19th International Conference on Environmental Science and Technology

Kos, Greece, 3 to 6 September 2025

Maritime transport impact on pollution in Saronikos Gulf: modelling, insight and perspectives from two research projects.

Kolovoyiannis V.[1*], Mazioti A.A.[1], Potiris M.[1], Mamoutos I.[1], Krasakopoulou E.[1], Tragou E.[1], Zervakis V.[1], Majamäki E.[2], Hänninen R.[2], Sofiev M.[2], Fridell E.[3], Kukkonen J.[2,4], Jalkanen J.-P.[2], Poupkou A.[5], Liora N.[6], Skylaki E.[7], Parinos C.[7], Gogou A.[7], Mihalopoulos N.[8], Zerefos Ch.[5]

[1]Laboratory of Physical and Chemical Oceanography, Department of Marine Sciences, University of the Aegean, Greece

[2]Finnish Meteorological Institute, Erik Palmeninaukio 1, FI-00560 Helsinki, Finland

[3]IVL Swedish Environmental Research Institute, Valhallavagen, 81 114 28 Stockholm, Sweden

[4]University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK

[5]Research Centre for Atmospheric Physics and Climatology, Academy of Athens, 10680 Athens, Greece

[6]Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

[7]Institute of Oceanography, Hellenic Centre for Marine Research (HCMR), 19013 Anavyssos, Greece

[8]Institute for Environmental Research and Sustainable Development, National Observatory of Athens, 152 36 Palaia Penteli, Greece

*corresponding author: Vassilis Kolovoyiannis

e-mail: vkol@aegean.gr

Abstract This work concisely presents findings and insight on the impact of shipping on pollution of an eastern Mediterranean coastal marine ecosystem - Saronikos Gulf, Greece. Advanced modelling tools (STEAM, SILAM, Delft3D) were employed to assess shipping-related pollution from direct discharges and atmospheric emissions of heavy metals, PAHs and Elemental (black) Carbon (EC). Simulations for 2018 revealed that shipping contributed < 1% to total pollutant loads. Projections for 2050 under various traffic and fuel scenarios indicated that open-loop scrubber discharges could increase concentrations locally. The fate of fine EC particles was also investigated, showing that EC from shipping represents a small fraction of total atmospheric deposition, though some accumulation in marine sediments occurs. High-resolution Delft3D simulations, forced by seasonal EC deposition data accounting for all sources from the WRF-CAMx modelling system, were used to evaluate EC transport and distribution in the Gulf. Results showed increased EC levels in Elefsis Bay for January and July 2019 and decreasing gradients offshore, in agreement with field observations, reflecting source importance and seasonal variation. Findings highlight the limited yet important role of shipping in localized marine pollution.

Keywords: Shipping emissions, scrubber effluent, black carbon dispersion, modelling, marine pollution

1. Introduction

Maritime transport exerts multiple pressures on the environment through direct discharges and atmospheric emissions, influencing air quality, climate, and marine ecosystems. Wastewater streams from ships, including scrubber wash-water, sewage, and greywater, contain contaminants such as heavy metals and PAHs. While much research has focused on air pollution and climate effects, less is known about marine impacts of these waste streams (Jalkanen et al. 2024). In particular, the widespread use of open-loop Exhaust Gas Cleaning Systems (EGCS or scrubbers) to comply with sulfur regulations has raised concerns about new pollution pathways, as toxic effluents are discharged directly into the sea (Zervakis et al. 2025). Concurrently, EC, a by-product of incomplete combustion, is a climate-active pollutant and a persistent material that accumulates in marine sediments. Shipping emissions contribute ultrafine EC particles, deposited onto the ocean through wet and dry deposition. Once in the water, particulate EC can bind to other pollutants, influence nutrient cycles, and affect biological processes such as phytoplankton growth. However, the fate and transport of EC in marine systems remain not well understood. This work presents findings from two research projects that assess maritime transport's contribution to pollution in Saronikos Gulf, a heavily impacted Eastern Mediterranean coastal basin: the Horizon 2020 EMERGE project, and the EU-Greece co-funded NAVGREEN project.

2. Methods

Both studies applied an integrated, high-resolution, multi-model framework to assess the impact of shipping-related pollution in Saronikos Gulf (Fig. 1a). For EMERGE, ship discharges were quantified using the STEAM model, which estimates waste stream volumes (e.g., scrubber, grey, black water) combined with pollutant concentration data to calculate gridded mass fluxes. Emissions for 2050 were simulated under two contrasting scenarios: high-scrubber use and alternative fuel (LNG/methanol). Atmospheric emissions of metals and EC were simulated using the SILAM chemical transport model, with two runs (with/without shipping) to estimate deposition due to shipping. SILAM used CAMS emissions data and ECMWF IFS meteorological forcing, with shipping emissions from STEAM introduced at two atmospheric layers to represent vessel size. Marine dynamics was reproduced using Delft3D-FLOW, forced by ERA5 atmospheric data and ocean boundary conditions from ROMS. Delft3D-WAQ simulated the pollutants' fate in the marine environment, including advection and settling of

EC under various particle settling velocity scenarios and a dynamic parameterization accounting for flocculation due to salinity, temperature, and suspended solids. For NAVGREEN, Delft3D-WAQ simulated the fate of elemental carbon (EC) particles (2.5 μm). Hydrodynamic conditions were simulated at high resolution using Delft3D-FLOW, and EC deposition forcing came from WRF-CAMx simulations by the Academy of Athens (Poupkou et al. 2024), providing hourly wet and dry deposition fields for winter and summer (January and July 2019), accounting for seasonal variability.

3. Results and Discussion

Integrated modelling quantified pollutant loads from shipping in 2018 (5 heavy metals, 2 PAHs), accounting for both direct discharges and atmospheric deposition. Shipping contributed <1% to total pollutant loads overall but caused local increases near Piraeus and major shipping lanes. Projections suggest that high scrubber use may increase pollutant concentrations (e.g. Pb +20%), while clean fuels and no scrubbers reduce impacts, highlighting EGCS risks (Kolovoyiannis et al. 2025). Atmospheric EC deposition from shipping was found to be minor compared to other sources in 2018, though local accumulation occurred in Elefsis Bay (Mazioti et al. 2024); settling velocity significantly influences EC fate in the marine environment.

Simulation of the fate of EC 2.5μm particles for winter & summer conditions (Jan & Jul 2019) indicates higher concentrations in Elefsis Bay, with gradients decreasing offshore, consistent with HCMR field observations (Fig 1b, c). Sources and seasonality of depositional fluxes define the spatiotemporal variability of water column EC concentrations, highlighting the influence of atmospheric conditions and emission patterns.

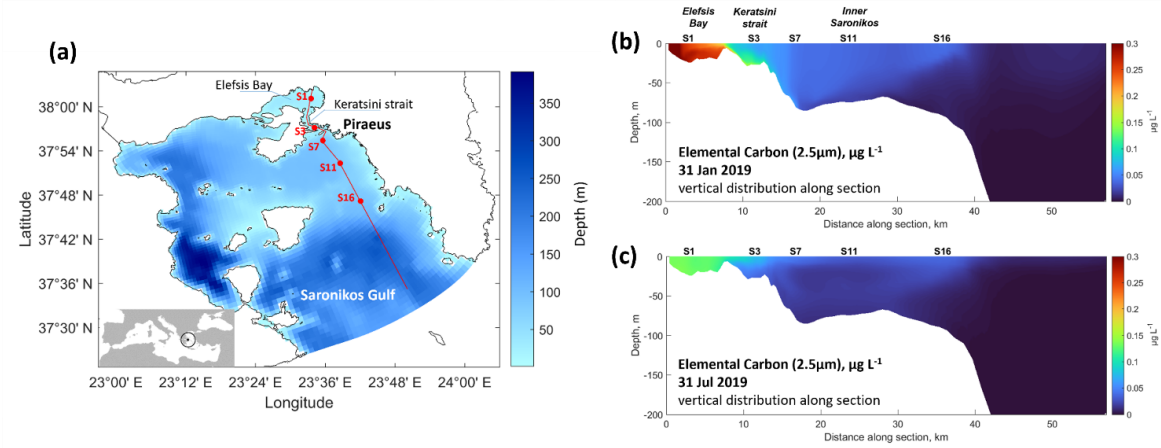

Figure 1. (a) Bathymetry and model domain of the study area. (b, c) Vertical distribution of Elemental Carbon concentrations (μg L^{-1}) along section depicted in (a) after 1-month simulations for winter (b, Jan 2019) and summer conditions (c, Jul 2019). Results from the project NAVGREEN.

Acknowledgments

This research was funded by the European Union's Horizon 2020 Research and Innovation Program, Grant Agreement No 874990 "Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions" - EMERGE project and the European Union - Next Generation EU - National Recovery and Resilience Plan (NRRP) – Greece 2.0. Project "NAVGREEN – Green Shipping of Zero Carbon Footprint" (Project Code: TAEDR-0534767).

References

Jalkanen et al., (2024). Environmental Impacts of Exhaust Gas Cleaning Systems in the Baltic Sea, North Sea, and the Mediterranean Sea Area. Finnish Meteorological Institute, Helsinki, Finland. ISBN 978-952-336-189-8.

Kolovoyiannis et al. (2025). Modelling the impact of present and future maritime transport on marine pollution at an environmentally sensitive coastal ecosystem (Saronikos gulf, eastern Mediterranean). *Marine Pollution Bulletin,* **219**, 118335.

Mazioti et al. (2024), The shipping industry as a source of fine black carbon particles in the marine environment: a preliminary study for the case study of Saronikos Gulf, *Technical Annals*, **1(8)**.

Poupkou, et al., (2024). Exploring the impact of shipping emissions on PM levels in the Eastern Mediterranean. In:*Electronic Proceedings of the 22nd International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes (HARMO22),* 10-14 June 2024, Pärnu, Estonia (Code 204606).

Zervakis et al., (2025). A novel method to assess the dilution of complex mixtures in the marine environment: application to marine scrubber water effluents. *Marine Pollution Bulletin,* **216**, 117956.