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Report

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Report iNEST – Young Researchers workshop: Advancing in understanding the Gulf of Trieste coastal dynamics through interdisciplinary research

15 July 2025 – Adriatico Guesthouse (Trieste)

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Introduction

This report collects the abstracts of the presentations given during the “iNEST-Young Researchers Workshop: Advancing in understanding the Gulf of Trieste coastal dynamics through interdisciplinary research”, which took place on 15 July 2025 at the Adriatico Guesthouse (ICTP, Trieste).

The workshop was organised as part of the Interconnected Nord-Est Innovation Ecosystem (iNEST) project, with the aim of highlighting the contribution of young researchers to the study of the Gulf of Trieste. The event provided an opportunity to present the preliminary results from the three funded young researchers projects – NEREIDES, REDEFINE and IF-MA – and to share novel approaches to understanding the complex interactions between river and marine systems.

The works presented covered a wide range of disciplines, including physical oceanography, biogeochemistry, data management and innovative modelling approaches, all with the common goal of improving our knowledge of the Gulf of Trieste and supporting the development of a Digital Twin of the Northern Adriatic Sea.

This collection of abstracts reflects the diversity of perspectives and methods presented during the workshop and it aims to serve both as a reference for participants and as a basis for future collaborations within the iNEST community.

NEREIDES: North Adriatic Environmental Risks connEcted with Isonzo plumes Discharge and possiblE Solutions

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Keywords: HF radar, sea surface currents, Isonzo River discharge, drifters, GoT hydrodynamics

The NEREIDES project, funded under the iNEST Young Researchers call, aims to investigate and better understand the increasing physical and biogeochemical risks to the Gulf of Trieste (GoT), in particular the risks associated with extreme weather and marine events such as coastal storms, strong river discharges and strong winds. These events, which are becoming more frequent due to climate change, pose a significant threat to ecosystems and coastal infrastructures.

NEREIDES aims to improve knowledge of GoT dynamics through integrated monitoring, modelling, and analysis. NEREIDES develops and applies tools to study the influence of the Isonzo plume on GoT circulation, focussing on:

- Validation of surface currents from HF radar (WERA) with drifters;
- Analysis of the combined effect of winds and river discharge on surface dynamics;
- Assimilation of HF radar data into the MITgcm hydrodynamic model;
- Analysis of wave impacts on the GoT hydrodynamics by combining HF radar and wave buoy data [1];
- Support to biogeochemical investigations, through joint physical and biochemical sampling in the GoT [2][3].

A case study in October-November 2023 showed strong interactions between river discharge, winds and sea surface currents. HF radar data, meteorological model outputs (WRF) and hydrometric data were analysed [4]. During Bora events, the usual cyclonic circulation is accentuated and the surface currents normally leave the GoT, while during strong southerly wind events the circulation becomes anticyclonic and the surface currents enter the GoT. In the case of a significant river outflow in combination with southerly winds the circulation is anticyclonic in the central part of the GoT and cyclonic in the northern part. Drifter deployments in October 2024 and May 2025 confirmed that the surface currents agree well with the radar observations. High correlation values were found between radar and drifter velocity components. In contrast, the comparison with the model output showed a lower agreement, highlighting the importance of radar data assimilation.

The drifters consistently followed the low-salinity water of the Isonzo plume, suggesting their strong role in surface transport.

Joint deployments carried out in 2025 in collaboration with ARPA FVG compared CODE and Stokes drifters behaviour, showing different responses. In fact, depth sensitivity - CODE drifters follow currents at ~1 m depth, as they are equipped with sails that reach about 1 m depth, while Stokes drifters are more affected by wind and waves, as they resemble discs.

In October 2025, a new WERA HF radar will be installed in Aurisina to replace the old system which is currently no longer working. New deployments will be planned to:

- Continue drifter-radar validation using multiple drifter types;
- Integrate physical and biogeochemical data from joint sampling;
- Improve model forecasts through advanced data assimilation techniques.

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Coastal monitoring in Gulf of Trieste through the integration of oceanographic instruments data and numerical models

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Keywords: wave measurements, coastal hydrodynamics, High Frequency Radar, wave buoy

Coastal variables monitoring and study are crucial activities for researchers to develop and enhance their knowledge about how climate changes effects are modifying maritime hydrodynamics. This study focuses on local effects on the hydrodynamic circulation and significant wave height in the Gulf of Trieste (GoT) through coastal high frequency radars (HFRs) measurements and wave buoys. The variables investigated are the mean wave direction (θw) and spectral significant wave height (Hm0).

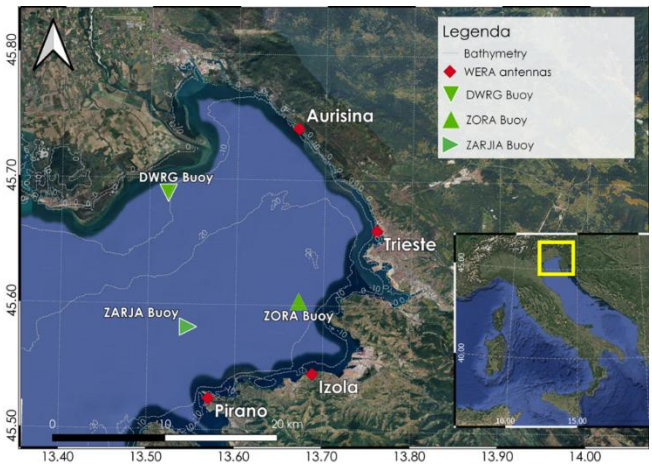

Figure 1. Location of wave buoys (green triangle) and WERA radar antennas (red squares).

The HFRs network installed in GoT are composed by four WERA (WEllen RAdar) systems installed in the east and south part of the gulf and operating at a frequency of 24.5 MHz. Three wave buoys are installed in the central and north parts of the GoT at different depths (Figure 1).

While two main winds, form NE and SW, dominate the Adriatic Sea [1], [2], the sea states recorded in the GoT by the wave buoys is almost homogeneous. Finally, the numerical model proposed by the Copernucus Marine Service (CMS, Product: "MEDSEA_MULTIYEAR_WAV_006_012") was considered to compare the measurement with the numerical model outputs. In fact, spectral models as those proposed by the CMS show difficulties in replicating the extreme events [3], [4], underestimating up to 30% [5] the values of the significant wave height. The HFR measurements can return spatial information about waves improved by the calibration process. By joining the HFR and wave buoys data

and implementing the numerical model results, this research shows innovative methods to deepen knowledge and monitoring the extreme events that characterize the study area.

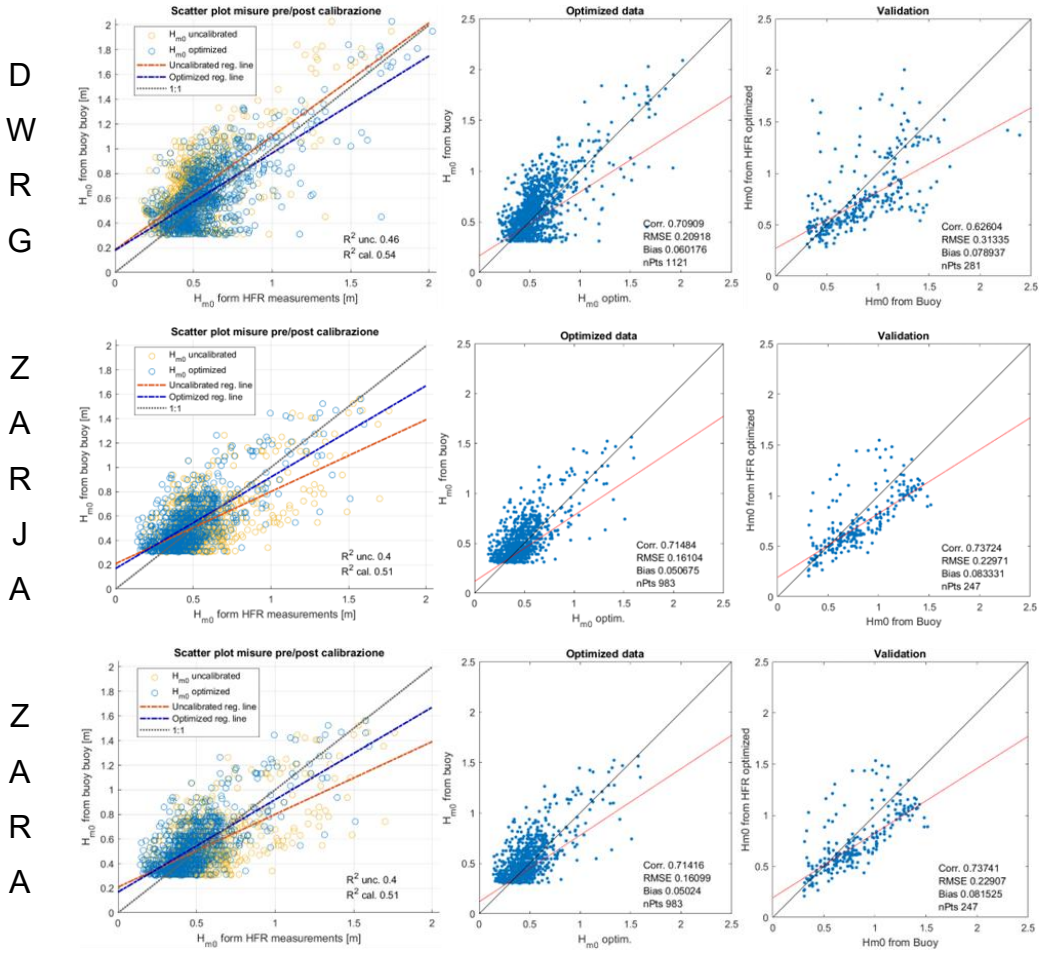

Figure 2. Scatter plot of HFR wave measurement calibration and validation process

The calibration-validation process identifies the best fitting process to obtain a measurement setting able to return valuable information in all different sea state condition (Figure 2).

This process chain is crucial to track the evolution of the extreme events in the GoT, returning spatial information useful for safety in navigation, reduce the coastal risk and track the evolution of the climate changes effects.

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4D-Var approach to HF Radar data assimilation in the Gulf of Trieste: constraining model dynamics with observations

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Keywords: ocean modelling, HF radar, data assimilation

The Gulf of Trieste (GoT) is a shallow embayment in the Adriatic Sea, representing the northernmost section of the Mediterranean Sea. Owing to its physical, ecological and anthropogenic characteristics, efforts have been made to develop oceanographic forecast systems of its state. A fundamental component of such systems is data assimilation, to improve the forecast accuracy.

Here we propose a novel method to integrate sea surface currents observations from the High Frequency Radar (HFR) array deployed along the GoT shores into a numerical ocean model, the MITgcm, via a 4DVar approach.

Usually, given the non linear nature of the equations governing geophysical fluid dynamics, namely the Navier-Stokes equation, the 4DVar method is computationally expensive, requiring multiple forward and backward integrations in time.

Also, the 2-dimensional nature of the HF radar observations against the 3-dimensional simulated fields of velocities require the propagation of the surface information to the deeper layers, usually by means of a covariance matrix.

Here a simplified dynamical model, based on unsteady Ekman theory, tackles both issues: the model relates wind stress to sea currents in an analytical solvable manner; this allows for a cheaper 4DVar minimisation. The analysis step of assimilation produces then an updated estimate of the wind stress, which is then fed to the MITgcm model; in this way the model's dynamics drives the propagation of the information provided by the HFR surface observations to the deeper layers' circulation.

First simplified tests show promising results, with work still ongoing to refine the algorithm, with the final goal of being able to constrain the MITgcm velocities with the radar observations, a useful tool to track and even predict, for example, the dispersion of hazardous contaminants, as in the case of oil spills.

Updated insight on the Isonzo River (NE Italy) flow rate in the period 1998-2022

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Keywords: flow rate calculation; flow propagation time; Gulf of Trieste; rating curve; Soča River

This study investigates the seasonal and interannual variability of the Isonzo River flow rate in its lower course in the period 1998-2022. It expands upon a previous study, which focused on the gauging stations of Solkan (Slovenia) and Turriaco (Italy) for the period 1998-2005. Here we added data from the period 2006-2022 and extended the network of gauging stations to those of Gorizia, Gradisca d'Isonzo and Pieris with data from 1998 to 2022. We also included ADCP (Acoustic Doppler Current Profiler) data from the vicinity of the river mouth for the period 2015-2022. We calculated flow rates starting from hydrometric heights downstream of Solkan (for which flow rate values were already available) and analysed them to obtain a comprehensive spatio-temporal overview of the river's flow and new insights into the propagation of flow between stations. This integrated information will potentially be useful for the calibration and validation of models and could orient future research in this study area.

Preliminary analysis of sea intrusion in the Isonzo River delta inlet

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Keywords: Isonzo River, ADCP (Acoustic Doppler Current Profiler), Hydrodynamic, Saline intrusion, Transitional/estuarine environment

Hydrodynamic processes in river mouths represent a complex interplay of fluvial discharge, tidal influence, and saline intrusion. In this work, firstly we focus on the monitoring system of the Isonzo Current meter, explaining the data acquisition, processing and preliminary analysis of data. Continuous measurements of velocity, direction, temperature, and flow rate using a Acoustic Doppler Current Profiler (ADCP) have enabled the identification of two distinct flow regimes: high discharge related to flood events and low discharge conditions related to high tide and drought period. The study also integrates conductivity-temperature-depth (CTD) profiles to quantify the extent of saltwater wedge in the river mouth during extreme droughts. These results are essential for understanding estuarine dynamics, particularly in a climate context marked by increasingly frequent extreme events.

Riverine load of inorganic nutrients and carbon into the Gulf of Trieste: the REDEFINE project preliminary results

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Keywords: Gulf of Trieste; river discharge; inorganic nutrients; carbonate system

The REDEFINE (RivEr DischargEs in the GulF of TrIeste: a coNtribution to the improvEment of the digital twin of the northern Adriatic Sea) project aims to contribute to the implementation of the digital twin of the northern Adriatic Sea (NAd) by studying the contribution of the main rivers of Friuli Venezia Giulia, namely Isonzo, Timavo and Tagliamento, to the Gulf of Trieste (GoT), the northernmost basin of the NAd.

The GoT is a shallow basin whose hydrology, biogeochemistry and productivity can be influenced by rivers, the major allochthonous source of freshwater, total alkalinity (TA) and nutrients in the area [1,2]. The Isonzo River (ISO) is the main freshwater input into the GoT and generally shows significant seasonal variations in discharge, with two main flooding periods related to snowmelt and rainfall [3]. The second freshwater source is the Timavo River (TIM), which flows underground for about 38 km before re-emerging in proximity of its mouth. The Timavo has complex hydrological characteristics related to its karstic nature, as the flow at the mouth is also influenced by underground circulation within the karst aquifer. Moreover, since Timavo has several minor springs scattered along the coastline, the permanent spring located in Aurisina (AUR) was selected for this study. Although the Tagliamento River (TAG) is known to have the highest discharges compared to Isonzo and Timavo [4], it is rarely considered a relevant tributary to the GoT due to the prevailing cyclonic circulation characterising the NAd. Nevertheless, intense and frequent wind conditions can generate highly variable and even opposite surface layer circulations [5], making the contribution of TAG relevant for the GoT.

Here we present the data from the monthly sampling carried out for the REDEFINE project (from October 2024 to June 2025) in different hydrologic conditions (dry and flood periods) together with previous data collected, with the same frequency, since January 2022.

During the investigated period, TIM was generally characterized by higher dissolved inorganic carbon (DIC) and TA concentrations and lower isotopic composition of DIC (δ^{13}C-DIC) than ISO and TAG, likely as a consequence of the different catchment basins and the nature of the rivers' course (hypogeous *vs*. surface). This difference is particularly marked in AUR, because of the increased mineral dissolution, lower degassing and reduced biological consumption during the hypogean course of Timavo river. The distinct characteristics of the catchment basins of the rivers investigated are also highlighted by different Mg/Ca and Sr/Ca molar ratios.

The average annual discharge of TA, DIC and nutrients under different hydrological conditions highlighted that riverine nutrient and inorganic carbon load are highly related to the runoff which strongly varies on the interannual scale. However, the total river transport of nutrients and carbon is in line with previous studies [1,4].

The REDEFINE results will be coupled with discharge data measured by a local authority (Environmental Protection Agency of the Region Friuli Venezia Giulia) and a water management company (AcegasApsAmga S.p.A., Trieste, Italy) to: (i) provide a baseline for assessing the impact of FVG rivers on the GoT; (ii) support future studies on oligotrophication and acidification; (iii) contribute to the development of the NAd digital twin and the forecasting models on climate change effects on the GoT.

Ultimately, the REDEFINE project also aims to assess the investigated rivers as sources of microbial pollution, including antibiotic resistant bacteria, potentially pathogenic bacteria and genetic determinants playing a role in the spread of antimicrobial resistance (AMR). These data will be interpreted in light of the biogeochemical characterisation of the river waters to provide new insights into the ecology of AMR dissemination through the environment, essential for developing effective action plans against AMR threat.

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Dynamics of inorganic nutrients and carbonate system in the Gulf of Trieste following a high runoff event

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Keywords: Nutrients, carbonate system, river freshwater plume

Rivers and submarine springs draining carbonate watersheds are important sources of nutrients and dissolved inorganic carbon in the Gulf of Trieste (GoT), contributing significantly to the biological productivity and increase of alkalinity of coastal waters [1]. Here, we analyse the nutrient and carbon dynamics within the estuary-coastal water systems during an autumn flood event.

A fast-response, high-resolution synoptic sampling was conducted to study the Isonzo River (Soča) discharge plume (flow rate > 1700 m^3 s^{-1}), on board of a research vessel along a river mouth to offshore transect. The transect included four stations of different distances from the river estuary (IN1 ≈ 1.9 km; IN2 ≈ 3 km; IN3 ≈ 4.6 km; IN4 ≈ 6.9 km). Physico-chemical properties along the water column were recorded using a multiparametric CTD probe, while discrete samples were collected at two depths (surface SUP - 0.5 m and bottom - FON) by means of 5 L Niskin bottles. The analysed parameters included inorganic nutrients (nitrate – NO_3, nitrite - NO_2, ammonia – NH_4, phosphate - PO_4 and silicate - SiO_2) and carbonate system descriptors (total scale pH - pHT and total alkalinity - TA), while total dissolved CO_2 (DIC), CO_2 partial pressure (pCO_2) and aragonite saturation state (ΩAra) were derived from pHT_{insitu} and TA using CO2Sys v3.0 software (https://github.com/dpierrot/co2sys_xl).

At the time of sampling, the surface freshwater layer (FW - salinity <18) extended almost to IN4 station, in which mixed seawater (MSW) conditions were observed throughout the water column (salinity 36.7). Nutrients and the carbonate system differed strongly between FW and MSW, as the Isonzo plume proved to be a major source of NO_3 (≥ 40 µmol L^{-1}), PO_4 (≥ 0.19 µmol L^{-1}), SiO_2 (≥ 28 µmol L^{-1}) and TA (≥ 2900 µmol kg^{-1}). FW was also characterised by low pH (pHTinsitu ≤ 7.954), high DIC (≥ 2807.28 µmol kg^{-1}) and CO_2 oversaturated (≥

832.64 µatm pCO_2), when compared with surrounding air (≈ 420-430 µatm pCO_2 [2]) and MSW (≤ 491.95 µatm pCO_2), forming a low ΩAra surface water layer (≤ 1.68). On the contrary, IN4 exhibited MSW conditions throughout the water column, low nutrient concentrations (NO_3 ≤ 0.82 µmol L^{-1}, PO_4 ≤ 0.02 µmol L^{-1}, SiO_2 = 2.52 µmol L^{-1}), dissolved oxygen close to saturation (92-96%) and pH within typical marine range (pHTinsitu = 8.087-8.079).

Strong evidence of sediment organic matter remineralization was observed within 3 km from the river mouth at the bottom of IN1 and IN2, where the lowest pH ($IN2_{fon}$ pHT_{insitu} 8.018), dissolved oxygen ($IN2_{fon}$ 4.35 mL L^{-1}) and the highest NH_4 ($IN2_{fon}$ 3.49 µmol L^{-1}) values were detected. The concentration of NH_4 (≥ 1.52 µmol L^{-1}) and NO_2 (≥ 0.15 µmol L^{-1}), detected in the surface water layer of IN1 and IN2, resulted over twice higher than those found upstream in the river course (0.428 µmol L^{-1} for NH_4 and 0.076 µmol L^{-1} for NO_2 [3]).

Overall, the Isonzo plume appears to be a source of fresh inorganic nutrients (NO_3, PO_4 and SiO_2), alkalinity and CO_2 (low pH, high DIC and pCO_2). The results of this study also suggest a shift from an autotrophic to a heterotrophic system within 3 km of the Isonzo estuary, causing minima in oxygen saturation and pH, increase of CO_2, and a release of nutrients at the bottom layer of the water column. Although the FW layer was rich in alkalinity, it yielded a low ΩAra value, raising further questions about the impact of climate change and the resilience of the GoT. A second sampling campaign, during a spring flood event, will provide further information to better understand land-ocean fluxes, aiming particularly to underpin the importance of these fluxes for the biological processes under different seasonal conditions.

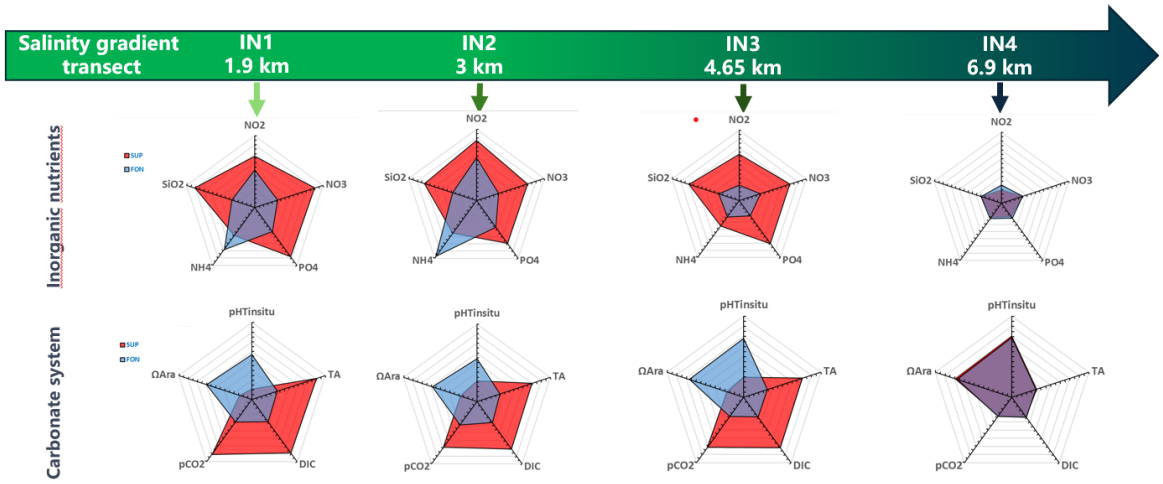

Figure 1. Nutrient and carbonate system dynamics along the Isonzo freshwater plume.

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Influence of the Isonzo River plume on benthic communities and ecosystem processes: preliminary results

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Keywords: Isonzo River, plume, benthic communities, ecosystem processes

River plumes can influence coastal ecosystems, as they can significantly alter physical, chemical and biological conditions of the adjacent coastal areas. This study investigates the extent to which the input of freshly deposited organic material from the Isonzo River (northern Adriatic Sea) affects the structure of benthic communities and the main biological processes. Following the ecosystem approach, Gross Primary Production (GPP), Prokaryotic C Production (PCP) and Community Respiration (CR) in surface sediments were investigated. The abundance and structure of microphytobenthos (MPB) and macrozoobenthos (MZB) were also assessed. Sampling was carried out approximately one month (November 2024) after a consistent plume event, occurred on 6th October 2024, along two transects perpendicular (stations IN1–IN4) and parallel (stations IN5, IN6; see Fig. 1) to the Isonzo River mouth.

Preliminary results showed that benthic PCP ranged from 0.55 ± 0.11 (IN6) to 1.98 ± 0.09 μg C g^{-1} h^{-1} (IN2), with the highest values observed at stations along the transect perpendicular to the mouth of the Isonzo River. On average, PCP rates in these sites were 58.0 ± 25.2% higher than along the parallel transect, indicating a more intense prokaryotic activity in sediments subject to a major settlement of riverine material. However, IN1, despite being the closest to the river mouth, exhibited lower values than IN2 likely due to bottom currents that may remove freshly deposited organic matter, thereby reducing the availability of substrate for benthic processes. Similarly, oxygen consumption in the sediment, used as a proxy of benthic respiration, was markedly higher along the perpendicular transect, with

an average of –6.93 ± 0.1 mg C m^{-2} h^{-1}, compared to i the parallel transect (–0.31 ± 0.1 mg C m^{-2} h^{-1}). Similarly, respiration rates in sediments near the river mouth were on average 95.6 ± 1.9% higher (IN1 – IN4), suggesting intense respiratory activity likely stimulated by the organic input of riverine origin. Further, the highest abundance of microphytobenthos (MPB) was recorded at IN5; the most abundant group was represented by diatoms (97.15%) and only a small percentage of spores and cyanobacteria, 1.64 and 1.45% respectively. Overall, low MPB abundances were obtained because of low light conditions in November at these depths (5.8–18.8 m). At IN1, the fresh-water genus *Melosira* reached the highest relative abundance whereas at all stations the most abundant genus was *Nitzschia*, a nutrient-loving taxon that generally grows in high organic loads. This genus was also represented by the highest number of species. The highest diatom richness (d = 2.66) and diversity (H' = 4.39) were recorded at IN2 where species were evenly distributed. In contrast, the lowest diversity (H' = 3.27) and highest dominance (λ = 0.14) were recorded at IN1, likely due to the prevalence of species of genus *Nitzschia*. Regarding macrozoobenthic communities, the station near the river mouth (IN1) hosted communities with low abundance (276.7 ind. m^{-2}), probably due to the low deposition of organic material as a result of the high current velocity near the seabed. In contrast, IN6, located 3 km south of the river mouth, where the deposition of organic material was higher, hosted a more abundant community (906.7 ind. m^{-2}), but with a high density of few species, such as *Kurtiella bidentata* and *Amphiura chiajei*, and thus a low diversity (H' = 2.67). The biomass did not show the same pattern as the abundance. The lowest biomass (11.08 g m^{-2}) was measured at IN5, while the highest (20.60 g m^{-2}) at IN2. The cluster analysis based on species composition divided the stations into three main groups: IN1 was separated from the other stations, IN3 and IN4, with more marine-influenced communities, clustered together, while IN2, IN5 and IN6 formed the third group, sharing a similar community structure.

These results highlight how the Isonzo River discharge exerts a strong spatial influence on benthic communities and biological processes by structuring phototrophic and heterotrophic communities and enhancing microbial activity and respiration rates in surface sediments.

Figure 1. Sampling area in front of the Isonzo River mouth. Orange dots indicate sediment sampling stations after the plume, which are included in this study. Perpendicular transect: stations IN1–IN4; parallel transect: stations IN5-IN1-IN6.

Implementation of FlowCam for the study of the Microplankton community in the Northern Adriatic Sea (IF-MA)

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Keywords: Microplankton, quantitative imaging analysis, Gulf of Trieste

The IF-MA project investigates the microplankton community of the Northern Adriatic Sea using FlowCam 8000, an advanced imaging system for automated analysis. Microplankton (20–200 µm) includes key autotrophic and heterotrophic organisms such as diatoms, dinoflagellates, ciliates, and small metazoan larvae, playing a central role in marine productivity and biogeochemical cycles. Given the impact of climate change on plankton communities, enhancing the monitoring of this functional group is critical for understanding ecosystem dynamics and health.

A main objective of the project was the development of a Standard Operating Protocol (SOP) for the application of FlowCam to microplankton analysis in the region. Image libraries for over 30 species commonly found in the Gulf of Trieste during late winter were created to enable accurate classification, quantification, and biomass estimation. These libraries enhance the system's performance in delivering automated, high-resolution assessments of community composition and biodiversity.

We will present the first comparative results between classical microscopy methods and FlowCam-based quantitative imaging analysis. While traditional microscopy remains the gold standard in terms of taxonomic detail, it is labor-intensive and time-consuming. FlowCam, by contrast, significantly reduces processing time and provides immediate image-based data, showing strong potential for routine monitoring and large-scale studies.

Validation was conducted through parallel analyses of samples collected during the INEST project near the Isonzo River mouth. Preliminary findings show how the adoption of FlowCam, supported by robust protocols and libraries, may also contribute to early warning systems for harmful algal blooms, offering a rapid and efficient tool for environmental management and public health protection in coastal marine areas.

Evaluation of past and present distribution of contaminants in surface marine sediments of coastal environments (northern Adriatic Sea)

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Keywords: sediments, trace elements, grain-size proxy, baseline, contamination

The occurrence of contaminants in coastal sediments is often associated with anthropogenic inputs. This study focuses on the collection, analysis, and integration of historical data concerning inorganic and organic contaminants in marine-coastal sediments of the northern Adriatic Sea. The aim is to develop a comprehensive and up-to-date database that reflects the spatial distribution and concentration of contaminants in accordance with current regulatory frameworks.

As a case study, a geochemical-environmental approach was applied to the eastern sector of the Gulf of Trieste, an area strongly influenced by urban and industrial activities, to identify the source (lithogenic or anthropogenic) of metal(loid)s, determine site-specific natural background values, and detect potential anomalies [1]. Surface sediment samples revealed exceedances of environmental quality standards (EQSs) for Cr, Ni, Hg, Pb, As, and Cd. To account for the site-specific geochemical characteristics, a normalisation approach using Al as a grain-size proxy was applied, and enrichment factors (EFs) were calculated using regional functions derived from a sediment core collected in a less impacted area [2]. Offshore sediments showed negligible contamination, whereas elevated EFs were observed near the coast indicating localised anomalies. The most notable enrichment was observed for Hg, with an average EF approximately 14 times higher than the local baseline, followed by Cu, Cd, Mo, Pb, and Zn. Conversely, Cr and Ni, despite exceeding EQS values, were found to be of lithogenic origin, highlighting the importance of site-specific assessment methods.

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Coastal marine observatories in the Gulf of Trieste

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Keywords: Gulf of Trieste, Marine Observatory System, Oceanographic Buoy, Technological Development

The Gulf of Trieste Platform is an advanced marine observing system integrating real-time meteorological, oceanographic, chemical, and biogeochemical measurements with long-term in situ sampling and numerical modeling. Its core components include:

1. The Coastal Marine Observatory of the Gulf of Trieste, comprising the MAMBO-1 meteo-oceanographic buoy and for real-time water-column.
2. A high-frequency radar system (WERA, 24.5 MHz) for real-time mapping of surface currents and wave fields, developed in collaboration with Slovenian institutions (NIB).
3. The Marine Weather Monitoring Network of Civil Protection – FVG, composed of meteo-oceanographic buoys (MAMBO 2,3 and 4), directional wave buoys (DWRG), and river current stations in the Isonzo River.
4. The Marano Grado Lagoon Monitoring System MALO recently implemented composed of meteo-oceanographic buoy and current meters located at the lagoon inlet.

The infrastructure is supported by the Technological Development and Field Support Facility (TEC), which specializes in the design, deployment, and maintenance of meteo-oceanographic buoys, measuring systems, and experimental observational networks. TEC provides expertise in data acquisition, processing, and preliminary interpretation, and manages mechanical workshops, electronics laboratories, and a naval tank. Its team supports operational oceanography, notably the HF Radar network, the MAMBO-1 buoy in the Gulf of Trieste.

Together, these facilities contribute to European research infrastructures such as ITINERIS, ICOS and Danubius - RI, and deliver high-quality, freely accessible marine data to the scientific community and environmental stakeholders.

From Raw Data to Clear Insights: The Gulf of Trieste Geoportal, A Multidisciplinary Collaborative Effort for Data Accessibility and Understanding

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Keywords: geoportal; observing system; NRT data; Gulf of Trieste

For over two decades, OGS has managed a network of meteorological and oceanographic instruments in the Gulf of Trieste, providing Near Real Time (NRT) data in support of long-term environmental monitoring and scientific research [1]. The observing system was initiated in 1999 with the deployment of the MAMBO (*Monitoraggio AMBientale Operativo*) buoy at the Miramare Marine Protected Area. This buoy, which also contributes to the Italian Long-Term Ecosystem Research Network (LTER) [2], marked the beginning of a long-term commitment to environmental monitoring in the region.

Over the years, growing scientific and societal demands for consistent, high-resolution, and long-term time series have driven the expansion of this network. This growth has introduced increasing complexity in both the technical maintenance of instruments and the management of diverse, high-volume datasets. The marine environment presents additional challenges for data acquisition and transmission, further emphasizing the need for robust data handling workflows. The heterogeneity of the parameters recorded and the instruments used require coordinated efforts among technicians, technologists, and researchers to ensure continuous operation and data reliability.

One key challenge is that, for efficiency reasons, the raw data transmitted lacks metadata. However, this limitation necessitates post-transmission metadata reconstruction to ensure proper interpretation and reuse. The National Oceanographic Data Centre (NODC) addresses this by assigning accurate and complete metadata in order to ensure that data products adhere to FAIR principles—Findability, Accessibility, Interoperability, and Reusability [3]. The use of controlled vocabularies and community-adopted standards, including those provided by the British Oceanographic Data Centre (BODC), is instrumental in achieving semantic interoperability.

To ensure standardized and interoperable data access, the ERDDAP™[4] platform was adopted, enabling seamless dataset integration and user-friendly distribution through web services and multiple export formats.

To facilitate user-friendly data visualization and access, within the framework of the PNRR-iNEST project the geoportal [5] for the Gulf of Trieste observing system is being implemented and updated, with the addition of information and tools. This web-based platform provides real-time, user-friendly visualization of monitoring station data, including physical and biogeochemical parameters. The geoportal represents a major step forward in making environmental data not only more accessible but also more actionable, especially for stakeholders involved in marine environmental management and policy development. Furthermore, it enables the scientific community to better analyze the temporal dynamics of marine processes through interactive graphical tools that support both data exploration and decision-making.

By integrating high-frequency observational data with semantic enrichment, standardized access protocols, and intuitive visualization, the Gulf of Trieste observing system stands as a model for regional environmental monitoring. The development of the geoportal in particular underscores the importance of coupling advanced technological infrastructure with user-centered design to maximize the impact of marine data for science, management, and society.

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A deep learning approach for coastal downscaling: the Northern Adriatic Sea case-study

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Keywords: U-nets, super-resolution, northern Adriatic Sea, forecasts

The presentation focuses on the work published in Adobbati et al. 2025 [1], where we propose a method based on neural networks for coastal downscaling. We prove its effectiveness on the northern Adriatic Sea area, a marginal region of the Mediterranean characterized by strong spatial and temporal variability, where river inputs significantly influence the physical and biogeochemical state and dynamics, especially near the coast. We trained a neural network on a reanalysis dataset, covering the period from 2006 to 2017, with a horizontal resolution of about 750 m, using as input the regional-scale products of the Marine Copernicus Service for the Mediterranean Sea (with resolution of about 4.5 km), and the flow-rates on 19 rivers discharging into the northern Adriatic Sea.

The architecture composes a U-net with a Multi-Layer Perceptron, which are trained together. We show that training each variable separately produces better results than a multivariate approach, whereas the river discharges have a positive contribution in the learning process of the neural network.

We demonstrate that our architecture is capable of recovering fine-scale features that are not captured by low-resolution models, by validating our results both against a subset of the reanalysis not used during the training, and against observational data (satellite and in situ).

An interesting application of our method concerns the optimization of regional short-term forecasting systems. In particular, the Copernicus Marine Service daily provides ten-day forecasts for both physical and biogeochemical variables at the Mediterranean scale. The trained neural network can be applied to these products on the northern Adriatic Sea to obtain either more accurate initial conditions for nested downscaling simulations or directly high resolution forecasts at a very low computational cost.

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A GPR-SDE-based Reduced Order Model for Forecasting and Digital Twins

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Keywords: What-if scenarios, reduced order models, large scale dynamical systems, Mediterranean sea

This talk presents the development of a Digital Shadow of the Mediterranean Copernicus Analysis and Forecast System, a project under the iNEST initiative, jointly developed by SISSA and OGS. A Digital Shadow is a surrogate model designed to replicate the system's behavior efficiently, incorporating data assimilation and uncertainty quantification. The system, consisting of physics and biogeochemistry components, is aimed at improving short-term and long-term forecasts for the Mediterranean region. The methodology is novel and combines three techniques: quadratic manifold dimensionality reduction, Gaussian Process Regression, and Stochastic Differential Equations (SDEs). These methods are employed to approximate system behavior with reduced computational complexity, enabling faster predictions without compromising too much accuracy. The model's performance is validated through the comparison of forecasted and observed data, ensuring that uncertainty quantification aligns with expected confidence intervals. Additionally, parallel computing is utilized by splitting the Mediterranean Sea into different basins to enhance computational efficiency. This approach offers significant potential for both short-term and long-term forecasting applications. A Digital Twin extension that considers what-if scenarios regarding the Po flow is presented, in the context of the development of the Digital Twin of the North Adriatic Sea.