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Final report

SURV-EMIS | CONSOLIDATION SHIP EMISSION MONITORING OVER THE NORTH SEA

RT/22/SURV-EMIS

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ABSTRACT

The SURV-EMIS project, conducted by the Royal Belgian Institute of Natural Sciences, addresses air pollution from shipping in the North Sea by leveraging an airborne "sniffer" sensor. This sensor monitors the emissions of sulphur oxides (SOx), nitrogen oxides (NOx), and black carbon (BC), enforcing international maritime regulations such as MARPOL Annex VI. The project plays a pioneering role globally, achieving significant compliance monitoring through aerial surveillance and data-driven port inspections.

It highlights reductions in SO2 emissions due to stricter international regulations but underscore challenges with NOx emissions, which remain high due to rising shipping activity and limited regulatory effectiveness. The project also investigates black carbon emissions, contributing critical data to advocate for future international regulatory measures.

Methodological innovations include advanced sniffer sensors, real-time ship plume sampling, and integration with port inspection systems, increasing inspection efficiency. Scientific recommendations emphasize the need for more robust enforcement, improved regulations, and expanded monitoring capabilities, including emerging pollutants like airborne microplastics.

This project demonstrates the potential of airborne monitoring to enhance maritime compliance enforcement while providing a model for international collaboration and policy development.

Keywords

Ship Emissions Monitoring, Airborne Sniffer Sensor, Maritime Air Pollution, MARPOL Annex VI Enforcement, SO2, NOx, BC

1. INTRODUCTION

The Belgian Coast Guard aircraft have been fighting marine pollution caused by shipping since 1990. Since 2015, the RBINS has equipped its surveillance aircraft with innovative 'sniffer' sensors. These sensors measure sulphur, nitrogen and soot emissions from individual seagoing vessels. With the sniffer aircraft, the strict international ship emission standards on the North Sea can be monitored. If a suspicious SOx or NOx emission is measured in the smoke plume of a ship, this ship is targeted for a port inspection in the next European port of call. With this extension, Belgium plays a pioneering role internationally in the monitoring of ship emissions. These types of measurements allow in situ large-scale checks for compliance with international guidelines on air pollution from ships. With more than 4,500 inspections over five years, significant added value for port inspections is realised. Belgium is the only country to apply a sniffer sensor in its coastguard aircraft, making it an international leader in this field.

2. MOTIVATION AND OBJECTIVES OF THE PROJECT

2.1 Air pollution from ships

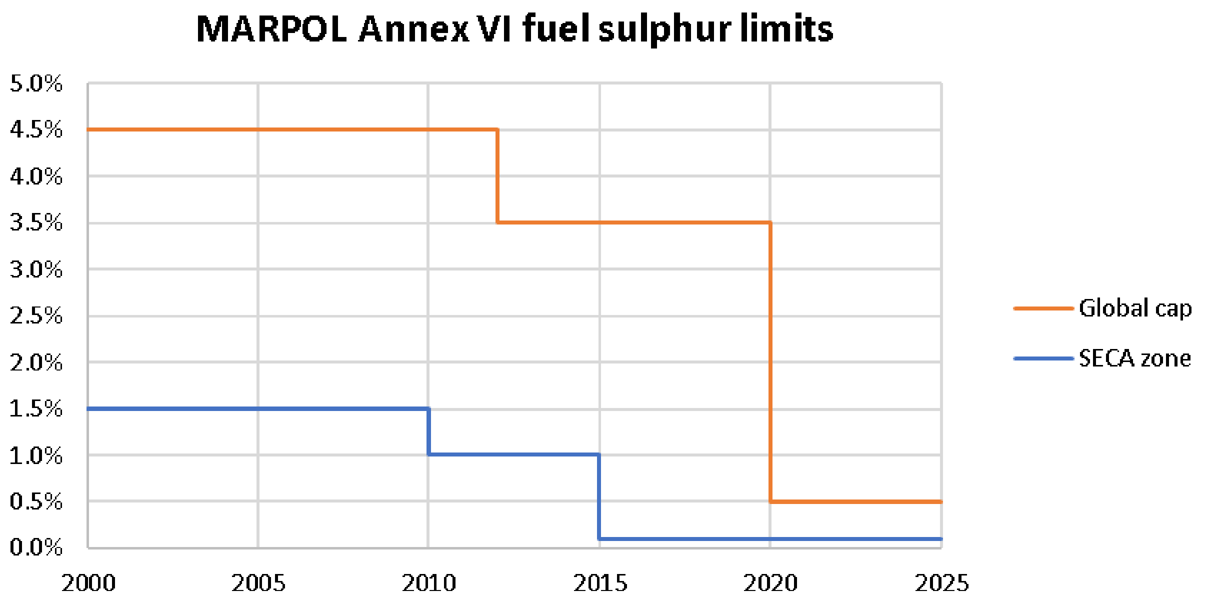
Shipping affects people and the environment in several ways. By burning fossil fuels, mainly cheap heavy fuel oil, it is responsible for a significant proportion of global emissions of pollutants to air. Besides carbon dioxide (CO2), pollutants such as sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM2.5) and black carbon are also present to a significant extent in exhaust gases. Scientists estimate that air pollution from shipping caused 800,000 premature deaths worldwide in 2017 (Sofiev et al., 2018). Ships also emit many greenhouse gases. This is mainly CO2, but black carbon also contributes to global warming, second only to CO2 in terms of their overall contribution to global warming.

During fuel combustion, the sulphur present is largely oxidised to sulphur oxides SOx (mainly SO2), while the residual fraction gives rise to the formation of sulphur particles (fraction of particulate matter). SO2 can cause asthma and alter lung function in children; in adults, it can lead to cardiovascular disease and respiratory problems. It is also behind the formation of toxic fog or smog. NOx in combustion gases also have a negative impact on public health: the nitrogen dioxide (NO2) component can lead to increased sensitivity to allergens and cause even more severe respiratory problems in people with asthma or chronic respiratory diseases, while NOx further plays an important role in the formation of particulate matter and the eutrophication of the marine and terrestrial environment. In the lower atmosphere, they also behave as ozone precursors. Formation of ozone near the ground also leads to respiratory problems and ozone is also a greenhouse gas. SOx and NOx emissions from ships are also major contributors to water acidification in high-traffic zones and coastal regions, and in the air, SO2, via a reaction with water to form sulphuric acid (H2SO4), is partly responsible for the acid rain that damages infrastructure and ecosystems.

2.2 International maritime policies

2.2.1 SO2

In 2000, stricter standards were agreed for sulphur content in marine fuels in certain sea areas, referred to as Sulphur Emission Control Areas (SECA). The North Sea and English Channel became an SECA area in 2006, following the Baltic Sea. Since 1 January 2015, even stricter emission limits have applied here and ships are only allowed to use fuel with a sulphur content of no more than 0.1% (previously 1.0%, and before 2010 1.5%). Outside the SECA, the maximum sulphur content was tightened from 3.5% to 0.5% on 1 January 2020 by the Global Sulphur Cap of MARPOL Annex VI. Scientists calculated that its implementation on a global scale could result in up to 270,000 avoided premature deaths (Sofiev et al., 2018). In the European Union, the efficient implementation of MARPOL Annex VI rules is a top priority, and SOx emissions from shipping are regulated by the Sulphur Directive (Directive (EU) 2016/802). To comply with the regulations, ships in SECA areas must switch to lower sulphur fuels or natural gas (usually LNG), or use an approved exhaust gas cleaning system (so-called scrubbers).



Evolution of MARPOL Annex VI sulphur limits for marine fuel in SECA areas (blue) and globally (orange). Graph based on IMO guidelines © KBIN/BMM

2.2.2 NOx

MARPOL Annex VI also sets limits for NOx emissions from marine diesel engines in Nitrogen Emission Control Areas (NECA).

The limits apply to any engine with a power above 130 kW, and depend on the optimum operating speed (Revolutions Per Minute - RPM). The nature of the emission limitation is very different from that for sulphur: where for sulphur the content in the fuel is limited, the limit for NOx is expressed in emissions, as amount of NOx per unit of engine power (g NOx/kWh). Three emission levels are defined based on the date of construction (keel laying) of the ship, known as Tiers. Ships built between 2000 and 2011 must meet the Tier I standard (9.8-17.0 g/kWh) in the NECA, ships built after 2011 must meet the Tier II standard (7.7-14.4 g/kWh), and ships built from 2021 onwards will have to meet the Tier III standard (2.0 - 3.4 g/kWh). For ships built between 1990 and 2000 with a power greater than 5000kW or with a cylinder size greater than 90l, the Tier I standard will also apply. No standard was set for older ships.

The NECA for the North Sea and Baltic Sea will come into force on 1 January 2021, and Tier III will also be in force from then on. The regulations aim to reduce NOx emissions from ships operating in the NECAs by up to 80% between 2021 and 2040. For the North Sea and Baltic Sea, the NECA area geographically corresponds to the SECA area. From 2021, we therefore refer to it as the ECA area.

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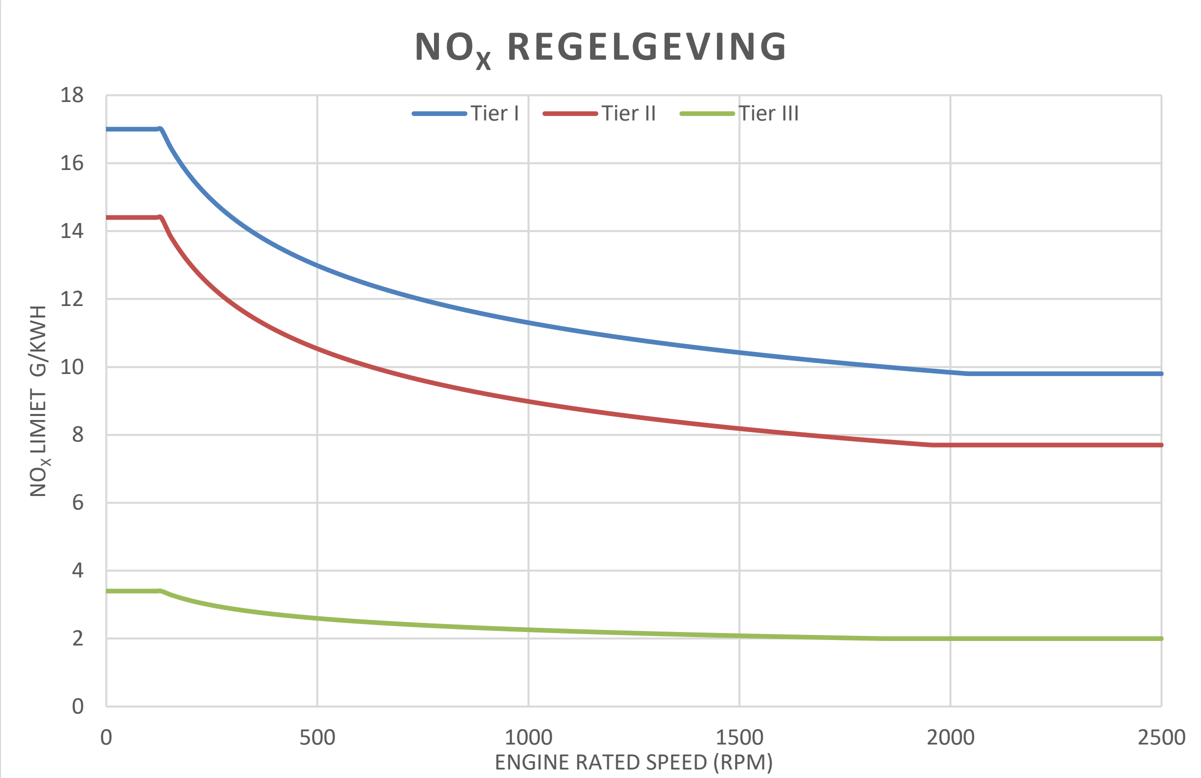
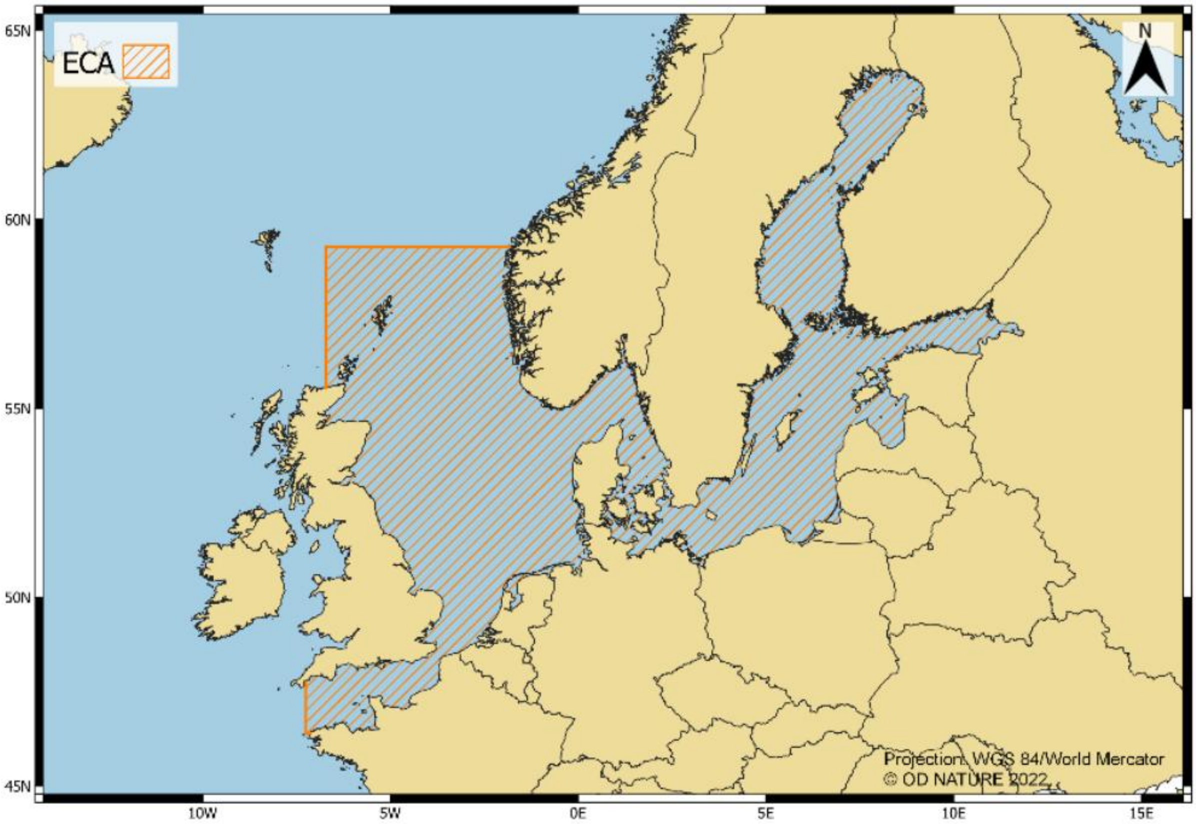


NOx Tier standards, Tier-I applies to ships keeled from 2000, Tier-II to ships keeled from 2011 and Tier-III to ships keeled from 2021. © KBIN/BMM

2.2.3 BC

There is still little information on effective BC emissions from ships, several experimental campaigns have shown that BC emissions from ships are a significant contributor to air pollution problems. An additional aspect is that ships have started using new very low-sulphur fuel oils to comply with stricter sulphur standards. However, recent studies show that when using some of these new generation fuels, BC emissions can be higher than for conventional heavy fuel oil, for example, for certain types of new fuels, BC emissions can increase by up to 85% at certain engine loads.

IMO has already recognised this and called on the various member states to provide reliable data of BC emissions from shipping. The mapping of BC emissions from shipping in the North Sea can contribute to a better understanding of the global BC emissions from shipping and can therefore be a driver for additional international regulatory measures on BC emissions from ships.



The North Sea and Baltic Sea ECA area. Border coordinates based on IMO guidelines © KBIN/BMM

2.3 Objectives of the project

Therefor additional SOx/NOx/BC sniffer flights are necessary. The national aerial observation program is supported by Science Policy and the FPS Justice and North Sea: the personnel and the program management fall under Science Policy, the performed monitoring tasks under the FPS Justice and North Sea. BELSPO covers with this project a large part of the fixed costs for the scientific part, but the number of hours to optimize the capacity is only very partially financed. The project consists of 2 parts:

1. Executing 20 extra flight hours on a yearly basis for SOx/NOx/BC emission monitoring of individual ships above the North Sea (mainly in and around the Belgian sea areas), according to standard operational procedures developed within MUMM (cf. QA Manual).

2. Related sensor and data management:

   (i) ICT-related costs, software updates & support, sensor/database running & maintenance costs;

   (ii) digitalisation of sensor data and annual data analyses.

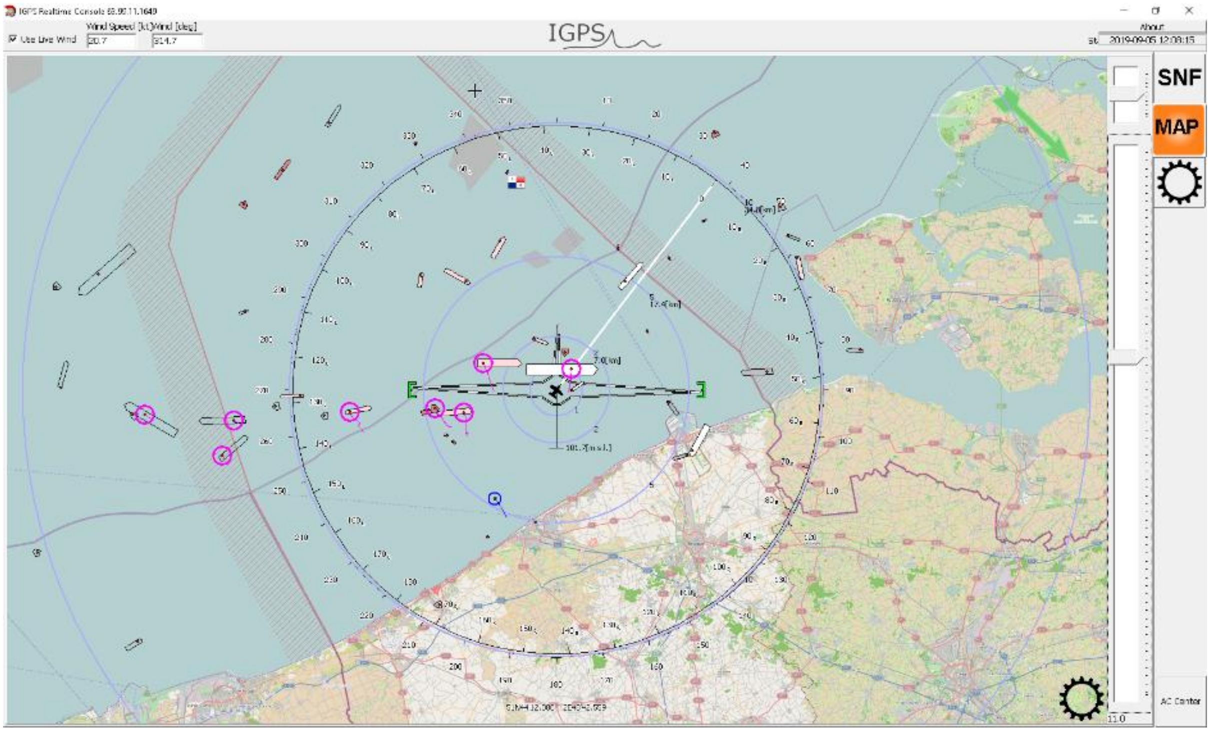
The results of aerial compliance monitoring and follow-up by port inspection services will be used for scientific papers on FSC, NOx, BC, and regulatory follow-up. Additionally, the results will be presented at international meetings such as the OTSOPA and NSN meetings of the BONN Agreement. Furthermore, requests are regularly received to present the monitoring results at scientific conferences (e.g., Clean Shipping), maritime industry events (e.g., RBSA, the Royal Belgian Shipowners' Association), and for guest lectures, training sessions, and workshops.

3. METHODOLOGY

3.1 Sniffer sensor

The sniffer sensor in the Belgian coast guard aircraft was developed by Chalmers University (Gothenburg, Sweden) and marketed by FluxSense (Sweden). This sniffer incorporates several scientific gas analysis instruments used for air quality measurements worldwide, with the Thermo 43i TLE (measuring SO2), the LICOR 7200R (CO2), the Ecotech Serinus 40 (NOx) and since 2021 the Microaeth MA300 (BC) as the main sensors. To perform a measurement, the emission plume is flown through. Via a probe on the belly of the aircraft, outside air is continuously pumped through the sensors in the sniffer and immediately analysed. This monitoring can be carried out all year round and during most weather conditions. To obtain accurate measurements, the instruments are calibrated before each flight. Within Belgium, supporting expertise was found at Leefmilieu Brussel (IBGE) and the Vlaamse Milieu Maatschappij (VMM). Among other things, these bodies are used to perform the calibrations and provide advice on the quality management and maintenance of the sensors.

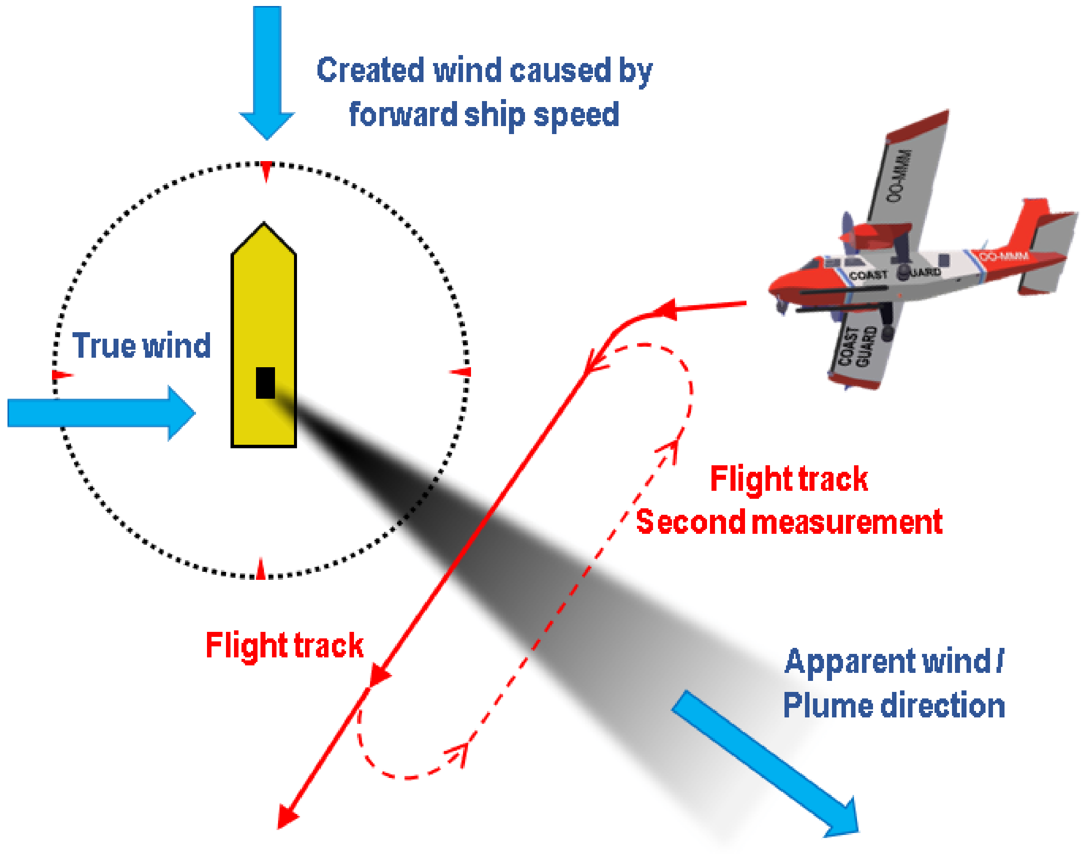
A probe on the outside through the abdomen is connected to the sniffer sensor on board the Coast Guard aircraft. © *KBIN/BMM*



The sniffer system features customised software for sensor operation and visualisation of measurements. It uses an electronic nautical chart with integrated AIS display (Automatic Ship Identification System). On the sea chart, ships are displayed with an indication of the location of the smoke plume. This is calculated on the basis of current wind data and a ship's course and speed, provided by the on-board computer. © KBIN/BMM

3.2 Flight procedures and ship approach

Sampling smoke plumes from ships with a sniffer sensor is not without risk. A well-considered ship approach is crucial. This is determined based on wind direction and force, along with the ship's course and speed. A ship is not flown straight towards it and the smoke plume is sampled at an angle of about 90°. This is done at a height of 30-100m and at a distance of 100-500m from the ship. Depending on wind speed and direction, the plume may be higher or lower than the vessel's exhaust. Locating it can sometimes be challenging, but with trained military pilots, one approach attempt is often sufficient to obtain a successful measurement. With five years of experience, pilots are able to ensure a successful measurement in 97% of cases in one to a maximum of three attempts.



Schematic representation of a ship approach. © KBIN/BMM

Operators of MUMM during a ship approach in practice. © KBIN/BMM

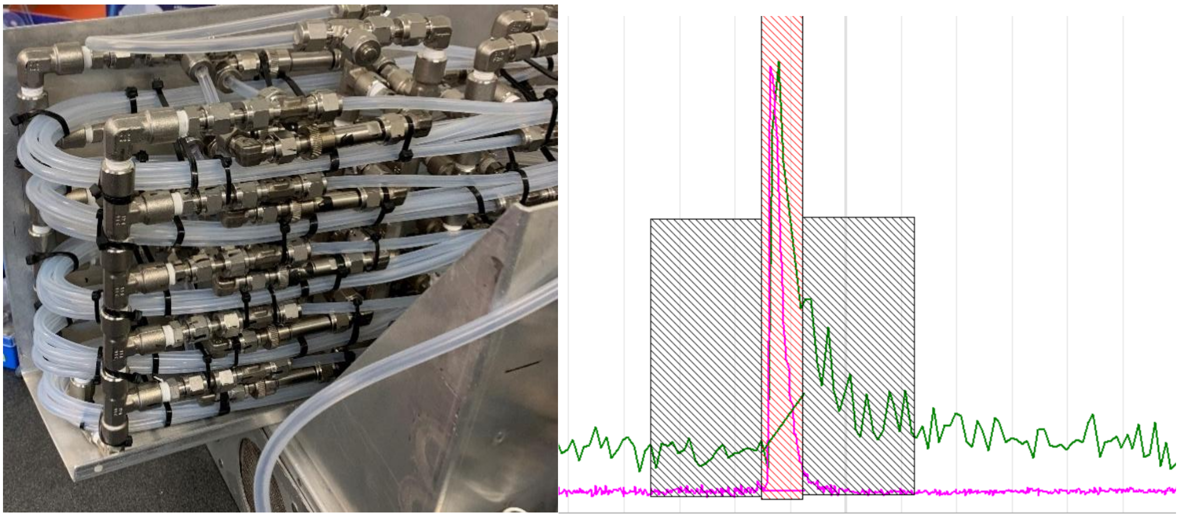
3.3 Determination of sulphur content

The estimation of the Fuel Sulphur Content (FSC) of the fuel used is obtained from the ratio of SO2 to CO2 in the smoke plume using the following equation (in accordance with IMO Marine Environment Protection Committee - MEPC technical guidelines; Balzani et al., 2014):

$$FSC = 0.232 \times \frac{\int [SO_2 - SO_{2,bkg}]_{ppb} dt}{\int [CO_2 - CO_{2,bkg}]_{ppm} dt} [\% \, zwavel]$$

The subscript 'bkg' indicates ambient concentrations in the vicinity of the ship's smoke plume. The constant 0.232 represents the sulphur-carbon atomic weight ratio multiplied by the carbon fraction in marine fuel (87%). This assumes that all sulphur is converted into SO2. However, this is only partially the case, as some of the sulphur is converted to sulphur particles and SO3. In addition, the SO2 sensor also has a cross-sensitivity to NO, which is currently eliminated using the NOx sensor.

As standard, the SO2 sensor is equipped with a hydrocarbon kicker that can remove certain Volatile Organic Compounds (VOCs) from the gas stream. However, this only operates at a very low flow rate and was therefore initially removed from the sniffer. However, as a result, VOCs cause a significant tail in the SO2 measurements in some cases. The problem was remedied until recently by excluding the tail of the plume from the sulphur content calculation, but was completely eliminated by incorporating an in-house developed super-kicker consisting of 10 hydrocarbon kickers connected in parallel.



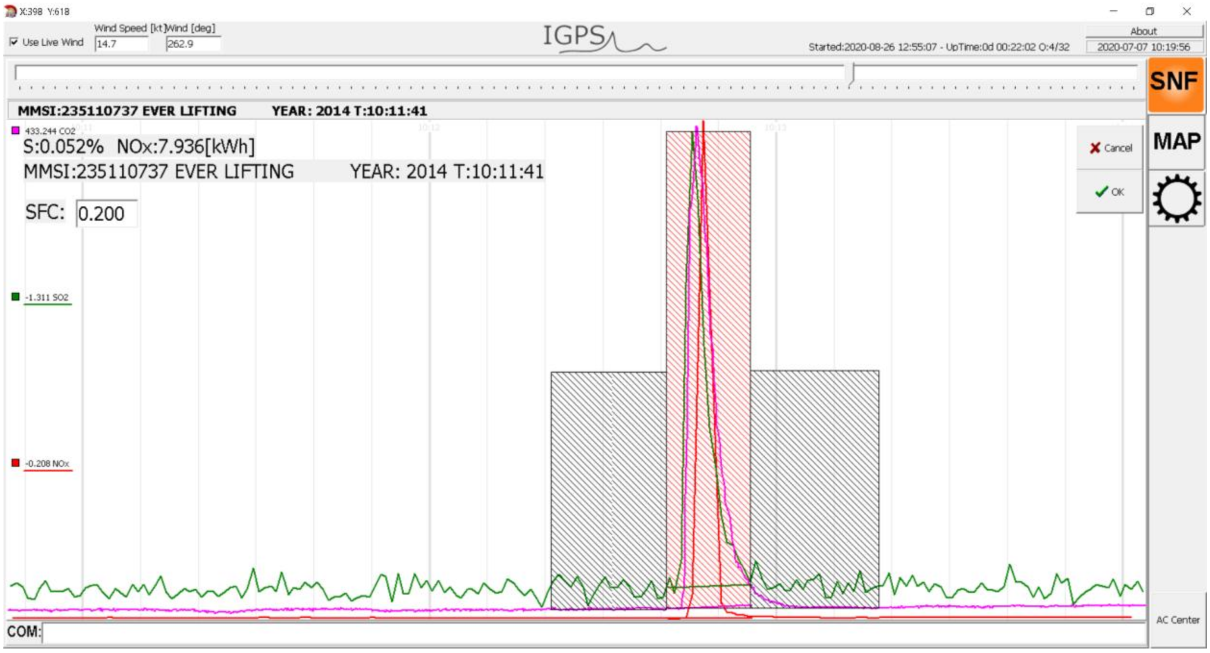
The figure on the right visualises the VOC effect: the SO2 curve (green line) does not immediately return to the background concentration (tail) after the measurement. Ward Van Roy of BMM developed a super-hydrocarbon kicker that eliminates the influence of VOCs on the SO2 measurements. © KBIN/BMM

3.4 Measuring nitrogen oxides

De NO_x-emissiefactor in g NO_x/kWh kan bepaald worden door de volgende vergelijking (Balzani et al., 2014):

$$NO_x[g/kWh] = 3.33 \times \frac{\int [NO_x - NO_{x,bkg}]_{ppb} . dt}{\int [CO_2 - CO_{2,bkg}]_{ppm} . dt} \times SFOC$$

Herein, SFOC (Specific Fuel Oil Consumption) is the fuel consumption in g fuel/kWh. An average consumption of 200g/kWh is initially assumed for SFOC. If a suspiciously high NOx value is obtained, the ship is contacted to verify the effective fuel consumption, in order to adjust the measurement. As the limit depends on the keel laying, a database containing the keel laying data of more than 90% of the world fleet of ships larger than 75m was compiled in cooperation with the Dutch Inspectorate for the Environment and Transport (ILT) and the European Maritime Safety Agency (EMSA) and reflects this information in the sniffer software.



Adaptation of sniffer software for NOx enforcement (green = SO2, purple = CO2, red = NOx), keel laying date per ship is immediately available and SFOC can be entered per emission measurement. © *KBIN/BMM*

3.5 Measuring back carbon

Since 2021 black carbon measurements have been taken. Black carbon is a harmful fraction of particulate matter created by incomplete combustion. These measurements are purely done for scientific reasons because there is no legislation for black carbon yet. So checking standards is not an issue here. However, by the collection of data contributes to the awareness for the need for legislation.

The problem with black carbon is that the World Health Organisation (WHO) has not yet set guidelines. It is well known that carbon black is harmful to health but the extent of it has not yet been formally defined.

Moreover, black carbon has a negative impact on climate change. It absorbs sunlight and therefore traps heat in the atmosphere. When the carbon particles settle on glaciers or ice, they prevent the reflection of the sun's rays, resulting in even more warming. That is why there is a voluntary ban on the use of heavy fuel oil for Arctic waters. The measurements show that black carbon emissions from ocean-going vessels cannot be underestimated. 10% of ships emit very high levels of black carbon leading to climate change contribution that higher than from their CO2 emissions.

In collaboration with DG Shipping, RBINS is taking samples of fuel from suspected ships. This way we will investigate whether there is a link between the composition of the fuel and high black carbon emissions.

3.6 Designating suspect vessels

Cooperation and communication with the European Port Inspection or Port State Control (PSC) network is a crucial aspect in the use of aerial monitoring for MARPOL Annex VI enforcement. PSC is responsible for conducting and coordinating port inspections to implement the EU Sulphur Directive, but in the period without a sniffer could only rely on an almost random selection of ships for inspection by identifying suspicious ships based on air monitoring, port inspections can take more targeted samples making them more efficient. Moreover, ships leaving and departing EU ports from the ECA area, or in transit through the ECA, could not be checked through PSC inspections, leading to PSC compliance rates that gave a distorted picture of reality. The findings of suspected sniffer measurements at sea are therefore reported to the relevant inspection authorities at the next European port of call immediately after the flight. In addition, the results of all other measurements are entered via an automated protocol that was developed by MUMM into Thetis-EU, a database managed by EMSA and accessible by all EU Member States. As this information also includes compliant ships, it helps in carrying out port inspections across Europe more efficiently. In Belgium, such inspections are carried out by FPS Mobility (DG Shipping).

For the time being, no official reports are being drawn up purely on the basis of sniffer measurements at sea. This will only happen if sufficient evidence of infringement is found during a port inspection with fuel sampling. In the future, however, air measurements could be used for direct enforcement of the SOx and NOx directives.

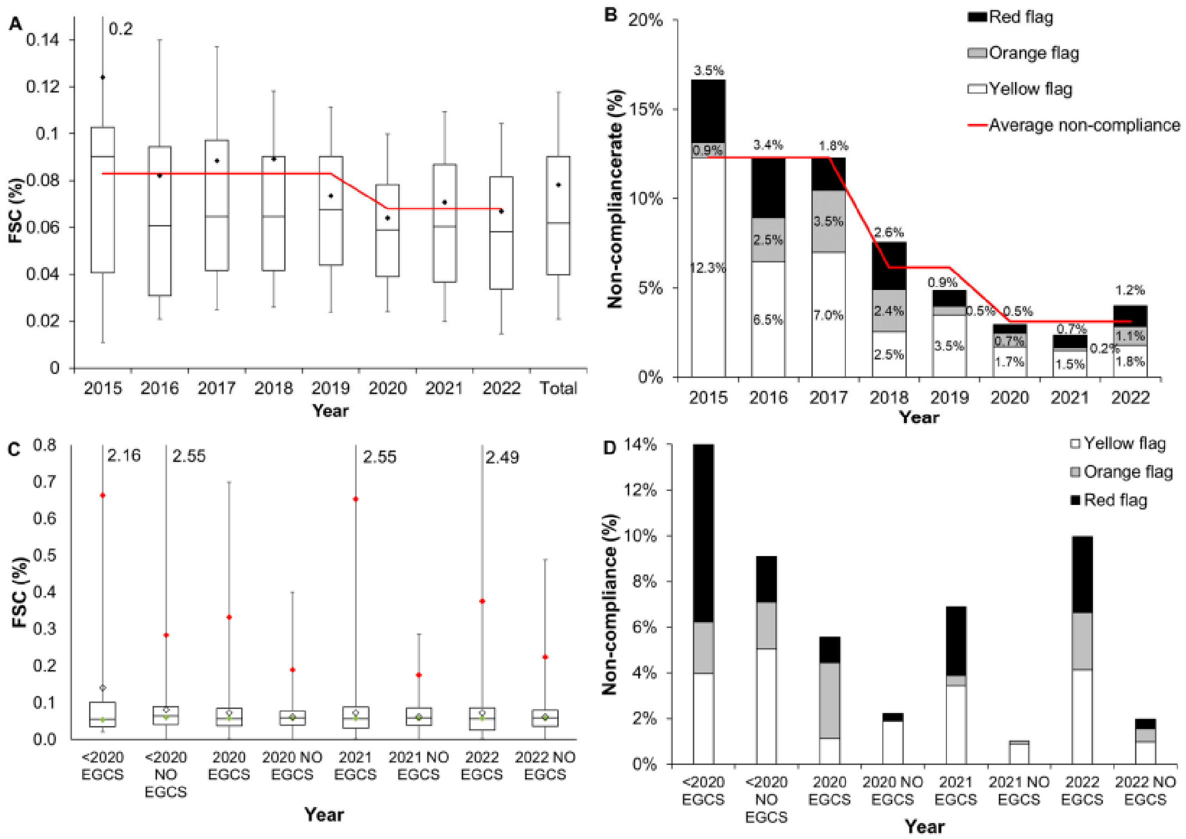
4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

For in depth scientific results and recommendations, we would like to refer to the series of scientific publications that have resulted from this project.

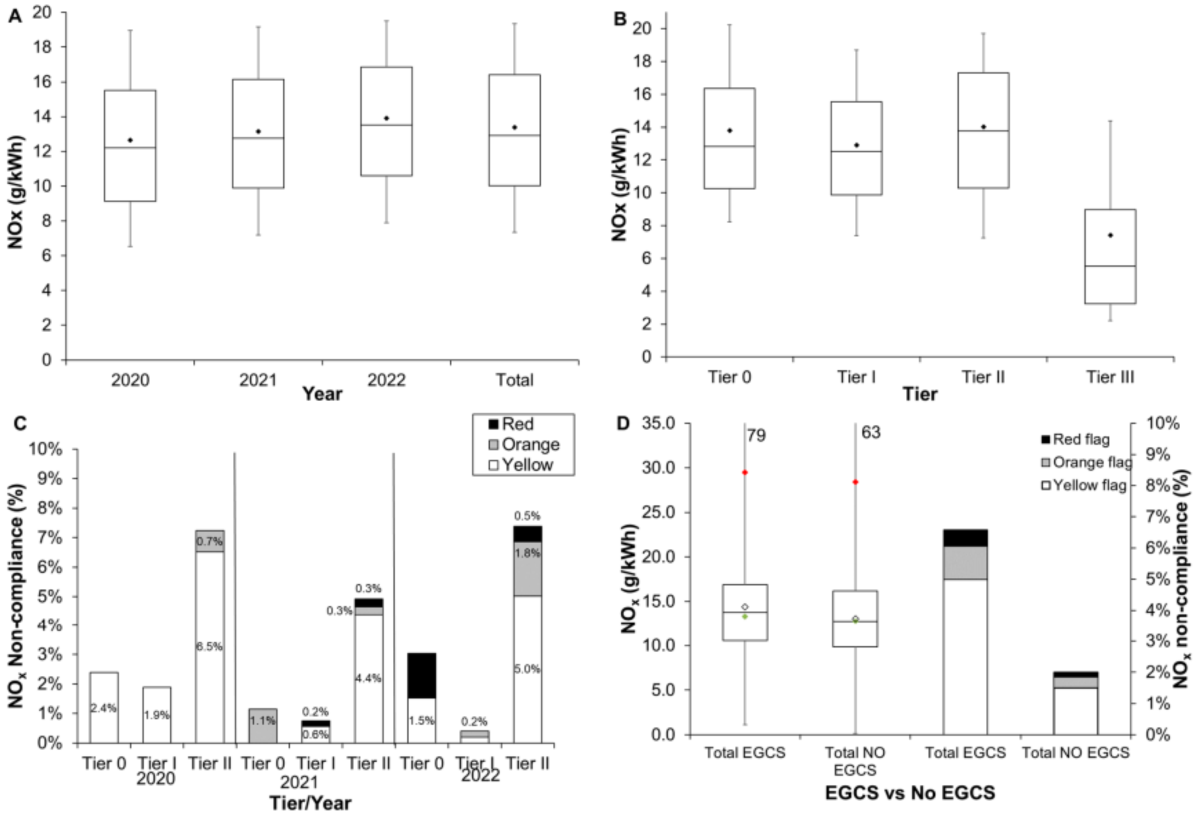
As a general conclusion of the sniffer project and recent research by the Royal Belgian Institute of Natural Sciences it was demonstrated that the international regulations have successfully led to a reduction of SO2 emissions from ships in the southern North Sea, resulting in decreased SO2 pollution levels in Flanders. However, the project also showed that the ship-source SO2 pollution in Flanders is on the rise, this can mainly be attributed to an increase in shipping. However a substantial part of this increase can be attributed to an enhanced use of exhaust gas cleaning systems (EGCS) also called scrubbers. Thus, the study found that the use of these scrubbers is not without controversy. Ships equipped with scrubbers were more often found to fail to meet emission standards and, more worryingly, on average they emit more SO2. A reason for this can be found in the fact that these ships use heavy fuel oil where normally the scrubbers clean the exhaust gases. However, the study found that for 10% of the observed vessels, the scrubbers were not in use or were malfunctioning and, in those cases, emit drastically more SO2. Previous research by the RBINS already showed that these scrubbers could also have detrimental effects on the acidification of the North Sea, as sulphur compounds present in heavy fuel oil are filtered out of the exhaust gases by the scrubbers and are then discharged into the sea, where they form sulphuric acid.

In addition, international regulations were found to be much less effective in achieving a reduction in NOx emissions from shipping in the southern North Sea. It was found that shipping is even expected to become the largest source of NOx pollution for Flanders by 2025. This is partly due to the increase in shipping, the decrease in other NOx emission sources such as traffic and industry, but to a significant extent also due to an increase in NOx emissions from recently built ships, a subject on which RBINS has previously published. The RBINS is therefore actively working within international agreements and in cooperation with other Belgian government agencies on proposals for stricter regulations to reduce NOx emissions from shipping.

Furthermore, a detailed sniffer quality management system was compiled and made available to the public. The described standard operational procedures are not only important to ensure that all measurements are carried out according to a harmonized approach and with the utmost certainty. The procedures described can also be used by other countries setting up their own airborne monitoring operations. Although the described standard operational procedures (SOP) are highly adapted to the sniffer system used by the Belgian coastguard, they can also serve as a model for other countries when establishing their own procedures



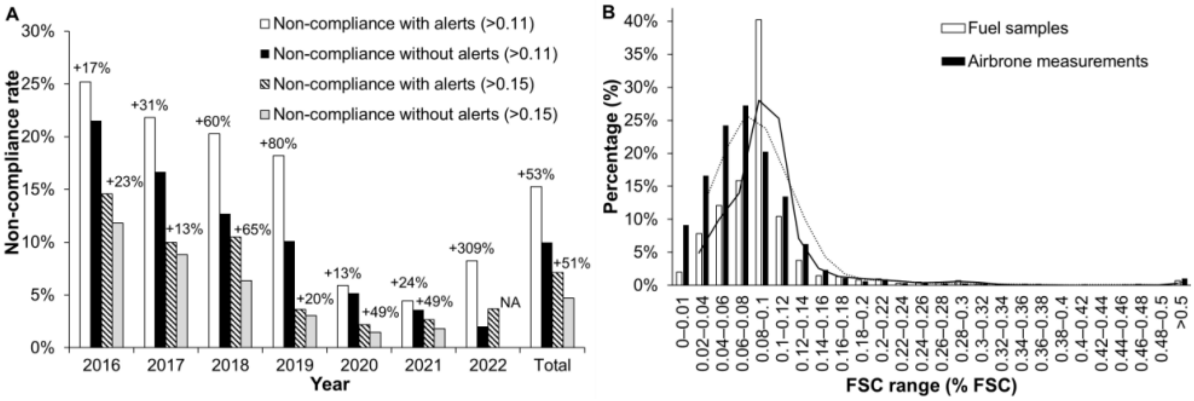
Evolution of the average corrected FSC concentration from 2015–2022 with median 10, 25, 75, and 90% percentiles and mean FSC per year (), with mean FSC for the period before and after 2020 (red line). (A) Non-compliance evolution based on the corrected FSC data from 2015–2019. (B) Mean, median, 25, and 75 percentile boxplots for monitored FSC for EGCS OGVs and nonEGCS OGVs. The overall mean is provided in white diamonds (♦). The mean non-compliant FSC is provided in red diamonds (◊); the mean compliant FSC is provided in green diamonds (◊). (C) Compliance rate of EGCS OGVs compared to OGVs without EGCS. (D) When the upper whiskers exceeded the limits of the graphs, the value was noted on the graph. © KBIN/BMM



Boxplot with median 10, 25, 75, 90% percentiles, and mean NOx emissions per year (A) and per tier level (B). NOx non-compliance per tier and per year (Tier III is not represented due to the absence of Tier III data between 2020 and 2021) (C). Boxplot with median 10, 25, 75, 90% percentiles, and mean NOx emissions between EGCS and non-EGCS OGVS. The overall mean is provided in white diamonds (◊). The mean non-compliant FSC is provided in red diamonds (♦); the mean compliant FSC is provided in green diamonds (♦). On the right side of this graph the NOx noncompliance difference between EGCS and non-EGCS OGVs is provided (D). provided in green diamonds (◊). On the right side of this graph the NOx non-compliance difference between EGCS and non-EGCS OGVs is provided (D). © KBIN/BMM

Besides the above mentioned findings on real world emissions, it was shown that by including airborne alerts in the enforcement chain, the number of non-compliant detections in Belgian ports increased by 53%.. Additionally, 41% of all MARPOL Annex VI issued fines in Belgium, were a result of airborne alerts However, it is demonstrated that up to 80% of all observed potential non-compliant ships were not followed up or when followed up, the inspection (with a fuel sample analysis) could not confirm the observed non-compliance. Often the latter is a result of a delayed follow-up in ports. This highlights the strong incentive to further explore the use of remote measurements as legal evidence to tighten the MARPOL Annex VI enforcement chain. It is found that inspections of EGCS ships after airborne alerts improved the inspection results drastically, and airborne alerts accounted for 2/3 of the sanctioned EGCS ships in Belgium.

The project demonstrated the effectiveness of using airborne sniffer measurements in enforcing MARPOL Annex VI regulations. It also highlights the potential of airborne monitoring to provide reliable legal evidence and improve the enforcement chain. However, more large-scale field validation experiments are needed, and regulations need to be improved to allow the assessment of real world NOx emissions and compliance verification by port inspection authorities.



Improvement of PSC inspections as a result of the airborne alerts (A) and histogram of the FSC values from fuel samples and airborne measurements (B). © *KBIN/BMM*

With these lessons learned RBINS formulated recommendations for policymakers based on the experience gained. One of the main mechanism is the cooperation with the other contracting parties of the Bonn Agreement regarding MARPOL Annex VI to strive for an effective monitoring strategy within the Bonn Agreement. The eighth and closing chapter of this thesis describes the legal consideration of remote measurements. The recommendations of this project are discussed within the Bonn Agreement and within IMO's subsidiary bodies and will, albeit slowly, find their way into the IMO decision-making bodies.

One of the main reasons why the RBINS is so committed to the BA is precisely to share our gained experiences and best practices. It is our hope that the methods developed will also find continuation in other countries. That is also the reason we have attended numerous international meetings and conferences from one side of the world to the other. Also, for this reason, Ward Van Roy signed up as a co-convenor for the MARPOL Annex VI Technical Working Group.

It is important to note that the work does not end here. The Belgian remote monitoring operations have already been extended to measure airborne microplastics. In the future, this could be further expanded to include nitrogen particles, particulate matter (PM), methane and N2O. In addition, we hope to continue upgrading the measurement systems with state-of-the-art sensors to further improve measurement uncertainty, however most likely this will be part of the next Belgian coastguard aircraft.

Academic contributions	Policy contributions
• Improvement of existing methods for airborne remote monitoring of FSC • Development of methods for airborne remote monitoring of NO_x • Improvements of existing remote measurement techniques • Collection of largest set of airborne remote measurements to date • Assessment of real-world uncertainty of remote measurements • Detailed insights on compliance levels within the North Sea ECA for SO_x and NO_x • Insights on average real world SO_x Emissions factors • Insights on average real world NO_x Emissions factors for different tiers • Spatial analysis of compliance levels within North Sea and Baltic Sea ECA • Temporal analysis of compliance levels within North Sea and Baltic Sea ECA	• Development of manual with SOPs for airborne remote monitoring of FSC and NO_x • Development of reporting mechanism for remote measurement alerts • Evaluation of added value of airborne monitoring for port inspection authorities • Cost benefit analysis of airborne monitoring operations • Description of developments within the Bonn Agreement • Detailed insight in efficiency of international regulations at sea in European ECAs • Detailed analysis of compliance issues with EGCS ships • Observed higher NO_x emission levels and compliance for Tier II versus Tier I • Observed higher NO_x emissions at lower engine loads • Observed issues with introduction of Tier III • Provisions of detailed recommendations to improve current regulations

Key academic and policy contributions of the SURV-EMIS project and the doctoral dissertation of Ward Van Roy. © KBIN/BMM

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5. DISSEMINATION AND VALORISATION

Overview outreaching

Maritime Air Pollution MAP & FUEL technologies Europe – Amsterdam (18/5/2022) Presentation : Effective enforcement : The Belgian Marpol Annex VI compliance monitoring program – Results, challenges and future prospects

Third web conference Sulphur 2020 Enforcement (10/3/2022) Presentation: Airborne Marpol Annex VI NOx Compliance Monitoring

Pint of Science (11/5/2022) Presentation: Airborne monitoring of ship emissions

KBRV (9/1/2023) Presentation: Airborne Marpol Annex VI NOx Compliance Monitoring

VLIZ Science day (1/03/2023) Presentation: Airborne monitoring of compliance to NOx emission regulations from ocean-going vessels in the Belgian North Sea

North Sea Network of Prosecutors and Investigators (25-26/4/23) Presentation: Status MARPOL Annex VI Working Groups SOWG & TWG

OPTIMARE/AERODATA operator conference (10-11/5/2023) Presentation: Status MARPOL Annex VI

NOx Workshop Den Haag (13/11/2023) Presentation: Observation of real-world NOx emissions in European NECA

VOKA (16/11/2023) Presentation: Application of remote measurements for compliance monitoring and enforcement of SO2 and NOx emissions under MARPOL Annex VI

Zeevaartschool (19/02/2024) Presentation Ship emission monitoring Using the Belgian Coastguard Aircraft

6. PUBLICATIONS

Overview publications (2022-2024)

Airborne monitoring of compliance to sulfur emission regulations by ocean-going vessels in the Belgian North Sea area. (2022) Atmospheric Pollution Research (13) 101445.

Airborne monitoring of compliance to NOx emission regulations from ocean-going vessels in the Belgian North Sea area. (2022) Atmospheric Pollution Research (13) 101518.

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The Role of Belgian Airborne Sniffer Measurements in the MARPOL Annex VI Enforcement Chain. (2023) Atmosphere (14) 623.

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Uitstoot van Schepen in de Noordzee, waar rook is is vuur. (2024) Grote Rede (VLIZ) (59).
Luchtvervuiling, scheepvaart in het vizier. (2024) EOS

7. ACKNOWLEDGEMENTS

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8. AWARDS

EU Greening Initiative EMSA-EFCA-FRONTEX (2024) Special Commendation in Greening Operations category