Copernicus Marine Service

COPERNICUS MARINE
8th GENERAL ASSEMBLY

EstuarIO

Estuarine box model for interfacing rivers and Ocean

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

PROGRAMME OF THE EUROPEAN UNION
Copernicus Europe's eyes on Earth
Copernicus Marine Service
implemented by MERCATOR OCEAN INTERNATIONAL

EstuarIO

Copernicus Marine Service *Evolution Project*

SERVICE EVOLUTION
COPERNICUS MARINE SERVICE
Until 7 August 2024
Contract 21036-COP-INNO SCI

Centro Euro-Mediterraneo sui Cambiamenti Climatici

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STIIMA Rosalia Maglietta (Co-I)

EstuarIO Objectives

❖Better representation of **river release** in the **Mediterranean and Black Sea** operational systems within **Copernicus Marine Service** to improve the river plume and the basin-wide thermohaline dynamics

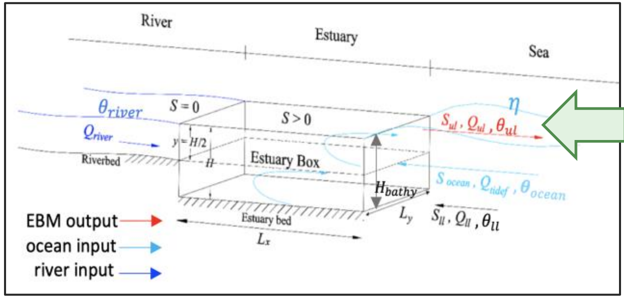
❖ *Release of an **Estuary Box Model Tool**, merging machine learning ML-based and physics-based approaches, to be coupled with the Copernicus BS-MFC and Med-MFC*

❖ ***Tailored EBM** for the **target rivers** Rhone, Ebro, Po, Danube by (i) high 3D finite element modeling of the river-sea continuum and (ii) EO Satellite observations to support the EBM train and test*

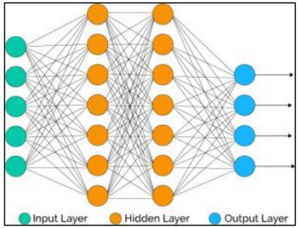
The *low complexity* *1D* box modeling of the estuaries

- ***AIM***: **fill the gap** between hydrology and mesoscale ocean modelling

https://www.estuaryboxmodel.org



ML Ensemble Learner



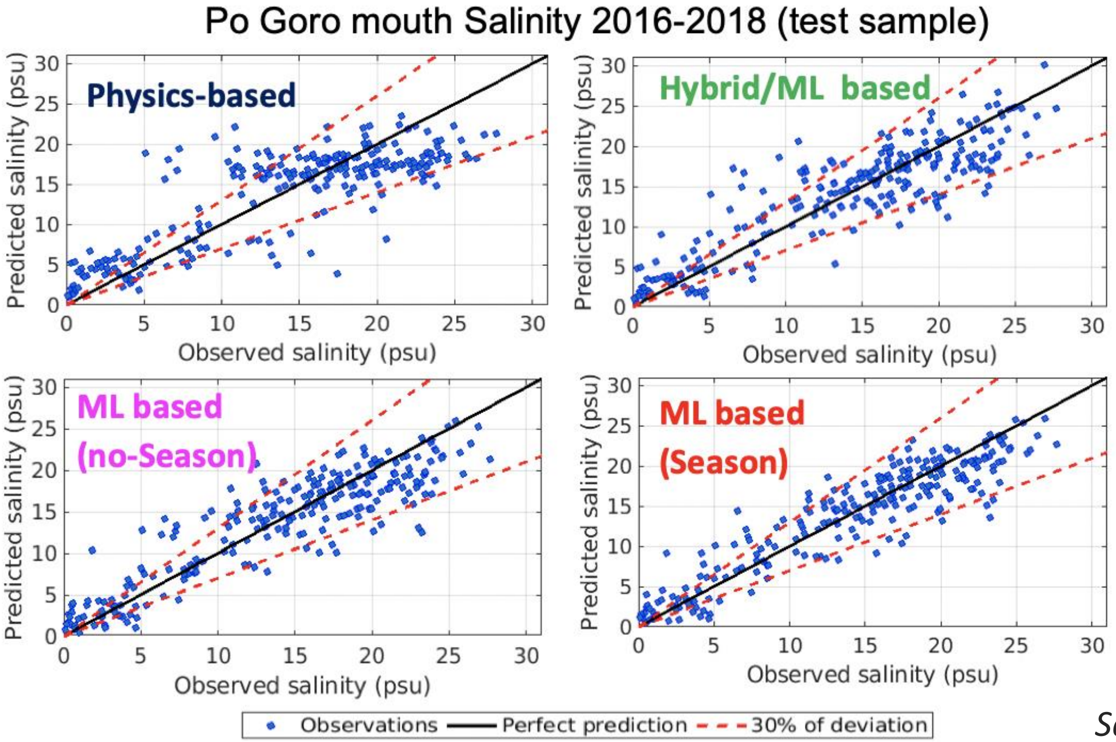
- **GEOMEYRY HYPOTHESIS:** 2-layer rectangular box with constant width L_y and **time dependent water depth $H_{tot_{mouth}} = H_{bathy} + \eta$** and **estuary length L_x**, 2 open cross sections estuary head and mouth
- **PHYSICAL HYPOTHESIS**: incompressible, steady state and diurnal tidal cycle average equations
- **CODES**: **physics-based, hybrid** and **full ML based**

Verri et al 2020, 2021; Maglietta et al 2024 under review

Estuary head Input	Q_{river}	$S = 0$	θ_{river}	$H_{tot_{head}} = H_{bathy}$

Estuary mouth Input/Output							
Input	Q_{ll}	$S_{ll} > 0$	θ_{ll}	Q_{tide_f}	$\overline{S_{ocean}} > 0$	$\overline{\theta_{ocean}} > 0$	$H_{tot_{mouth}} = H_{bathy} + \eta$
Output	$Q_{ul} > Q_{river}$	$S_{ul} > 0$	$\theta_{ul} \neq \theta_{river}$	$SWI\ L_x$	$mixing\ C_k$		

The *low complexity* ***1D*** box modeling of the estuaries



NRMSD= 0.15 psu, CORR= 82%

NRMSD= 0.13 psu, CORR= 89%

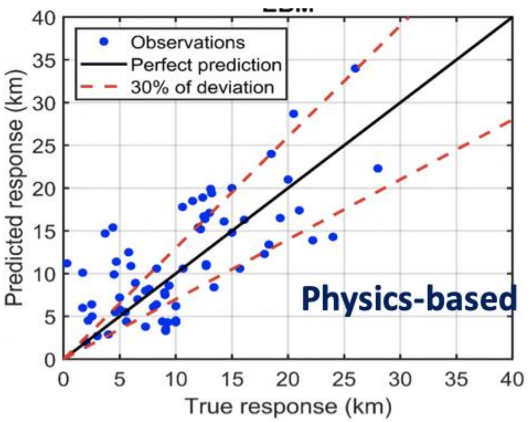
NRMSD= 0.12 psu, CORR= 90%

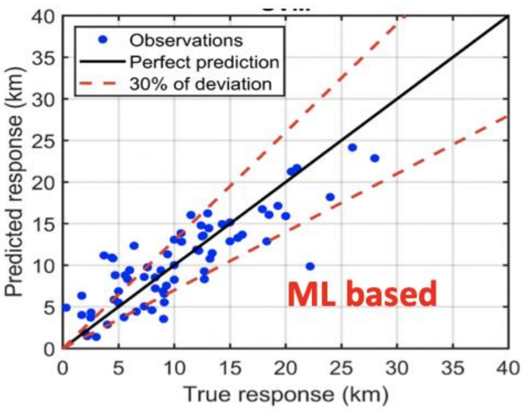
NRMSD= 0.10 psu, CORR= 93%

Saccotelli et al 2024 under review

The *low complexity* *1D* box modeling of the estuaries

Po branches Salt wedge intrusion length 2003-2017





NRMSD=0.18 CORR=71%

NRMSD=0.12 CORR=84%

Saccotelli et al 2024 under review

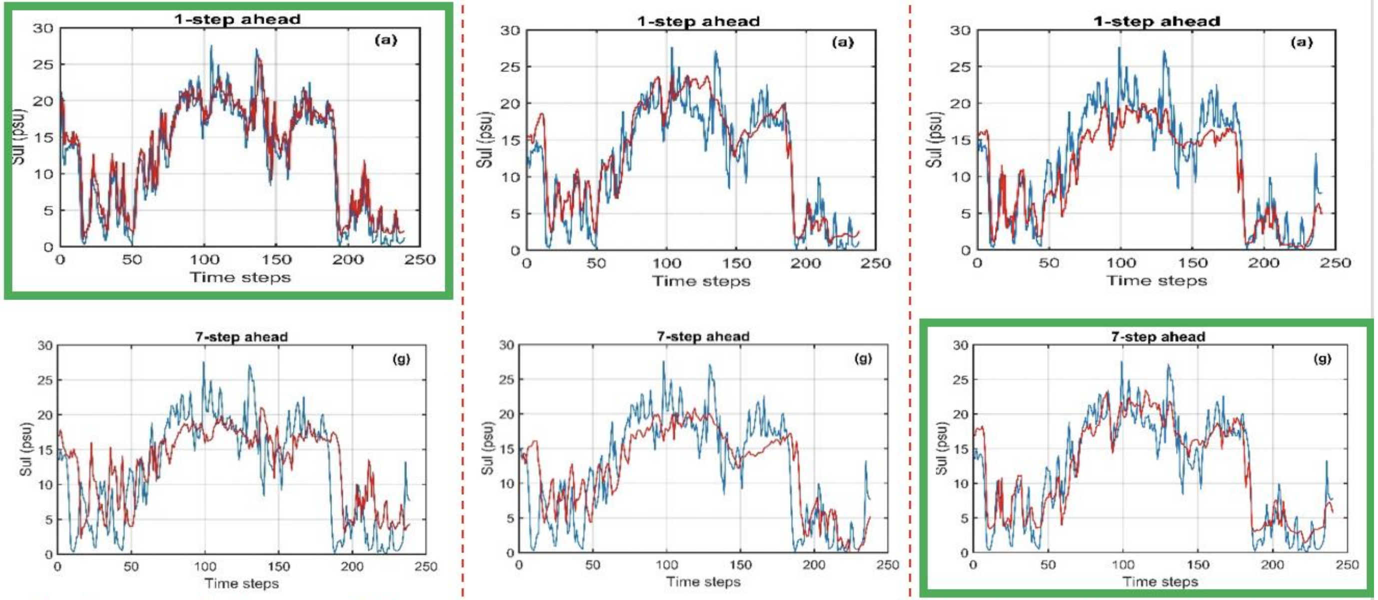
The *low complexity* ***1D*** box modeling of the estuaries

Deep Learning algorithm ***LSTM*** for estuary ***salinity forecasting***

Saccotelli et al 2024 under review

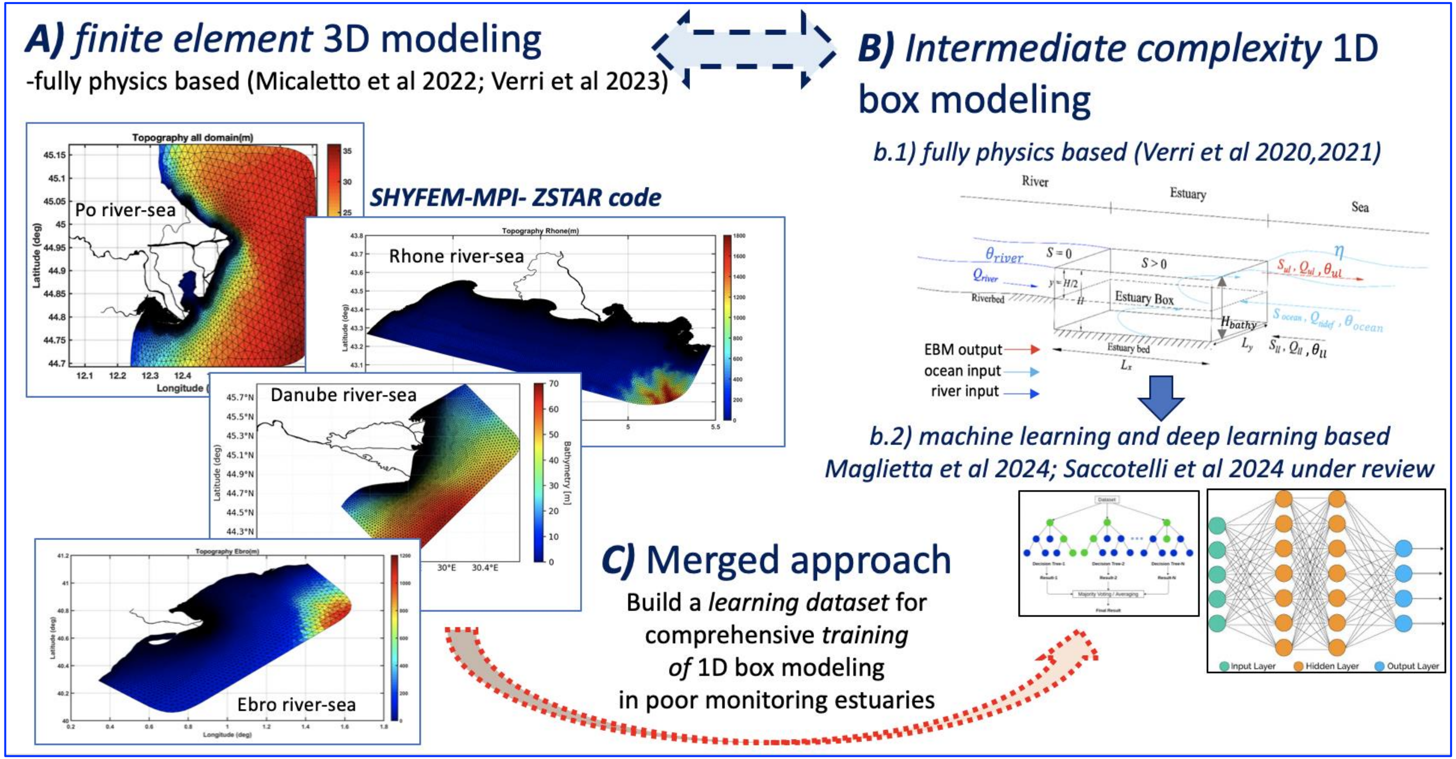
3 LSTM schema have been **trained** and compared on **1step to 7steps** ahead forecasting

LSTM config1 | LSTM config2 | LSTM config3



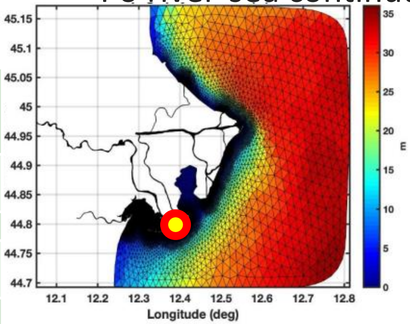
features=salinity, n_{input}=3day | *features=runoff, n_{input}=4day* | *features=all, n_{input}=1day*

The estuary box modeling ***training*** **& *testing*: *merged strategy***



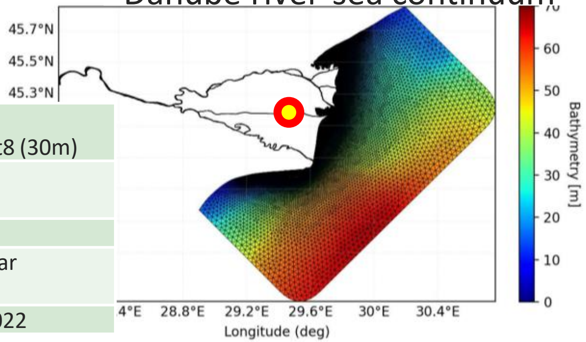
The estuary box modeling *training* & *testing*: *merged strategy*

Po river-sea continuum



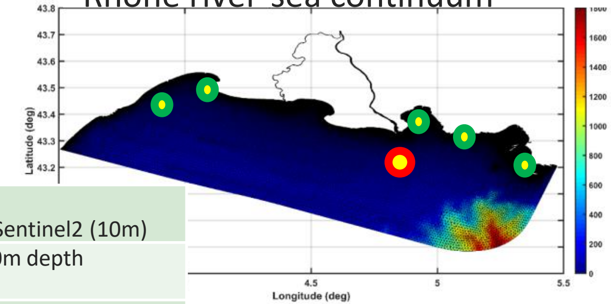
Bathymetry data source	Emodnet (100m)+multibeam surveys
Bathymetry data values	1 to 35m depth
Horiz. res.	2km to 10m
Elements number	77496 triangular elements
Time window	Dec2017-Dec2018

Danube river-sea continuum



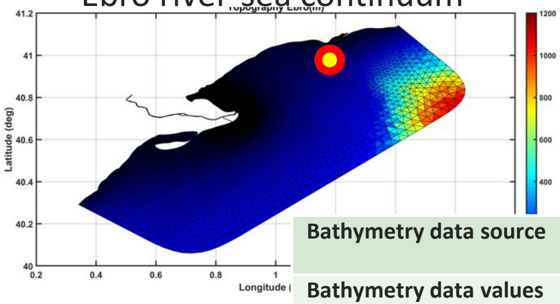
Bathymetry data source	Emodnet (100m)+Landsat8 (30m)
Bathymetry data values	1 to 67m depth
Horiz. res.	2km to 70m
Elements number	265000 triangular elements
Time window	Apr2021-May2022

Rhone river-sea continuum



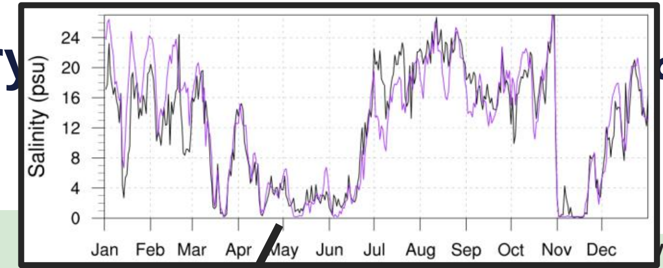
Bathymetry data source	Emodnet (100m)+Sentinel2 (10m)
Bathymetry data values	1 to 2000m depth
Horiz. res.	3km to 15m
Elements number	100000 triangular elements
Time window	Jan 2019-Dec2020

Ebro river-sea continuum

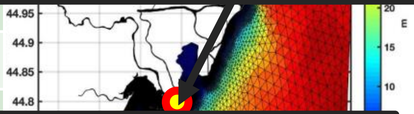


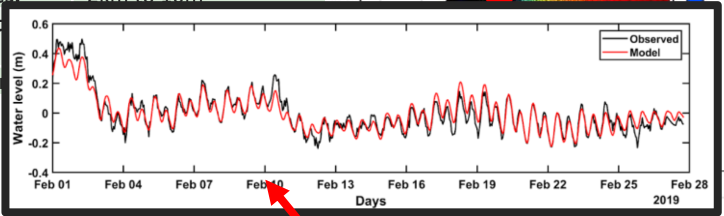
Bathymetry data source	Emodnet (100m)+multibeam surveys (2 m)
Bathymetry data values	1 to 1200m depth
Horiz. res.	3km to 30m
Elements number	62000 triangular elements
Time window	Jan 2019-Dec2020

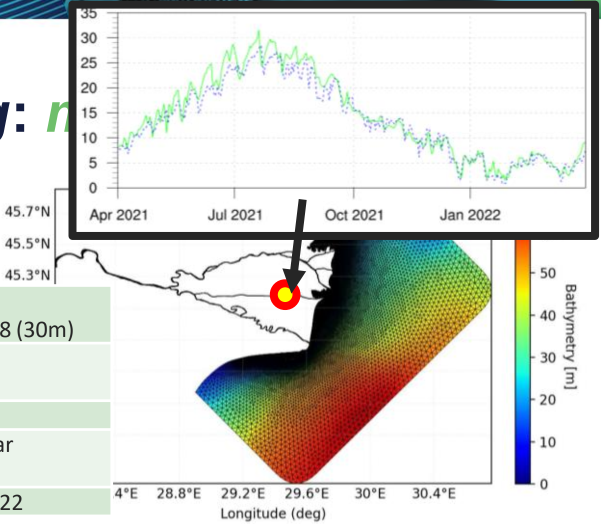
The estuary … & testing: m…



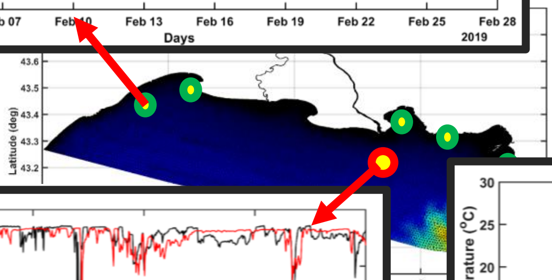
Bathymetry data source	Emodnet (100m)+multibeam surveys
Bathymetry data values	1 to 35m depth
Horiz. res.	2km to 10m
Element… number	
Time wi…	



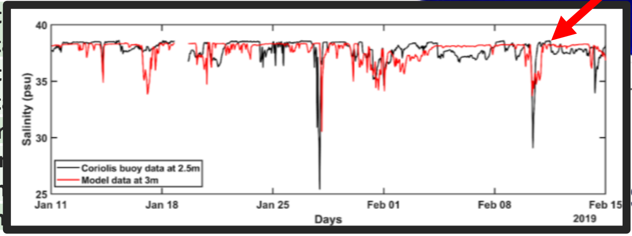




…data source	Emodnet (100m)+Landsat8 (30m)
Bathymetry data values	1 to 67m depth
Horiz. res.	2km to 70m
Elements number	265000 triangular elements
Time window	Apr2021-May2022



Bat… dat…	
Bat… dat…	
Hor…	
Ele… nu…	
Tim…	



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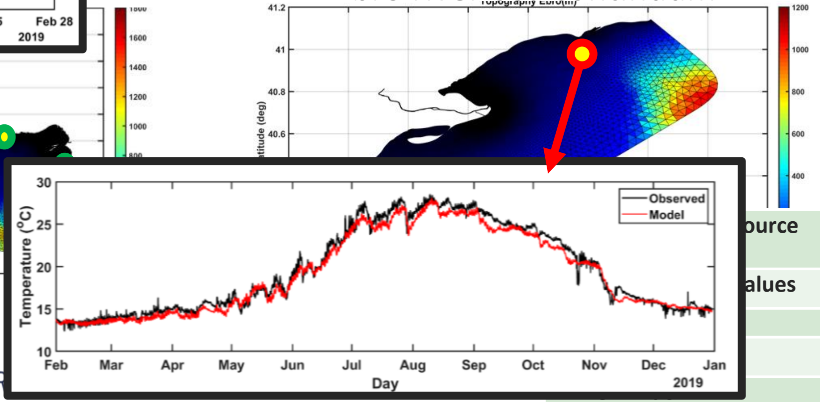
Ebro river-sea continuum



…ource	Emodnet (100m)+multibeam surveys (2 m)
…alues	1 to 1200m depth
	3km to 30m
	62000 triangular elements
	Jan 2019-Dec2020

EO Satellite for retrieving Rhone and Danube river *bed depth*

Along river bathymetry Extraction

-Selection of *Sentinel2 (10m) and Landsat8 (30m) images of reflactance*

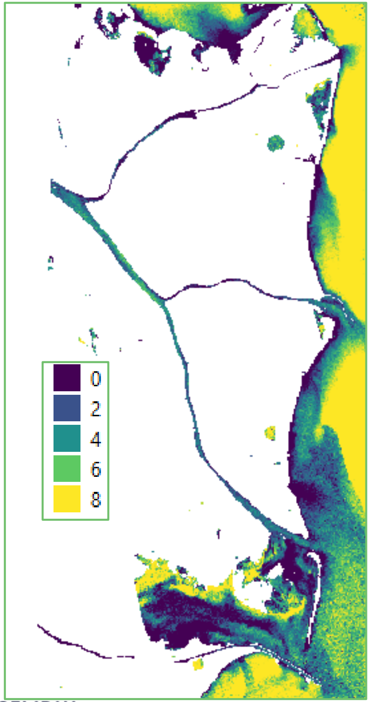
-EXP ACOLITE atm correction

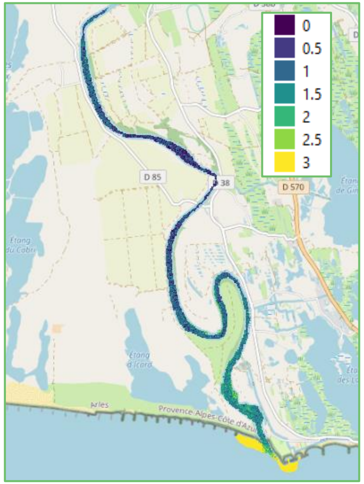
-*Band ratio algorithm (Cabellaro and Stumpf 2020)*

$$pSDB = \frac{\ln(1000 * \pi Rrs(\lambda_i))}{\ln(1000 * \pi Rrs(\lambda_j))}$$

-a best fit linear curve to get actual depth

$$SDB = m_1 pSDB - m_0$$





EO Satellite for retrieving river *mouth tracers*

Testing EBM outflowing Temperature with NEW *EO Satellite*

ST_B10 product (30m res.) from Landsat 8 and 9 datasets (Single Channel Landsat Surface Temperature - USGS)

↓

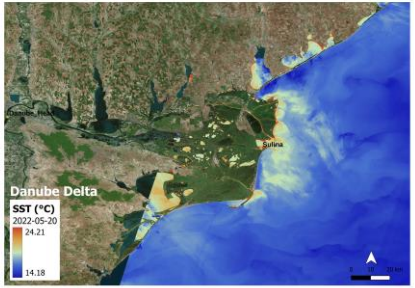
Cloud and land masking

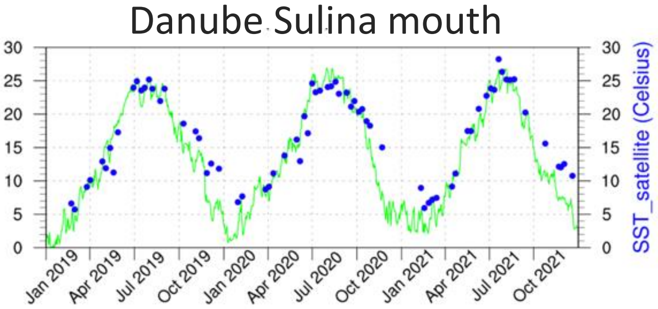
↓

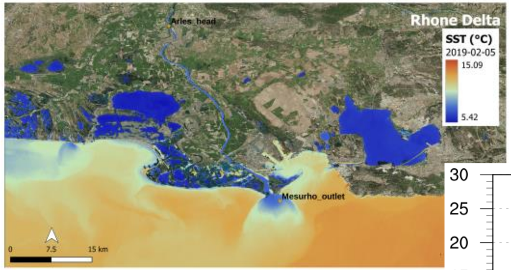
cross-calibration with in-situ buoys

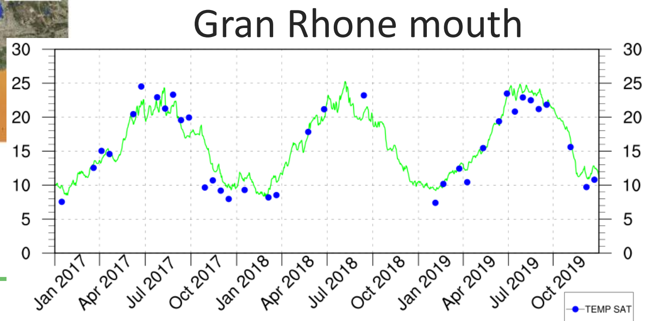
↓

final temperature data (calibrated)









EO Satellite for retrieving river *mouth tracers*

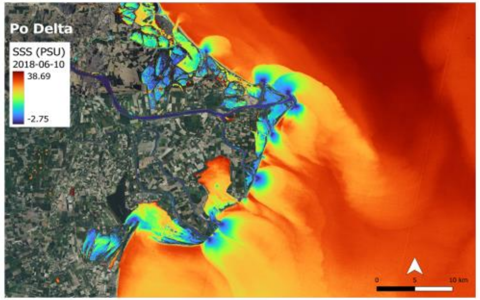
Testing EBM outflowing Salinity
with NEW *EO Satellite*

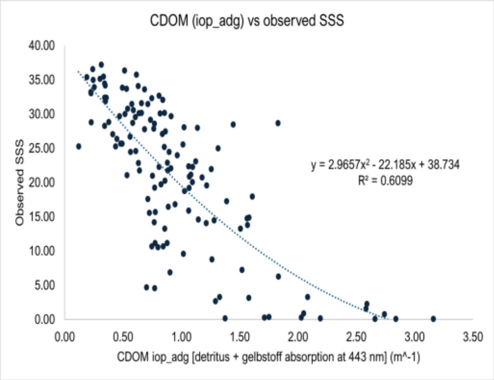
C2RCC processor for atmospheric correction and retrieval of water constituents from optical satellite imagery using neural nets; **CDOM as proxy to salinity** (Sentinel 2 resampled to 10m, NASA ozone & sea level pressure data, buoy obs)

correlation (satellite-derived CDOM vs observed SSS of selected in-situ buoys) to obtain SSS equation

sea surface salinity data

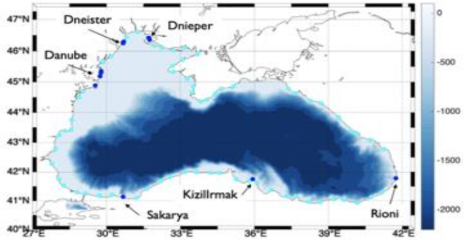
Po delta mouths





The EBM-NEMO offline 2way coupling within Copernicus MFCs

EBM +BS-MFC Workplan



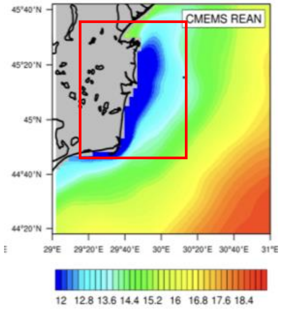
Control Run forced by river runoff data as in EAS4 operational system

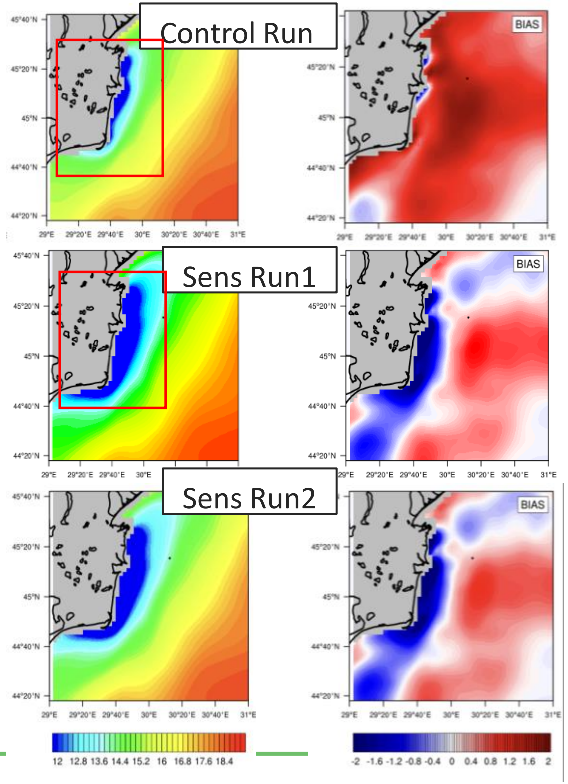
Sensitivity Run1 using updated river runoff and salinity values evaluated by **CMCC-EBM** for **Danube** river

Sensitivity Run2 as Run1 plus river temperature evaluated by **CMCC-EBM** for **Danube** river

➢ **Spring Surface Salinity**

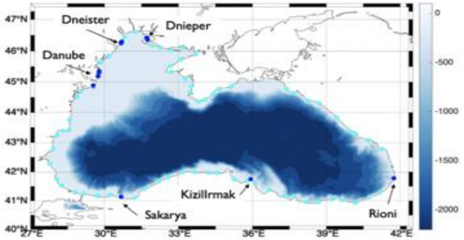
Benchmark





The EBM-NEMO offline 2way coupling within Copernicus MFCs

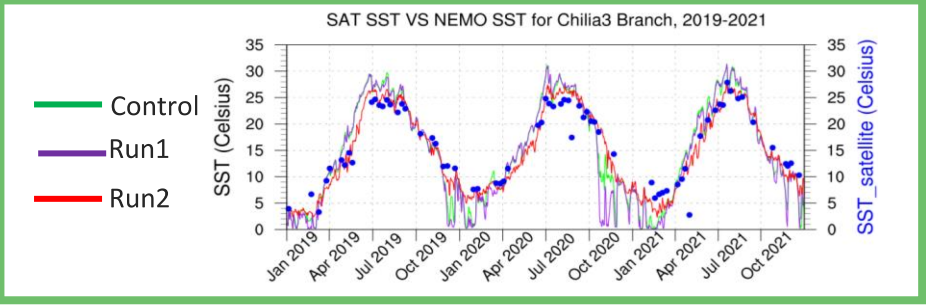
EBM +BS-MFC Workplan



Control Run forced by river runoff data as in EAS4 operational system

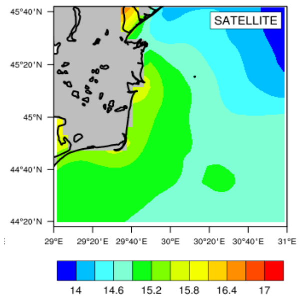
Sensitivity Run1 using updated river runoff and salinity values evaluated by CMCC-EBM for Danube river

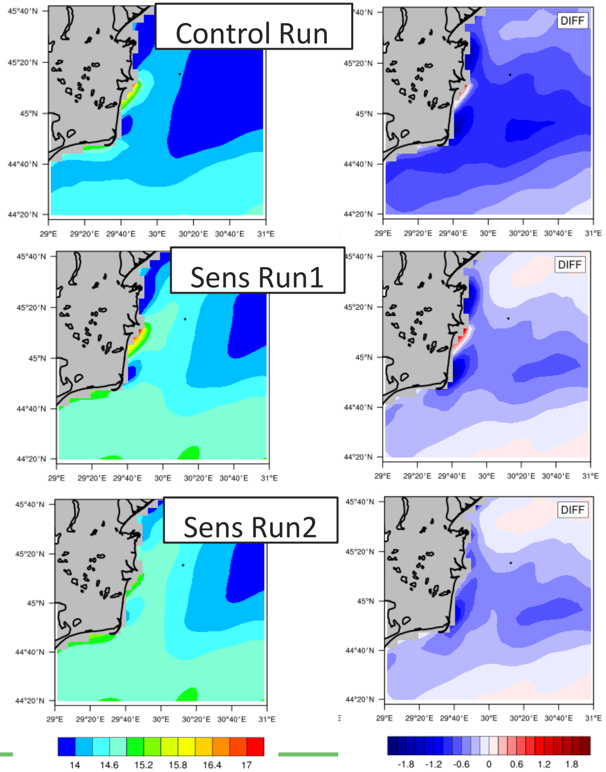
Sensi



- **Spring Surface Temperature**

Benchmark





Concluding Remarks

The intermediate complexity *1D EBM* is a flexible and powerful Tool to estimate river release and SWI length estimate for both forecast and climate purposes

The Learning dataset built with 3D unstructured modeling of the river-sea continuum provide enough data for training ML-based EBM

ML-based EBM is found to outperform physically-based EBM

The CMEMS MFCs benefit from the use of an EBM to better represent the river release in terms of volume flux and tracer values

EO Satellite is a promising additional way to monitor the estuarine areas, supporting EBM training and testing

Next Steps

Relocate EBM by ML clustering techniques

2-way online coupling between EBM and BS MFC a& Med MFC

Comprehensive evaluation of EO Satellite SSS and validation of EBM outflowing salinity using satellite estimates as benchmark

Publications

Under review

- Maglietta, R., Verri, G., Saccotelli, L., De Lorenzis, A., Cherubini, C., Caccioppoli, R., Dimauro, G., Coppini, G., 2024. Advancing Estuarine Box Modeling: a Novel Hybrid Machine Learning and Physics-Based Approach. Environmental Modelling & Software (under review)
- Saccotelli, L., Verri, G., De Lorenzis, A., Cherubini, C., Caccioppoli, R., Coppini, G., Maglietta, R., 2024. Enhancing estuary salinity prediction: a Machine Learning and Deep Learning based approach. Applied Computing and Geosciences (under review)
- Verri G., De Lorenzis A., Da Costa V., Pinardi N., Coppini G., Sorolla A., Löchner A., Martí E. Salt-wedge estuary's response to rising sea level, reduced discharge and Nature Based Solution Frontiers in Climate (under review)

EGU 2024 Abstracts

- Faelga, R. A., Verri, G., and Silvestri, S.: Water surface temperature and salinity estimation from EO satellites for estuarine dynamics assessment in the Mediterranean and Black Sea, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-19590, https://doi.org/10.5194/egusphere-egu24-19590, 2024.
- Viola, F., De Lorenzis, A., and Verri, G.: A novel toolbox for accurate thalweg determination in riverbed profiling and Salt Wedge Intrusion length extraction, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-3042, https://doi.org/10.5194/egusphere-egu24-3042, 2024.

Thank you for the attention!

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