THE SCIPPER PROJECT

Shipping Contributions to Inland Pollution Push for the Enforcement of Regulations

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Executive summary

This deliverable lists SCIPPER's scientific publications in journals and conferences (Section 1), and consortium's participations in conferences, workshops, webinars, and other scientific and stakeholders' events with oral presentations (Section 2) for the communication and dissemination of project's results. In addition, it includes the workshops organized by SCIPPER (Section 3) and the scientific papers prepared for submission to peer-reviewed journals and conferences before the end of SCIPPER (Section 4). The estimated targets, according to the Grant Agreement, were 12 journal publications and 14 conferences' participation. It should be noted that SCIPPER started on 1st May 2019, thus COVID-19 pandemic restrictions on travelling and events' organisation lasted for a large part of the project's lifetime. Nevertheless, SCIPPER consortium surpassed the estimated targets, since 14 peer-reviewed journal papers and 32 conference abstracts and papers were published, and partners have participated in 38 external events with oral presentations up to 31/01/2023, i.e., end date of the project.

List of abbreviations

1. Shipping Contributions to Inland Pollution Push for the Enforcement of Regulations (SCIPPER)
2. European Commission (EC)
3. Grant Agreement (GA)

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1 Scientific publications

1.1 Publications in peer-reviewed journals

During the 45-month implementation of SCIPPER, 14 open access scientific papers in peer-reviewed journals have been published:

1. **Georgoulias, A.K., Boersma, K.F., van Vliet, J., Zhang, X., van der A, R., Zanis, P., de Laat, J. (2020). Detection of NO_2 pollution plumes from individual ships with the TROPOMI/S5P satellite sensor.** ***Environmental Research Letters, 15*****(12), 124037.** https://doi.org/10.1088/1748-9326/abc445

Abstract

This paper presents an analysis of tropospheric NO_2 column measurements from the TROPOspheric Monitoring Instrument onboard the Copernicus Sentinel 5 Precursor satellite (TROPOMI/S5P) for an oceanic area in the central Mediterranean on 2 July 2018. The day and area were selected because of the stable and cloud-free weather conditions with low wind speeds throughout most of the area, while covering one of the busiest worldwide international shipping corridors. In addition, the area was affected by sunglint, i.e. sunlight that is directly reflected by the ocean surface waves to the satellite which greatly enhances the signal-to-noise ratio of the satellite observations. The satellite measurements reveal plume-like emission structures in tropospheric NO_2 columns while automated identification signal (AIS) data of ship locations reveal a total of 185 ships in the area. Combined with information about wind speed and wind direction within 3 h prior to the TROPOMI/S5P overpass, the ship tracks can almost perfectly be aligned with the plume-like tropospheric NO_2 structures. In addition, information about ship length and ship speed, combined with an analysis of ship tracks and ship position, reveal that nearly all emission plume-like tropospheric NO_2 structures can be attributed to the largest ships, mostly container ships and crude oil tankers. Overall, our results show for the first time ever that NO_2 emission plumes from ships can be detected and attributed to individual ships using satellite measurements, while also providing strong support for using satellite sunglint measurements.

2. **Seppälä, S. D., Kuula, J., Hyvärinen, A.-P., Saarikoski, S., Rönkkö, T., Keskinen, J., Jalkanen, J.-P., and Timonen, H. (2021). Effects of marine fuel sulfur restrictions on particle number concentrations and size distributions in ship plumes in the Baltic Sea.** ***Atmospheric Chemistry and Physics, 21*****(4), 3215-3234.** https://doi.org/10.5194/acp-21-3215-2021

Abstract

Exhaust emissions from shipping are a major contributor to particle concentrations in coastal and marine areas. Previously, the marine fuel sulfur content (FSC) was restricted globally to 4.5 m/m%, but the limit was changed to 3.5 m/m% at the beginning of 2012 and further down to 0.5 m/m% in January 2020. In sulfur emission control areas (SECA), the limits are stricter: the FSC restriction was originally 1.50 m/m%, but it decreased to 1.00 m/m% in July 2010 and again to 0.10 m/m% in January 2015. In this work, the effects of the FSC restrictions on particle number concentrations (PNCs) and particle number size distributions (NSDs) are studied in the Baltic Sea SECA. Measurements were made on a small island (Utö, Finland; 59°46′50 N, 21°22′23 E) between 2007 and 2016. Ship plumes were extracted from the particle number size distribution data, and the effects of the FSC restrictions on the observed plumes as well as on the ambient concentrations were investigated. Altogether, 42 322 analyzable plumes were identified during the 10-year measurement period. The results showed that both changes in the FSC restrictions reduced the PNCs of the plumes. The latter restriction (to 0.10 m/m% in January 2015) also decreased the ambient particle number concentrations, as a significant portion of particles in the area originated from ship plumes that were diluted beyond the plume detection limits. The overall change in the PNCs of the plumes and ambient air was 27 and 32%, respectively, for the total FSC change from 1.50 m/m% to 0.10 m/m%. The decrease in the plume particle number concentration was caused mostly by a decrease in the concentration of particle sizes of between approximately 33 and 144 nm. The latter restriction also reduced the geometric mean diameter of the particles, which was probably caused by the fuel type change from residual oil to distillates during the latter restriction. The PNC was larger for the plumes measured at daytime than for those measured at night-time, likely because of the photochemical aging of particles due to UV light. The difference decreased with decreasing FSC, indicating that a lower FSC also has an impact on the atmospheric processing of ship plumes.

3. **Stylogiannis, A., Kousias, N., Kontses, A., Ntziachristos, L., Ntziachristos, V.A. (2021). Low-Cost Optoacoustic Sensor for Environmental Monitoring. *Sensors, 21*(4), 1379.** https://doi.org/10.3390/s21041379

Abstract

Attention to Black Carbon (BC) has been rising due to its effects on human health as well its contribution to climate change. Measurements of BC are challenging, as currently used devices are either expensive or impractical for continuous monitoring. Here, we propose an optoacoustic sensor to address this problem. The sensor utilizes a novel ellipsoidal design for refocusing the optoacoustic signal with minimal acoustic energy losses. To reduce the cost of the system, without sacrificing accuracy, an overdriven laser diode and a Quartz Tuning Fork are used as the light source and the sound detector, respectively. The prototype was able to detect BC particles and to accurately monitor changes in concentration in real time and with very good agreement with a reference instrument. The response of the sensor was linearly dependent on the BC particles concentration with a normalized noise equivalent absorption coefficient (NNEA) for soot equal to 7.39×10^{-9} W cm^{-1} $Hz^{-1/2}$. Finally, the prototype was able to perform NO_2 measurements, demonstrating its ability to accurately monitor both particulate and gaseous pollutants. The proposed sensor has the potential to offer a significant economic impact for BC environmental measurements and source appointment technologies

4. **Grigoriadis, A., Mamarikas, S., Ioannidis, I., Majamäki, E., Jalkanen, J.-P., Ntziachristos, L. (2021). Development of exhaust emission factors for vessels: A review and meta-analysis of available data. *Atmospheric Environment: X, 12*, 100142**. https://doi.org/10.1016/j.aeaoa.2021.100142

Abstract

The maritime sector is characterized by high contribution in the emission of harmful pollutants such as NO_X, PM, and SO_X. The sector is making decisive steps to drastically reduce its environmental footprint by applying new technology and fuels as a reaction to the increasingly stringent emissions regulatory framework. In order to calculate the contribution of shipping to current emission inventories and to project future developments under different policy scenarios reliable and diversified emission factors have to be developed. In this context the present paper develops a new set of emission factors for ships, based on a review and statistical processing of shipping emission measurements available in literature. To offer significant resolution and versatility for use under different operating conditions, the developed emission factors are expressed as a function of the ship engine load. These emission factors are also distinguished according to the engine and fuel types that are met in practice. The absolute values of the developed emission factors highlight the emission performance of ships per pollutant, while the load dependent functions produced reveal how this emission performance of ships changes under various operating conditions. Finally, a comparison of the developed load dependent emission factors with modal emission factors retrieved from literature is performed specifically for NO_X emissions. This comparison indicates the differences and similarities between the two methods as a measure of uncertainty in the estimation of emissions using the proposed emission factor dataset.

5. **Walden, J., Pirjola, L., Laurila, T., Hatakka, J., Pettersson, H., Walden, T., Jalkanen, J.-P., Nordlund, H., Truuts, T., Meretoja, M., Kahma. K. (2021). Measurement report: Characterization of uncertainties of flux measurements and fuel sulfur content from ship emissions at the Baltic Sea. *Atmospheric Chemistry and Physics, 21*(24), 18175-18194.** https://doi.org/10.5194/acp-21-18175-2021

Abstract

Fluxes of gaseous compounds and nanoparticles were studied using micrometeorological methods at Harmaja in the Baltic Sea. The measurement site was situated beside the ship route to and from the city of Helsinki. The gradient (GR) method was used to measure fluxes of SO_2, NO, NO_2, O_3, CO_2, and N_{tot} (the number concentration of nanoparticles). In addition, the flux of CO_2 was also measured using the eddy-covariance (EC) method. Distortion of the flow field caused by obstacles around the measurement mast was studied by applying a computation fluid dynamic (CFD) model. This was used to establish the corresponding heights in the

undisturbed stream. The wind speed and the turbulent parameters at each of the established heights were then recalculated for the gradient model. The effect of waves on the boundary layer was taken into consideration, as the Monin–Obukhov theory used to calculate the fluxes is not valid in the presence of swell. Uncertainty budgets for the measurement systems were constructed to judge the reliability of the results. No clear fluxes across the air–sea nor the sea–air interface were observed for SO_2, NO, NO_2, NOx (= NO + NO_2), O_3, or CO_2 using the GR method. A negative flux was observed for N_{tot}, with a median value of -0.23×10^9 m^{-2} s^{-1} and an uncertainty range of 31% – 41%. For CO_2, while both positive and negative fluxes were observed, the median value was −0.081 μmol m^{-2} s^{-1} with an uncertainty range of 30% – 60% for the EC methods. Ship emissions were responsible for the deposition of N_{tot}, while they had a minor effect on CO_2 deposition. The fuel sulfur content (FSC) of the marine fuel used in ships passing the site was determined from the observed ratio of the SO_2 and CO_2 concentrations. A typical value of 0.40 ± 0.06% was obtained for the FSC, which is in compliance with the contemporary FSC limit value of 1% in the Baltic Sea area at the time of measurements. The method to estimate the uncertainty in the FSC was found to be accurate enough for use with the latest regulations, 0.1% (Baltic Sea area) and 0.5% (global oceans).

6. **Au, C. N., Delea, C., Schneider, J., Oeffner, J., Jahn, C. (2021). A web-oriented architecture for deploying multiple unmanned vehicles as a service. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 15(1), 155–164.** https://doi.org/10.12716/1001.15.01.15

Abstract

Providing a robotic-assisted service in scenarios involving multiple Unmanned Vehicles (UVs) in possible beyond-visual-Line-Of-Sight (LoS) operations, safety and security are critical concerns. We develop a web-oriented, human-in-the-loop infrastructure to explore how the service provider can secure their system, enforce instant access control over dynamic operator-robot connections, and ensure the integrity, availability, and traceability of communicated data. Our proposed minimal viable solution requires an authentication server to verify user identity, a back server with a database to handle user requests and state-transition events, and aRabbitMQ (RMQ) server to trace the origin of data.

7. **Karjalainen, P., Teinilä, K., Kuittinen, N., Aakko-Saksa, P., Bloss, M., Vesala, H., Pettinen, R., Saarikoski, S., Jalkanen, J.P., Timonen, H. (2022). Real-world particle emissions and secondary aerosol formation from a diesel oxidation catalyst and scrubber equipped ship operating with two fuels in a SECA area.** ***Environmental Pollution,*** **292(Part A), 118278.** https://doi.org/10.1016/j.envpol.2021.118278

Abstract

SO_x Emissions Control Areas (SECAs) have been established to reduce harmful effects of atmospheric sulfur. Typical technological changes for ships to conform with these regulations have included the combustion of low-sulfur fuels or installment of SO_x scrubbers. This paper presents experimental findings from high-end real-time measurements of gaseous and particulate pollutants onboard a Roll-on/Roll-off Passenger ship sailing inside a SECA equipped with a diesel oxidation catalyst (DOC) and a scrubber as the exhaust aftertreatment. The ship operates between two ports and switched off the SO_x scrubbing when approaching one of the ports and used low-sulfur fuel instead. Measurement results showed that the scrubber effectively reduced SO_2 concentrations with over 99% rate. In terms of fuel, the engine-out PM was higher for heavy fuel oil than for marine gas oil. During open sea cruising (65% load) the major chemical components in PM having emission factor of 1.7 g kg_{fuel}^{-1} were sulfate (66%) and organics (30%) whereas the contribution of black carbon (BC) in PM was low (~4%). Decreased engine load on the other hand increased exhaust concentrations of BC by a factor exceeding four. As a novel finding, the secondary aerosol formation potential of the emitted exhaust measured with an oxidation flow reactor and an aerosol mass spectrometer was found negligible. Thus, it seems that either DOC, scrubber, or their combination is efficient in eliminating SOA precursors. Overall, results indicate that in addition to targeting sulfur and NO_x emissions from shipping, future work should focus on mitigating harmful particle emissions.

8. **Riess, T. C. V. W., Boersma, K. F., van Vliet, J., Peters, W., Sneep, M., Eskes, H., and van Geffen, J. (2022). Improved monitoring of shipping NO_2 with TROPOMI: decreasing NOx emissions in European seas during the COVID-19 pandemic, *Atmospheric Measurement Techniques, 15,* 1415-1438.** https://doi.org/10.5194/amt-15-1415-2022

Abstract

TROPOMI (TROPOspheric Monitoring Instrument) measurements of tropospheric NO_2 columns provide powerful information on emissions of air pollution by ships on open sea. This information is potentially useful for authorities to help determine the (non-)compliance of ships with increasingly stringent NOx emission regulations. We find that the information quality is improved further by recent upgrades in the TROPOMI cloud retrieval and an optimal data selection. We show that the superior spatial resolution of TROPOMI allows for the detection of several lanes of NO_2 pollution ranging from the Aegean Sea near Greece to the Skagerrak in Scandinavia, which have not been detected with other satellite instruments before. Additionally, we demonstrate that under conditions of sun glint TROPOMI's vertical sensitivity to NO_2 in the marine boundary layer increases by up to 60 %. The benefits of sun glint are most prominent under clear-sky situations when sea surface winds are low but slightly above zero (±2 m s^{-1}). Beyond spatial resolution and sun glint, we examine for the first time the impact of the recently improved cloud algorithm on the TROPOMI NO_2 retrieval quality, both over sea and over land. We find that the new FRESCO+ (Fast Retrieval Scheme for Clouds from the Oxygen A band) wide algorithm leads to 50 hPa lower cloud pressures, correcting a known high bias, and produces 1–4×10^{15} molec. cm^{-2} higher retrieved NO_2 columns, thereby at least partially correcting for the previously reported low bias in the TROPOMI NO_2 product. By training an artificial neural network on the four available periods with standard and FRESCO+ wide test retrievals, we develop a historic, consistent TROPOMI NO_2 data set spanning the years 2019 and 2020. This improved data set shows stronger (35% – 75%) and sharper (10% – 35%) shipping NO_2 signals compared to co-sampled measurements from OMI. We apply our improved data set to investigate the impact of the COVID-19 pandemic on ship NO_2 pollution over European seas and find indications that NOx emissions from ships reduced by 10% – 20% during the beginning of the COVID-19 pandemic in 2020. The reductions in ship NO_2 pollution start in March–April 2020, in line with changes in shipping activity inferred from automatic identification system (AIS) data on ship location, speed, and engine.

9. **Sokhi, R. S., Moussiopoulos, N., Baklanov, A., Bartzis, J., Coll, I., Finardi, S., Friedrich, R., Geels, C., Grönholm, T., Halenka, T., Ketzel, M., Maragkidou, A., Matthias, V., Moldanova, J., Ntziachristos, L., Schäfer, K., Suppan, P., Tsegas, G., Carmichael, G., Franco, V., Hanna, S., Jalkanen, J.-P., Velders, G. J. M., and Kukkonen, J. (2022). Advances in air quality research – current and emerging challenges. *Atmospheric Chemistry and Physics,* 22(7), 4615-4703.** https://doi.org/10.5194/acp-22-4615-2022

Abstract

This review provides a community's perspective on air quality research focusing mainly on developments over the past decade. The article provides perspectives on current and future challenges as well as research needs for selected key topics. While this paper is not an exhaustive review of all research areas in the field of air quality, we have selected key topics that we feel are important from air quality research and policy perspectives. After providing a short historical overview, this review focuses on improvements in characterizing sources and emissions of air pollution, new air quality observations and instrumentation, advances in air quality prediction and forecasting, understanding interactions of air quality with meteorology and climate, exposure and health assessment, and air quality management and policy. In conducting the review, specific objectives were (i) to address current developments that push the boundaries of air quality research forward, (ii) to highlight the emerging prominent gaps of knowledge in air quality research, and (iii) to make recommendations to guide the direction for future research within the wider community. This review also identifies areas of particular importance for air quality policy. The original concept of this review was borne at the International Conference on Air Quality 2020 (held online due to the COVID 19 restrictions during 18–26 May 2020), but the article incorporates a wider landscape of research literature within the field of air quality science. On air pollution emissions the review highlights, in particular, the need to reduce uncertainties in emissions from diffuse sources, particulate matter chemical components, shipping emissions, and the importance of considering both indoor and outdoor sources. There is a growing need to have integrated air pollution and related observations from

both ground-based and remote sensing instruments, including in particular those on satellites. The research should also capitalize on the growing area of low-cost sensors, while ensuring a quality of the measurements which are regulated by guidelines. Connecting various physical scales in air quality modelling is still a continual issue, with cities being affected by air pollution gradients at local scales and by long-range transport. At the same time, one should allow for the impacts from climate change on a longer timescale. Earth system modelling offers considerable potential by providing a consistent framework for treating scales and processes, especially where there are significant feedbacks, such as those related to aerosols, chemistry, and meteorology. Assessment of exposure to air pollution should consider the impacts of both indoor and outdoor emissions, as well as application of more sophisticated, dynamic modelling approaches to predict concentrations of air pollutants in both environments. With particulate matter being one of the most important pollutants for health, research is indicating the urgent need to understand, in particular, the role of particle number and chemical components in terms of health impact, which in turn requires improved emission inventories and models for predicting high-resolution distributions of these metrics over cities. The review also examines how air pollution management needs to adapt to the above-mentioned new challenges and briefly considers the implications from the COVID-19 pandemic for air quality. Finally, we provide recommendations for air quality research and support for policy.

10. **Guevara, M., Jorba, O., Petetin, H., Denier van der Gon, H.A.C., Kuenen, J., Super, I., Jalkanen, J.-P., E. Majamäki, E., Johansson, L., Peuch, V.-H., Pérez Garcia-Pando C. (2022). European primary emissions of criteria pollutants and greenhouse gases in 2020 modulated by the COVID-19 pandemic disruptions.** ***Earth System Science Data, 14*****(6), 2521-2552.** https://doi.org/10.5194/essd-14-2521-2022

Abstract

We present a European dataset of daily sector-, pollutant- and country-dependent emission adjustment factors associated with the COVID-19 mobility restrictions for the year 2020. We considered metrics traditionally used to estimate emissions, such as energy statistics or traffic counts, as well as information derived from new mobility indicators and machine learning techniques. The resulting dataset covers a total of nine emission sectors, including road transport, the energy industry, the manufacturing industry, residential and commercial combustion, aviation, shipping, off-road transport, use of solvents, and fugitive emissions from transportation and distribution of fossil fuels. The dataset was produced to be combined with the Copernicus CAMS-REG_v5.1 2020 business-as-usual (BAU) inventory, which provides high-resolution (0.1° × 0.05°) emission estimates for 2020 omitting the impact of the COVID-19 restrictions. The combination of both datasets allows quantifying spatially and temporally resolved reductions in primary emissions from both criteria pollutants (NOx, SO_2, non-methane volatile organic compounds – NMVOCs, NH_3, CO, PM_{10} and $PM_{2.5}$) and greenhouse gases (CO_2 fossil fuel, CO_2 biofuel and CH_4), as well as assessing the contribution of each emission sector and European country to the overall emission changes. Estimated overall emission changes in 2020 relative to BAU emissions were as follows: −10.5% for NOx (−602 kt), −7.8% (−260.2 Mt) for CO_2 from fossil fuels, −4.7% (−808.5 kt) for CO, −4.6% (−80 kt) for SO_2, −3.3% (−19.1 Mt) for CO_2 from biofuels, −3.0% (−56.3 kt) for PM_{10}, −2.5% (−173.3 kt) for NMVOCs, −2.1% (−24.3 kt) for $PM_{2.5}$, −0.9% (−156.1 kt) for CH_4 and −0.2% (−8.6 kt) for NH_3. The most pronounced drop in emissions occurred in April (up to −32.8% on average for NOx) when mobility restrictions were at their maxima. The emission reductions during the second epidemic wave between October and December were 3 to 4 times lower than those occurred during the spring lockdown, as mobility restrictions were generally softer (e.g. curfews, limited social gatherings). Italy, France, Spain, the United Kingdom and Germany were, together, the largest contributors to the total EU27 + UK (27 member states of the European Union and the UK) absolute emission decreases. At the sectoral level, the largest emission declines were found for aviation (−51% to −56%), followed by road transport (−15.5% to −18.8%), the latter being the main driver of the estimated reductions for the majority of pollutants. The collection of COVID-19 emission adjustment factors (https://doi.org/10.24380/k966-3957, Guevara et al., 2022) and the CAMS-REG_v5.1 2020 BAU gridded inventory (https://doi.org/10.24380/eptm-kn40, Kuenen et al., 2022b) have been produced in support of air quality modelling studies.

11. **Lauenburg, M., Karl, M., Matthias, V., Quante, M., Ramacher, M. O. P. (2022). City Scale Modeling of Ultrafine Particles in Urban Areas with Special Focus on Passenger Ferryboat Emission Impact.** ***Toxics*****, *10*(1):3.** https://doi.org/10.3390/toxics10010003

Abstract

Air pollution by aerosol particles is mainly monitored as mass concentrations of particulate matter, such as PM_{10} and $PM_{2.5}$. However, mass-based measurements are hardly representative for ultrafine particles (UFP), which can only be monitored adequately by particle number (PN) concentrations and are considered particularly harmful to human health. This study examines the dispersion of UFP in Hamburg city center and, in particular, the impact of passenger ferryboats by modeling PN concentrations and compares concentrations to measured values. To this end, emissions inventories and emission size spectra for different emission sectors influencing concentrations in the city center were created, explicitly considering passenger ferryboat traffic as an additional emission source. The city-scale chemical transport model EPISODE-CityChem is applied for the first time to simulate PN concentrations and additionally, observations of total particle number counts are taken at four different sampling sites in the city. Modeled UFP concentrations are in the range of 1.5–3 × 10^4 cm^{-3} at ferryboat piers and at the road traffic locations with particle sizes predominantly below 50 nm. Urban background concentrations are at 0.4–1.2 × 10^4 cm^{-3} with a predominant particle size in the range 50–100 nm. Ferryboat traffic is a significant source of emissions near the shore along the regular ferry routes. Modeled concentrations show slight differences to measured data, but the model is capable of reproducing the observed spatial variation of UFP concentrations. UFP show strong variations in both space and time, with day-to-day variations mainly controlled by differences in air temperature, wind speed and wind direction. Further model simulations should focus on longer periods of time to better understand the influence of meteorological conditions on UFP dynamics.

12. **Karl, M., Pirjola, L., Grönholm, T., Kurppa, M., Anand, S., Zhang, X., Held, A., Sander, R., Dal Maso, M., Topping, D., Jiang, S., Kangas, L., and Kukkonen, J. (2022). Description and evaluation of the community aerosol dynamics model MAFOR v2.0.** ***Geoscientific Model Development, 15*****, 3969-4026.** https://doi.org/10.5194/gmd-15-3969-2022

Abstract

Numerical models are needed for evaluating aerosol processes in the atmosphere in state-of-the-art chemical transport models, urban-scale dispersion models, and climatic models. This article describes a publicly available aerosol dynamics model, MAFOR (Multicomponent Aerosol FORmation model; version 2.0); we address the main structure of the model, including the types of operation and the treatments of the aerosol processes. The model simultaneously solves the time evolution of both the particle number and the mass concentrations of aerosol components in each size section. In this way, the model can also allow for changes in the average density of particles. An evaluation of the model is also presented against a high-resolution observational dataset in a street canyon located in the centre of Helsinki (Finland) during afternoon traffic rush hour on 13 December 2010. The experimental data included measurements at different locations in the street canyon of ultrafine particles, black carbon, and fine particulate mass PM_1. This evaluation has also included an intercomparison with the corresponding predictions of two other prominent aerosol dynamics models, AEROFOR and SALSA. All three models simulated the decrease in the measured total particle number concentrations fairly well with increasing distance from the vehicular emission source. The MAFOR model reproduced the evolution of the observed particle number size distributions more accurately than the other two models. The MAFOR model also predicted the variation of the concentration of PM_1 better than the SALSA model. We also analysed the relative importance of various aerosol processes based on the predictions of the three models. As expected, atmospheric dilution dominated over other processes; dry deposition was the second most significant process. Numerical sensitivity tests with the MAFOR model revealed that the uncertainties associated with the properties of the condensing organic vapours affected only the size range of particles smaller than 10 nm in diameter. These uncertainties therefore do not significantly affect the predictions of the whole of the number size distribution and the total number concentration. The MAFOR model version 2 is well documented and versatile to use, providing a range of alternative parameterizations for various aerosol processes. The model includes an efficient numerical integration of particle number and mass concentrations, an operator splitting of processes, and the use of a fixed sectional method. The model could be used as a module in various atmospheric and climatic models.

13. **Fink, L., Karl, M., Matthias, V., Oppo, S., Kranenburg, R., Kuenen, J., Moldanova, J., Jutterström, S., Jalkanen, J.-P., and Majamäki, E. (2022). The contribution of shipping to air pollution in the**

Mediterranean region – a multimodel evaluation: Comparison of photooxidants NO_2 and O_3. *EGUsphere* [preprint]. https://doi.org/10.5194/egusphere-2022-415

Abstract

Shipping has a significant contribution to the emissions of air pollutants such as NO_x and particulate matter (PM), and the global maritime transport volumes are projected to increase further in the future. The Mediterranean Sea contains the major route for short sea shipping within Europe and contains the main shipping route between Europe and East Asia. Thus, it is a highly frequented shipping area, and high levels of air pollutants with significant contributions from shipping emissions are observed at monitoring stations in many cities along the Mediterranean coast.
The present study is part of the EU H2020 project SCIPPER (Shipping contribution to Inland Pollution Push for the Enforcement of Regulations). Five different regional chemistry transport models (CAMx, CHIMERE, CMAQ, EMEP, LOTOS-EUROS) were used to simulate the transport, chemical transformation and fate of atmospheric pollutants in the Mediterranean Sea for 2015. Shipping emissions were calculated with STEAM version 3.3.0, and land-based emissions were taken from the CAMS-REG v2.2.1 dataset for a domain covering the Mediterranean Sea on a resolution of 12x12 km^2 (or 0.1° x 0.1°). All models used their standard setup for further input. Ship contribution was calculated with the zero-out method. One run using the tagging method was performed with LOTOS-EUROS. The model outputs were compared against each other and to measured background data at monitoring stations.
The results showed differing outputs regarding the time series and pattern of model outputs but similar results with regard to the overall underestimation of NO_2 and overestimation of O_3. The contribution from ships to the total NO_2 concentration was especially high at the main shipping routes and coastal regions (25 % to 85 %). The contribution from ships to the total O_3 concentration was lowest in regions with the highest NO_2 contribution (down to -20 %). A comparison of the zero-out and tagging methods has shown that the annual mean ship contribution to the total NO_2 concentration is smaller (up to 75 %) and has a lower range when the tagging method is used. CAMx and CHIMERE simulated the highest ship contributions to the NO_2 and O_3 air concentrations. Additionally, the strongest correlation was found between CAMx and CHIMERE, which can be traced back to the usage of the same meteorological input data. The CMAQ, EMEP and LOTOS-EUROS simulated values were within one range for the NO_2 and O_3 air concentrations. Regarding deposition output, larger differences between the models were found when compared to air concentration. These uncertainties and deviations between models are caused by deposition mechanisms, which are unique within each model. A reliable output from models simulating ship contributions can be expected for air concentrations of NO_2 and O_3.

14. **Kurchaba, S., van Vliet, J., Verbeek, F. J., Meulman, J. J., Veenman, C. J. (2022). Supervised segmentation of NO2 plumes from individual ships using TROPOMI satellite data. *Remote Sensing, 14*(22), 5809.** https://doi.org/10.3390/rs14225809

Abstract

The shipping industry is one of the strongest anthropogenic emitters of NOx - a substance harmful both to human health and the environment. The rapid growth of the industry causes societal pressure on controlling the emission levels produced by ships. All the methods currently used for ship emission monitoring are costly and require proximity to a ship, which makes global and continuous emission monitoring impossible. A promising approach is the application of remote sensing. Studies showed that some of the NO_2 plumes from individual ships can visually be distinguished using the TROPOspheric Monitoring Instrument on board the Copernicus Sentinel 5 Precursor (TROPOMI/S5P). To deploy a remote-sensing-based global emission monitoring system, an automated procedure for the estimation of NO_2 emissions from individual ships is needed. The extremely low signal-to-noise ratio of the available data, as well as the absence of the ground truth makes the task very challenging. Here, we present a methodology for the automated segmentation of NO_2 plumes produced by seagoing ships using supervized machine learning on TROPOMI/S5P data. We show that the proposed approach leads to more than a 20% increase in the average precision score in comparison to the methods used in previous studies and results in a high correlation of 0.834 with the theoretically derived ship emission proxy. This work is a crucial step towards the development of an automated procedure for global ship emission monitoring using remote sensing data.

1.2 Conferences' publications

SCIPPER's consortium have submitted 32 abstracts and/or papers that are published in conferences' book of abstracts and proceedings.

1. Winnes, H., Fridell, E., Ntziachristos, L., Mamarikas, S., Jalkanen, J.-P., Duyzer, J., Verbeek, R. Weigelt, A., Vliet, J., Mellqvist, J. (2020). Gaps in current regulations for ship emissions. In Toni Lusikka, (ed.), *Proceedings of TRA2020, the 8th Transport Research Arena: Rethinking transport – towards clean and inclusive mobility*. Finland: Finnish Transport and Communications Agency Traficom (ISSN-online: 2669-8781) (abstract No 827)[1].
2. Seppälä, S., Timonen, H., Keskinen, J., Hyvärinen, A.-P., Saarikoski, S. (2020). Effects of marine fuel sulphur restrictions on particle properties of ship plumes in atmospheric environment at the Baltic Sea, *2020 European Aerosol Conference, 31.8-4.9.2020 (Online), Abstract ID 407.*
3. Mamarikas, S., Kousias, N., Tsegas, G., Barmpas F., Ntziachristos L. (2020). Maritime pollutants emissions – methods for ensuring ships compliance to regulations. *Proceedings of the 7th Environmental Conference of Macedonia* (pp 161) in Greek and in English (ISBN: 978-618-8196-2-8, ISSN: 1791-4280)[2].
4. Karl, M., Pirjola, L., Grönholm, T., Anand, S., Zhang, X., Dal Masso, M, Kukkonen, J. (2021). Development of the community aerosol dynamics model MAFOR. In *Program and abstracts of the 2021 European Aerosol Conference* (pp 1084).
5. Grigoriadis, A., Mamarikas, S., Ntziachristos, L. (2021). Emission performance of major ship classes: An estimation based on a new set of emission factors and realistic activity profile data. *IOP Conference Series: Earth and Environmental Science, 899*, 012005 (https://doi.org/10.1088/1755-1315/899/1/012005).
6. Kurchaba, S., van Vliet, J., Meulman, J.J., Verbeek, F.J., Veenman, C.J. (2021). Improving evaluation of NO_2 emission from ships using spatial association on TROPOMI satellite data. In X. Meng, F. Wang, C.T. Lu, Y. Huang, S. Shekhar, X. Xie (Eds), *Proceedings of the 29th International Conference on Advances in Geographic Information Systems (SIGSPATIAL '21)* (pp 454 - 457). Association for Computing Machinery, New York, USA (https://doi.org/10.1145/3474717.3484213).
7. Fink, L., Matthias, V., Karl, M., Petrik, R., Majamäki, E., Jalkanen, J.-P., Oppo, S., Kranenburg, R. (2021). The contribution of shipping to air pollution in the Mediterranean region – a model evaluation study. *EGU General Assembly 2021*, online, 19–30 Apr 2021, EGU21-8344, https://doi.org/10.5194/egusphere-egu21-8344.
8. Kurchaba, S., Veenman, C. J., van Vliet, J., Verbeek, F. J. (2021). Estimating Individual Sea Vessel NO_2 Emissions using Spatial Autocorrelation on S5P-TROPOMI Satellite Data. *EGU General Assembly 2021*, online, 19–30 Apr 2021, EGU21-3886, https://doi.org/10.5194/egusphere-egu21-3886.
9. Rieß, C., Boersma, F., van Vliet, J., Eskes, H., van Geffen, J., Stammes, P., Boot, W., de Laat, J., Peters, W., Veefkind, P. (2021). Improving cloud retrievals for accurate detection of ship NO_2 plumes from S5P-TROPOMI. *EGU General Assembly 2021*, online, 19–30 Apr 2021, EGU21-9662, https://doi.org/10.5194/egusphere-egu21-9662.
10. Sundström, A.-M., Majamäki, E., Jalkanen, J.-P., Ialongo, I., Tamminen, J. (2021). Detecting single ship plumes from TROPOMI NO_2 data. *EGU General Assembly 2021*, online, 19–30 Apr 2021, EGU21-14623, https://doi.org/10.5194/egusphere-egu21-14623.
11. Kangasniemi, O., Simonen, P., Karppinen, A., Dal Maso, M. (2021). Determining the volatility distribution and simulating the evaporation behaviour of ship exhaust emission. In T. Laurila, A. Lintunen, M. Okuljar (eds), *Proceedings of the Atmosphere and Climate Competence Center (ACCC) Research Flagship and Finnish Atmospheric Science Network Conference 2021* (pp 105-106). Finnish Association for Aerosol Research, Finland (ISBN 978-952-7276-71-6)[3].
12. Simonen, P., Dal Maso, M., D'Anna, B., Temime-Roussel, B., Lanzafame, G.M., Mellqvist, J., Conde, V., Hallquist, Å., Armengaud, A., Timonen, H., Barreira, L., Teinilä, K., Saarikoski, S., Markkula, L., Kalliokoski, J., Keskinen, J. (2021). Ship emission measurements in SCIPPER project. In T. Laurila, A. Lintunen, M. Okuljar

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[3] http://www.faar.fi/wp-content/uploads/2021/11/ACCC_proceeding_2021.pdf (last accessed: 20/01/2023)

(eds), *Proceedings of the Atmosphere and Climate Competence Center (ACCC) Research Flagship and Finnish Atmospheric Science Network Conference 2021* (pp 240-241). Finnish Association for Aerosol Research, Finland (ISBN 978-952-7276-71-6)[3].

13. Sundström, A.-M., Majaniemi, E., Jalkanen, J.-P., Ialongo, I., J. Tamminen, J. (2021). Emission signatures of single ships in satellite NO_2 observations. In T. Laurila, A. Lintunen, M. Okuljar (eds), *Proceedings of the Atmosphere and Climate Competence Center (ACCC) Research Flagship and Finnish Atmospheric Science Network Conference 2021* (pp 251-252). Finnish Association for Aerosol Research, Finland (ISBN 978-952-7276-71-6) [3].
14. Mamarikas, S., Matthias, V., Karl, M., Simonen, P., Keskinen, J., Fridell, E., Winnes, H., Moldanova, J., Hallquist, Å., Mellqvist, J., Conde, V., Verbeek, R., Duyzer, J., Timonen, H., Jalkanen, J.-P., Sundström, A.-M., Stylogiannis, A., Ntziachristos, V., Smyth, T., Yang, M., Deakin, A., Proud, R., Oeffner, J., Schneider, V.E., Beecken, J., Weigelt, A., Oppo, S., Armengaud, A., D'Anna, B., Temime-Roussel, B., Knudsen, B., Knudsen, J., Kousias, N., Irjala, M., Buckers, L., van Vliet, J., Ntziachristos, L. (2022). Monitoring of ship emissions to enforce environmental regulations. The SCIPPER project. In S. Hausberger, S. Minarik. G. Fontaras (eds), *Proceedings of the 24th International Transport and Air Pollution (TAP) Conference* (pp 208-217). Publications Office of the European Union, Luxembourg (doi:10.2760/019404)[4].
15. Verbeek, R., Smyth, T., Deakin, A., Kousias, N., Irjala, M., Oeffner, J., Schneider, V., Snee, D., van Heesen, D. (2022). Real Sailing Emissions for maritime vessels using sensors and satellite data transmission. In S. Hausberger, S. Minarik. G. Fontaras (eds), *Proceedings of the 24th International Transport and Air Pollution (TAP) Conference* (pp 218-227). Publications Office of the European Union, Luxembourg (doi:10.2760/019404)[4].
16. Kurchaba, S., van Vliet, J., Verbeek, F. J., Meulman, J. J., and Veenman, C. J. (2022). NO_2 ship-plume segmentation with supervised learning on TROPOMI/S5P satellite data, *EGU General Assembly 2022*, Vienna, Austria, 23–27 May 2022, EGU22-5472, https://doi.org/10.5194/egusphere-egu22-5472.
17. Boikos, C. K., Siamidis, P., Barbas, F., Ntziachristos, L. (2022). CFD dispersion modelling of ship emissions in the port of Marseille. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on Air Quality: Science and Application*. (pp 148). Published by Aristotle University of Thessaloniki, Greece and University of Hertfordshire, UK, ISBN: 978-1-3999-2835-9 (https://doi.org/10.18745/PB.25560).
18. Fink, L., Matthias, V., Karl, M., Oppo, S., Piga, D., Majamäki, E., Jalkanen J-P., Kuenen, J., Kranenburg, R., Moldanova, J., Sara Jutterström, S. (2022). Contribution of shipping to air pollution in the Mediterranean region – model evaluation of five regional scale chemistry transport models. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on Air Quality: Science and Application*. (pp 34). Published by Aristotle University of Thessaloniki, Greece and University of Hertfordshire, UK, ISBN: 978-1-3999-2835-9 (https://doi.org/10.18745/PB.25560).
19. Moldanova, J., Timonen, H., Verbeek, R., Simonen, P., Weigelt, A., Temime-Roussel, B., Mellqvist, J., Weisheit, J., Rantala, T., Kousias, N., Haedrich, L., Knudsen, J., Smyth, T., Salberg, H., Merelli, L., Barreira, L., Teinilä, K., Saarikoski, S., Verhagen, V.E., van Hassen, D., Indrajuana, A.P., Rostedt, A., Markkula, L., Kalliokoski, J., Beecken, J., Lanzafame, G.M., D'Anna, B., Conde Jacobo, V., Ching Nok, A., Irjala, M., Knudsen, B., Ntziachristos, L. (2022). Measurement campaign for characterising and monitoring of emissions from vessel with alternative fuels and NOx emission control. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on Air Quality: Science and Application*. (pp 86). Published by Aristotle University of Thessaloniki, Greece and University of Hertfordshire, UK, ISBN: 978-1-3999-2835-9 (https://doi.org/10.18745/PB.25560).
20. Karl, M., Pirjola, L., Grönholm, T., Zhang, X., Dal Maso, M., Held, A., Anand, S., Kukkonen, J. (2022). Open access aerosol dynamics model MAFOR. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on Air Quality: Science and Application*. (pp 65). Published by Aristotle University of Thessaloniki, Greece and University of Hertfordshire, UK, ISBN: 978-1-3999-2835-9 (https://doi.org/10.18745/PB.25560).
21. Lauenburg, M., Karl, M. (2022). City-scale modelling of ultrafine particles. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on*

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22. Majamäki, E., Grönholm, T., Johansson, L., Jalkanen, J.-P., Kukkonen. J. (2022). Modelling emissions originating from marine LNG engines. In: N. Moussiopoulos, R. S. Sokhi, G. Tsegas, E. Fragkou, E. Chourdakis1, I. Pipilis (Eds), *Proceedings of Abstracts 13th International Conference on Air Quality: Science and Application*. (pp 78). Published by Aristotle University of Thessaloniki, Greece and University of Hertfordshire, UK, ISBN: 978-1-3999-2835-9 (https://doi.org/10.18745/PB.25560).
23. Stylogiannis, A., Kousias, N., Kontses, A., Ntziachristos, L., Ntziachristos, V. (2022). A Low – Cost Optoacoustic Sensor for Black Carbon. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 139)[5].
24. Moldanova, J., Timonen, H., Simonen, P., G. M. Lanzafame, G.M., Verbeek, R., Kousias, N., Salberg, H., Merelli, L., Barreira, L., Teinilä, K., Saarikoski, S., Markkula, L., Kalliokoski, J., D'Anna, B., Temime-Roussel, B., Ntziachristos, L. (2022). Measurement campaign for characterisation and monitoring of emissions from vessel with alternative fuels and NOx emission control. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 166)[5].
25. Lanzafame, G.M, Simonen, P., Temime-Roussel, B., Le Berre, L., Hallquist, Å.M., Mellqvist, J., Conde, V., Marchand, N., Karppinen, A., Keskinen, J., Dal Maso, M., Irjala, M., Somero, A., Armengaud, A., Ntziachristos, L., D'Anna, B. (2022). Primary and Secondary emission from shipping in the Mediterranean Sea. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 672) [5].
26. Kangasniemi, O., Simonen, P., Kalliokoski, J., Hallquist, Å.M., Moldanova, J., D'Anna, B., Lanzafame, G.M., Temime-Roussel, B., Mellqvist, J., Conde, V., Jalkanen, J.-P., Armengaud, A., Karl, M., Ntziachristos, L., Keskinen, J., Dal Maso, M. (2022). Modelling the evaporation and condensation of a ship exhaust emission aerosol using genetic optimization algorithm. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 1000) [5].
27. Simonen, P., Markkula, L., Kalliokoski, J., Timonen, H., Barreira, L.M.F., Moldanova, J., D'Anna, B., Temime-Roussel, B., Lanzafame, G.M., Kangasniemi, O., Teinilä, K., Saarikoski, S., Salberg, H., Ntziachristos, L., Keskinen, J., Dal Maso, M. (2022). Measuring ship exhaust particle volatility. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 1065) [5].
28. Timonen, H., Barreira, L.M.F., Simonen, P., Moldanova, J., Markkula, L., Kalliokoski, J., D'Anna, B., Temime-Roussel, B., Lanzafame, G.M., Salberg, H., Teinilä, K., Saarikoski, S., Ntziachristos, L., Keskinen, J., Dal Maso, M. (2022). Chemical composition of fresh primary and aged secondary emissions from a passenger ship. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 1123) [5].
29. Le Berre, L., Chazeau, B., Temime-Roussel, B., Lanzafame, G.M., Armengaud, A., Sauvage, S., Ntziachristos, L., Marchand, N., D'Anna, B., Wortham, H. (2022). PM_1 source apportionment in a Mediterranean Port City in summer using metallic trace elements. In *Abstract Book of the 11th International Aerosol Conference (IAC 2022)*, (pp 1294) [5].
30. Oppo, S., Fiorentino, E.A., Armengaud, A., Boikos, C., Ntziachristos, L., Ribstein, B., Mahé, F., D'Anna, B., Lanzafame, G.M., Gunti, Q. (2022). Intercomparison between observations and 3D high resolution models for pollutants dispersion in the harbors of Marseille and Toulon in 2021. In: S. Trini-Castelli, A. I. Miranda, B. Augusto, J. Ferreira (Eds), *HARMO21 Proceedings* (pp 595-599). Published by Universidade de Aveiro, Aveiro, Portugal.
31. Le Berre, L., Chazeau, B., Temime-Roussel, B., Lanzafame, G.M., Armengaud, A., Sauvage, S., Ntziachristos, L., Marchand, N., D'Anna, B., Wortham, H. (2022). Metallic Trace Elements Shipping Profile by PM1 Source Apportionment in a Mediterranean Port City. In *Abstract Book of the 40th American Association for Aerosol Research (AAAR 2022)*, (pp 20). American Association for Aerosol Research (AAAR), Reston (VA), USA.
32. Simonen, P., Dal Maso, M., Moldanova, J., Timonen, H., Barreira, L.M.F., Teinilä, K., Saarikoski, S., D'Anna, B., Temime-Roussel, B., Lanzafame, G.M., Markkula, L., Kalliokoski, J., Keskinen, J. (2022). Secondary aerosol formation from ship engine exhaust. In: A. Ovaska and E. Männistö (Eds), Abstract Book of the ACCC &

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Finnish Atmospheric Science Network Conference 2022, (pp 252-253). Finnish Association for Aerosol Research, Finland (ISBN 978-952-7276-71-6)[6].

The following paper has been submitted, accepted, and presented by the authors to the conference but proceedings were not published till 31.01.2023 (end of SCIPPER project):

1. Mamarikas, S., Matthias, V., Karl, M., Fink, L., Simonen, P., Keskinen, J., Dal Maso, M., Fridell, E., Moldanova, J., Hallquist, Å., Mellqvist, J., Conde, V., Verbeek, R., Duyzer, J., van Dinther, D., Timonen, H., Jalkanen, J.-P., Sundström, A.-M, Majamäki, E., Stylogiannis, A., Ntziachristos, V., Smyth, T., Yang, M., Deakin, A., Proud, R., Oeffner, J., Schneider, V.E., Beecken, J., Weigelt, A., Griesel, S., Schoppmann, H., Oppo, S., Armengaud, A., D'Anna, B., Lanzafame, G.M., Knudsen, B., Knudsen, J., Kuosa, M., Irjala, M., Buckers, L., van Vliet, J., Ntziachristos, L. Assessing Shipping Induced Emissions Impact on Air Quality with Various Techniques: Initial Results of the SCIPPER project. Paper submitted and presented at 9th Transport Research Arena (TRA 2022), Lisbon 14 – 17 November 2022.

1.3 Other publications

1. Plymouth Marine Laboratory; Yang, M., Bell, T., Pewter, J., et al. (2022). Atmospheric Chemistry and Meteorological dataset from the Penlee Point observatory. Accessible at https://catalogue.ceda.ac.uk/uuid/2ca4d30810cd4b98a71b1993598434af

[6] https://www.faar.fi/wp-content/uploads/2022/11/RS257_ACCC_FASN_abstract_book.pdf (last accessed 20/01/2023)

2 Participation in external events

Table 2-1 lists all external events (conferences, workshops, webinars, technical meetings, and other events) that SCIPPER consortium members participated with oral presentations.

Table 2-1: List of external events

Event Date	Event Name	Event Organizer	Venue	Event Type	Partner
4-6 Sept 2019	Shipping & Environment II	Interreg BSR CSHIPP platform, Gothenburg Air and Climate Network (GAC), International Surface Ocean - Lower Atmosphere Study (SOLAS), CHALMERS and the BONUS secretariat	Conference Centre Wallenberg, Gothenburg (Sweden)	Conference	IVL
17 July 2019	Marine Hybridisation	Marine Business Technology Centre	Marine Biological Association – Plymouth (UK)	Workshop / Meeting	PML
15 Oct 2019	Journee pleniere GDR Suie	CNRS	Marseille (France)	Workshop / Meeting	AMU
5 Nov 2019	2nd Workshop of EU Research & Innovation Maritime Projects - The Hellenic contribution	Danaos	Danaos Auditorium, Piraeus (Greece)	Workshop / Meeting	AUTH
20 Nov 2019	4th Mediterranean Shipping Conference - On the way to a Mediterranean Emission Control Area	Nature and Biodiversity Conservation Union (NABU)	Piraeus Chamber of Commerce and Industry, Pireas (Greece)	Conference	AUTH
18-22 May 2020	12th International Conference on Air Quality	AUTH, Hertfordshire	Online	Conference	AUTH
31 Aug - 4 Sept 2020	European Aerosol Conference 2020	European Aerosol Assembly	Online	Conference	FMI
26-20 Oct 2020	TROPOMI OMI Workshop	KNMI	Online	Scientific Workshop	FMI
30 Oct - 1 Nov 2020	7th Environmental Conference of Macedonia	Association of Greek Chemists – Brach of Central and West Macedonia	Online	Conference	AUTH
10 Dec 2020	1st International webconference "Sulphur 2020 Enforcement"	ILT	Online	Conference	ILT
30 Mar - 1 Apr 2021	24th International Transport Air Pollution Conference (TAP 2021)	Graz University of Technology	Online	Conference	AUTH, TNO
19-30 Apr 2021	EGU General Assembly 2021	European Geosciences Union	Online	Meeting	FMI, ILT
27-28 Apr 2021	2nd LEC Sustainable Shipping Technologies Forum	Large Engines Competence Center (LEC GmbH) and Hamburg Port Authority	Online	Workshop	AUTH, IVL

26 May 2021	ERMES (European Research for Mobile Emission Sources) Plenary	ERMES	Online	Plenary meeting	AUTH
3 Jun 2021	The contribution of maritime logistics to the Greek economy (in Greek)	International Hellenic University	Online	Webinar	AUTH
14-18 June 2021	Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes (HARMO 20)	University of Tartu	Online	Conference	AUTH
30 Aug 2021 - 3 Sept 2021	European Aerosol Conference 2021	European Aerosol Assembly	Online	Conference	HEREON
8 Sept 2021	Technologies for the Transition to Climate Neutral Shipping	UN Sustainable Development Solutions Network (SDSN), EIT Climate - KIC Hub Greece, Maritime ClimAccelerator,	Online	Technical Workshop	AUTH
22-23 Sept 2021	SEADEVCON '21	Marine.media	Port of Hamburg (Germany)	Conference & Exhibition	CML
18-22 Oct 2021	International Technical Meeting on Air Pollution and its Application	VITO	Auditorium UPC, Barcelona (Spain)	Conference	HEREON
23-24 Oct 2021	2nd International Conference on Environmental Design	Hellenic Open University	Online	Conference	AUTH
31 Oct 2021	Europe – Korea Conference on Science and Technology Day 3 (EKC 2021)	Marine Business Technology Centre	Radisson Blu Hotel Paris (France)	Conference	AMU
Nov 2021	BSH-Talk	BSH	Online	Public talk	BSH
22 Nov 2021	Aus Wissenschaft wird Praxis: Optimierung zur Klimafreundlichkeit (in German)	German Maritime Centre	Online	Webinar, public event with registration	CML
22-23 Nov 2021	ACCC & Finnish Atmospheric Science Network Conference	Atmosphere and Climate Competence Center	University of Helsinki (Finland)	Conference	TAU
22-26 Nov 2021	Atmospheric Science Conference (ATMOS-) 2021	European Space Agency	Online	Conference	FMI
28 Apr 2022	3rd Mediterranean Air Day – the Ports	AtmoSud and Qualitair Corse	Palais du commerce et de la mer, Toulon (France) & Online	Conference	AUTH
5 May 2022	1st meeting of the MAVI (MARPOL Annex VI) Technical Working Group (MAVI-TWG) of the BONN Agreement	Bonn Agreement Secretariat	Online	Technical meeting	AUTH, BSH, Explicit
11 May 2022	Conference on Maritime Emissions	Danish Clean Air Vision	Christiansborg Palace,	Conference	IVL, Explicit

			Copenhagen (Denmark)		
18-19 May 2022	31. Meeresumwelt symposium - 2022 (31. Marine Environment Symposium) (in German)	BSH, Umwelt Bundesamt, Bundesamt für Naturschutz, Bundesministeriums für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz	Katholische Akademie, Hamburg (Germany)	Conference/ Symposium	BSH, HEREON
27 June - 1 July 2022	13th International Conference on Air Quality – Science and Application	Aristotle University of Thessaloniki (Greece) and University of Hertfordshire (UK)	Aritotle University of Thessaloniki (Greece) and online	Conference	AUTH, FMI, IVL, HEREON
18-21 July 2022	Europe-Korea Conference on Science and technology EKC2022	Association des Scientifiques Coréens en France	Palais du Pharo, Marseille (France)	Conference	ATMOSUD
27 Aug 2022	BSH Open day	BSH	Rostock, Germany	Open day	BSH
4-9 Sept 2022	International Aerosol Conference 2022	Hellenic Association for Aerosol Research (HAAR)	Megaron Athens International Conference Centre, Athens (Greece)	Conference	AUTH, TAU, FMI, IVL, AMU
19-21 Sept 2022	EU-SHIPPING-BCE 2022	ETA Florence	Eugenides Foundation, Athens (Greece), online	Conference	AUTH
22 Sept 2022	Seminar: Monitoring of ultrafine particles	TSI-Germany	Frankfurt a. M. (Germany)	Seminar	BSH
14-17 November 2022	9th Transport Research Arena (TRA 2022)	National Innovation Agency (ANI), Institute for Mobility and Transport (IMT), Engineering Schools Consortium (CEE), National Laboratory for Civil Engineering (LNEC), Magellan – European Affairs Association and co-organized with the European Commission	Lisbon Congress Center, Lisbon (Portugal)	Conference	AUTH
21-22 Nov 2022	ACCC & Finnish Atmospheric Science Network Conference	Atmosphere and Climate Competence Center	Tampere University (Finland)	Conference	TAU

3 SCIPPER stakeholders' workshops

During SCIPPER's lifetime, the following stakeholders' workshops were realized:

1. Stakeholder event at the beginning of SCIPPER held in Brussels on the 26th of June 2019 with the participation of the project partners, stakeholders involved in shipping, as well as representatives of the European Commission.
2. SCIPPER stakeholder workshop on Monitoring Maritime Emission Compliance held online on 8th June 2021.
3. SCIPPER and EMERGE H2020 projects seminar "Monitoring and decrease of shipping emissions", held during Posidonia Exhibition in Athens (Greece) on 9th June 2022.
4. SCIPPER stakeholder workshop on Technical Capabilities and Policy Recommendations on Shipping Emissions Monitoring held in Chalkidiki (Greece) and online on 18th October 2022.
5. Invited session of Transport Research Arena 2022 held on 15th November 2022 at Lisbon Congress Centre (Portugal).
6. Meeting with European Commission on 27th January 2023. Details of this meeting are included in D6.2: Stakeholder event minutes (final event).

3.1 SCIPPER stakeholder event at the beginning of the project

The first meeting with stakeholders in the context of the Horizon 2020 funded project "SCIPPER - Shipping Contribution to Inland Pollution Push for the Enforcement of Regulations" was conducted on 26th June 2019 in Brussels, Belgium, as a follow up of the kick off meeting of the project. The meeting with stakeholders targeted to:

- Introduce the concept of SCIPPER to parties involved with shipping activities;
- Discuss issues of stakeholders' interest that can be studied in the context of the project implementation;
- Exchange knowledge and experience on shipping emissions between stakeholders and the partners of SCIPPER consortium.

The meeting was attended by stakeholders that are being involved in maritime activities (engine manufacturers, port authorities), as well as representatives of the EC. During the meeting a discussion on shipping emissions' aspects was performed, relevant to the knowledge and expertise of the stakeholders, receiving feedback that will be taken into consideration in setting up and implementing various project activities. This event was prescribed in the GA. Details of this meeting are included in D6.10: Stakeholder event minutes (kick off).

3.2 SCIPPER stakeholder workshop on Monitoring Maritime Emission Compliance

On the 8th June 2021, the SCIPPER project held the online Stakeholder Workshop on Monitoring Maritime Emission Compliance via Zoom app. Participants from port authorities, ship owners, technology providers, international and European institutions and organisations, national authorities and research institutions attended the workshop. The purpose of the workshop was twofold; to disseminate up-to-now project activities and to collect input from stakeholders on maritime emission monitoring and compliance based on their experiences, current activities, and future developments.

Prof. Leonidas Ntziachristos from Aristotle University of Thessaloniki and Coordinator of SCIPEER project presented the project's objectives and concept and the latest developments on SCIPPER measurement campaigns. Prof. Johan Mellqvist from Chalmers University of Technology presented the results of the first SCIPPER measurement campaign in the port of Marseille (France) that took place on September of 2020. The results focused on the comparison of the different remote measurement instrumentation, i.e., a mini-sniffer operated on drone and a shipborne medium sniffer. Dr. Jörg Beecken, Researcher at the German Federal Maritime and Hydrographic Agency presented the results of the second SCIPPER measurement campaign in Wedel (Germany) that took place between 7 September and 15 October 2020. Emissions of SO_2, NO_X, CO_2 and particulate matter from several passing ships were monitored using land-based sites as well as Unmanned Aerial Vehicles (UAV). In parallel, 60 fuel samples were taken on-board of 34 selected vessels in order to retrieve Fuel Sulphur Content. Dr. Tim Smyth, Head of Science at Marine Biogeochemistry and Observations at Plymouth Marine Laboratory discussed about cost effective technologies for real-time ship to shore emission data reporting and presented the different sensors to be tested in SCIPPER measurement campaigns.

Roger Strevens, Head of Sustainability at Wallenius Wilhelmsen discussed about the enforcement of emissions compliance from the shipowner perspective. He also stressed out the importance of compliance for a shipping company and the challenges for good data, jurisdictional rights, penalties, and enforcement measures. Leo Buckers, Coordinator-Senior Inspector at Human Environment and Transport Inspectorate of Dutch Ministry of Infrastructure and Water Management, discussed about the handling of the sulphur noncompliance, the necessity of instruments and methodology to check that the actual ship emissions are in accordance with those at the time of certificating of the engine (for enforcing NO_X/Tier) and the deployment of on-board measurement instruments. Dr. Olaf Trieschmann, Senior Project Officer at European Maritime Safety Agency presented the present status and further development of EMSA Remotely Piloted Aircraft Systems (RPAS) services and discussed the necessary developments that EMSA sees to further improve remote compliance monitoring. The presentations can be found at https://www.scipper-project.eu/library.

3.3 SCIPPER and EMERGE H2020 projects seminar

SCIPPER and EMERGE H2020 projects participated in Posidonia 2022 Exhibition by organizing the seminar "Monitoring and decrease of shipping emissions" on 9 June 2022 at Metropolitan Expo, Athens (Greece). The purpose of the seminar was to present the latest findings of the two projects on how innovative methods for monitoring emissions together with new fuels and emission control technologies can lead to decreased emissions from vessels. The methods presented, included low-cost on-board sensors, drones, remote monitoring stations and satellite observations that can assist ship operators and enforcement authorities ensure the operation of ships within applicable emission limits. With regard to emission control, the performance of scrubbers as well as the impact of VLSFO and methanol over HFO were also discussed.

Figure 3-1: Photos of SCIPPER and EMERGE seminar at Posidonia 2022 Exhibition

Prof. Leonidas Ntziachristos from Aristotle University of Thessaloniki, Coordinator of SCIPEER project and partners to EMERGE introduced the background, objectives and monitoring activities of the two projects. M.Sc. Elisa Majamäki from the Finnish Meteorological Institute presented the different modelling approaches for evaluating shipping

emissions and emissions impact on air quality under different scenarios studied in the two projects. Alexandre Armengaud from AtmoSud presented the results of the study of ship emissions effect on urban area with the high-resolution model application in the port of Marseille based on emissions measured during a SCIPPER campaign. Prof. Evangelia Krasakopoulou from University of Aegean presented the EMERGE case studies, including experiments to characterize waste streams to water from shipping (resulting from emission control technologies) and atmospheric and ocean circulation modeling of shipping emissions and their effects on marine ecosystems. Prof. L. Ntziachristos gave a presentation on the results of the different technical possibilities to monitor vessel emissions explored in four SCIPPER campaigns and their impact. Dr. Jana Moldanova from Swedish Environmental Research Institute presented the insights from the onboard measurement campaigns of SCIPPER and EMERGE where different fuels and abatements methods were investigated so as to assess the impacts of new fuels and emissions controls on emissions of regulated and unregulated pollutants. Moreover, the SCIPPER overview and SCIPPER campaigns banners were presented and projects' flyers were disseminated to the audience.

It should be noted that Posidonia is an international shipping exhibition, has long been established as one of the major calendar events of the shipping industry, and Posidonia 2022 attracted the most influential personalities from the Greek and international shipping community and major companies and organisations active in all sectors of the shipping industry. More specifically, Posidonia 2022 welcomed 1,964 exhibiting companies from 88 countries and territories and was attended by 28,892 visitors from 103 countries. In total the exhibition was attended by 40,950 participants including exhibitors, visitors and media representatives. The international exhibition Posidonia first took place in 1969 and has been taking place every two years ever since.

3.4 SCIPPER stakeholder workshop on Technical Capabilities and Policy Recommendations on Shipping Emissions Monitoring

On 18th October 2022, the SCIPPER project held the hybrid Stakeholders Workshop on Technical Capabilities and Policy Recommendations on Shipping Emissions Monitoring. Participants from port authorities, technology providers, national authorities and research institutions attended the workshop.

The purpose of the workshop was to get feedback from stakeholders on tentative recommendations of SCIPPER regarding the methods for onboard and remote monitoring, the impact of abatement technologies on air quality and the regulation for emission limits.

The first part of the workshop included presentations of SCIPPER work on the technical capabilities of shipping emissions monitoring. More specifically, Erik Fridell, from IVL Swedish Environmental Research Institute, introduced the scope of the workshop and the context of the discussion with the stakeholders at the second part of the workshop. Leonidas Ntziachristos, from Aristotle University of Thessaloniki and coordinator of SCIPEER, project presented in brief the project's activities implemented since the beginning of the project as well as the latest developments on SCIPPER measurement campaigns. Volker Matthias, from Helmholtz-Zentrum Hereon, gave a presentation for the impacts of regulations and technologies on air quality, the quantification of effects on air quality, and the scenarios for 2040 and 2050 that SCIPPER elaborated. Ruud Verbeek, from TNO Netherlands Organisation for Applied Scientific Research, presented the cost effectiveness of monitoring methods examined in SCIPPER, both remote sensing and on-board monitoring. Johan Mellqvist, from Chalmers University of Technology, presented the SCIPPER work on quality assurance and reporting harmonisation for remote techniques.

In the second part of the workshop, stakeholders were divided in small groups in order to discuss with SCIPPER consortium and express their opinion on the following issues:

- All ships should in the future be equipped with sensors for NO_X, SO_X and PM with associated tamper-proof data systems for monitoring by relevant authorities. Is this reasonable and what are the alternatives?
- Legal framework and reporting harmonization should be developed. How can this be put in place?
- Should a real-world cycle, be developed, or other rules for monitoring during operation to ensure low emissions during operation? How can include limits for ammonia be included, strengthen follow ups of emissions?
- Should emission regulations for PM and other substances be developed and applied? What is ongoing and which substances are most important?

The stakeholders' group in general supported the application of onboard sensors for monitoring emissions. It was also suggested that existing systems, such as MRV could be extended for reporting of air pollutants. Further, the

problems with NO_X-emissions at low engine loads were acknowledged and it was suggested to first target high emitters, i.e., ships with large engines. Regulations for black carbon and methane was suggested by the group but also for nitrous oxide and ammonia for the case that ammonia becomes a widespread fuel. This event was prescribed in the GA. Details of this workshop are included in D6.2: Stakeholder event minutes (final event).

Figure 3-2: Photos of SCIPPER stakeholder workshop at Chalkidiki, Greece

3.5 Invited session of Transport Research Arena 2022

Leonidas Ntziachristos (SCIPPER project), along with Åke Sjodin (CARES project), Jesus Javier Fernandez Orio (AVIATOR project) and Andrew Winder (MODALES project) co-organized the invited session "Reduction of transport impact on air quality" of the 9th Transport Research Arena (TRA 2022) that took place on Tuesday 15.11.2022 at 8.30 - 10.00 at Lisbon Congress Centre.

This session presented main experiences, evidence, results and outputs from projects funded under the LC-MG-1-1-2018 call of European Union's Horizon 2020 research and innovation programme which aimed at (a) better understanding the health impacts of transport pollution, (b) exploring methods that are technically feasible and mature for better monitoring and enforcement of air emission regulations, and (c) providing the users of vehicles with tools that can be used to decrease consumption and emissions. More specifically results from AVIATOR[7], CARES[8], MODALES[9], and SCIPPER on new tools and methods that can be used to decrease emissions of the current fleet of vehicles, vessels, and aircraft were presented.

3.6 Meeting with European Commission

SCIPPER consortium presented project's research findings, results, and outputs to the EC's representatives in a meeting held on 27th January 2023 in Brussels (Belgium). SCIPPER work, within five intensive experimental campaigns at major sea areas and ports of Europe where more than 1000 of ship plumes were measured, revealed the performance and capacity of different techniques for shipping emissions monitoring and regulations enforcement. Further assessments identified the impacts of shipping emissions on air quality, under different regulatory enforcement scenarios and concluded in policy recommendations. Details of this meeting are included in D6.2: Stakeholder event minutes (final event).

[7] AVIATOR: Assessing aViation emission Impact on local Air quality at airports: TOwards Regulation https://aviatorproject.eu

[8] CARES: City Air Remote Emission Sensing https://cares-project.eu

[9] MODALES: MOdify Drivers' behaviour to Adapt for Lower EmissionS https://modales-project.eu

4 Papers prepared for submission

This section lists scientific papers prepared till 31st January 2023 (end of SCIPPER) for submission to peer-reviewed journals for publication and to scientific conferences that will be held after the end of SCIPPER.

1. Smyth, T., Deakin, A., Pewter, J., Snee, D., Proud, R., Verbeek, R., Verhagen, V., Paschinger, P., Bell, T., Fishwick, J., and Yang, M. (2023) Faster, Better, Cheaper: Solutions to the atmospheric shipping emission compliance and attribution conundrum. Submitted in *Atmosphere - Special Issue "Atmospheric shipping emissions and their environmental impacts"* (status on 31st January 2023: under review).
2. van Dinther, D., Weigelt, A., Beecken, J., Mellqvist, J., Conde Jacobo, V., Blom, M., Duyzer, J. Comparison of emission factors of particles from shipping using different equipment. Submitted and accepted to *EGU General Assembly 2023*, 23–28 April 2023, Vienna, Austria, & Online.
3. Ntziachristos, L., Mamarikas, S., Verbeek, R., Grigoriadis, A. Monitoring shipping emissions with various techniques towards ensuring compliance to the new regulations: The SCIPPER project. Submitted and accepted to *8th International Symposium on Ship Operations, Management & Economics (SOME)*, 7-8 March 2023, Athens, Greece.
4. Beecken, J., Weigelt, A., Griesel, S., Mellqvist, J., Conde Jacobo, A.V., van Dinther, D., Duyzer, J., Knudsen, B., Knudsen, J., Ntziachristos, L. Performance assessment of state-of-the-art and new methods for remote compliance monitoring of sulphur emissions from shipping. Planned submission to *Atmospheric Measurement Techniques* in February 2023.
5. Prignon, M., Conde, V., Smyth T., Sundström, A.-M., van Vliet, J., Mellqvist, J. DOAS applied to shipping emission monitoring: compliance assessment and comparison to satellite measurements. Submitted to *EGU General Assembly 2023*, 23–28 April 2023, Vienna, Austria, & Online.
6. Mamarikas, S., Matthias, V., Karl, M., Simonen, P., Keskinen, J., Fridell, E., Winnes, H., Moldanova, J., Hallquist, Å., Mellqvist, J., Conde, V., Verbeek, R., Duyzer, J., Timonen, H., Jalkanen, J.-P., Sundström, A.-M., Stylogiannis, A., Ntziachristos, V., Smyth, T., Yang, M., Deakin, A., Proud, R., Oeffner, J., Schneider, V.E., Beecken, J., Weigelt, A., Oppo, S., Armengaud, A., D'Anna, B., Temime-Rousse, B., Knudsen, B., Knudsen, J., Kousias, N., Irjala, M., Buckers, L., van Vliet, J., Ntziachristos, L. The SCIPPER project: Overview and Results. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
7. Haedrich, L., Kousias, N., Raptis, I., Stylogiannis, A., Ntziachristos, V., Ntziachristos, L. A Low-Cost Optoacoustic Sensor for Black Carbon monitoring of Ships. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
8. Verbeek, R., Simonen, P., Moldanova, J., Smyth, T., Pewter, J., Deakin, A., Proud, R., Kousias, N., Irjala, M., Tuomas Rantala, Weisheit, J., Andy Chink Nok, Verhagen, V., Paschinger, P., Mamarik, S., Haedrich, L. Experiences with sensor based continuous emission monitoring for demonstration of maritime emissions compliance. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
9. Matthias, V., Fink,L., Grigoriadis, A., Hahn, J., Jalkanen, J.-P., Kuenen, J., Majamäki, E., Ntziachristos, L., Petrik, R., Schwarzkopf, D. Climate-friendly and pollution-free? Future shipping emissions and their potential environmental impacts. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
10. Fink, L., Karl, M., Matthias, V., Oppo, S., Kranenburg, R., Kuenen, J., Moldanova, J., Jutterström, S., Jalkanen, J.-P., Majamäki, E. A multi-model evaluation of potential impact from shipping on PM2.5 species in the Mediterranean Sea. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
11. Weigelt, A., Beecken, J., van Dinther, D., Griesel, S., Mellqvist, J. Size resolved particle emission behaviour for different types of vessels. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
12. Majamäki, E., Jalkanen, J.-P., Matthias, V., Moldanova, J., Johansson. L. Projections of shipping emissions in Europe in 2040 and 2050. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.

13. Conde, V., Mellqvist, J., Weigelt, A. Compliance monitoring of ship emissions with a Laser system: Preliminar Reports. Planned submission to the *25th International Transport and Air Pollution and 3rd Shipping and Environment Conference* (Joint TAP and SE conference), 25-28 September, Gothenburg, Sweden.
14. Boikos, C., Ntziachristos, L., Oppo, S., Armengaud, A. Shipping Emissions Impact on the Air Quality of Marseille Port Using CFD modelling. Planned submission to the *26th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction* (PRES'23), 8-11 October 2023, Thessaloniki, Greece.