1. Project Summary

We plan to develop big data-driven and machine learning based solutions for measuring, tracking and validating maritime traffic for reducing emissions and improving local air quality. We will implement and deploy a vessel emission model based on real ship movements and sensor-based emission data. The vessel emission model will be used to estimate air pollution from maritime traffic in ports. It will reflect spatial-temporal emission dynamics and aims to provide real-time tracking of traffic emissions. The impact on coastal city air quality will be estimated using a chemistry transport model. We will apply and evaluate our tools for Singapore port and one major German port[2]. Approaches will be developed to optimize emission mitigation strategies through the changes of port operations and maritime traffic management using big data analytics, simulation, and optimization.

A demonstrator will help port operators understand the shipping emission inventory by also capturing the spatial-temporal dynamic of pollutants and the process of their dispersal to urban areas. The demonstrator will provide decision support for port operators and policymakers to mitigate vessel emissions from the perspective of port operation and maritime traffic management. Collaboratively the partners from Germany and Singapore will evaluate the application of this newly implemented tools to the world's busiest transshipment port in Singapore and one major German port. The comparison will consider the corresponding maritime traffic management strategies. It is planned to install sensors on ships to validate emission factors in ship emission inventories. The project's activity will bring insights and potential collaboration opportunities for Singapore and Germany for combating air pollutions. Moreover, this project could enable real-time and accurate monitoring of the emission status of vessels and maritime traffic based on maritime big data, even without installing pollution sensors on all ships.

Key words: ship emissions, environmental protection, AIS, air pollution, maritime traffic management.

Project Summary (German)

Wir planen, auf Big Data und maschinellem Lernen basierende Lösungen zur Messung, Verfolgung und Validierung des Seeverkehrs zu entwickeln, um Emissionen zu reduzieren und die lokale Luftqualität zu verbessern. Wir werden ein Schiffsemissionsmodell implementieren und einsetzen, das auf realen Schiffsbewegungen und sensorgestützten Emissionsdaten basiert. Das Schiffsemissionsmodell wird verwendet, um die Luftverschmutzung durch den Seeverkehr in Häfen abzuschätzen. Es wird die räumlich-zeitliche Emissionsdynamik widerspiegeln und soll die Verkehrsemissionen in Echtzeit verfolgen. Die Auswirkungen auf die Luftqualität in Küstenstädten werden mithilfe eines Chemietransportmodells geschätzt. Wir werden unsere Tools in dem Hafen von Singapur und einen großen deutschen Hafen[1] anwenden und bewerten. Es werden Ansätze entwickelt, um Emissionsminderungsstrategien durch Änderungen des Hafenbetriebs und des Seeverkehrsmanagements mithilfe von Big-Data-Analyse, Simulation und Optimierung zu optimieren.

Ein Demonstrator wird den Hafenbetreibern helfen, das Schiffsemissionsaufnahme zu verstehen, indem er auch die räumlich-zeitliche Dynamik von Schadstoffen und den Prozess ihrer Ausbreitung in städtische Gebiete erfasst. Der Demonstrator wird Hafenbetreibern und politischen Entscheidungsträgern Entscheidungshilfe bieten, um die Schiffsemissionen aus Sicht

[1] Gespräche mit dem Hamburger Hafen zeigen Interesse der Hamburger Hafenbehörde

des Hafenbetriebs und des Seeverkehrsmanagements zu verringern. Gemeinsam werden die Partner aus Deutschland und Singapur die Anwendung dieser neu implementierten Tools auf den verkehrsreichsten Umschlaghafen der Welt in Singapur und einen großen deutschen Hafen bewerten. Der Vergleich berücksichtigt die entsprechenden Strategien für das Seeverkehrsmanagement. Es ist geplant, Sensoren auf Schiffen zu installieren, um Emissionsfaktoren in Schiffsemissionsinventaren zu validieren. Die Projektaktivität wird Singapur und Deutschland Einblicke ermöglichen und Optionen zur Zusammenarbeit bei der Bekämpfung der Luftverschmutzung aufzeigen. Darüber hinaus könnte dieses Projekt eine Echtzeit- und genaue Überwachung des Emissionsstatus von Schiffen und des Seeverkehrs auf der Grundlage maritimer Big Data ermöglichen, auch ohne die Installation von Verschmutzungssensoren auf allen Schiffen.

Schlüsselwörter: Schiffsemissionen, Umweltschutz, AIS, Luftverschmutzung, Seeverkehrsmanagement.

2. Main objectives of the research approach, including expected results / outcome

Our research objectives are

(a) to measure the accurate emissions of individual vessels under different navigational conditions (different navigational behavior, different emission processing devices, different engine operations) based on maritime big data,
(b) to quantify the relations between vessel emissions and urban air quality,
(c) to develop an integrated prototype model to track vessel movements and associated emissions,
(d) to provide tools for optimizing port traffic management in order to reduce the impact of vessel emissions on local air quality.

In this project, we will develop a big-data driven approach to estimate vessel emissions. It will integrate data from pollution sensors and vessel movements. The modelling will include two sub-modules: an activity-based vessel emission model and a chemistry transport model for the exhaust. The data-driven vessel emission model to be included in the demonstrator will be developed based on a hybrid approach consisting of classic correlation and machine learning. It will be calibrated/trained with sensor data. This model enables to monitor and track emissions of all vessels, including the those without on-board pollution sensors. This emission inventory will serve as input for a chemistry transport model. Thus, our tools offer the opportunity to identify regional pollution hotspots and heavy-pollution-prone vessels and demonstrate the relation between maritime traffic emissions and urban air quality. Lastly, we will develop a demonstrator to optimize the maritime traffic and port-related operation schedules to reduce the impact on local air quality. The vessel traffic modelling will simulate port traffic under different emission control strategies at specific ports (SG port and one German port[2]). Further traffic strategies will be developed for the optimization and evaluation of port traffic management. These activities will be conducted based on data analytics, simulation, and optimization approaches.

Both, governments and shipping companies, will benefit from this study. The port operator can better understand the spatial-temporal dynamics of vessel emissions to detect pollutant hotspots and to track important vessels. Additionally, our tools can quantify the dispersal of pollutants to the urban areas, incl. their chemical transformation. They also provide the port operators information for knowledge-based strategies for the mitigation of vessel emissions and their impact on local air quality. Our study will also help shipping companies to monitor emissions of their vessels.

[2] Discussions with Port of Hamburg indicate interest by the Hamburg Port Authority.

The deliverables include (a) A vessel emission model calibrated using field data; (b) a vessel emission tracking and forecasting prototype model; (c) a port traffic optimization model for emission reduction; (d) a demonstrator for maritime emission tracking and prediction of emission for selected ports.

3. Current state of the art in the field

Emissions of air pollutants from transport have increasingly attracted attention because of their significant impact on local air quality and public health. In the vicinity of major ports, a considerable amount of atmospheric pollution results from diesel engines aboard ships, despite the use of higher quality fuels in costal zones. For example, in Europe, the release of NOx and particulate matter (PM) from shipping is almost equal to the emissions from road-transport in 2020. In a coastal city, such as Singapore, the impact of air pollutants from marine traffic is even larger due to the high population density and heavy maritime traffic near the port and the Singapore strait, which should even gain more attention than road-traffic. Thus, it is paramount to monitor and track the shipping emission and their impacts on urban air quality, capture its spatial-temporal dynamics and develop optimal strategies to mitigate the emission generated from maritime traffic.

Contribution of others to the field:
In the past several studies provided inventories of ship emissions (e.g., Smith et al, 2015[3], Johannsson et al, 2017[4]). On regional scale the impact of emissions from marine vessels on regional air pollution was studied in detail for example in the North Sea and Baltic Sea (e.g., Jalkanen et al, 2009[5], Matthias et al., 2010[6], Aulinger et al, 2016[7], Karl et al, 2019[8]) or the region of the Yangtze River Delta (e.g. Feng et al., 2019[9]). Similarly, the impact of land transport emissions on air quality was studied for specific regions such as Europe (e.g., Reis et al, 2000[10], Karamchandani et al., 2017[11]). In 2017 a study by the European Commission's JRC Directorate for Space, Security in collaboration with the Directorate for Energy, Transport and Climate investigated estimating shipping emissions using vessel long range identification and tracking data. They concluded that LRIT data can be used to spatially grid shipping emissions over Europe

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[3] Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., O'Keeffe, E., Parker, S., Johansson, I., Aldous, I., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D. S., Ng, S.; Agrawal, A., Winebrake, J. J., Hoen, M., Chesworth, S., Pandey, A., 2015: Third IMO GHG. Study 2014. International Maritime Organization (IMO), London. UK, April 2015.

[4] Johansson, L., Jalkanen, J.-P., Kukkonen, J., 2017: Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution, Atmospheric Environment, Volume 167, 2017, Pages 403-415, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2017.08.042.

[5] Jalkanen, J.-P., Brink, A., Kalli, J., Pettersson, H., Kukkonen, J., and Stipa, T., 2009: A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area, Atmos. Chem. Phys., 9, 9209–9223, https://doi.org/10.5194/acp-9-9209-2009, 2009.

[6] Matthias, V., I. Bewersdorff, A., Aulinger, and M. Quante, 2010: The contribution of ship emissions to air pollution in the North Sea regions, Environ. Pollut., 158, 2241–2250, https://doi.org/10.1016/j.envpol.2010.02.013.

[7] Aulinger, A., Matthias, V., Zeretzke, M., Bieser, J., Quante, M., and Backes, A., 2016: The impact of shipping emissions on air pollution in the greater North Sea region – Part 1: Current emissions and concentrations, Atmos. Chem. Phys., 16, 739–758, https://doi.org/10.5194/acp-16-739-2016, 2016.

[8] Karl, M., J.E. Jonson, A. Uppstu, A. Aulinger, M. Prank, M. Sofiev, J.-P. Jalkanen, L. Johansson, M. Quante, and M. Matthias, 2019: Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models, Atmos. Chem. Phys., 19, 7019–7053, https://doi.org/10.5194/acp-19-7019-2019.

[9] Feng, J., Y. Zhang, S. Li, J. Mao, A.P. Patton, Y. Zhou, W. Ma, C. Liu, H. Kan, C. Huang, J. An, L. Li, Y. Shen, Q. Fu, X. Wang, J. Liu, S. Wang, D. Ding, J. Cheng, W. Ge, H. Zhu, and K. Walker, K. 2019: The influence of spatiality on shipping emissions, air quality and potential human exposure in the Yangtze River Delta/Shanghai, China, Atmos. Chem. Phys., 19, 6167–6183, https://doi.org/10.5194/acp-19-6167-2019.

[10] Reis, S., D. Simpson, R. Friedrich, J. Jonson, S. Unger, and A. Obermeier, 2000: Road traffic emissions – predictions of future contributions to regional ozone levels in Europe, Atmos. Environ.,34, 4701–4710, https://doi.org/10.1016/S1352-2310(00)00202-8.

[11] Karamchandani, P., Y. Long, G. Pirovano, A. Balzarini, and G. Yarwood, G. 2017: Source-sector contributions to European ozone and fine PM in 2010 using AQMEII modeling data, Atmos. Chem. Phys., 17, 5643–5664, https://doi.org/10.5194/acp-17-5643-2017.

with a realistic preview of the shipping routes (Alessandrini et al, 2017[12]). In addition the study showed how this approach could be integrated with land-based proxies, to improve the quality of emission inventories for the assessment of air quality and the emission of greenhouse gases.

Own previous contributions (see appendix for citations):
The impact of anthropogenic emissions on air quality has been studied by us on all scales from global to regional and local. For instance, in Paxian et al., (2010) a global emission model was build based on LLyod ship movement data. In Righi et al. (2013) we studied the impact of transport emissions - in particular from shipping - on the global atmospheric aerosol load. In recent years, we have been able to directly attribute fractions of regional pollutants to emissions from different sources in a single numerical simulation (e.g. Mertens et al., 2020a). Such methods have been used to investigate the influence of land transport emissions in Europe (Mertens et al, 2020b), but similar studies for shipping emissions are missing.[13]

Many maritime shipping emission studies produce pollution inventories without the integration of sensor data aboard ships. With the development of sensor and big data technologies, it is possible to track the movement of individual vessels and their pollution in real time. With an emission model calibrated by means of on-board pollutant sensor data, the vessel emissions can be monitored and tracked in real time using actual vessel movement data. This can help the port operator to get a more accurate inventory of the vessel emission around the port areas, find the hotspot of pollutants and track important vessels. Moreover, port operators can evaluate and optimize the port operations and traffic management to reduce vessel emissions based on the simulated vessel trajectory under different emission mitigation strategies.

Although the development and installation of services to measure the air quality and to monitor emissions in cities especially for road transport is already state of the art (TRL 9), investigations and developments concerning the contribution of maritime transport chains to air pollution have so far been more or less restricted to being one-off and at an academic level (TRL 3). With MAREMIS we plan to develop a demonstrator working in a real environment to minimize the gap and to achieve a TRL of up to 6

[12] Alessandrini, A., Guizzardi, D., Janssens-Maenhout, G., Pisoni, E., Trombetti, M., Vespe, M., 2017: Estimation of shipping emissions using vessel Long Range Identification and Tracking data. Journal of Maps, 13:2, 946-954, DOI: 10.1080/17445647.2017.1411842

[13] The German academic partner (DLR) has been running the internal 4-year-project TraK (Transport und Klima – Transport and Climate) since January 2018, which is project No. 3 in a row a projects considering the impact of transport (incl. shipping) on the atmosphere and climate. Both DLR-KN and DLR-PA participate in TraK, which has a budget of ~ 10 M€.