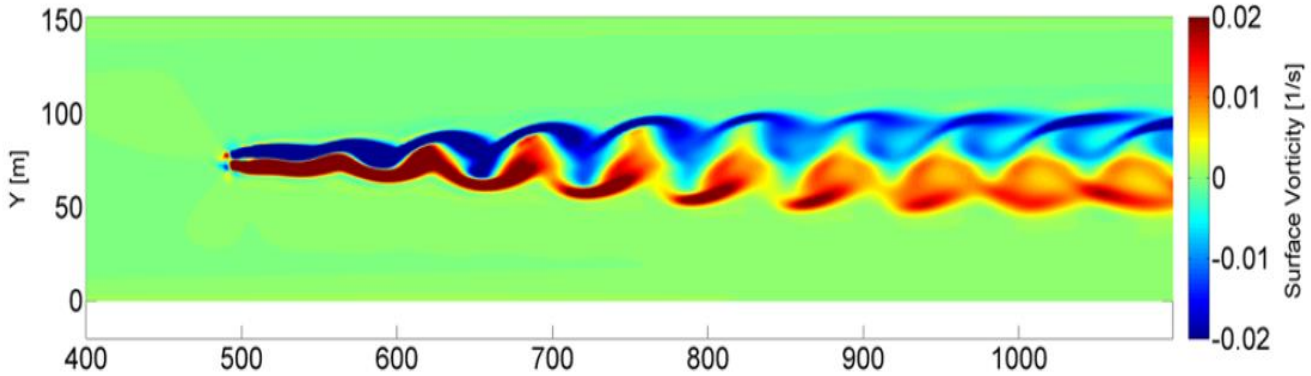
Kármán vortices
For $47<Re<10^5$ eddies are shed continuously from each side of the obstacle, forming rows of vortices in its wake.



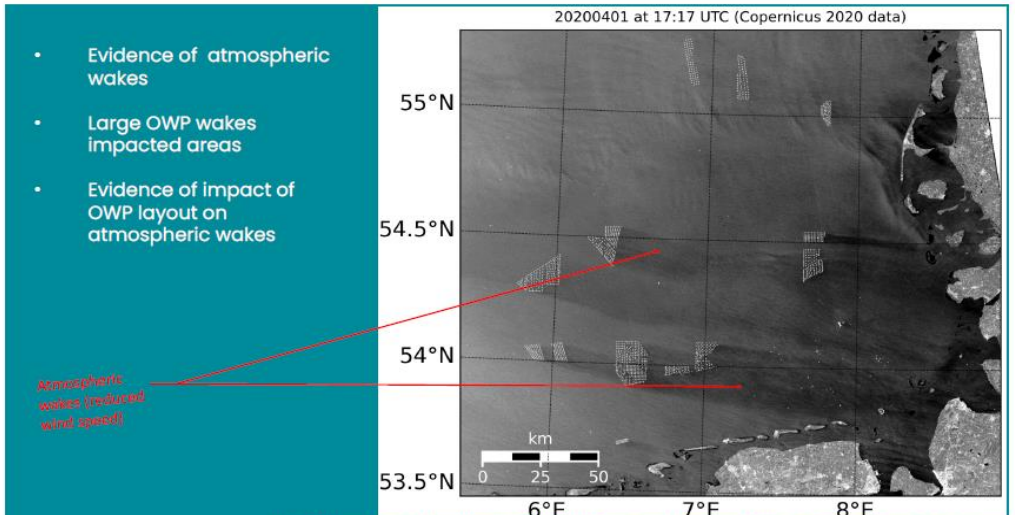
Impact of Wind Parks:
Wakes Behind Constructions



Many studies have been performed on the atmospheric component, but not so many on the oceanic one - why?

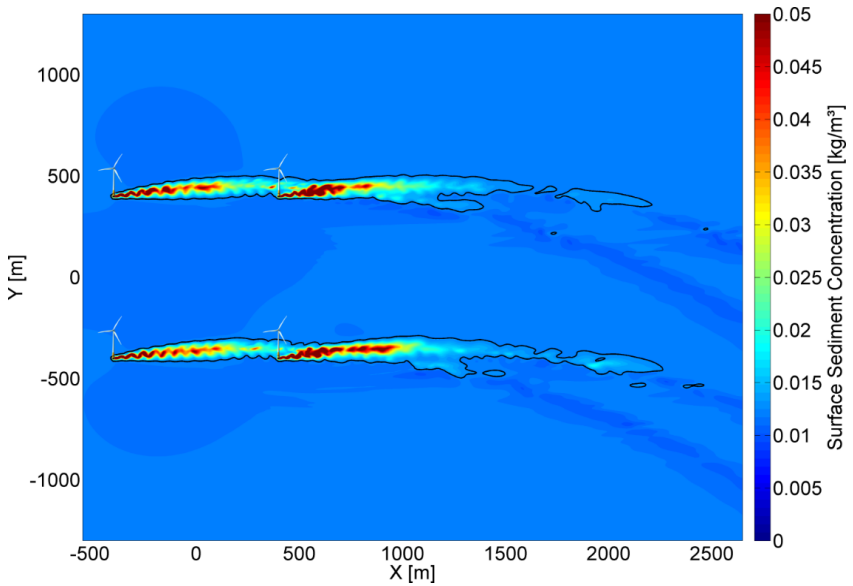


Grashorn and Stanev, (2016) Ocean Dynamics



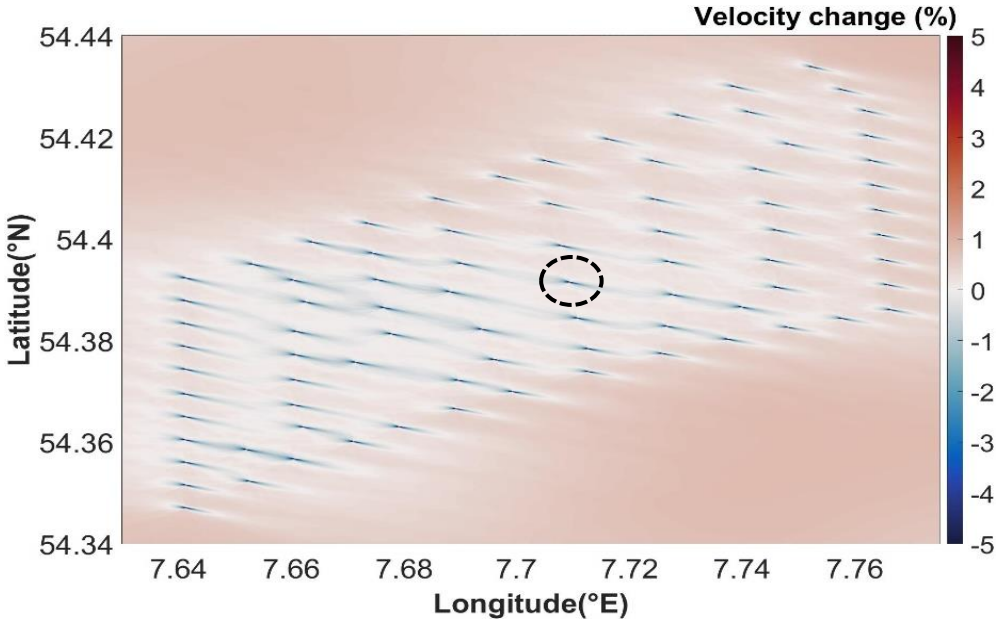
OWF in tidally dominated environments

SED-3D (sediment wakes at sea surface)

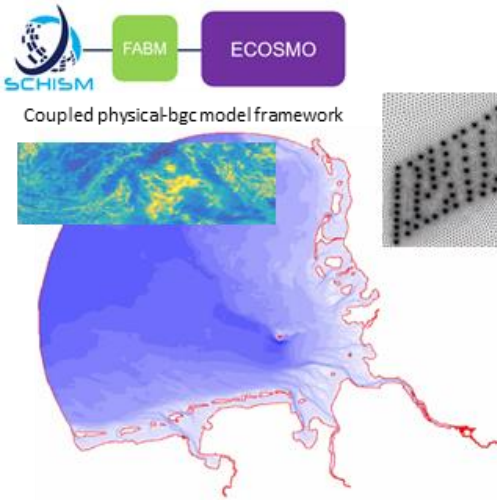


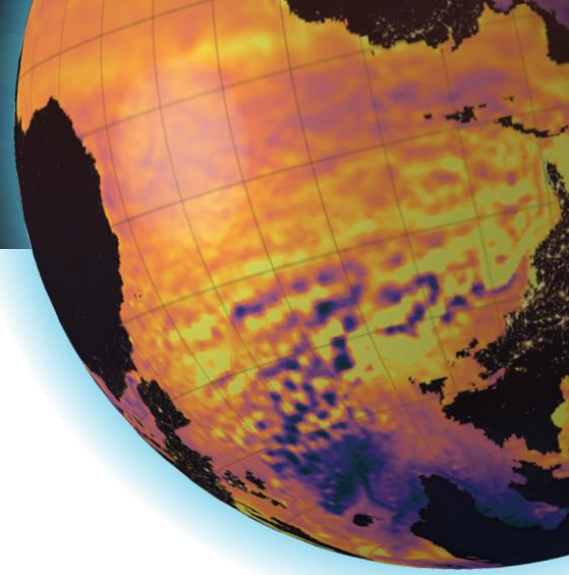
Grashorn et al (2019)

SCHISM – Velocity wakes



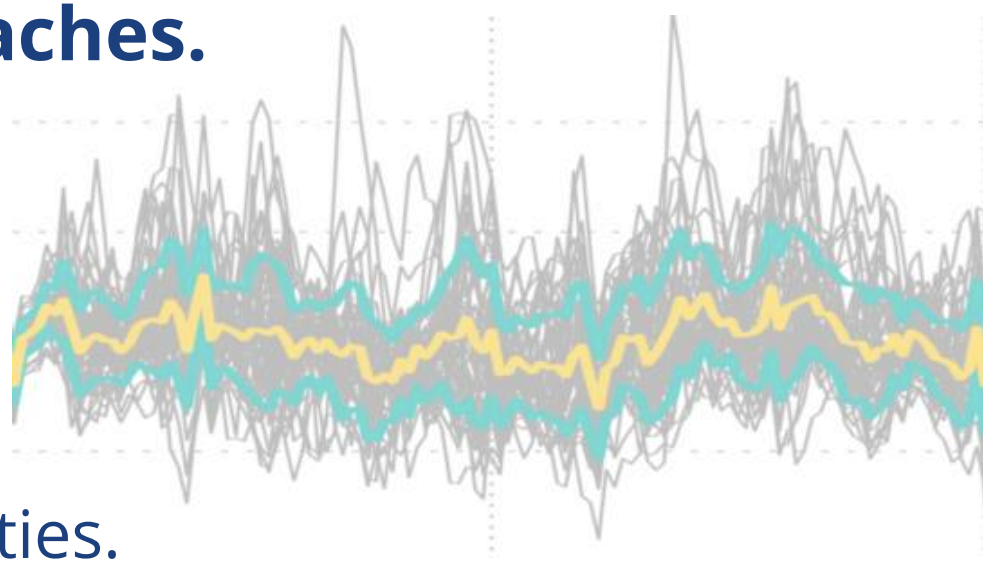
Hosseini et al (2024)





Coastal Operational Production Chains: New Modelling Techniques

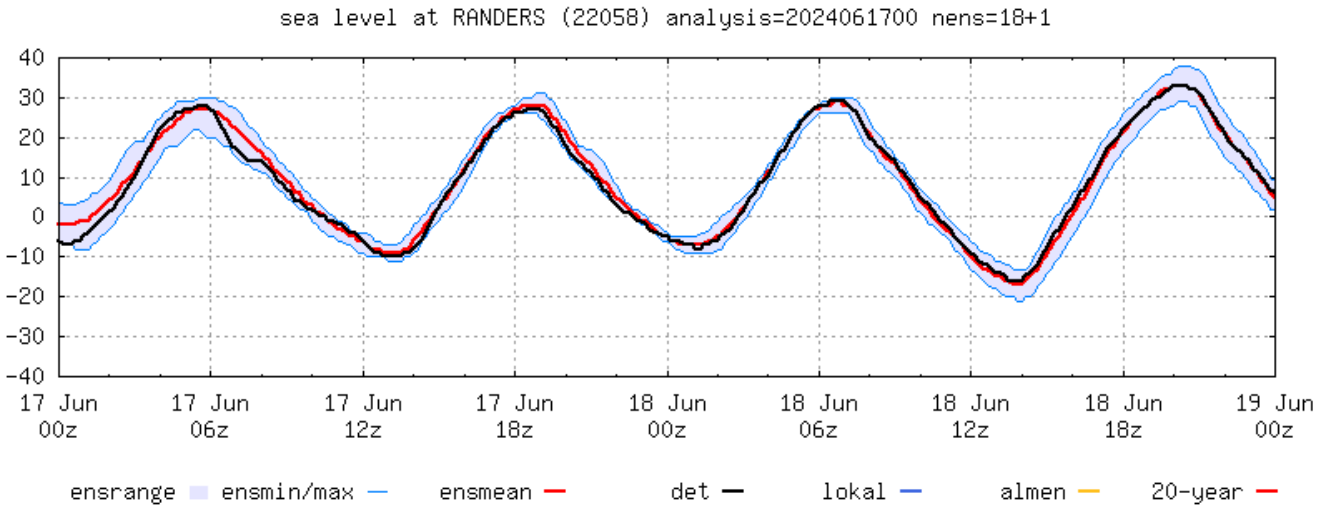
➔ New ensemble and stochastic approaches.



- Ensemble of opportunity,
  e.g. the aggregation of several products,
- Boundary perturbed ensembles.
- Stochastic models ensembles.
- Ensemble spread vs observations uncertainties.
- Geophysical location of dynamical structures (eddies, fronts, etc.).

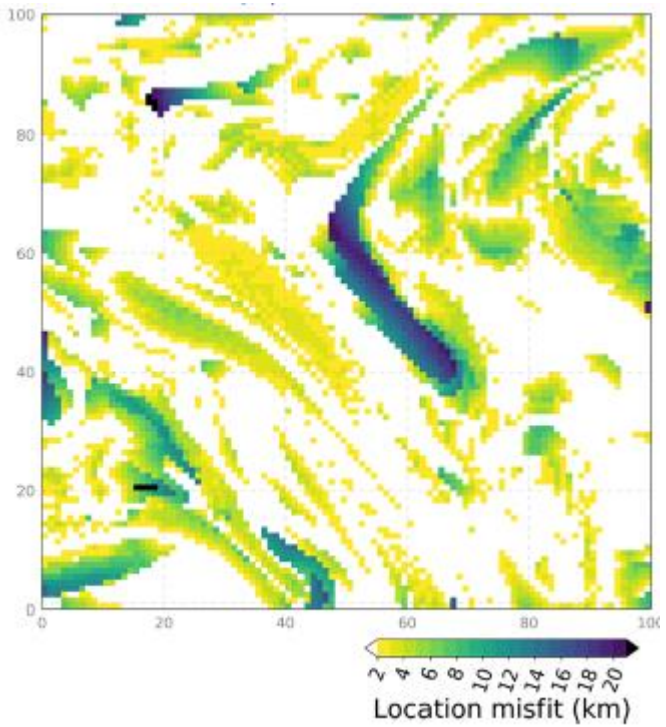
Coastal Operational Production Chains: New Modelling Techniques

➔ New ensemble and stochastic approaches.



Example of sea surface height from the DMI operational ensemble forecasts

Location misfit [km] of SSS after 15 days of simulation in an Initial Conditions perturbed Western Mediteranean Ensemble [Leroux et al., 2022]



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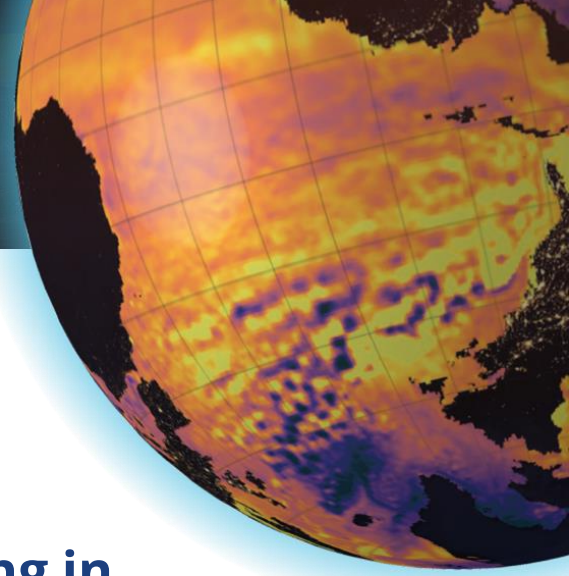


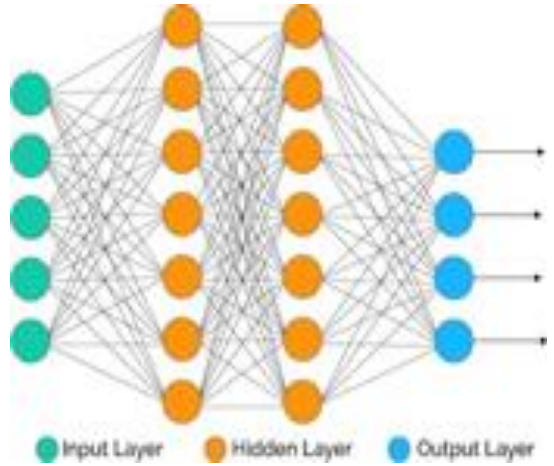
Operational Production Chains: New Modelling Techniques

➔ What are the opportunities and risks of using AI and machine learning in traditional coastal ocean forecasting frameworks?

Ocean science, creates knowledge through reproducible experiments and predictive models.

The rise of AI offers new ways to enhance regional and coastal ocean data analysis and modeling. Recent advancements in machine learning include: theories, methods, and architectures.

Enhanced integration of existing schemes into ocean modeling.



- AI methods (based on observations) for probabilistic forecasting.
- Synthetic high resolution map generation.
- Ability to correct systematic deficiencies of hindcasts.
- Downscaling

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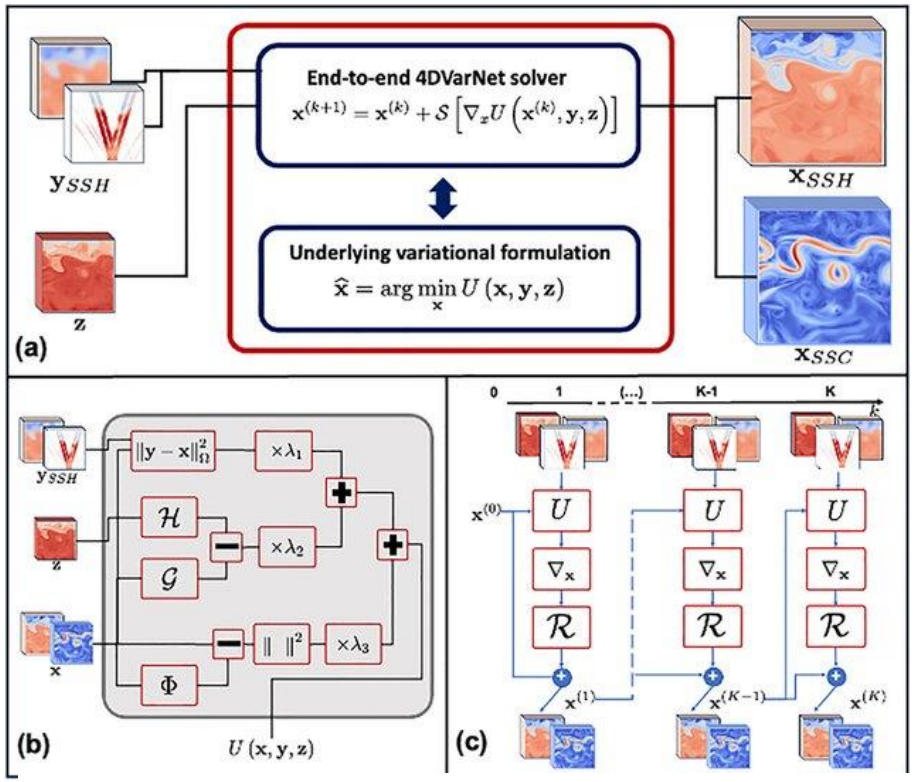
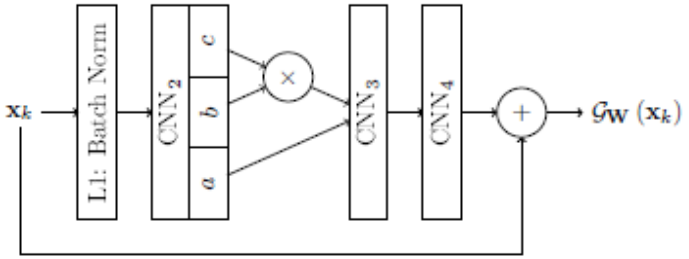
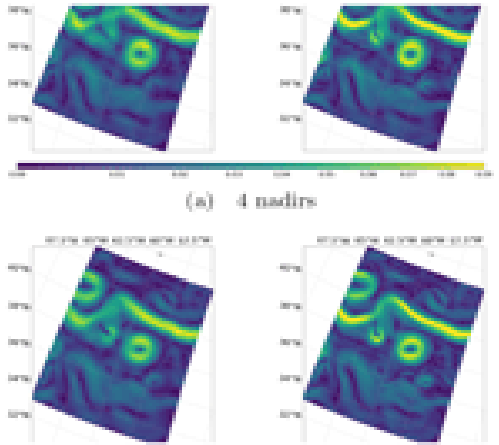
Inversion of Sea Surface Currents From Satellite-Derived SST-SSH Synergies With 4DVarNets



Beauchamp, M., et al 4DVarNet-SSHhttps://doi.org/10.5194/gmd-16-2119-2023, 2023.

Combining data assimilation and machine learning to emulate a dynamical model from sparse and noisy observations





Julien Brajard et al., 2020, https://doi.org/10.1016/j.jocs.2020.101171

Related Applications of ML in Downscaling

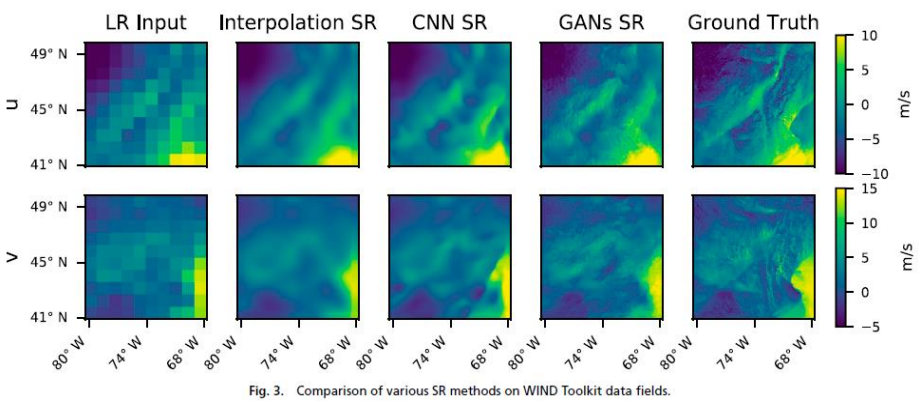
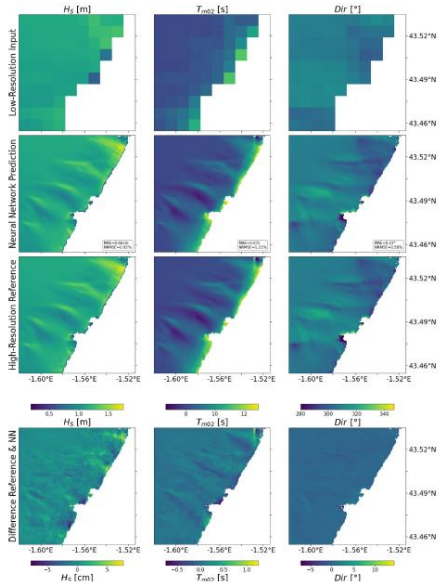
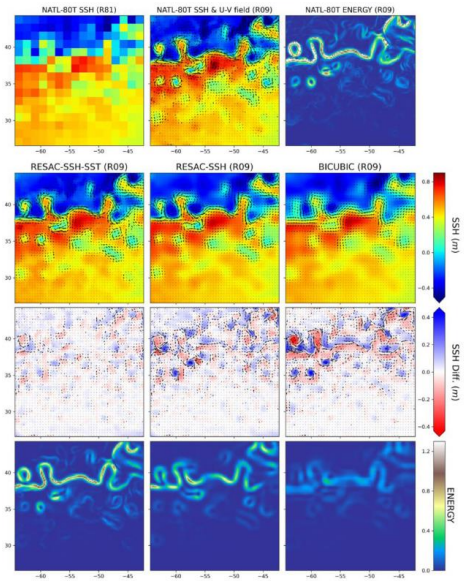


Fig. 3. Comparison of various SR methods on WIND Toolkit data fields.

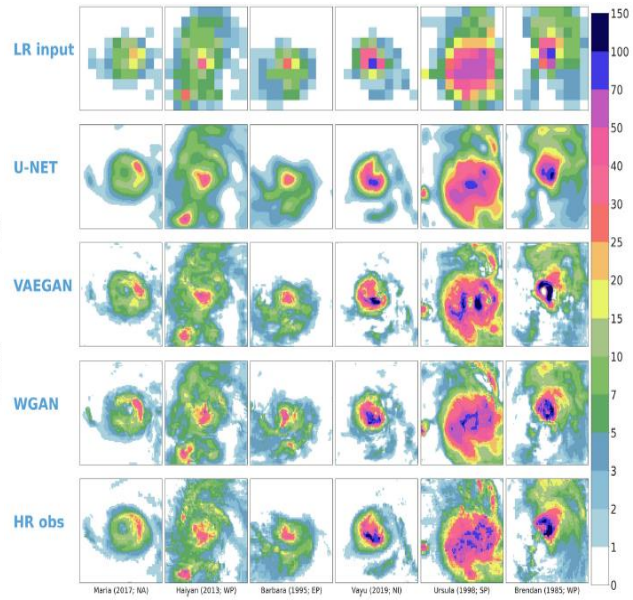
Wind, scale 50 (Stengel et al., 2020)



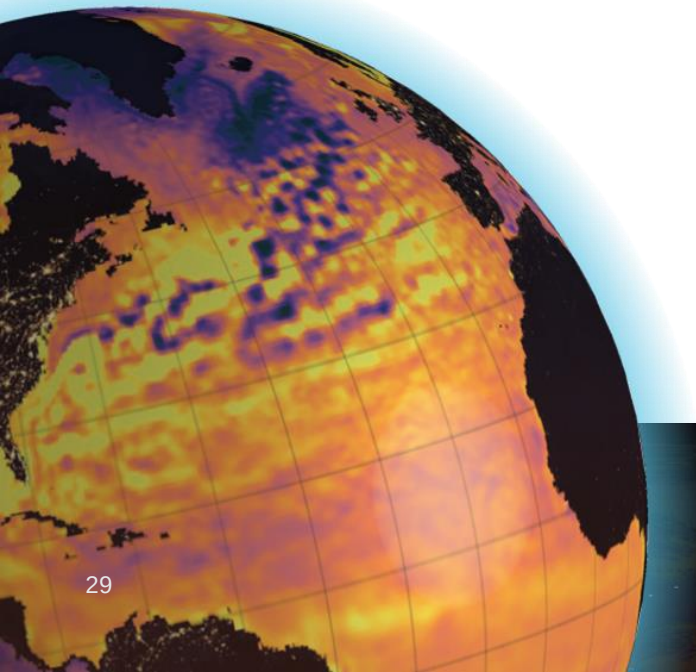
Wave parameters 800 m -> 50 m (Kuehn et al., 2023)



SSH and currents 120 km -> 13 km (Thiria et al., 2023)



Tropical cyclone rainfall, scale 10 (Vosper et al., 2023)



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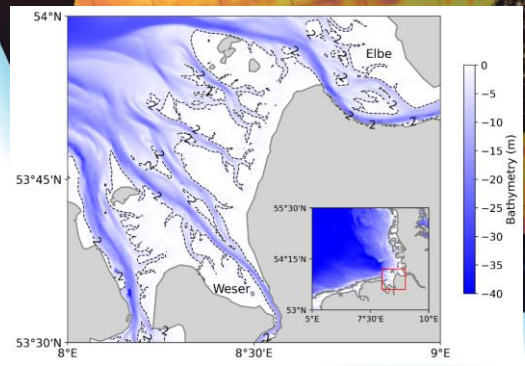
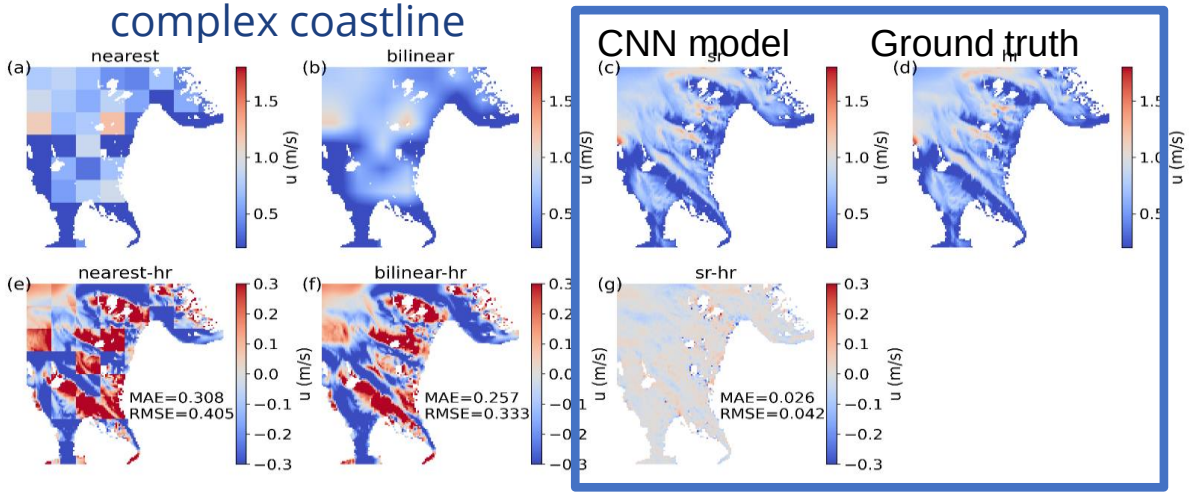
AI Applications for coastal predictions

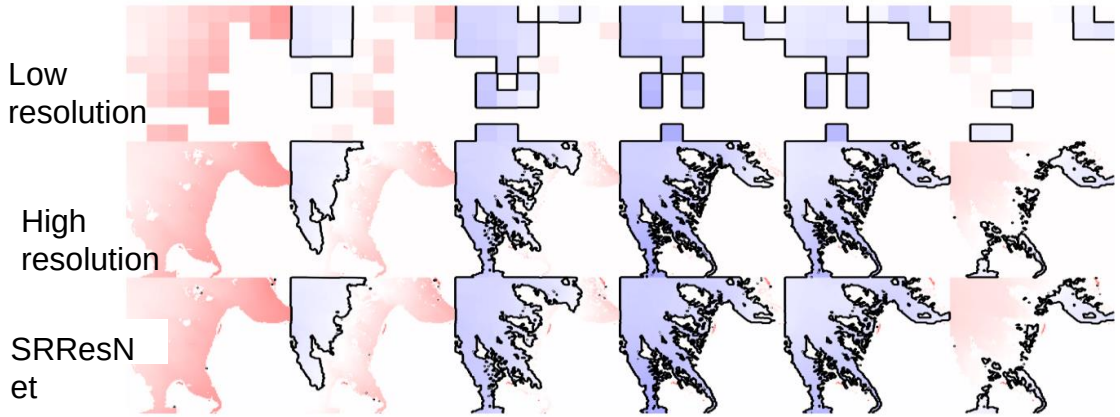
- Relevance
  - Efficient downscaling of coastal fields to a scale of 100 meters
  - Potential addition/alternative to regional marine services like COPERNICUS Marine
- Methodology
  - Super-resolution residual network (SRResNet), a CNN-based deep learning model, upscale factor up to 64
  - Datasets from high-resolution numerical model output in a coastal region with complex coastline



Part of the coastal region of German Bight: tidal range 2-4 m, frequent flooding and drying



Downscaled depth-averaged current *u* from SRResNet



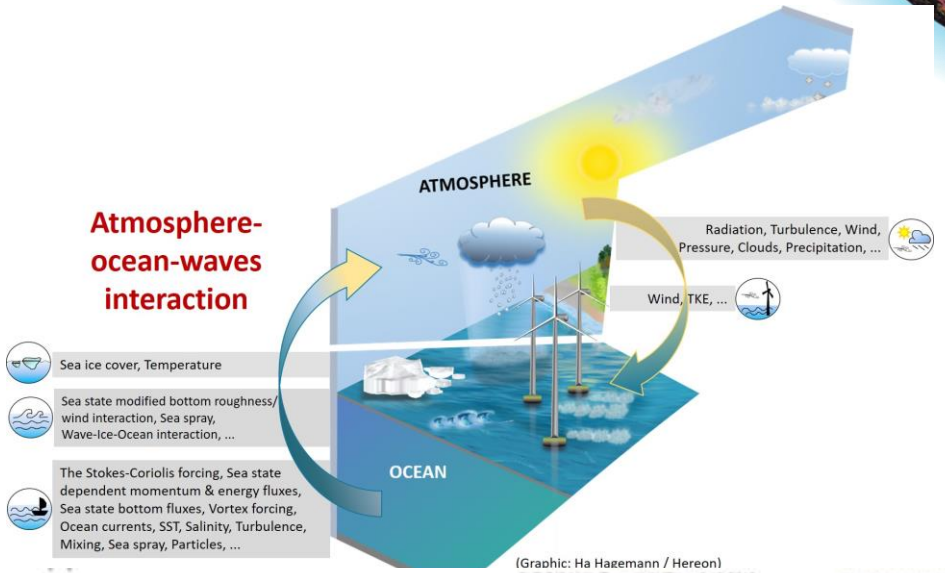
Normalized downscaled SSH from CNN model at 6 hours

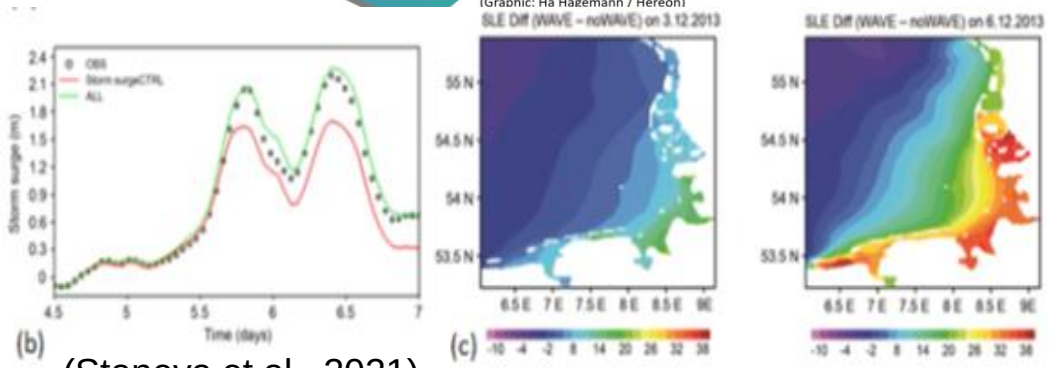
•Yuan, B., Jacob, B., Chen, W., & Staneva, J. (2024): Downscaling sea surface height and currents in coastal regions using convolutional neural network. Applied Ocean Research, Vol 151, 104153, doi:10.1016/j.apor.2024.104153

FOCCUS

Coupling with waves and atmosphere

- Increased demand for improved regional and coastal forecasts
- Reducing errors of state estimates at coastal scales – non-linear feedback between ocean and atmosphere
- Assessment of the degree of regional coupling
- Study the impact of on the quality of regional and coastal predictions
- Extreme weather events in the marine realm
- Substantial effects also on mean fields (climate simulations)





(Staneva et al., 2021)

Improve and advance the coastal dimension

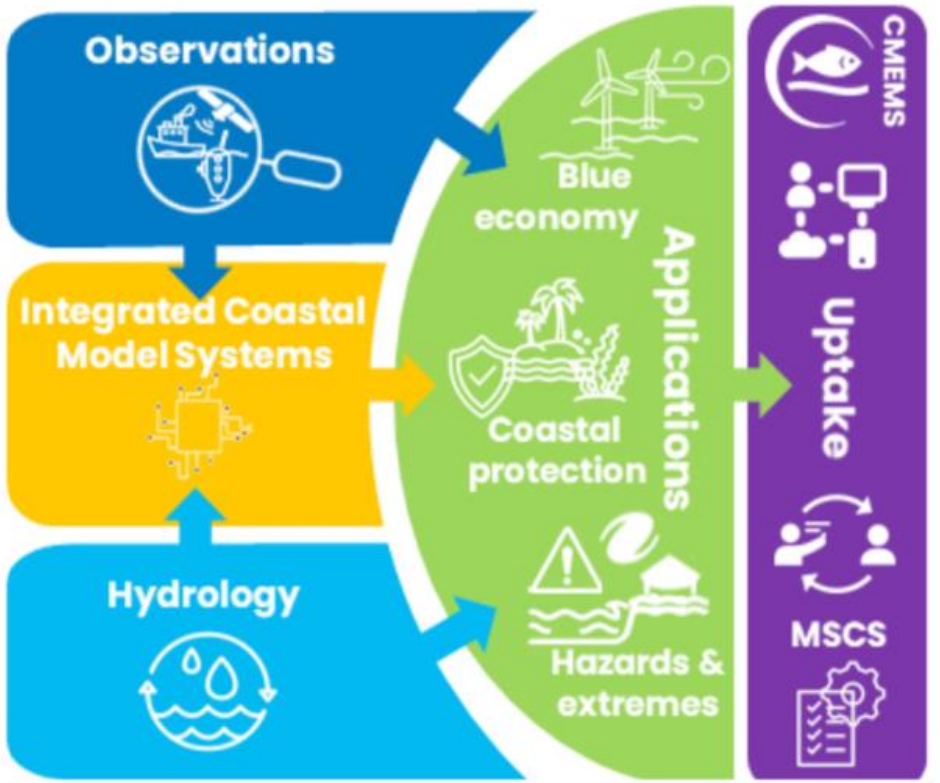
- Coupling of Global and Regional (Copernicus Marine) and coastal systems

implemented through **co-design and co-production**

- harmonization of products

Develop advanced and seamless coastal monitoring and forecasting systems

- joint effort based on novel approaches
- better constrain the coastal applications and models developed at the national and local levels



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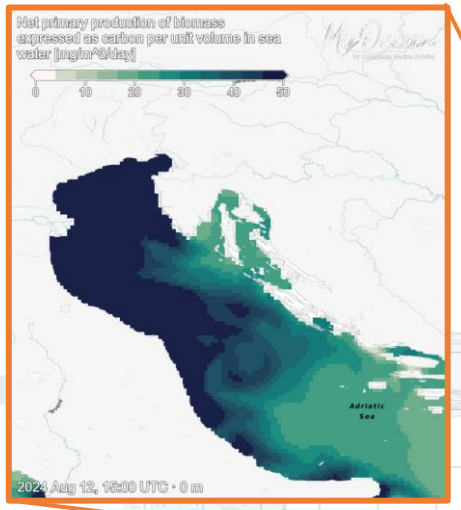
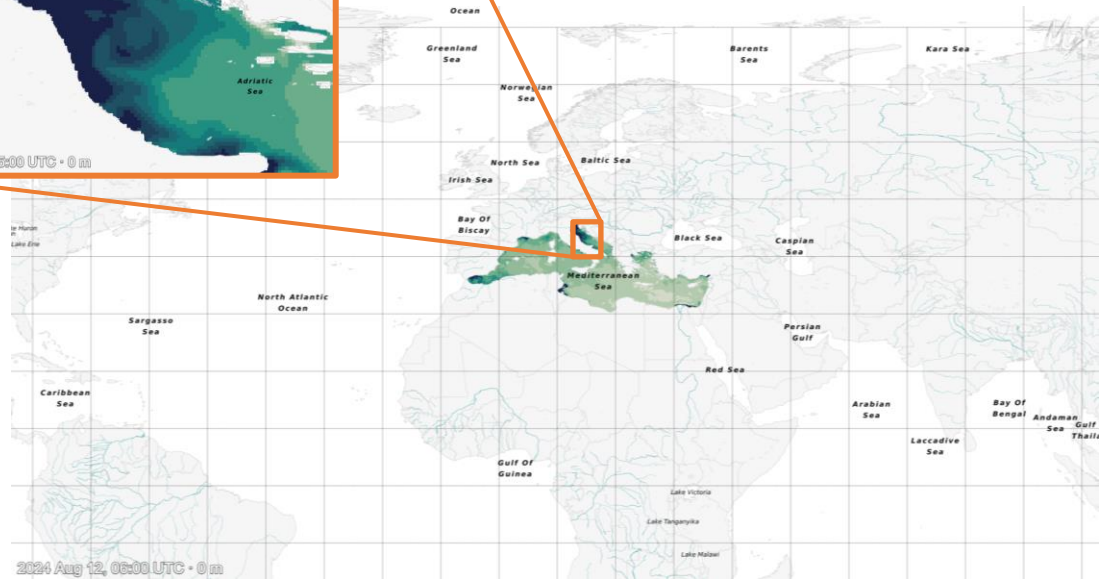
Why is coastal prediction vital?

Summer 2024 heat wave impacts in the Adriatic Sea





Multi aspect approach

FAIRSEA project

Interreg Italy - Croatia FAIRSEA

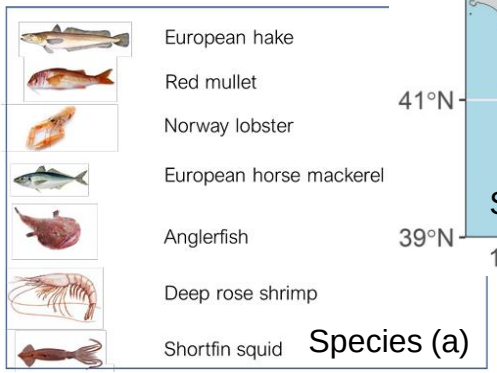
EUROPEAN UNION

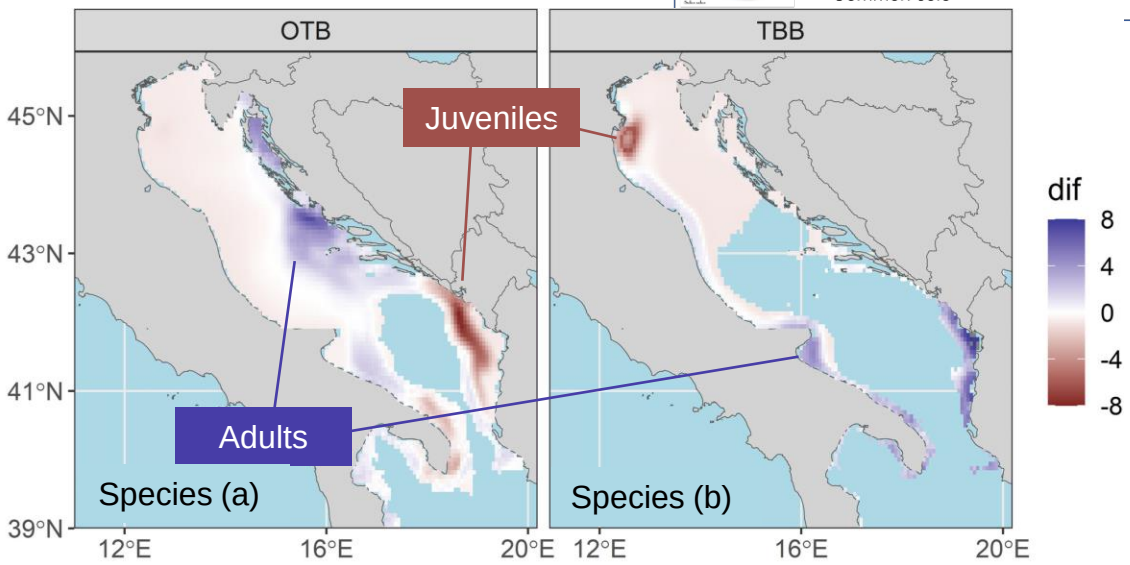
Fisheries in the Adriatic region - a shared ecosystem approach (2019-2021)

- Across territorial boundaries
- Physical, chemical and biological processes included
- Decision support tool for spatial management

Coastal bio end-to-end prediction

Differences of the Getis hot-spot index between adults and juveniles for 10 demersal species





Panzeri et al., 2024, Fish & Fisheries

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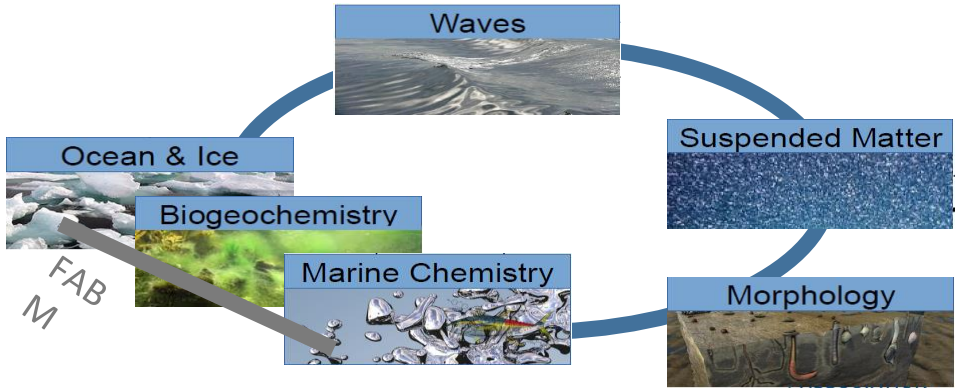
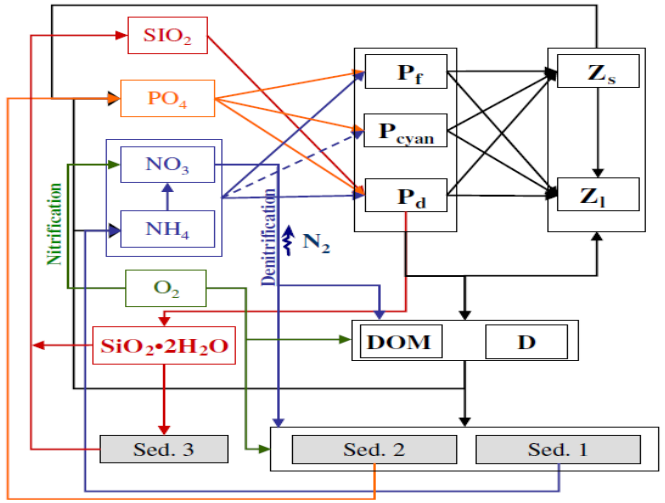
Coastal Forecasting biodiversity

The German Bight seen from satellite Sentinel-2 - image: Hereon

Coupled hydrodynamical-biogeochemical numerical model 3D

SCHISM — FABM — ECOSMO/ MAECS/ SPM





P_f	flagellates
P_{cyan}	cyanobacteria
P_d	diatoms
Z_l	large zooplankton
Z_s	small zooplankton
DOM	"dissolved organic matter"
D	detritus
Sed. 1	sediment
Sed. 2	phosphate sediment pool
Sed. 3	silicate sediment pool

- Unstructured geometry, wetting and drying algorithm, baroclinic, benthic-pelagic coupling
- Realistic runs with tidal motion, freshwater runoff, along-channel dispersion, lateral exchange (channel-flats)
- Relocatable - Cross-scale processes
- Land-ocean continuum - transport for materials, erosion. harmful algal blooms

Coastal bgc-benthic prediction

SYMPOSIUM OP'24

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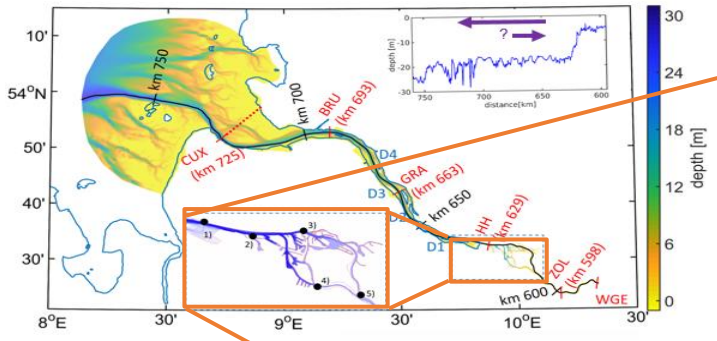
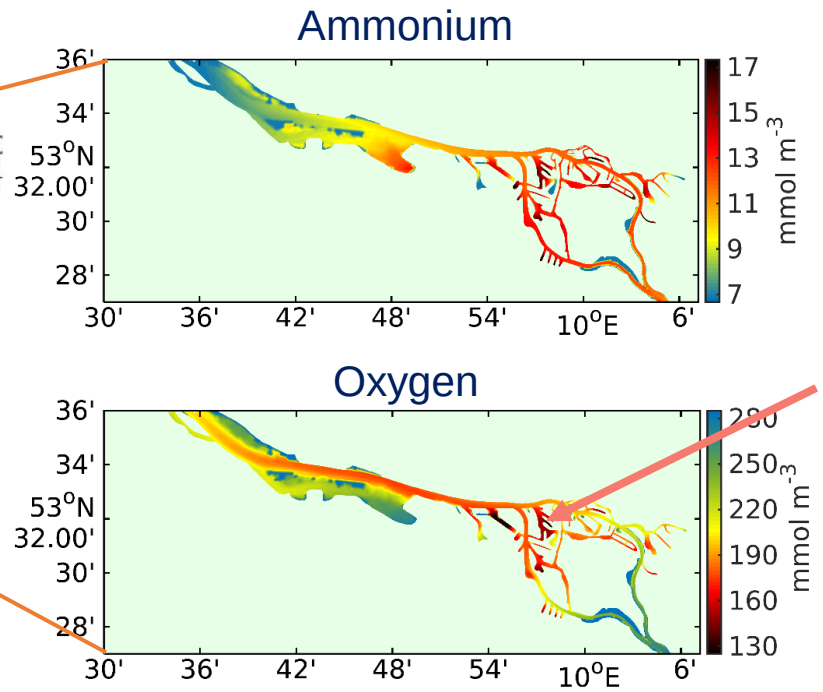
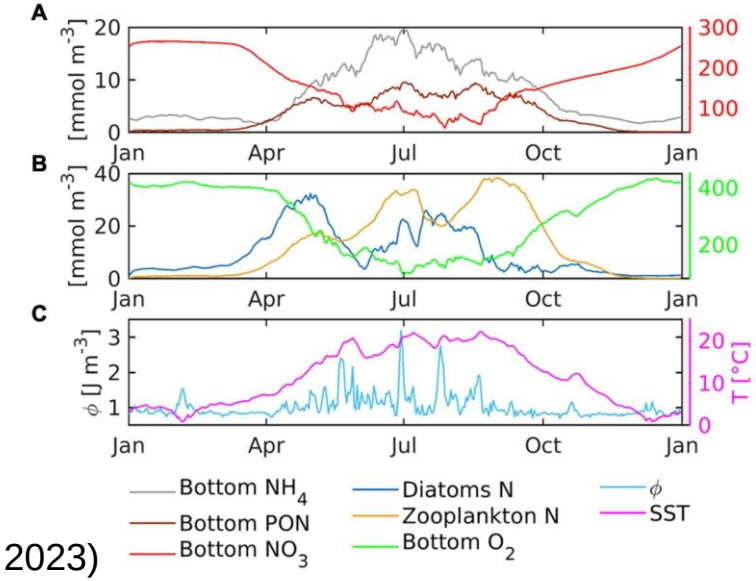
Coastal Forecasting biodiversity

- Accumulation of biogenic particles, sedimentation in port
- Port basins hotspots of ammonium release and oxygen depletion
- Heat waves, stratification trigger hypoxic response

Identification of estuarine hotspots of eutrophication







Coastal bgc-benthic prediction

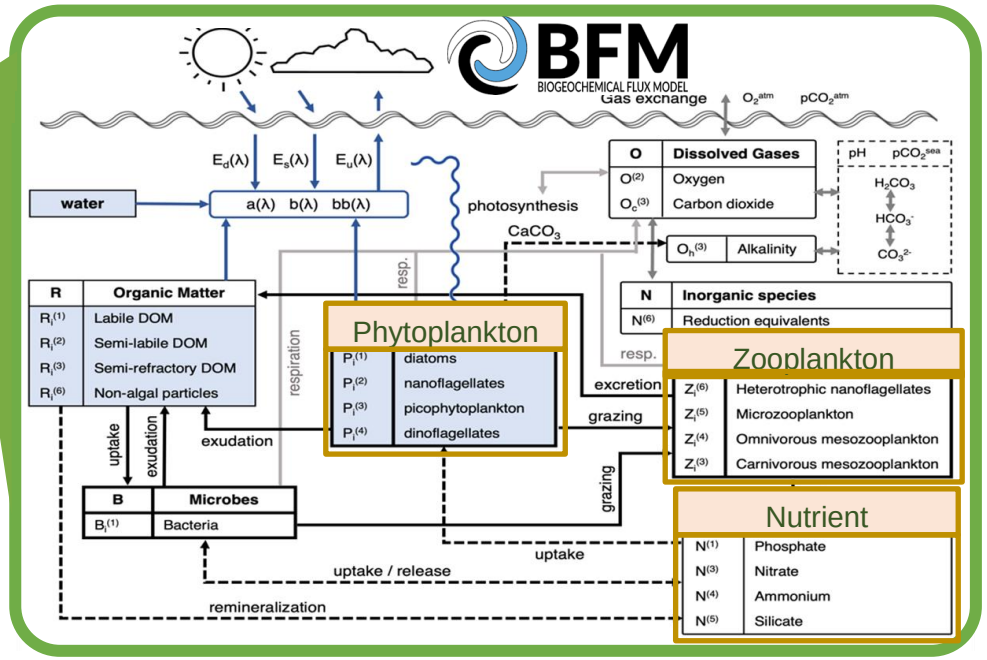
(Pein et al et al., 2023)

Helmholtz-Zentrum hereon

Coastal biogeochemical prediction

Transport – Diffusion – Reaction

- Current velocities
- Turbulent diffusivities
- Temperature, salinity, wind, irradiance



Salon et al., 2019, Ocean Science

- Interaction with ocean dynamics
- Boundary conditions
- Nesting
- Integration of modelling and observations

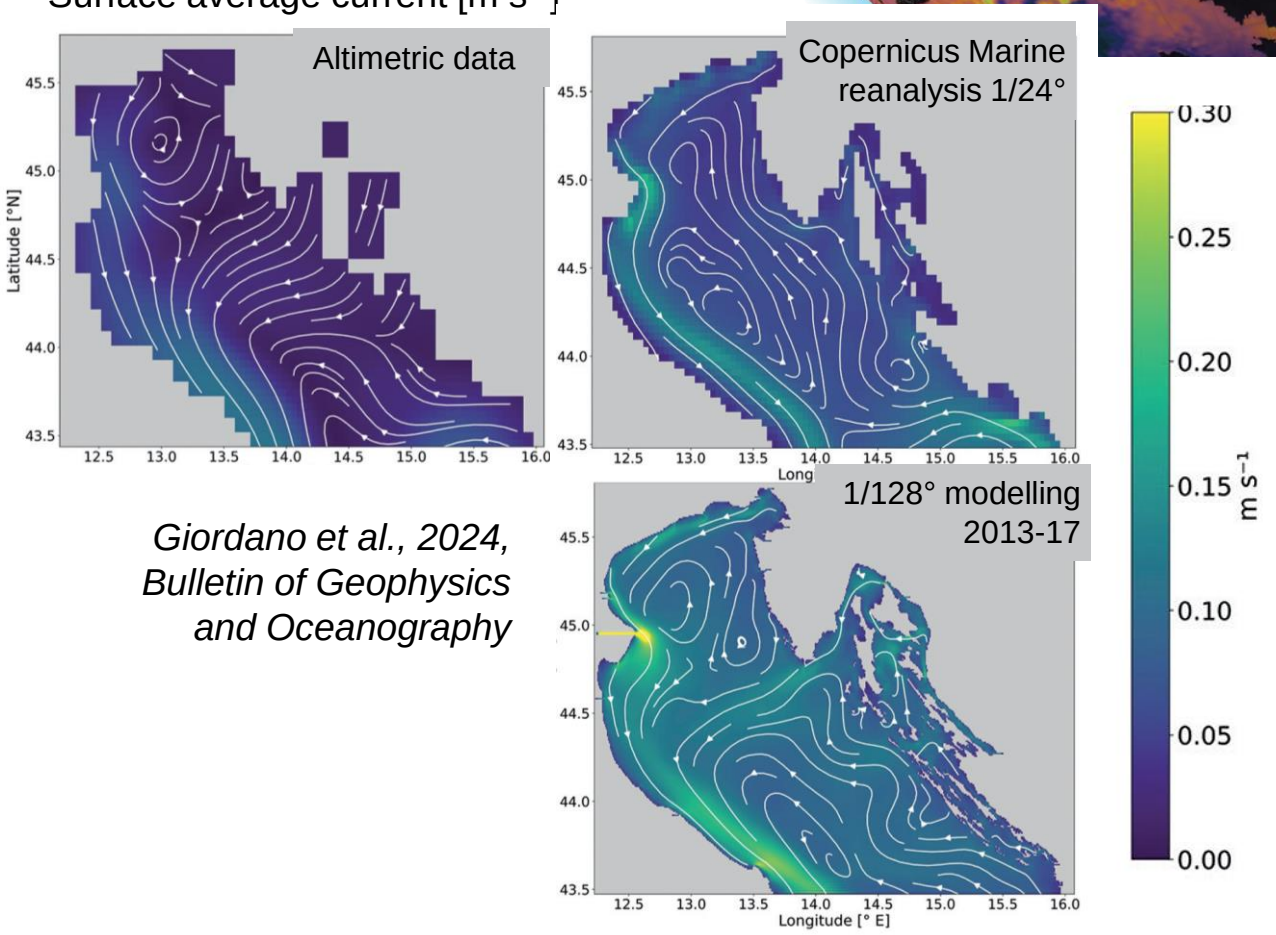
In a coastal environment

Interaction with ocean dynamics

- Temperature-dependent biogeochemical reactions
- Transport of biogeochemical components by ocean dynamics
- Nutrient supply by vertical and lateral advection

Temporal and spatial resolution

Surface average current [m s^{-1}]

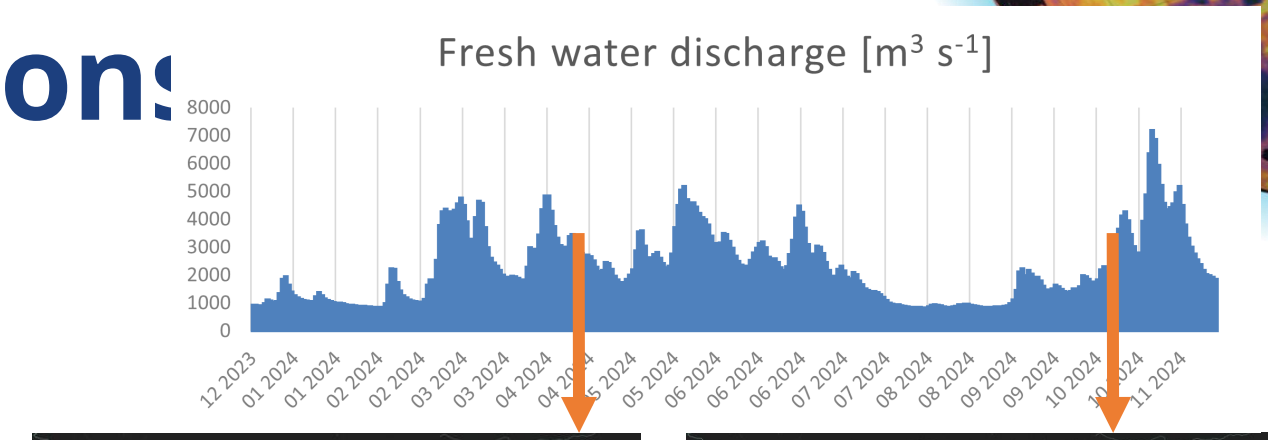


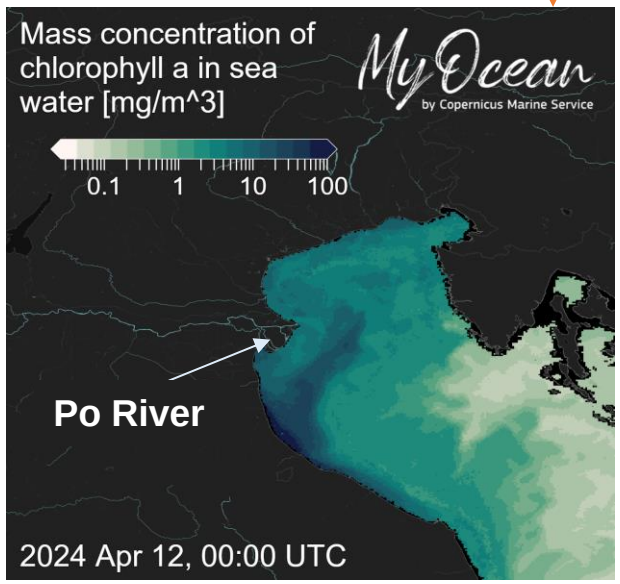
Giordano et al., 2024, Bulletin of Geophysics and Oceanography

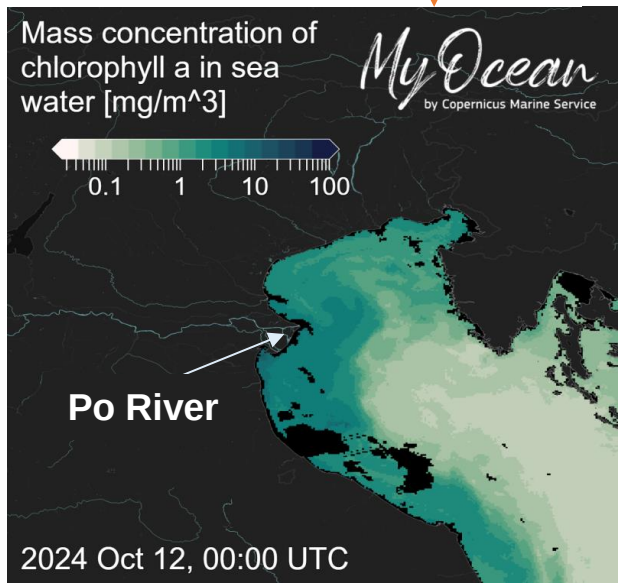
Boundary conditions

- Nutrient and carbon discharge
  - Spatial and temporal scales aligned with physics
  - Inclusion of near real time information (EFAS https://www.copernicus.eu/en/european-flood-awareness-system)
- Interaction with the bottom
  - Specific modelling and/or calibration

Temporal and spatial scales







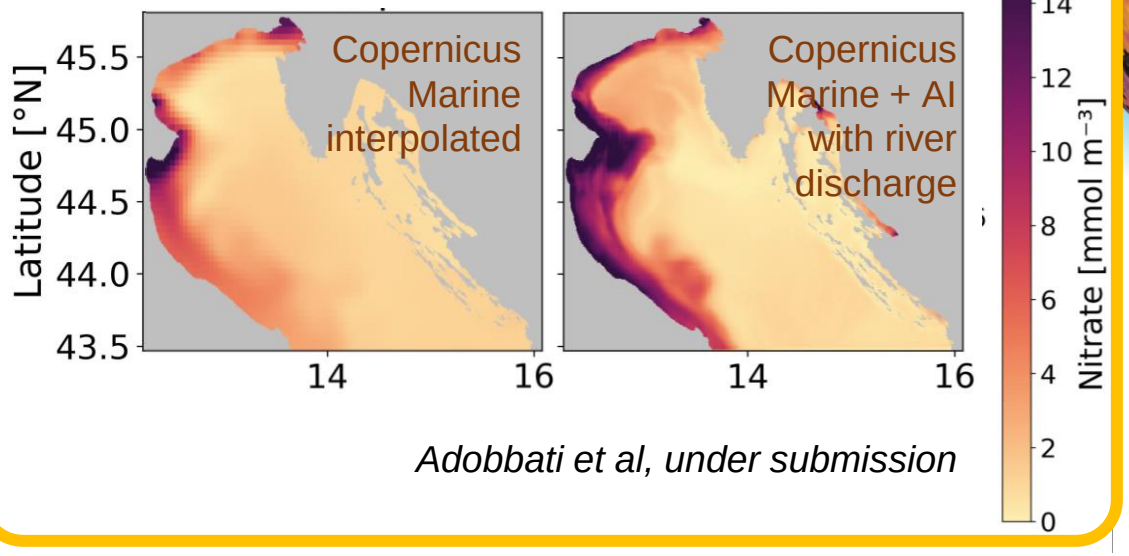
Satellite chlorophyll concentration [mg m^{-3}] - Copernicus Marine Service

Nesting

- Basin wide prediction systems
- Initial conditions
- Open boundary conditions

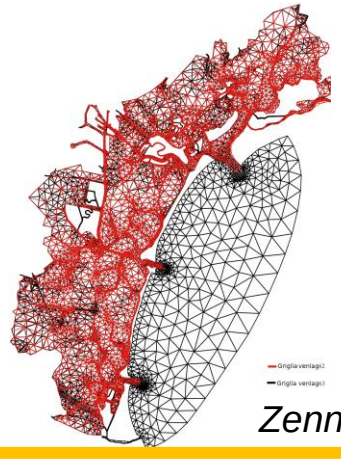
Interaction between coastal, regional, basin-wide scales

Use basin-wide model as initial condition



Adobbati et al, under submission

SHYFEM unstructured grid



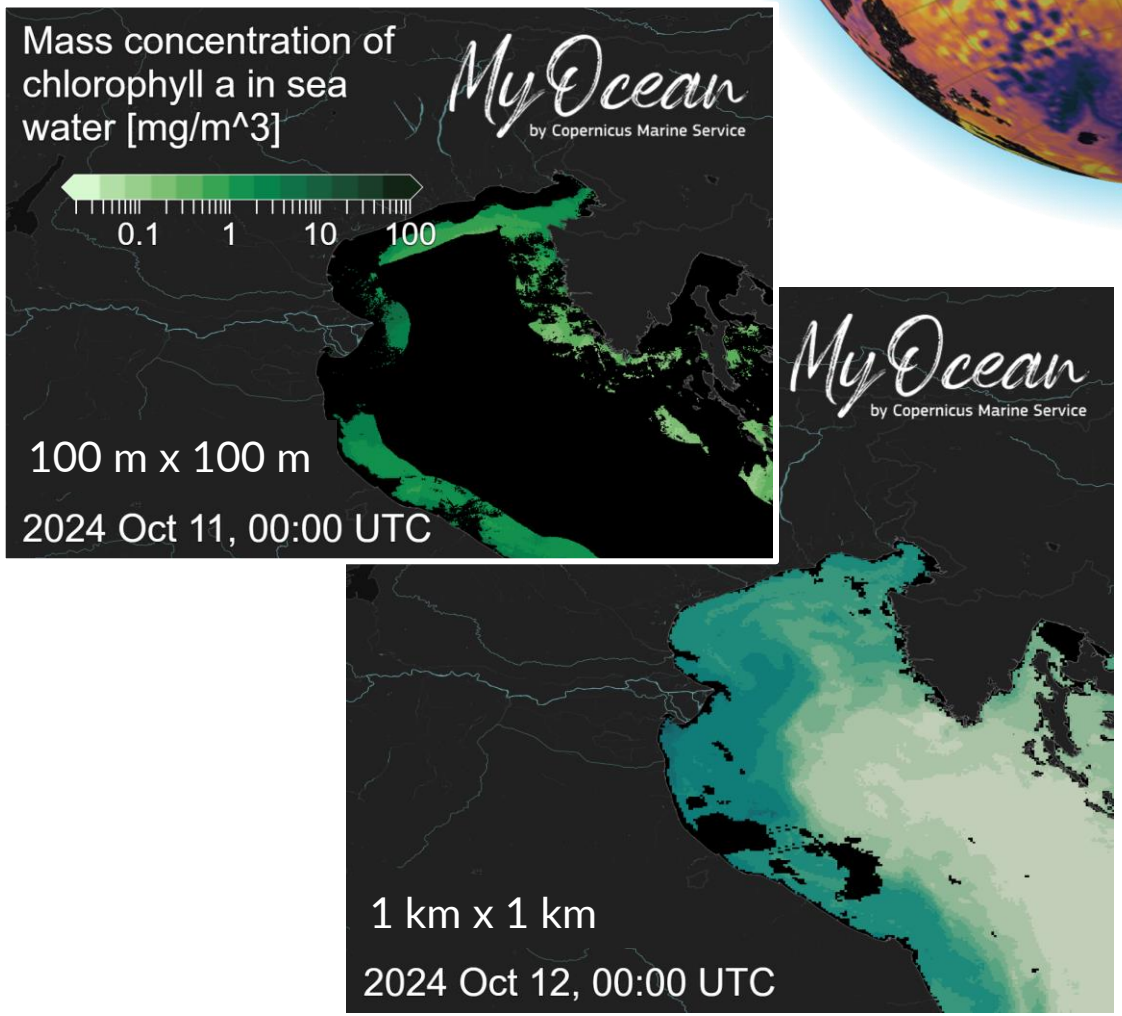
Venice Lagoon
3D hydrodynamic model
Coupled with
biogeochemistry, ecology,
sediment transport, pollution

Zennaro et al., 2024, Ecological Indicators

Observations

- Satellite
  - Available in near real time
  - Chlorophyll and optical variables
  - Surface with cloud coverage
  - Algorithms for coastal conditions

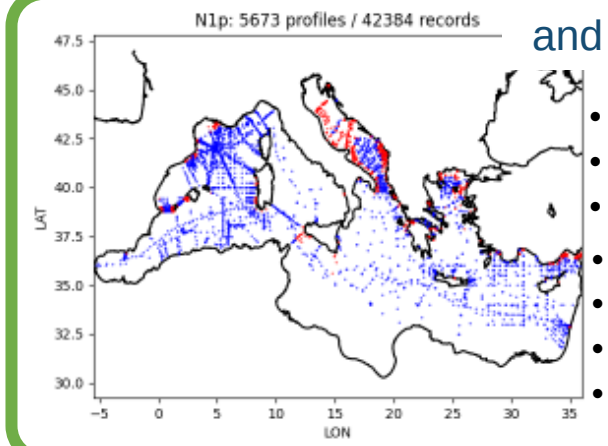
Copernicus Marine satellite product



Observations

- In situ
  - Large set of variables
  - Accessibility

European Marine Observation and Data Network (EMODnet)

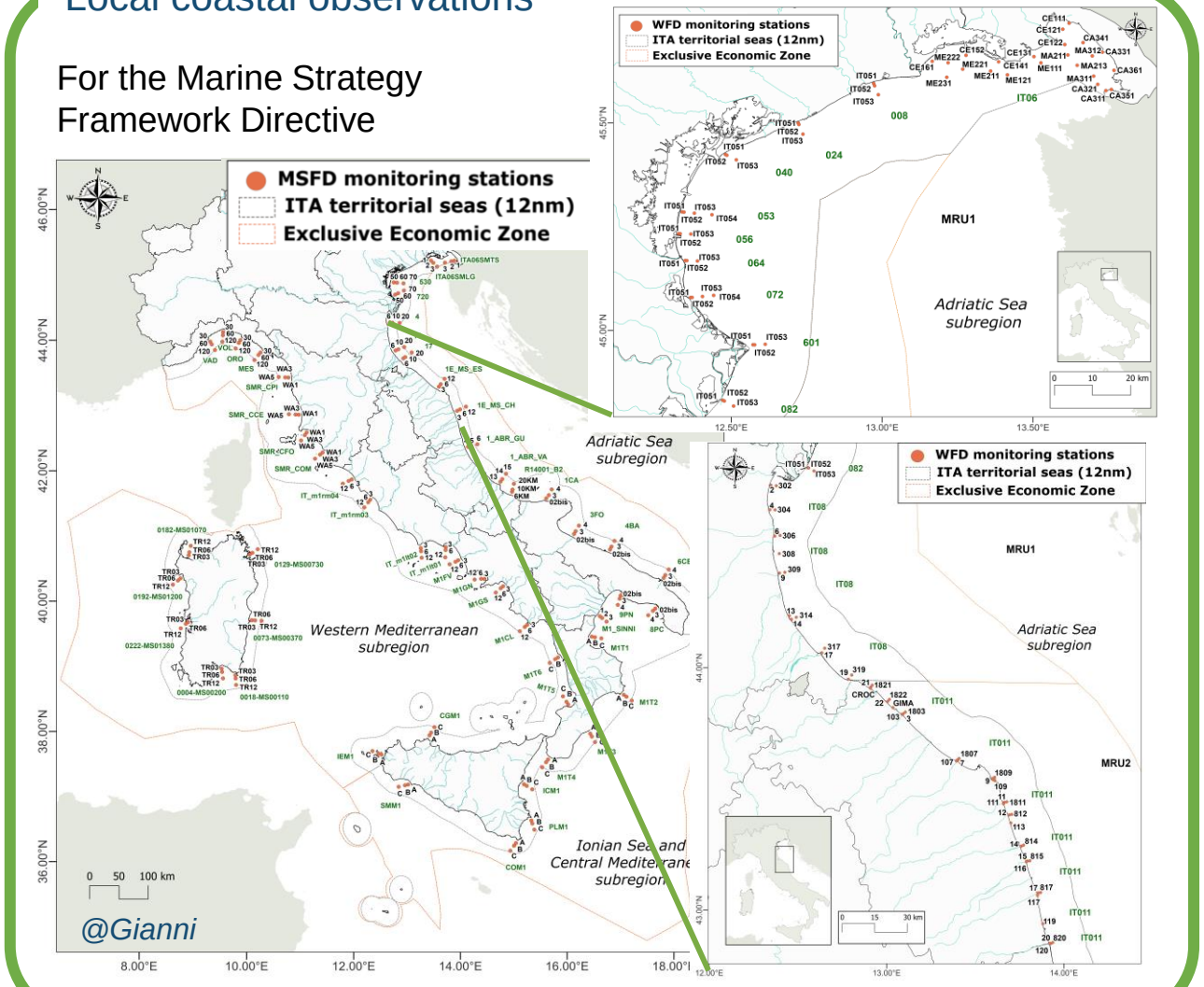


- Alkalinity
- Dissolved organic matter
- Partial pressure of CO2
- Phosphate
- Nitrate
- Ammonium
- Oxygen

@Di Biagio

Local coastal observations

For the Marine Strategy Framework Directive



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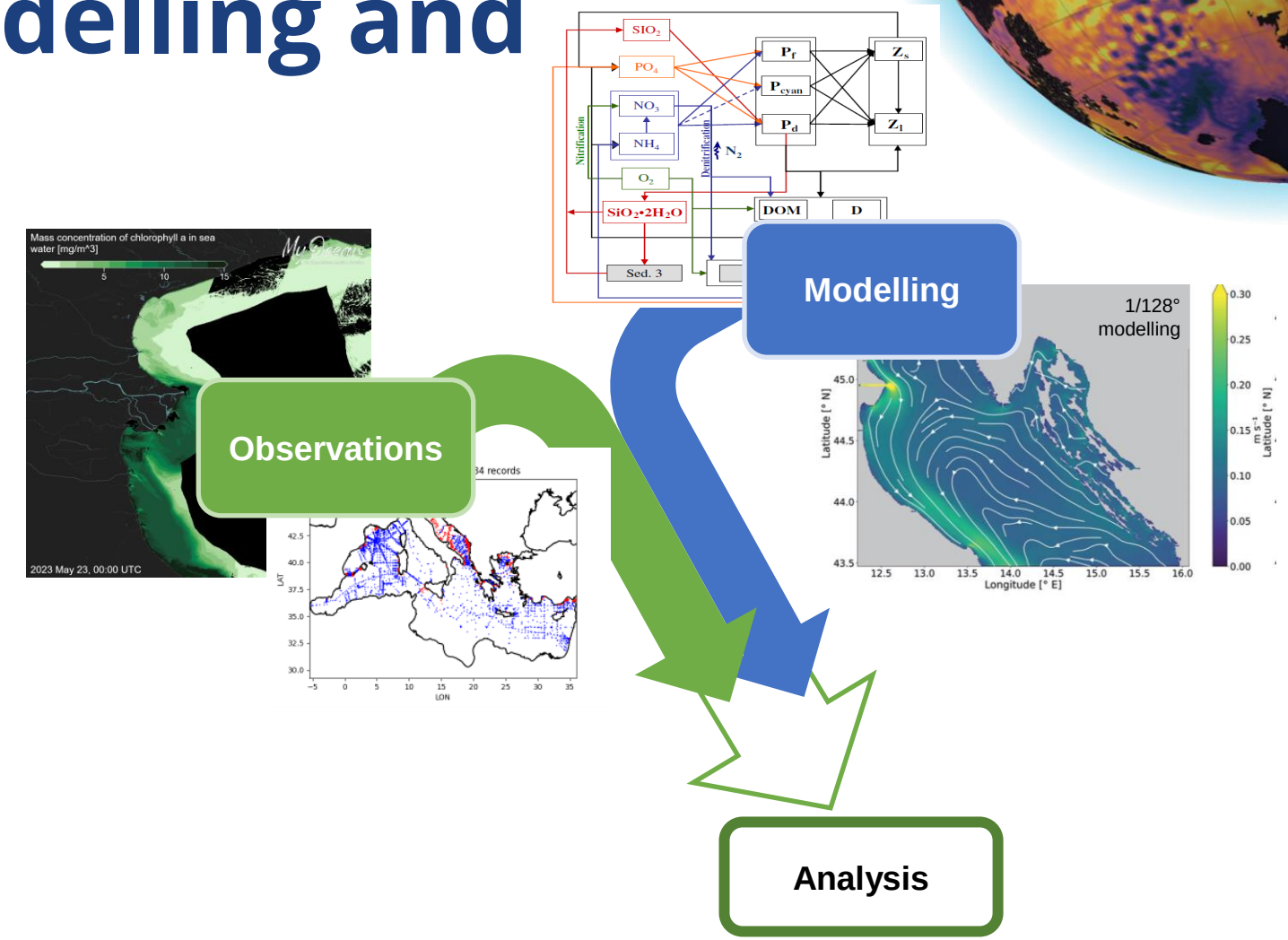
Integration of modelling and observations

Data assimilation

- Multivariate and multiplatform
- State or parameter estimation
- Coupled physical and biogeochemical assimilation



Seamless European HORZON Project

Data assimilation -DA

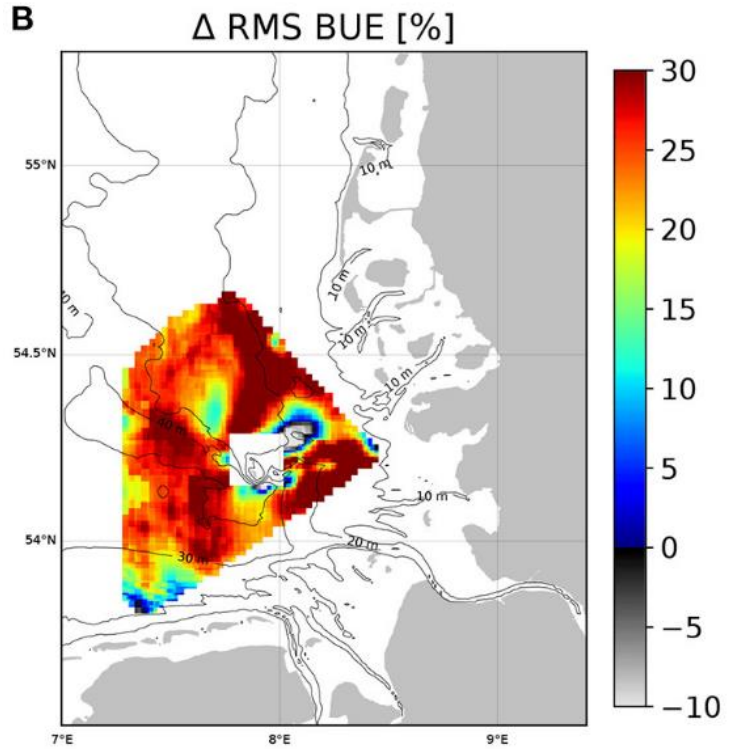
FOCCUS

Optimized coastal observations

- Optimized high-resolution coastal observation products
- Tailored observation operators allowing the simulation of innovative observations

Optimized DA scheme for coastal systems

- DA schemes suitable for coastal systems with short memory and strong dependence on boundary forcing
- Use of AI approaches to optimize DA methods, e.g. representation of model errors
- Strategies to integrate innovative DA methods into the Copernicus Marine downstream data flow



Improvement of surface currents achieved by 4DVAR assimilation of HFR observations

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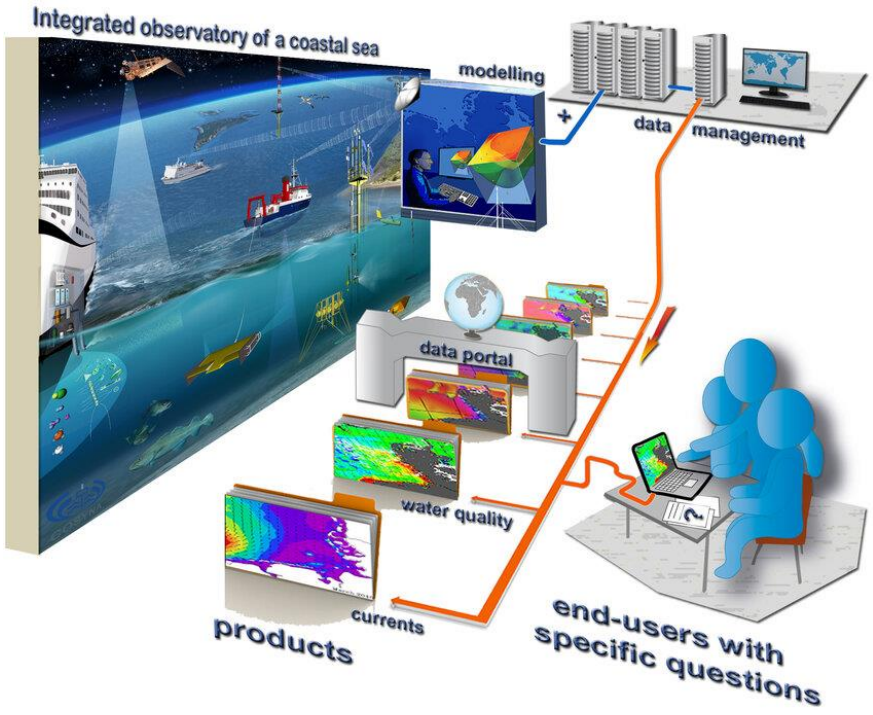
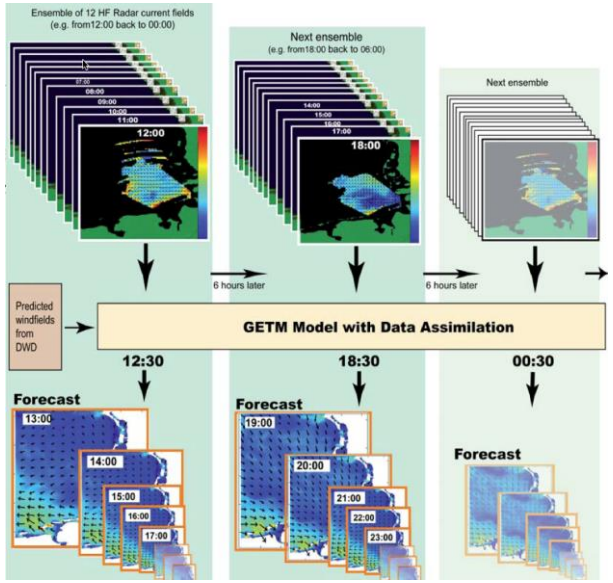
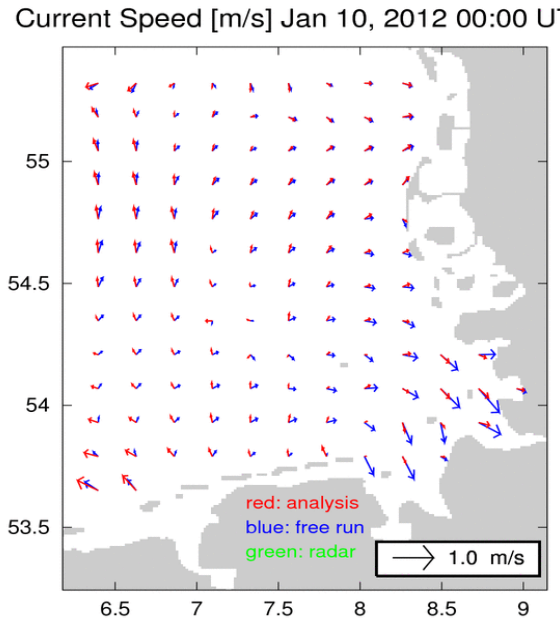
COSYNA - Coastal Observing and Forecasting System for Northern and Arctic Seas







Coastal Ocean Forecasting

Helmholtz-Zentrum hereon

User applications and societal benefits

MER Italian ongoing project (started 2024)

MARINE ECOSYSTEM RESTORATION

Finanziato dall'Unione europea NextGenerationEU

MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA

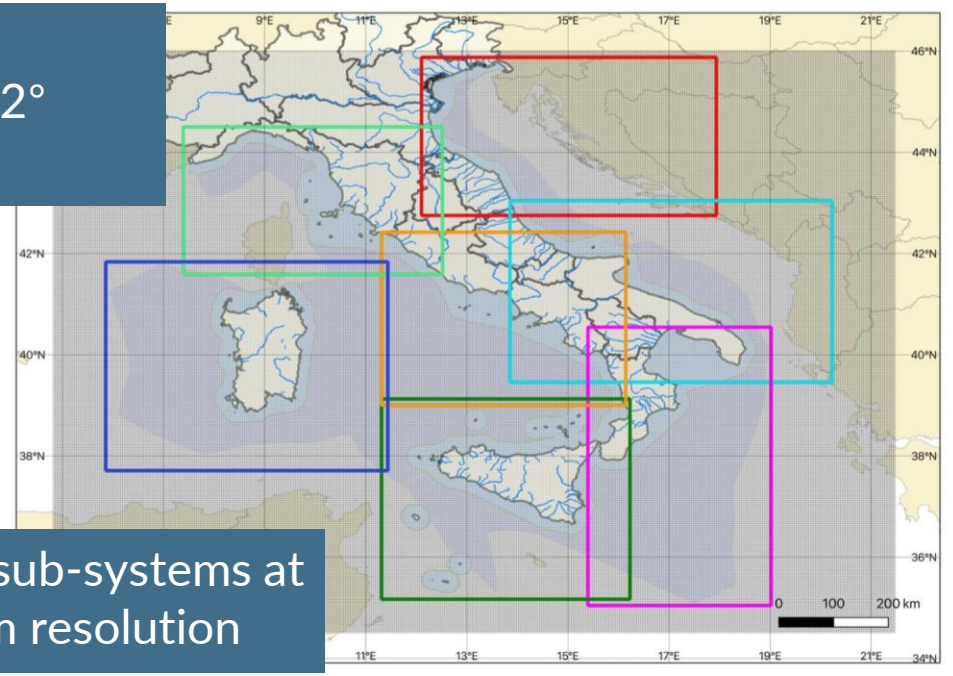
ISPRA

Operational prediction on Italian coastal systems

- Restoration and protection of the seabed and marine habitats
- Strengthening of the national system for the observation of marine and coastal ecosystems
- Mapping of coastal and marine habitats

MITgcm-BFM 1/192°
(500 m)
7 coastal system

Interfaces with European Copernicus services and other systems for ICs and BCs



+ 10 sub-systems at 100 m resolution

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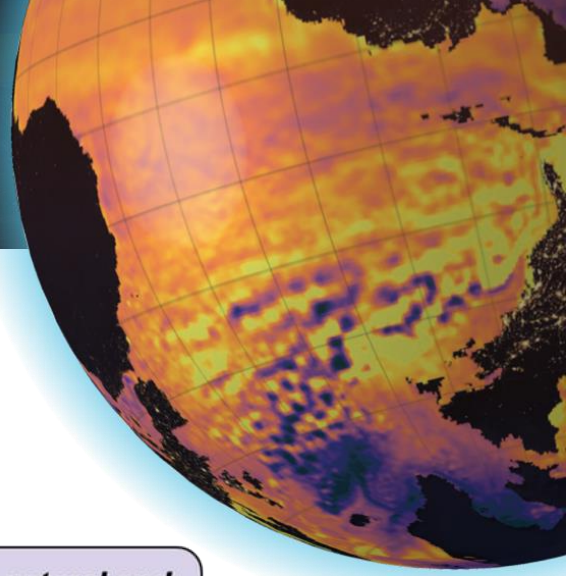


FOCCUS: Applications

FOCCUS

Environmental and Societal Challenges (ESCs)

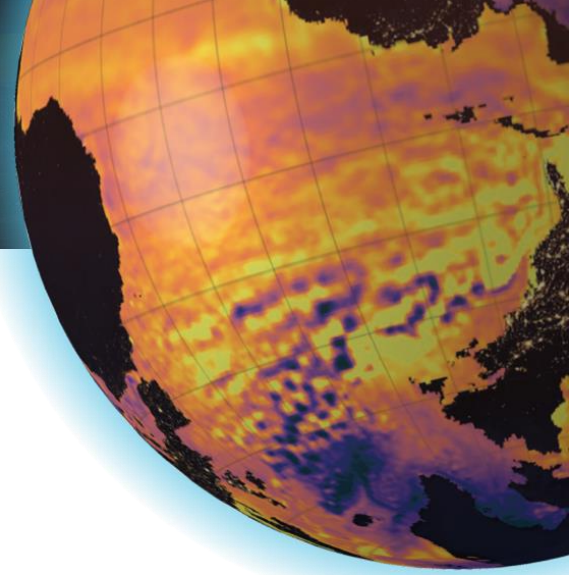
ESC 1 - Applications to better manage and protect the coastal area

ESC 2 - Applications to enhance blue economy

ESC 3 - Application related to natural and anthropogenic hazards and building resilience to climate change

Visit our oral presentation!
Thu. 21th 11:00
Room II

FOCCUS



Outlook - Optimizing integrated coastal prediction systems

From process studies to coastal operational oceanography

- Improve forecasting capabilities of short spatial-temporal scales
- Novel techniques

AI, Ensemble modelling

- Optimal use of observations in data assimilation and calibration

Novel High-Resolution observations

- Improved interfaces

Land-Ocean Continuum

Regional and basin-wide forecasting systems

- Interdisciplinary model integrations for fit-for-purpose applications

Integration in DTO technology

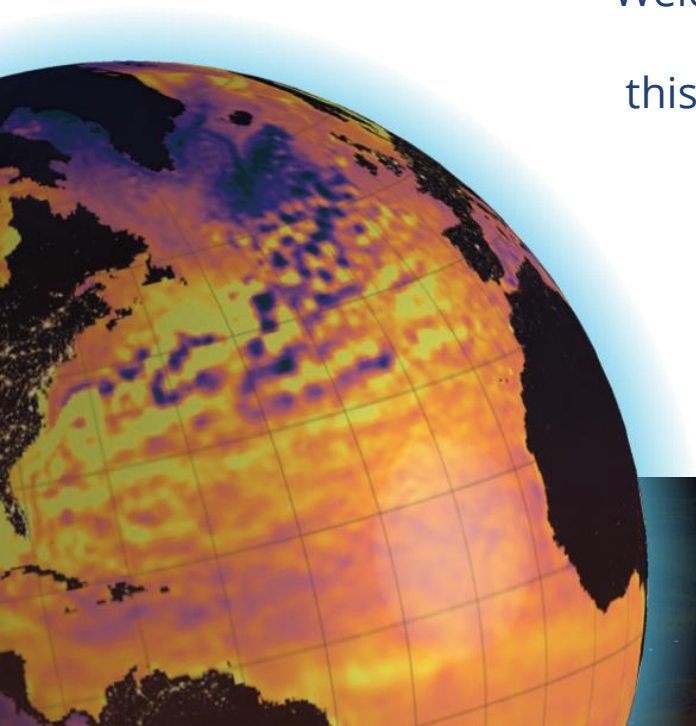
Coastal engineering, search and rescue ecosystem, green energy, coastal management, response to climate change

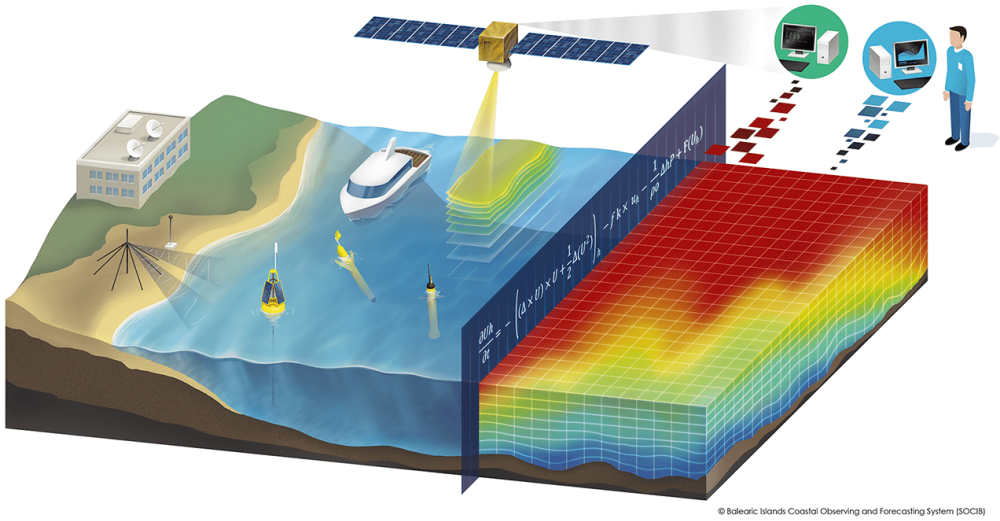
Networking

UN Ocean decade

Coastal Ocean and Shelf Seas Task Team (COSS-TT) meeting

Welcome to join the COSS-TT meeting
(Room III)
this Wednesday, 20 November, 2024
12:45-13:45





© Balearic Islands Coastal Observing and Forecasting System (SOCIB)

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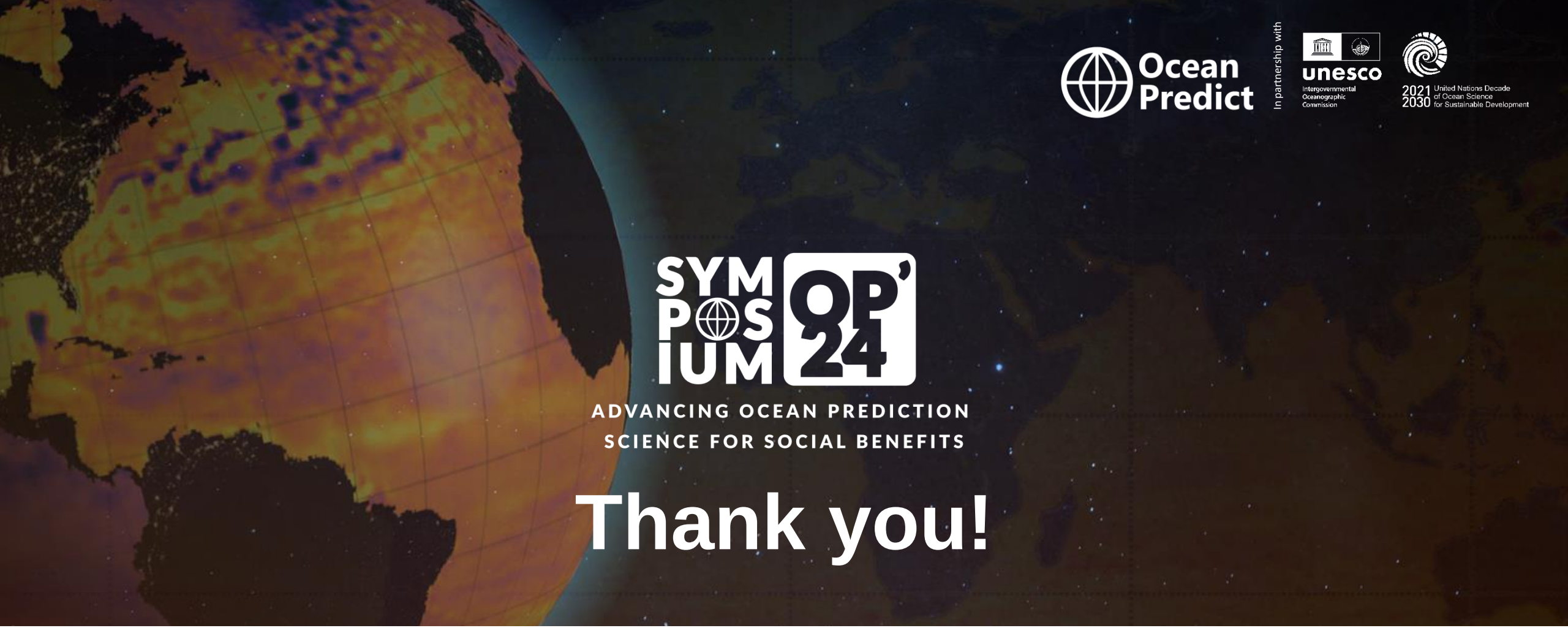

European Commission

Copernicus Marine Service

EU4oceanobs
INTERNATIONAL OCEAN GOVERNANCE
EU COMPONENT TO GLOBAL OCEAN OBSERVATIONS

esa

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

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Canada