River–coastal–ocean continuum modeling in Western Mediterranean Italian coasts: Assessment of near-river dynamics and salt wedge intrusion

I .Federico[1], S. Causio[1], S. Bonamano[1,2], V. Piermattei[1], D. Piazzolla[1], S. Scanu[1], A. Madonia[1], E. Jansen[1], G. De Cillis[1], G. Coppini[1], M. Marcelli[2]

[1] CMCC Foundation, Euro-Mediterranean Center on Climate Change, Italy
[2] Laboratory of Experimental Oceanology and Marine Ecology, University of Tuscia, Italy

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Motivation

- **River deltas** are **complex** areas with extremely dynamic **processes** (e.g. freshwater effects in denser water, two-layer flows, mixing processes) characterized by **compounding effects** among different characteristics involved (e.g. river width and slopes, wind regimes at the interface land-ocean, processes on the continental shelves)

- A **seamless unstructured-grid** approach could support to advance in the reproduction and understanding of the dynamics **across the scales**.

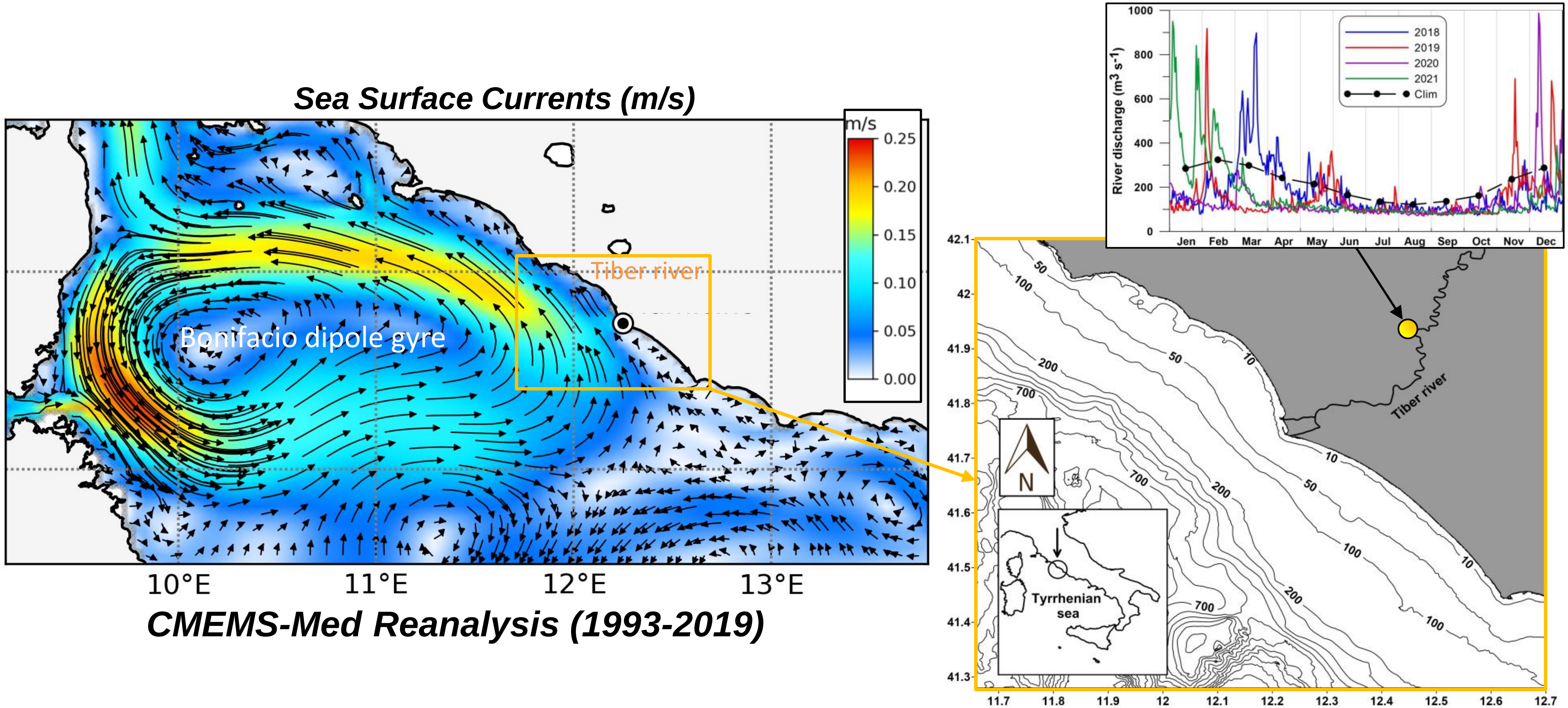
Objectives

1. Assess the **added-value** of **River-Coastal-Ocean continuum representation** with respect to a classical Coastal-Ocean configuration

2. Processes dominated by **near-river and coastal** factors: investigation on **local gyre** and identification of main drivers

3. Assess the capacity of model in **salt wedge intrusion** reproduction

<u>The study area</u>: the Tiber river and the Latium coasts in Tyrrhenian sea



- Tiber River is 405 km in length, flowing into the <u>**Tyrrhenian Sea**</u> forming an **estuary** with **two branches**
- The **southern branch** receives about the **80% of the Tiber flow discharge** (Mikhailova et al.1999).
- It impacts also the open-ocean circulation of Tyrrhenian Sea at subregional scale with a **strong coastal jet due to intense flood events** during winter season and with sea breeze regime in summer that can move the **river plume toward the offshore zone and trigger local coastal upwellings** (Inghilesi et al., 2012).

The river-costal-ocean modelling system

Model: unstructured-grid 3D **SHYFEM-MPI** model (Umgiesser et al., 2004; Micaletto et al., 2022)

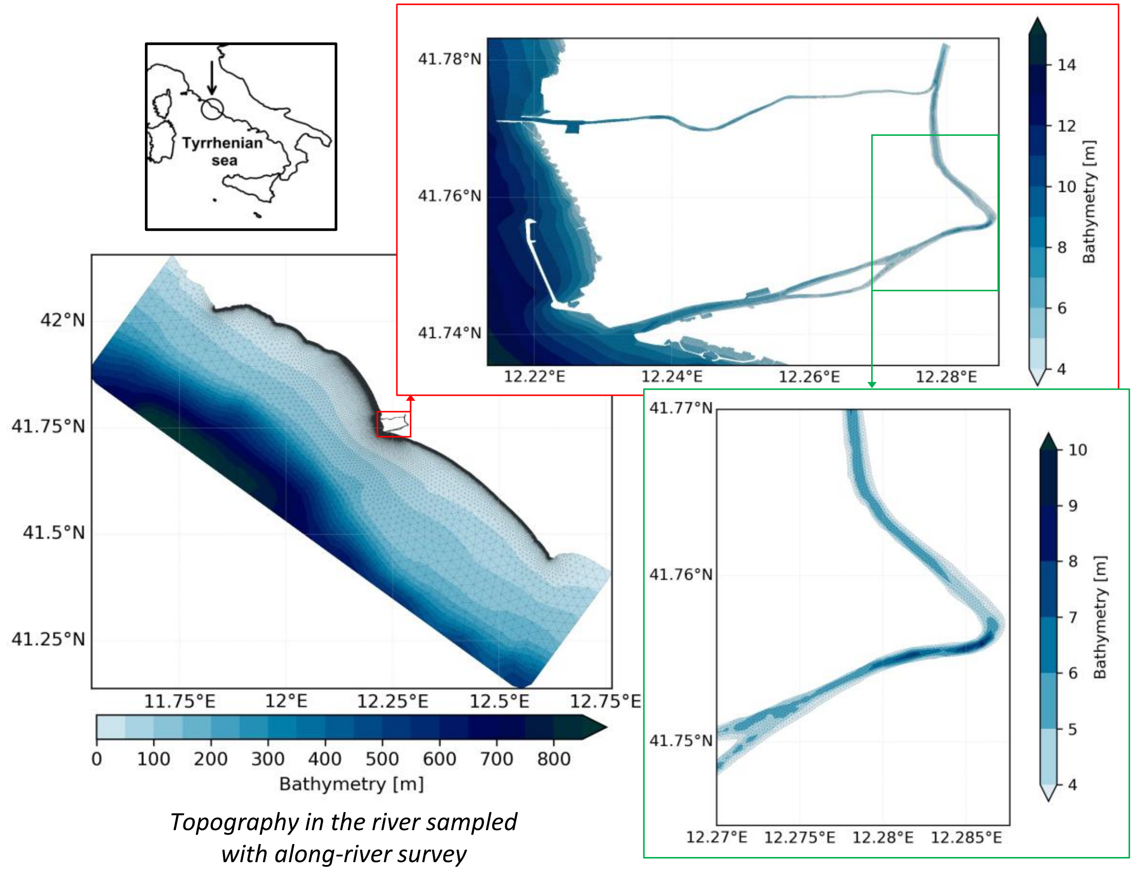
Hor. grid: variable mesh, from 1-2km in open-sea to 50-100m in the coastal waters to 10-20m in near- and along- Tiber river

Ver. grid: z-layer discretization; layer thickness is 1m in the first 30 layers, then progressively (stepwise) increased down to the bottom.

Init. and Lat. Open Bound. conds: 3D temperature, salinity and currents, and sea level from CMEMS-Med (1/24°) analysis

Atmos. forcing: ECMWF analysis with 6h frequency and 1/10° spatial resolution

River discharge: hourly values from Ripetta (Rome) discharge station



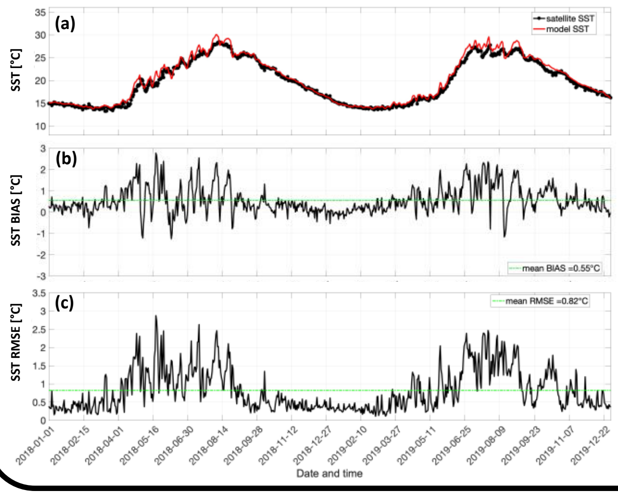
Horizontal unstructured-grid and bathymetry, with magnification of Tiber river branches

River-coastal-ocean continuum modelling

INTEGRATED COASTAL OBSERVING SYSTEM ACROSS the offshore, coastal, near-river and along-river SCALES

Validation across the scales (*Bonamano et al.*, 2023)

Offshore validation with satellite SST

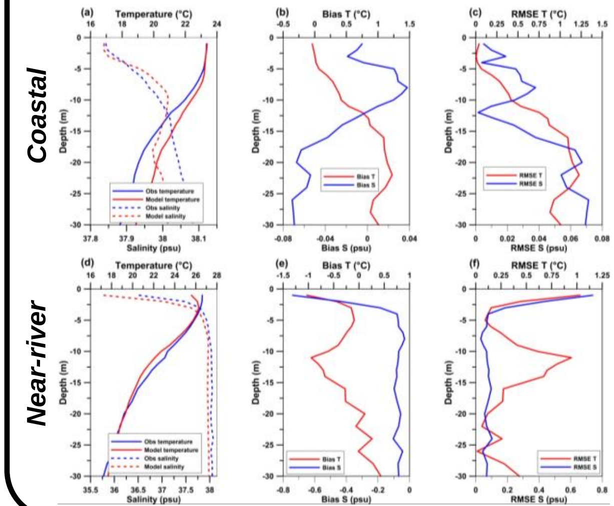


RCO model in active mode for 2018-2019.

Comparison with CMEMS SST, SST_MED_SST_L4_NRT_OBSERVATIONS_010_004.

Skills in agreement with other SHYFEM implementations (McKiver et al., 2016; Ilicak et al., 2021; Barletta et al., 2021)

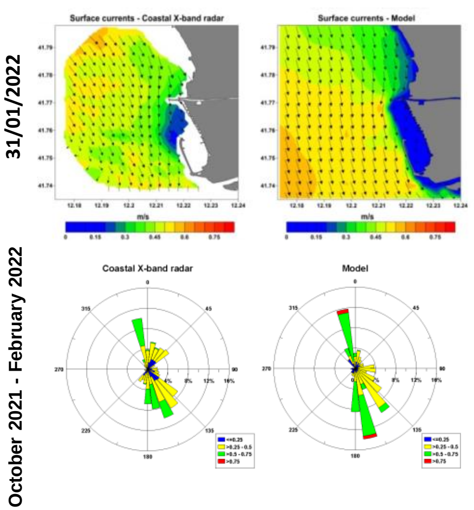
Coastal and near-river validation with CTD



A very well agreement is reported in surface layers while the higher discrepancies occur in the deeper layers (RMSE T = 1.25°C and RMSE S = 0.07 psu).

Also near-river results are satisfactory (max RMSE = 0.65psu) in reproducing such complex dynamical processes with a high salinity gradient and variability.

Coastal and near-port validation with X-band radar

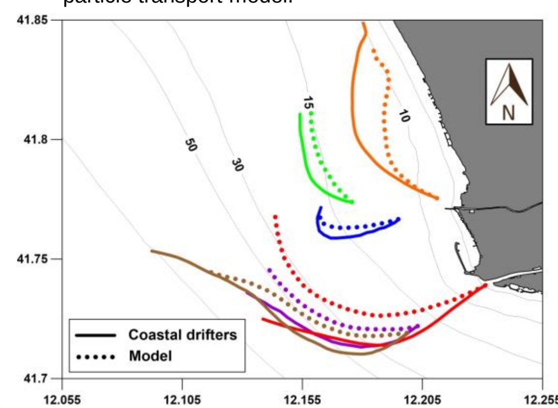


Surface current comparisons for different **wind-driven extreme events**, slight open-sea overestimation of model. Skills in agreement with other reference studies (e.g. García-León et al., 2022)

The current directions detected by X-band radar show **more variability**. The performance can be improved enhancing the **spatial and temporal resolution of wind forcing** and considering the wave effects on coastal circulation during surge events.

Coastal and near-river validation with drifters

The surface currents of model are provided to a downstream Lagrangian drifting objects model (Jansen et al., 2016), which is a 2D and 3D particle transport model.



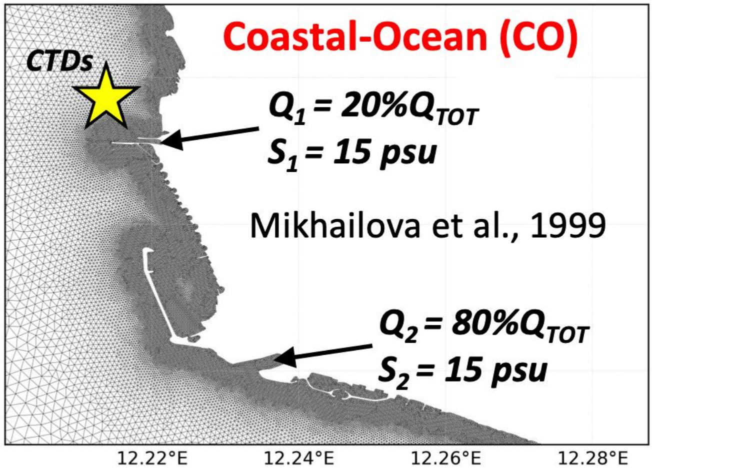
Highest accuracy of the model for the trajectory of drifters released near the northern mouth.

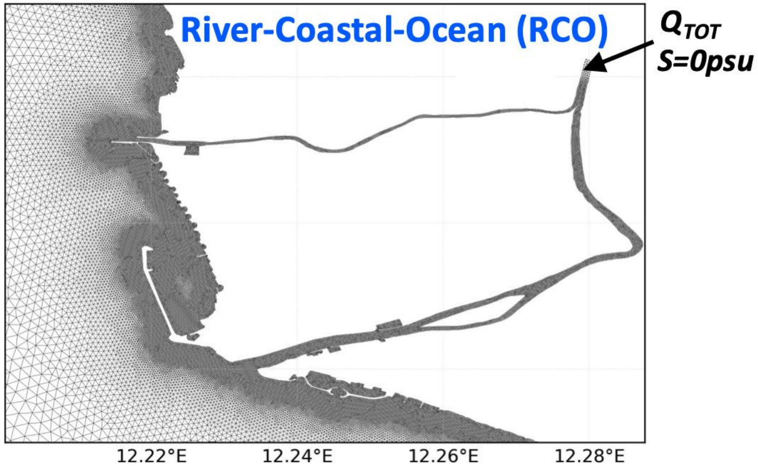
At the southern mouth, the performance improves as the distance from the river mouth increases.

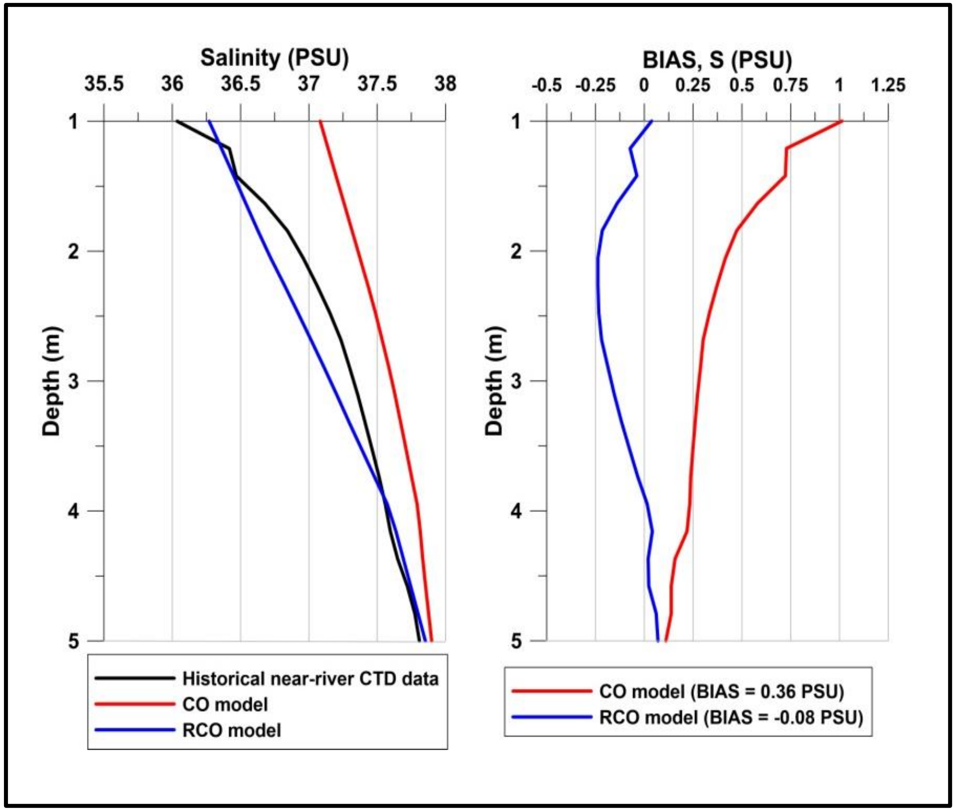
As already emerged from the comparison with the X-band radar data, the discrepancies between the modeled and observed data may be due to the low spatial / temporal variability of wind forcing

1. The role of the continuum river-costal-ocean representation

The horizontal domain configurations:
coastal-ocean vs. river-coastal-ocean representation

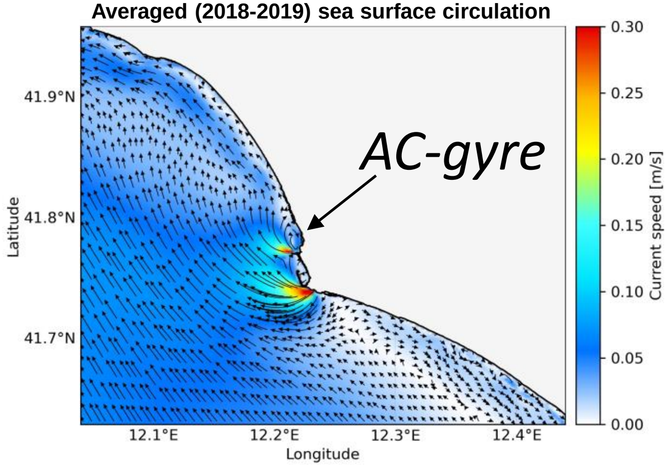






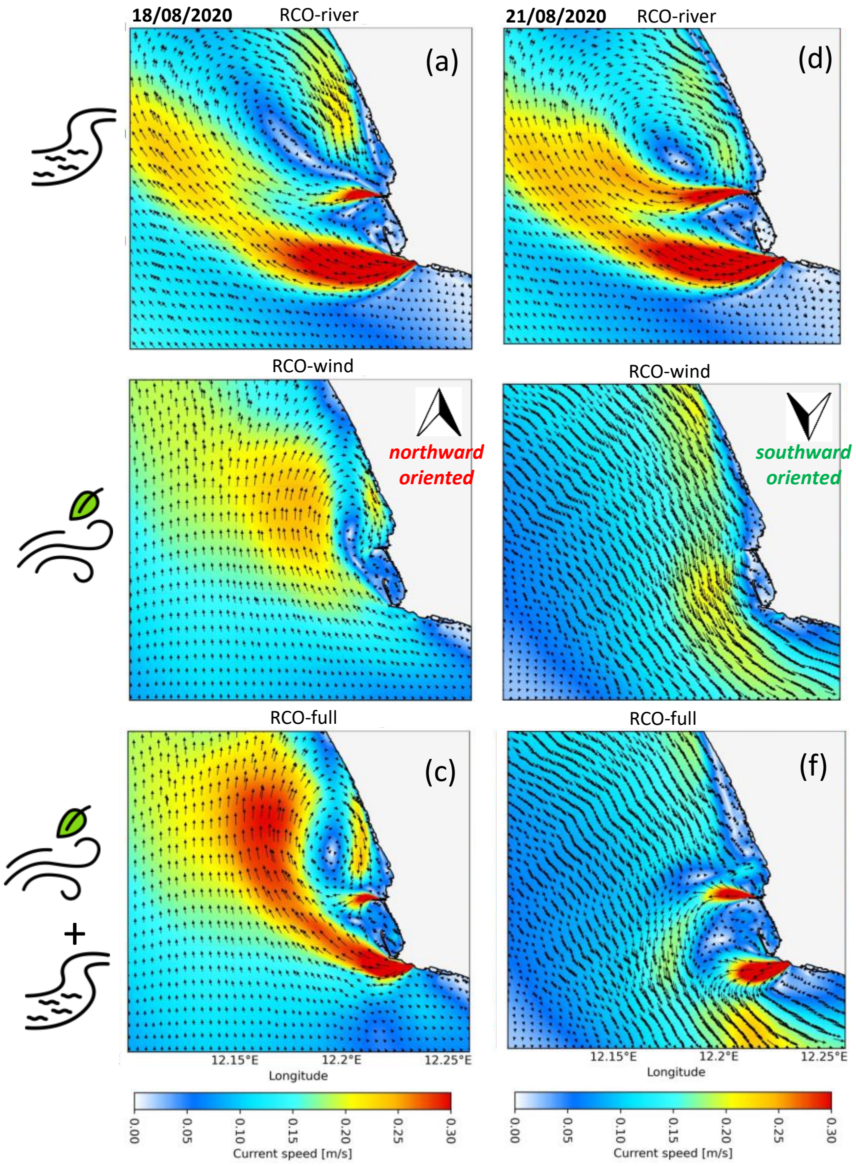
RCO representation gives a better accuracy in salinity (and temperature) than CO, avoiding tuning and calibration of discharge in the two branches and for different periods

2. River-induced anticyclonic gyre and main drivers



The surface velocity field is mainly characterized by **northward current circulation in the open-ocean**. This feature is in agreement with Med-CMEMS reanalysis and several literature studies (e.g. Artale et al., 1994; Moen et al., 1984)

The zone near the northern branch mouth of Tiber river indicates the presence of an **anticyclonic gyre**

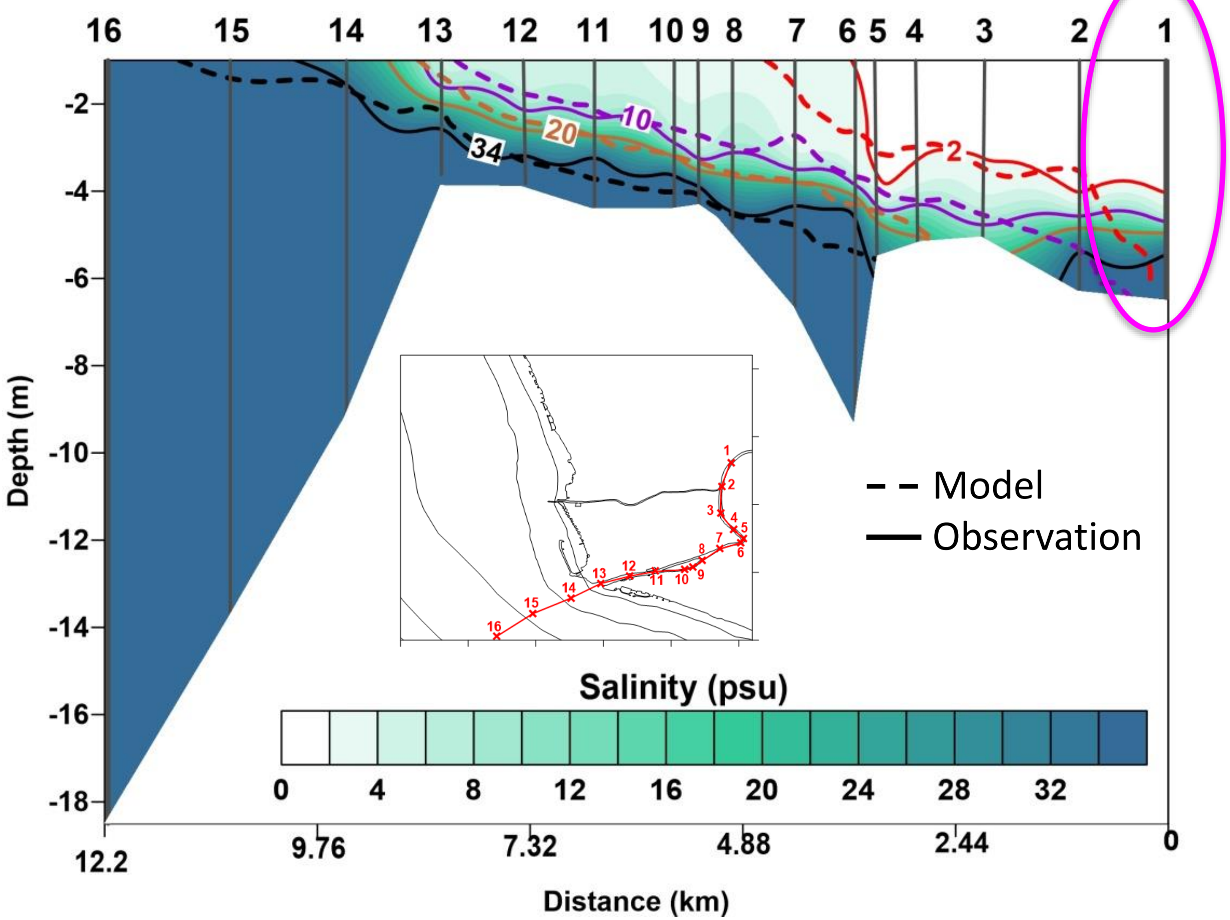


AC-gyre is clearly visible RCO-river experiments for both cases, with the **typical offshore bulge** and coastal current in the direction of Kelvin wave propagation (Kourafalou et al., 1996).

For RCO-wind, only in case of **northward currents** we have the presence of AC-gyre. This is clear connected to **the concave shape of the coastline** which promotes the formation of anticyclonic structures (Cosoli et al., 2020).

When both drivers are included, the **AC-gyre has a high extension and intensity with northward circulation**, while it has a much smaller dimension when upwelling-favorable wind moves the plume away from the coast favouring the offshore removal of freshwater.

3. Salt-wedge intrusion in the Tiber river



Along-river salinity section in the southern branch of Tiber river.
Colours represent the observations.

A typical **estuarine dynamics**, with the freshwater floating on top of the denser seawater, which moves upstream along the bottom up the river forming a wedge layer.

Similar pattern between model and observations up to station 3.

2 psu model isoline highlights a **drop up to 0 psu** at the bottom. This is due to the constant boundary of 0 psu imposed along the vertical section 1

The current RCO implementation, designed to reach the salt-wedge intrusion up to a limit of **8.8km upstream** (in agreement with Manca et al., 2014), requires an **upstream extension of the domain**, at least as shown for the Spring conditions here simulated.

Conclusions

- A **multi-scale, unstructured-mesh, fully-baroclinic model** has been used to simulate the hydrodynamics of the Tiber **river continuum** from the upstream of the river branches to the open ocean
- Thorough **validation across-the-scales** (offshore, coastal, near- and along- river) thanks to a new **integrated coastal observing system** (CTD, x-band radar, drifters, topography)
- Assessment of local processes, such as the formation of **near-river anticyclonic gyre** and the identification of **main drivers**
- **Salt wedge intrusion reproduction** gives an idea on the length of its intrusion.

Future perspectives

- An upstream extension of the domain could improve the **salt wedge intrusion**
- Include **wave effects** on hydrodynamics (e.g. radar results)
- Include **Data Assimilation** techniques for unstructured meshes
- Include a **generalized tilted time-dependent vertical discretization** (Verri et al., 2023) to increase the vertical resolution improving representation in the delta coastal zone and along the river branch

Thank you!

Ivan Federico, ivan.federico@cmcc.it