



**Ministry of Environment
of Denmark**

Environmental
Protection Agency

Airborne Monitoring of Sulphur Emissions from Ships in Danish Waters

2022 Campaign Results

Environmental Project
no. 2224

January 2023



Publisher: The Danish Environmental Protection Agency

Author: Explicit ApS, www.explicit.dk

Photos: Explicit ApS

ISBN: 978-87-7038-473-5

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Sources must be acknowledged.

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Acronyms / Definitions

2017 Campaign	DEPA 2017 Airborne Sulphur Monitoring Campaign
2018 Campaign	DEPA 2018 Airborne Sulphur Monitoring Campaign
2019 Campaign	DEPA 2019 Airborne Sulphur Monitoring Campaign
2020 Campaign	DEPA 2020 Airborne Sulphur Monitoring Campaign
2021 Campaign	DEPA 2021 Airborne Sulphur Monitoring Campaign
2022 Campaign	DEPA 2022 Airborne Sulphur Monitoring Campaign
AIS	Automatic Identification System
ANNEX VI	MARPOL Annex VI for the Prevention of Air Pollution from Ships
DEPA	Danish Environmental Protection Agency
EMSS	Explicit Mini Sniffer System
FSC	Fuel Sulphur Content
MARPOL	International Convention for the Prevention of Pollution from Ships
RSD	Relative Standard Deviation
SECA	Sulphur Emission Control Area

Summary

This report presents the results of the airborne activities to monitor ship sulphur emissions in Danish waters conducted during 2022 by Explicit ApS on behalf by the Danish Environmental Protection Agency (DEPA). The activity is part of the Danish Government's programme to enforce the sulphur regulation under MARPOL Annex VI.

The main findings of the 2022 report can be summarized as follows:

- Of the 602 ships measured during the period January-November 2022, 22 ships (3.7 %) were found to have substantially elevated fuel sulphur content levels at or above 0.15 %.
- This level is higher than the one recorded in 2021 (which was 2.2 %), proving that the pattern of sulphur emissions from ships in Danish waters has not yet reached a steady state.
- For the first time, the number of SECA non-compliant vessel is higher than in 2019, the year prior to the introduction of the 0.5 FSC % 'global sulphur cap'. Moreover, four different vessels have been measured non-compliant to the global cap, with estimated FSC values higher than 0.5 %.
- Some vessels docked in the Copenhagen harbour were found non-compliant. However, no apparent directional patterns are identified.

Although ships are aware of the regular airborne sulphur surveillance effort in Danish waters and, in the previous years, appeared to be adapting their behaviour accordingly, the 2022 Campaign proves that external factors influence the compliance with the regulations. The outbreak of war between Russia and Ukraine caused the price of low sulphur fuel oil to double. This could be the reason why the number of non-compliant vessels has increased.

The 2022 Campaign results highlight the importance and value of the airborne surveillance programme.

1. Operations

As in previous years, the 2022 Campaign was conducted using manned helicopter operations to survey a broad section of Danish waters.

All sulphur deployments in 2022 were conducted by Explicit ApS in collaboration with Charlie 9 Helicopters ApS as part of the Danish Government's programme to enforce the sulphur regulation under MARPOL Annex VI.

1.1 Measurement methodology and technology

No changes were made to the sensor technology or analysis methodology compared to the setup used in previous years. Reference is made to the 2017 Campaign report for details on the measurement methodology, instrumentation, and operational setup.

1.2 Aircraft platforms

All operations in 2022 were carried out using an Airbus H125 single-engine helicopter. No other aircraft platforms were used.

As in previous years, the helicopter was equipped with the EMSS in a dual configuration, i.e. with two parallel sensor instruments operated in tandem. For more information on the application of multiple parallel sampling, please see the 2017 Campaign report.

1.3 Operations



2022 campaign's operations started in January and lasted until November. Due to more favourable weather conditions, most of the operations have been run in the summer months, except for July which is usually a holiday month in Denmark.

Figure 1 and 2 show the distribution of the measurements collected per month and per hour interval.

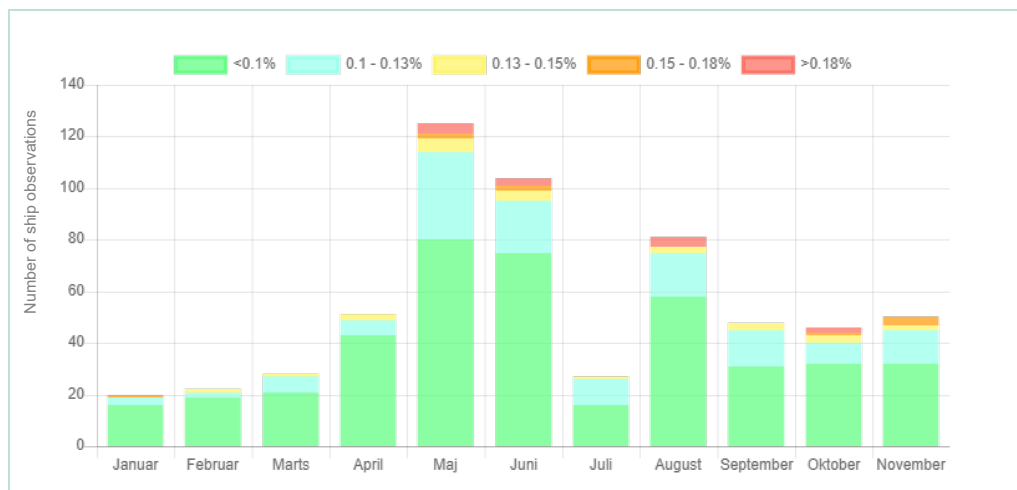


FIGURE 1. Distribution of measurements by campaign month; the colours indicate FSC levels. For further information read Chapter 2.2.

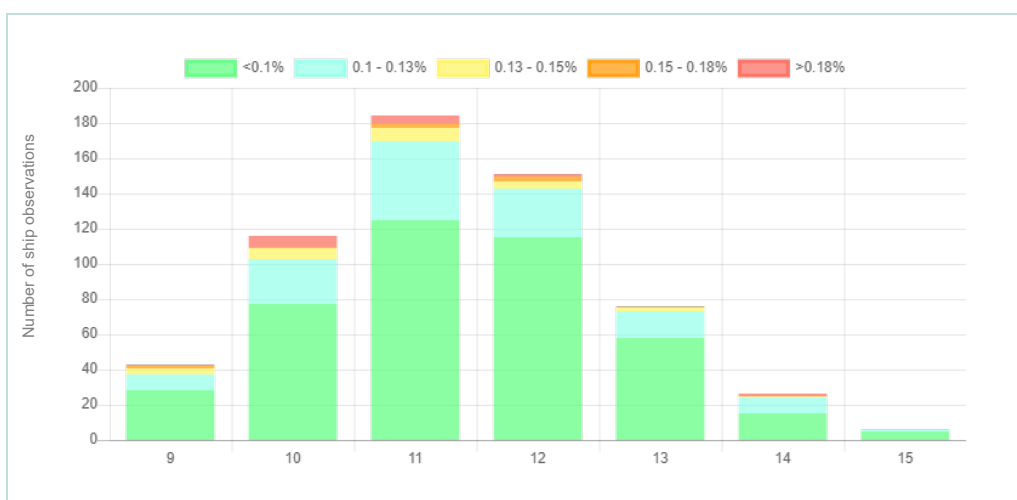


FIGURE 2. Distribution of measurements by hour interval; the colours indicate FSC levels. For further information read Chapter 2.2.

All operations were carried out in accordance with DEPA instructions. No technical issues were encountered during missions.

The airborne monitoring of ship sulphur emissions in Danish waters has been active since 2017; however, even if nowadays most of the ships are aware of the surveillance, the 2022 Campaign results show a different trend compared to the previous years. A detailed analysis is performed in Chapter 2: 2022 Campaign Results.



602

ship observations were collected and analysed for sulphur compliance in 2022.

2. 2022 Campaign Results

The percentage of non-compliant vessels (FSC > 0.15 %) recorded during the 2022 Campaign has increased with respect to the previous year, hitting the value of 3.7 %.

For the first time, the percentage of SECA non-compliant vessel is higher than in 2019, the year prior to the introduction of the 0.5 FSC % 'global sulphur cap'.

2.1 Dataset

The full dataset for the 2022 Campaign consists of 602 independent ship observations. Due to their frequent operation in Danish waters, 69 vessels were measured multiple times during the year, however most of them (58) were measured only twice.

Ships were observed throughout Danish waters with an emphasis on the international shipping lanes and areas with the highest maritime traffic density. Except for 17 anchored vessels, all ships were observed while underway. The map in Figure 3 depicts the location of all measurements, including vessel headings and corresponding FSC levels.

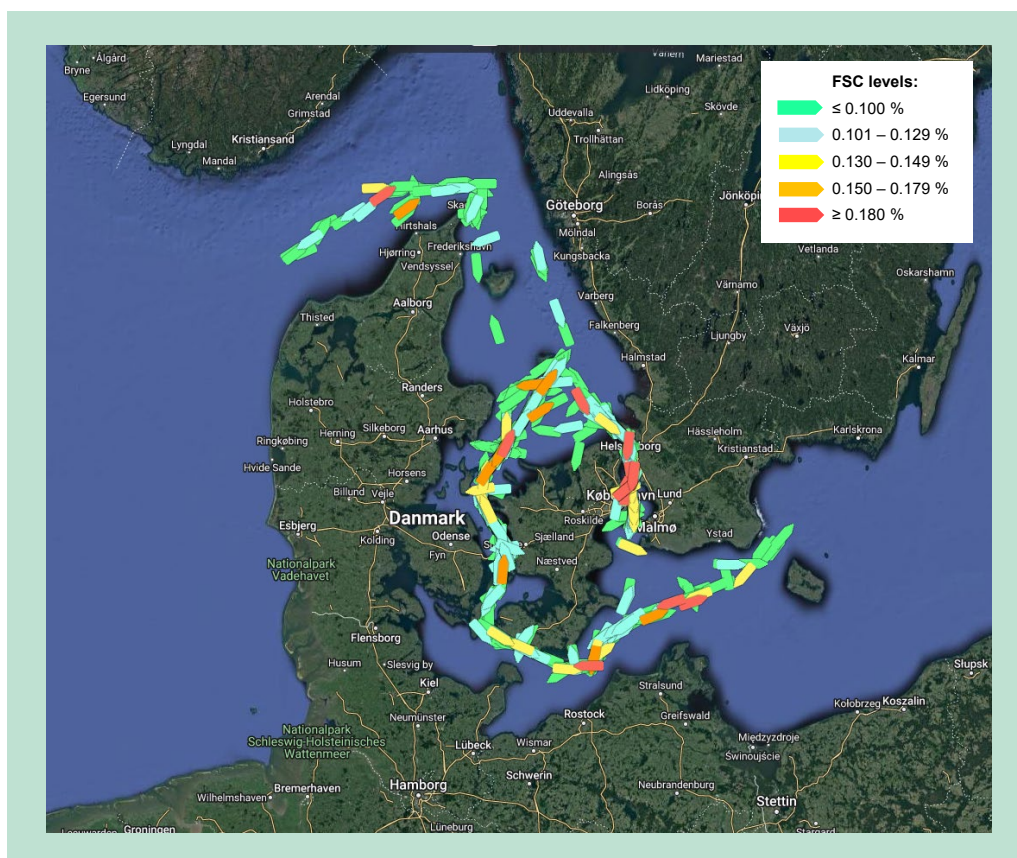


FIGURE 3. Geographical map of all measurements.

All ships were identified based on their AIS signals collected directly from the vessels during flight. No third-party sources have been used to establish ship ID. A breakdown of the dataset according to primary vessel type, based on the AIS data, is presented in Table 1.

TABLE 1. Distribution of measurements by vessel type. “Other” includes dredgers, fishing vessels, HSC.

Type	Cargo	Tanker	Passenger	Other	Total
Measurements	321	209	44	28	602
% of total	53 %	35 %	7 %	5 %	100 %

2.1.1 Measurement quality

Of the 602 ship observations, 562 measurements (93.4 %) were classified as high quality (≥ 6.00 in quality score) according to the systemic quality scoring protocol, meaning the operational team was able to successfully optimize the sampling position in the plume to satisfy all sensor requirements.

A breakdown of the quality scores is presented in Table 2. The methodology for the quality scoring protocol is described in detail in the 2017 Campaign report.

TABLE 2. Distribution by quality scores.

Quality score	Low (0-3)	Medium (3-6)	High (>6)	Total
Measurements	15	25	562	602
% of total	2.5 %	4.2 %	93.4 %	100 %

2.2 Observed FSC levels

The measurement distribution by FSC level is presented in Figure 4. This year’s overall distribution profile shows a median FSC value of 0.078 % and a peak at the 0.090-0.099 % FSC interval; this result confirms that the data shows no immediate bias.

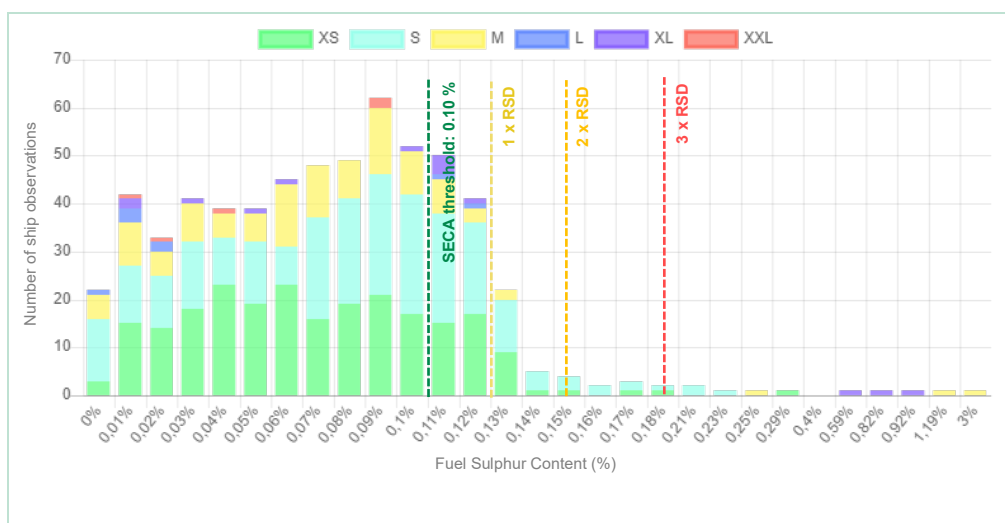


FIGURE 4. Distribution of measurements by measured FSC; the colours indicate difference in vessel sizes according to their length¹. The dotted lines indicate the various compliance cut-off levels for 1xRSD, 2xRSD and 3xRSD respectively.

¹ XS = <130m, S = 130-220m, M = 220-290m, L = 290-300m, XL = 300-366m, XXL = >366m.



It may be noticed that, unlike the past two years, there are a few measurements above the 0.5 % global cap threshold; this topic is further analysed in section 2.2.2.

As mentioned in previous reports, SO₂ is a highly reactive gas that 'stick' to most surface materials it comes into contact with. This phenomenon can cause a delay in the sulphur emissions of the exhaust gasses and eventually also elevated sulphur emissions due to the build-up process, explaining the existence of FSC levels between 0.10 % and 0.50 %. Moreover, the contamination of the fuel system is also a potential issue.

2.2.1 Comparison with previous campaigns observed FSC levels

While the 2021 and 2020 measurement distributions on different FSC levels (Figure 6, Figure 7) appear to have the same pattern, the distribution of the measurements collected during the 2022 Campaign looks slightly different (Figure 5). The data is more evenly spread through the 0 – 0.13 % FSC interval and the number of non-compliant observations (FSC > 0.15 %) has increased. Moreover, it is possible to identify a potential 'scrubber peak' at the 0.01% FSC level, which has not been observed since the 2019 Campaign.

Although the 2021 campaign was showing that the distribution of sulphur emissions in vessels' exhausts had reached a stable point compared to previous years, the 2022 Campaign results instead show how the distribution is still subjected to change.

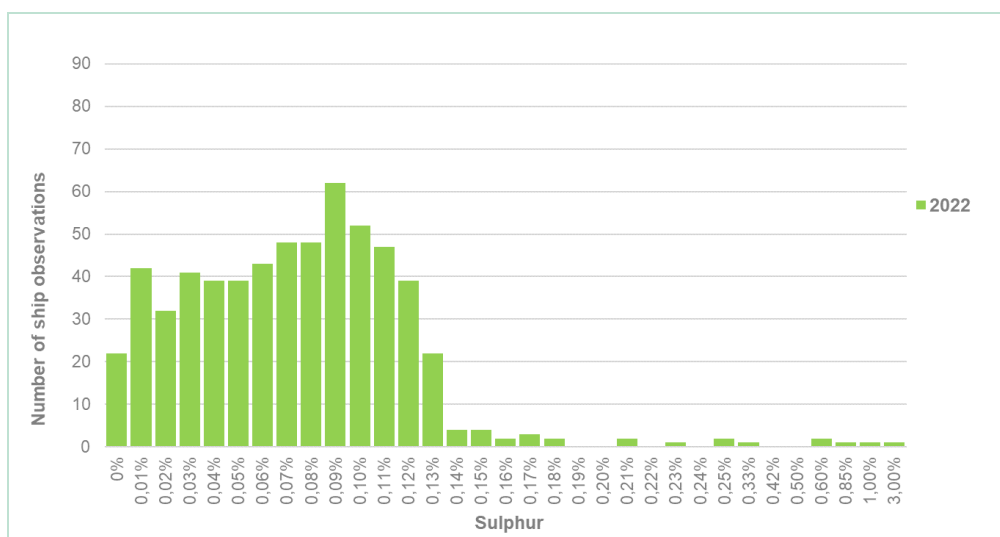


FIGURE 5. Distribution of measurements by measured FSC, 2022 Campaign

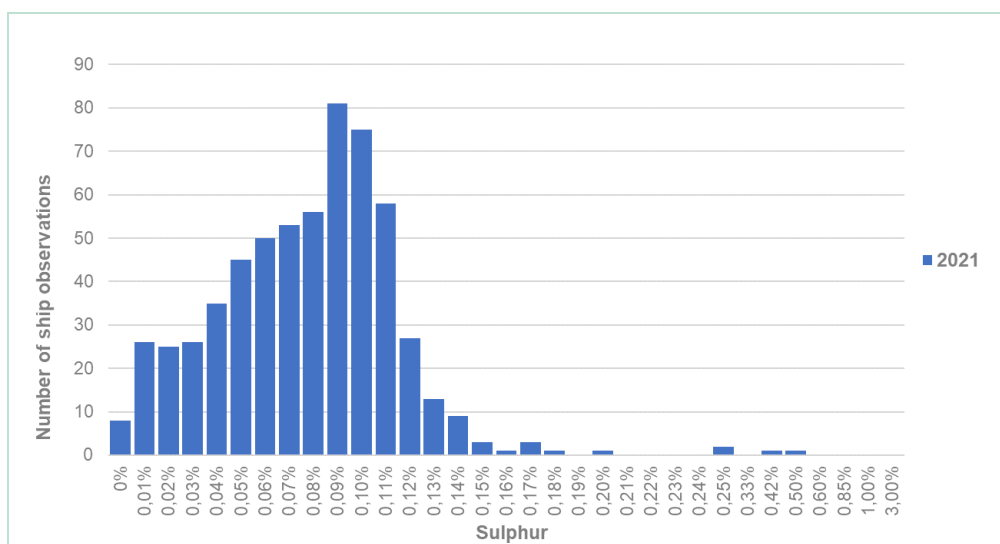


FIGURE 6. Distribution of measurements by measured FSC, 2021 Campaign

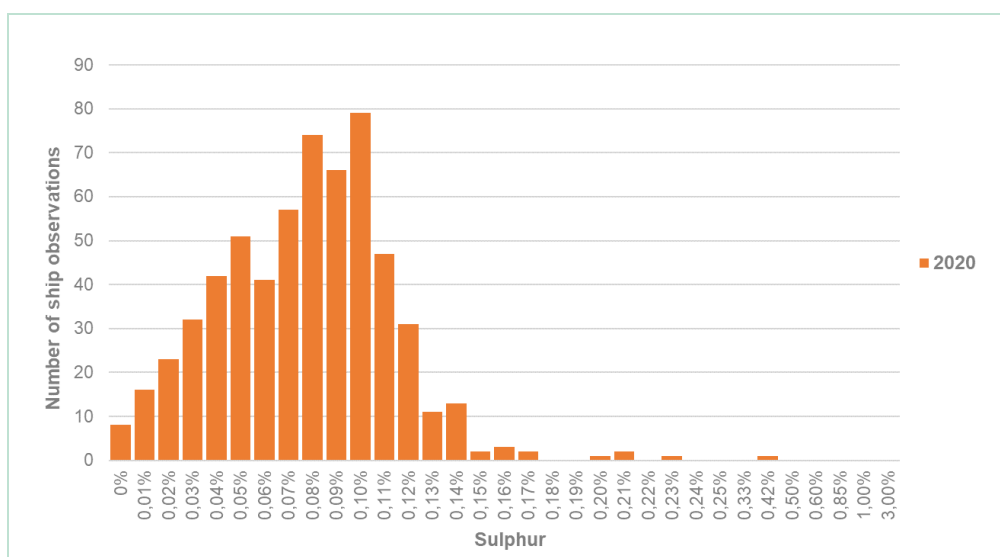







FIGURE 7. Distribution of measurements by measured FSC, 2020 Campaign

2.2.2 Distribution of FSC values by cut-off level

As shown in Figure 4, the threshold at which a measurement can be deemed to breach the compliance limit of 0.10 % FSC depends on the RSD uncertainty applied to the measurement. The higher the RSD applied, the stronger the probability that the measurement is in fact above the SECA threshold. In Table 3, all measurements are grouped according to their RSD level.

TABLE 3. FSC distribution by level of uncertainty

FSC	RSD	Colour	Measurements	% of total
≤ 0.100 %	N/A		420	69.8 %
0.101 – 0.129 %	N/A		131	21.8 %
0.130 – 0.149 %	1 x RSD		26	4.3 %
0.150 – 0.179 %	2 x RSD		9	1.5 %
≥ 0.180 %	3 x RSD		13	2.2 %
N/A ²			3	0.5 %
Total			602	100 %

At the 95 % coefficient level (2xRSD) – the recommended level used when interpreting fuel analysis results according to ISO 4259 – 3.7 % of all observations is non-compliant (FSC equal or higher than 0.15 %). Table 4 shows the percentage of non-compliant vessels in the campaigns performed from 2018 to 2022. For the first time, the percentage of non-compliant vessels is higher than in 2019, the year prior to the introduction of the sulphur global cap.

TABLE 4. SECA non-compliant observations (FSC equal or higher than 0.15 %)

Campaign	2022	2021	2020	2019	2018
SECA non-compliant observations	22 (out of 602)	13 (out of 600)	12 (out of 602)	22 (out of 615)	49 (out of 614)
%	3.7 %	2.2 %	2.0 %	3.6 %	7.3 %

Moreover, this year 4 different vessels have been measured non-compliant also with the global cap of 0.5 %, with estimated FSC levels of 0.6 % and 0.82 % (same vessel), 0.9 %, 0.3 % and 1.2 %.

TABLE 5. Global cap non-compliant observations (FSC higher than 0.5 %)

Campaign	2022	2021	2020	2019	2018
Global cap non-compliant observations	5 (out of 602)	1 (out of 600) ³	0 (out of 602)	2 (out of 615)	6 (out of 614)
%	0.83 %	0.17 %	0.00 %	0.33 %	0.98 %

A year-on-year comparison of the FSC values ≥ 0.15 % is shown in Figure 8. Once again, it can be observed that the percentage of non-compliant vessel has increased with respect to 2020 and 2021. In particular, cargo ships' non-compliance increased from 2.2 % in 2021 to 3.5 % in 2022, whereas tankers' non-compliance slightly decreased from 3.2 % in 2021 to 2.8 % in 2022. Further details on cargo and tanker vessels are presented in the following section.

² LNG vessels for which there are no sulphur emissions.

³ Only slightly above the threshold: FSC = 0.502 %

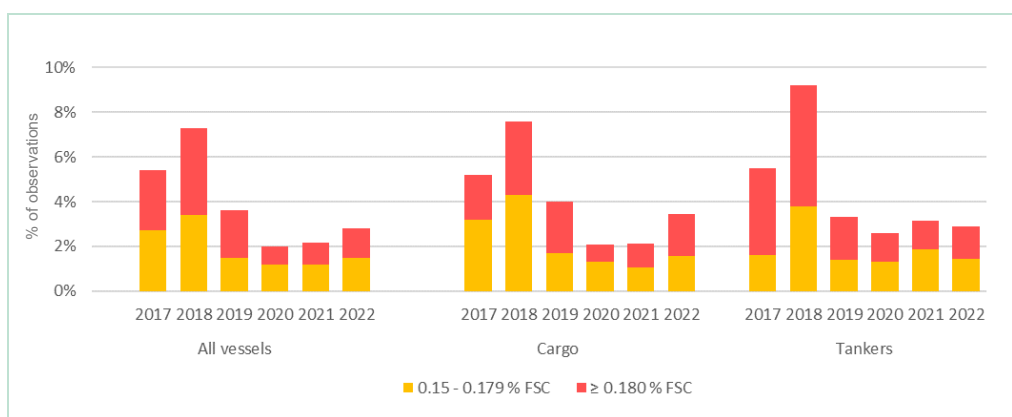


FIGURE 8. Observations with FSC values at or above 0.15 % FSC as a percentage share of the total number of measurements in a group (all, cargo or tankers)

2.2.3 Distribution of FSC values by vessel type

In Table 6, the FSC distribution is broken down by vessel type focusing only on cargo and tanker ships. These represent 88 % of the total dataset and thus make up the bulk of the data. The vessel type of the remaining 72 observations (12 %) is presented in Table 1.

TABLE 6. FSC distribution by vessel type and level of uncertainty

FSC	RSD	Colour	Cargo		Tanker	
			No.	% of total	No.	% of total
≤ 0.100 %	N/A	→	234	72.9 %	141	67.5 %
0.101 – 0.129 %	N/A	→	65	20.2 %	49	23.4 %
0.130 – 0.149 %	1 x RSD	→	9	2.8 %	12	5.7 %
0.150 – 0.179 %	2 x RSD	→	5	1.6 %	3	1.4 %
≥ 0.180 %	3 x RSD	→	6	1.9 %	3	1.4 %
N/A ⁴			2	0.6 %	1	0.5 %
Total			321	100 %	159	100 %

⁴ LNG vessels for which there are no sulphur emissions.

For all other types of vessels, 5 non-compliance observations were recorded, all regarding passenger vessels.

2.2.4 Distribution of FSC values by geographical location

No particular pattern is identified in the location of non-compliance, as illustrated on the map in Figure 3.

For the first time since the beginning of the helicopter monitoring, vessels have been measured docked in Copenhagen harbour; 4 out of 11 were found non-compliant.

Moreover, as in the previous campaigns, no clear directional patterns were observed. Non-compliance is found just as frequently with vessels heading outbound towards the North Sea as inbound from the North Sea or with vessels operating within the surveyed area.

2.3 Other observations

The increase in non-compliance could be correlated to the increase in the low sulphur ship fuel price, caused by the outbreak of war between Russia and Ukraine. According to data from Ship & Bunker, the average VLSFO (very low sulphur fuel oil) price at the world's top 20 bunker ports reached the peak value of \$1125 per ton in June, more than double its price in the previous year. With the prolongation of the Russia-Ukraine war, the price of bunker fuel will most likely keep oscillating and more vessels might try to switch to a cheaper - but more pollutant – fuel. This risk highlights the importance of the airborne monitoring of sulphur emissions from ships.

Airborne Monitoring of Sulphur Emissions from Ships in Danish Waters 2022

Abstract

This report has been written by Explicit ApS. The Danish Environmental Protection Agency (DEPA) has hired Explicit to survey the Sulphur content in ships' exhaust plumes in Danish waters by the use of a sniffer mounted on a helicopter.

There is legislation stating a maximum Sulphur content in ship fuels. There is a correlation between the measured Sulphur content in the exhaust plumes and the Sulphur content in the ship fuel. Readings from the sniffer therefore indicates whether or not ships comply with the Sulphur regulation.

The work described in the report is a part of DEPA's inspection in this field.

This report presents the results of the 2022 campaign. The survey consists of 602 measured ships from January 2022 to November 2022.

Resume

Denne rapport er skrevet af Explicit ApS. Miljøstyrelsen har indgået kontrakt med Explicit om overvågning af svovlindholdet i skibes udstødningsgasser i dansk farvand ved brug af en sniffer monteret på en helikopter.

Der er lovgivning, der angiver et maksimalt indhold af svovl i skibsbrændstof. Der er en sammenhæng mellem det målte svovlindhold i udstødningsgassen og svovlindholdet i skibsbrændstoffet. Sniffermålingerne kan således give en indikation af om de målte skibe overholder svovlreglerne.

Arbejdet, der er beskrevet i rapporten, er en del af Miljøstyrelsens tilsyn på området. Rapporten præsenterer resultaterne for 2022 kampagnen. Der er i perioden januar 2022 til november 2022 foretaget 602 målinger af skibe.

Annual report presented by Explicit ApS
in relation to EU tender no. 2019/S 211-517087.

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