ANNUAL REPORT ON GEOTRACES ACTIVITIES IN SLOVENIA

May 1st, 2024 to April 30th, 2025

New GEOTRACES or GEOTRACES relevant scientific results

The results of four relevant topics can be considered:

- The GMOS-Train project coordinated by prof. Milena Horvat (Jožef Stefan Institute – JSI, Ljubljana, Slovenia) undertook comprehensive scientific activities aimed at improving the understanding of mercury (Hg) cycling in coastal and open ocean environments. A key focus was the development and refinement of isotopic and analytical techniques to investigate the chemical transformations of mercury species. This included controlled laboratory experiments exploring photodegradation and methylation processes, such as the use of methylcobalamin to study abiotic methylation of inorganic mercury. These efforts were supported by the design of novel experimental setups and the application of high-precision isotopic measurements to track Hg and carbon fractionation.

  Extensive fieldwork was a cornerstone of the project, involving several large-scale oceanographic campaigns. These included the GEOTRACES SWINGS cruise in the Southern Indian Ocean, the TARA OCEANS cruise along the South American and African coastlines, and the RV Meteor expeditions to hydrothermal vents and continental margins. These missions employed ultra-clean sampling methods, CTD rosettes, and remotely operated vehicles (ROVs) to collect seawater and particulate samples across diverse marine environments. Coastal-to-open ocean transects, such as those in the Mediterranean, Baltic, and Northeast Atlantic, provided critical data on gradients in Hg speciation and fluxes.

  Complementary studies in transitional environments, such as the Étang du Prévost lagoon, explored how oxygen gradients and sediment interactions influence Hg dynamics and nutrient cycling. Investigations into the role of dissolved organic matter (DOM) revealed key differences between terrestrial and marine DOM, showing their contrasting effects on mercury stability, transformation rates, and bioavailability. These findings were underpinned by long-term observations at stations like MIO Endoume, which provided valuable time-series data.

  Capacity building and knowledge transfer were also integral to the project. Three specialized training courses were organized to share best practices in mercury sampling and analysis with early-career researchers and partner institutions. The integration of experimental, observational, and modeling approaches throughout the project enabled the identification of key drivers of Hg behavior in marine systems. Collectively, these activities provided the groundwork for improved global mercury assessments, model validation, and informed policy development under frameworks such as the Minamata Convention.

- In the Gulf of Trieste, Po-210 activity concentrations were measured across various marine compartments, including seawater, suspended particles, plankton fractions, and tissues of four fish species. Results showed higher Po-210 levels in particulate matter than in dissolved seawater and relatively consistent concentrations across different plankton size classes. In fish, Po-210 was most concentrated in internal organs like the liver and digestive tract, reflecting dietary intake as the primary exposure pathway. Bioaccumulation patterns varied by species, with Common Pandora contributing the highest estimated annual ingestion dose and European seabass the lowest. Overall, human exposure via fish consumption was found to be low.

- The Adriatic Sea, though a marginal sea, plays a significant role in the regional carbon budget, currently acting as a CO_2 sink with fluxes similar to those in the NW Mediterranean. Long-term data show an acidification trend of approximately 0.003 pH_T units per year, consistent with rates observed in other Mediterranean waters. Despite this, the Adriatic exhibits a relatively high buffering capacity, supported by elevated total alkalinity (TA) levels largely influenced by riverine inputs, especially from the Po River. Dense water formation and cascading processes efficiently transport TA and dissolved inorganic carbon to deeper layers. While aragonite saturation remains above critical thresholds year-round, lower values in bottom waters raise concerns for future impacts on calcifying organisms and phytoplankton.
  River discharge plays a crucial role in shaping the hydrology and biogeochemistry of the Gulf of Trieste (GoT), with the Isonzo and Timavo rivers serving as the main sources of freshwater, nutrients, and inorganic carbon. The study provides the first monthly biogeochemical characterization of both rivers during contrasting hydrological years (2022 and 2023), revealing that nutrient, total alkalinity (TA), and dissolved inorganic carbon (DIC) loads vary significantly with runoff. Timavo waters, influenced by their karstic and hypogeous nature, showed lower pH and higher TA and DIC compared to Isonzo. The ongoing research aims to improve understanding of riverine inputs, including often-overlooked coastal and submarine springs, and their role in regulating coastal productivity, acidification, and long-term ecosystem changes in the GoT.
- Rogoznica Lake (Dragon Eye) is a highly stratified, eutrophic marine system characterized by extreme environmental variability and recurring anoxic events. Long-term studies indicate significant accumulation of dissolved and particulate organic carbon (DOC and POC), particularly in the anoxic hypolimnion. Organic matter dynamics are further assessed through surface activity measurements (SAS and NSA) and stable isotope analyses ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$), revealing strong seasonal and vertical shifts linked to environmental drivers such as salinity, oxygen levels, and mixing events. Isotopic signatures and C:N ratios suggest a predominantly autochthonous origin of OM from phytoplankton, with episodic bacterial and terrestrial contributions. These findings highlight the sensitivity of OM composition to changing physicochemical conditions and underscore the importance of Rogoznica Lake as a natural laboratory for studying biogeochemical cycling under extreme environmental stress.

New projects and/or funding

- IAEA TC Project INT7022: ***Strengthening Ocean Health for Sustainable Development: A Global Approach using Isotopic and Nuclear Techniques*** started in 2024. The project aims to improve the health of the oceans and achieving the United Nations Sustainable Development Goals (SDGs) SDGs 13, 14, and 17, which relate to the insufficient integrated scientific research at the global level on marine pollution, climate change, ocean acidification, and the carbon cycle.
- N1-0359: ***Ocean Alkalinity Enhancement as a Strategic Lever for Ocean Change Mitigation Strategies*** national project supported by ARIS (2024-2026)
- ***REDEFINE (RivEr DischargEs in the GulF of TrIeste: a coNtribution to the improvEment of the digital twin of the northern Adriatic Sea)*** aims to contribute to the implementation of a digital twin of the northern Adriatic Sea (NAd) by providing updated data on the discharges of Isonzo, Timavo and Tagliamento rivers flowing into the Gulf of Trieste (GoT)

New GEOTRACES or GEOTRACES-relevant publications (published or in press)

ANDRON, Teodor Daniel, CORNS, Warren T., DEXTER, Matthew A., ŽIVKOVIĆ, Igor, KOTNIK, Jože, HORVAT, Milena. A traceable calibration for gaseous elemental mercury measurements in air and water. *Atmosphere*, 2025, 16/4, art. no. 421, pp. 1-12. DOI: 10.3390/atmos16040421.

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ŽIVKOVIĆ, Igor, HEIMBÜRGER-BOAVIDA, Lars-Eric, PETROVA, Mariia V., DUFOUR, Aurélie, BEGU, Ermira, HORVAT, Milena. Achieving measurement comparability in mercury speciation analysis in seawater: Key requirements and best practices. *Marine Chemistry*, 2025, 269, art. no. 104498, 12 pp. DOI: 10.1016/j.marchem.2025.104498.

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BENEDIK, Ljudmila, ROVAN STIPLOŠEK, Leja, FALNOGA, Ingrid, JERAN, Zvonka, LIPEJ, Lovrenc, PROSEN, Helena, FAGANELI, Jadran. Po-210 in plankton and fish from coastal waters (gulf of Trieste, northern Adriatic Sea). *Marine Chemistry*, 2024, 265-266, art. no. 104425. DOI: 10.1016/j.marchem.2024.104425.

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PAVONI, Elena, FLOREANI, Federico, PETRANICH, Elisa, CROSERA, Matteo, MARUSSI, Giovanna, ACQUAVITA, Alessandro, PISONI, Chiara, KLUN, Katja, FAGANELI, Jadran, COVELLI, Stefano. Effect of forced aeration on the biogeochemical cycle of nutrients and metal(loid)s as a remedy for hypoxia in a permanently stratified estuary (Gulf of Trieste, northern Adriatic Sea). *Marine pollution bulletin*, 2024, 205, art. no. 116632, pp. [1]-12. DOI: 10.1016/j.marpolbul.2024.116632.

BEDNARŠEK, Nina, VAN DE MORTEL, Hanna, PELLETIER, Greg, GARCÍA-REYES, Marisol, FEELY, Richard Alan, DICKSON, Andrew G. Assessment framework to predict sensitivity of marine calcifiers to ocean alkalinity enhancement – identification of biological thresholds and importance of precautionary principle. *Biogeosciences*. 2025, 22/2, pp. 473-498. DOI: 10.5194/bg-22-473-2025.

BEDNARŠEK, Nina, PELLETIER, Greg, KIMOTO, Katsunori, MACCREADY, Parker, KLINGER, Terrie, NEWTON, Jan A. Sensitivity of pteropod calcification to multi stressor variability in coastal habitats. *Marine environmental research*, 2025, 204, art. no.]106868, pp. 1-11. DOI: 10.1016/j.marenvres.2024.106868.

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LAUDICELLA, Vincenzo Alessandro, KRALJ, Martina, OGRINC, Nives, KRAJNC, Bor, FAGANELI, Jadran, GIANI, Michele, et al. Influence of karstic rivers and southern Adriatic waters on the CO_2 system of the Gulf of Trieste (Mediterranean Sea). V: *ICOS Science Conference 2024: book of abstracts: 10-12.9.24 Versailles, France & online*. [S. l.: s. n., 2024]. pp. [393-394].

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PhD thesis

TORRES-RODRIGUEZ, Natalia. *Marine mercury species dynamics and distribution*. Saint Paul: [N. Torres-Rodriguez], 2024.

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