



**Ministry of Environment
and Food of Denmark**
Environmental
Protection Agency

Airborne Monitoring of Sulphur Emissions from Ships in Danish Waters

2019 Campaign Results

Environmental Project
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Sources must be acknowledged.

Contents

Summary	5
1. Operations	6
1.1 Measurement methodology and technology	6
1.2 Aircraft platforms	6
1.3 Operations	6
1.4 Other observations	7
2. 2019 Campaign Results	9
2.1 Dataset	9
2.1.1 Measurement quality	10
2.2 Observed FSC levels	11
2.2.1 Distribution of FSC values by cut-off level	12
2.2.2 Distribution of FSC values by vessel type	13
2.2.3 Distribution of FSC values by geographical location	14
2.3 Other observations	14

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
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 2019 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 rules under MARPOL Annex VI.

This year's activities focused on the deployment of the manned helicopters for broader surveillance of maritime emissions using the Explicit Mini Sniffer System.

The main findings of the 2019 report can be summarized as follows:

- Of the 615 ships measured during the period March-December 2019, 22 ships (3.6%) were found to have substantially elevated fuel sulphur content levels at or above 0.15 %, the limit at which the instrumentation with 95 % confidence can detect a breach of the 0.10 % SECA threshold.
- This finding – corresponding to approx. 1:29 ships recorded as non-compliant – represents a significant decrease from the level in 2018 (7.3 %) and 2017 (5.4 %).
- In particular, no vessels were found with values above 0.64 % FSC which is the first year, since airborne surveillance was introduced in Danish waters, where no observations reached 1.0 % FSC.
- Also notable this year was the significant increase in observations below the 0.10 % SECA threshold. More than 70 % of all observations were recorded in the lowest part of the FSC spectrum, a significant shift from previous years and a sign of an overall improvement in the maritime sulphur emissions in Danish waters.
- The introduction of scrubbers on ocean-going vessels also appears to be having a positive effect on sulphur emissions with a new 'peak' in observations recorded at the very lowest end of the FSC spectrum around 0.01 % FSC. While presumably motivated primarily by the upcoming 2020 global sulphur cap, the introducing of scrubbers thus appears to be having a derived positive effect inside the SECA as well.
- More clearly than in other years, non-compliance was found to be concentrated North of the Great Belt and Øresund bridges in Kattegat and Skagerrak but with no apparent directional patterns. Similar levels of compliance were found for both inbound and outbound ships as well as ships operating locally.

It is the general observation of the surveillance team that ships operating in Danish waters appear to be increasingly accustomed to airborne sulphur checks, with no negative feedback received in dialogue with the ships, cementing the preventive impact of the airborne effort.

1. Operations

As in previous years, in 2019 airborne monitoring of sulphur emissions was conducted throughout Danish waters using a combination of innovative micro sensor technology and manned helicopter operations.

All sulphur deployments in 2019 were conducted by Explicit ApS in collaboration with Charlie 9 Helicopters ApS as part of the Danish Government's programme to enforce the sulphur rules 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 2017 and 2018. Reference is made to the 2017 Campaign report for details on the measurement methodology, instrument and operational setup.

1.2 Aircraft platforms

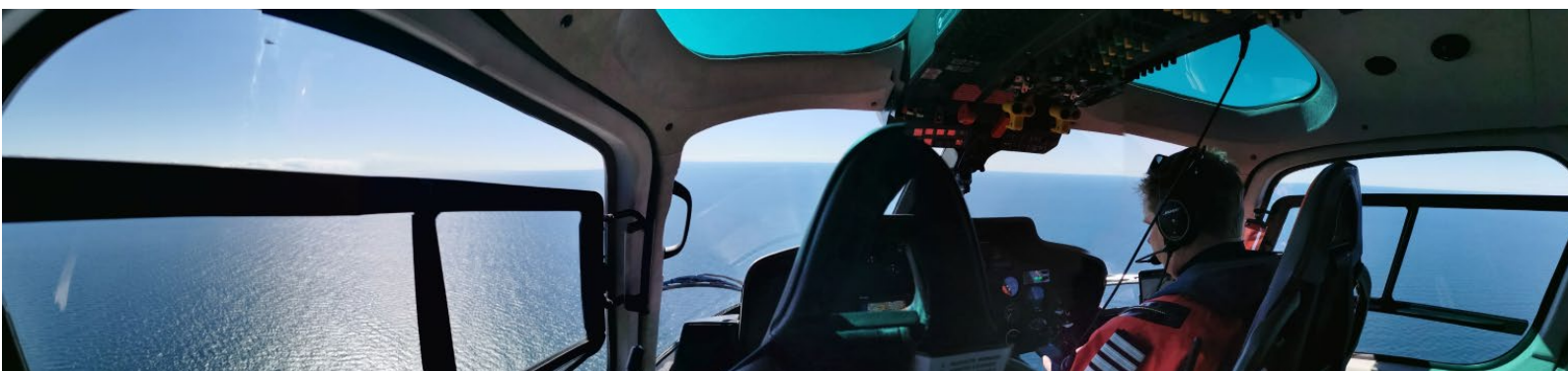
All operations in 2019 were carried out using an Airbus AS355NP twin-engine helicopter (see Images A-C). No other aircraft platforms were used.

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

1.3 Operations

The distribution of measurements over the full campaign period as well as by hour on the day, is presented in Figure 2 and 3 respectively.

The large number of vessels measured in October was primarily due to a longer back-to-back surveillance operation focusing on the waters of the North Sea, Skagerrak and Kattegat. Conversely, no flights were performed in November due to an extended period of bad weather.



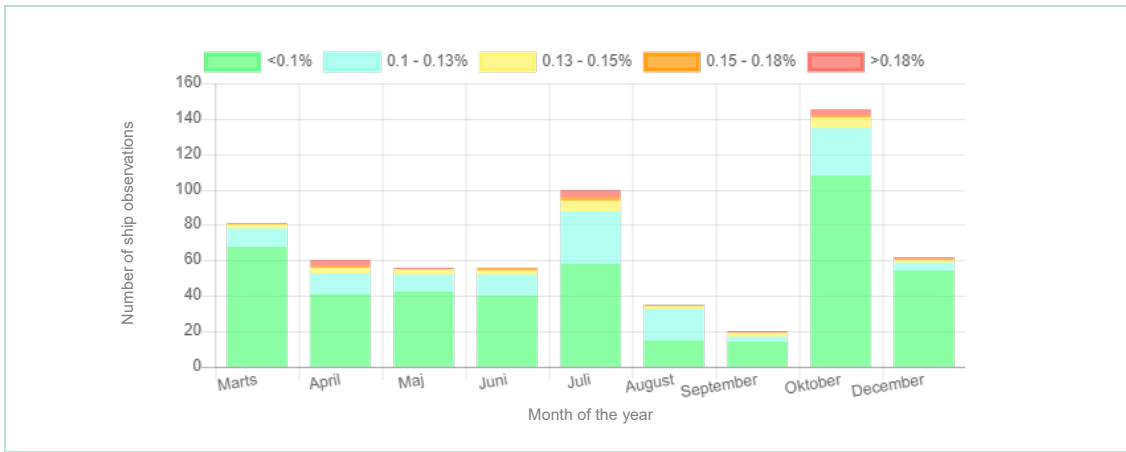


FIGURE 2. Distribution of measurements by campaign month. Note, the colours indicate FSC levels. For further see 2.2.

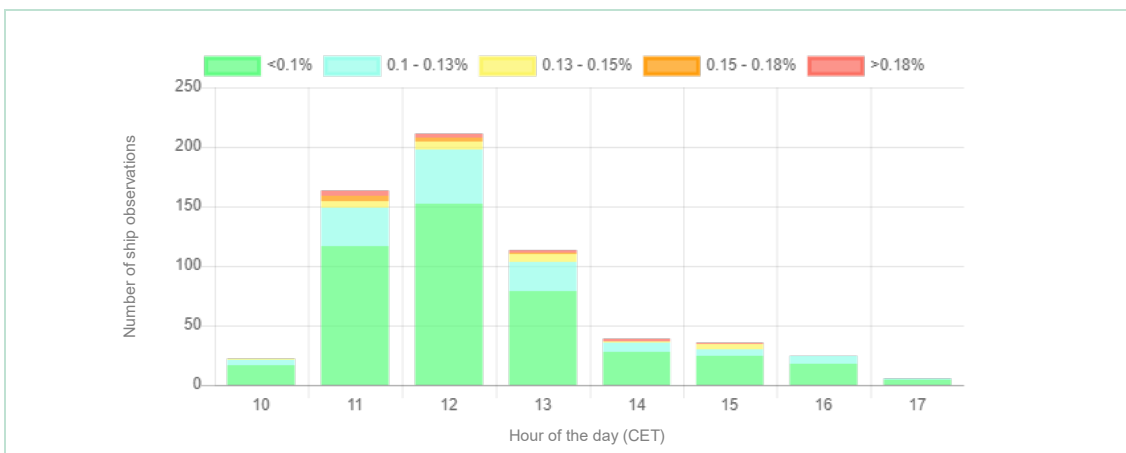


FIGURE 3. Distribution of measurements by hour interval. Note, the colours indicate FSC levels. For further see 2.2.

1.4 Other observations

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

Overall, it is the assessment of the operations team that ships in Danish waters are increasingly accustomed to regular airborne sulphur emissions checks. No observations of hostile or evasive actions were made in 2019 and few ships used the opportunity to communicate with the pilot team via maritime radio to clarify the intent of the aircraft on approach.

615

ship observations were
collected and analyzed for sulphur



2. 2019 Campaign Results

2019 saw a notable shift in the sulphur compliance data with less ships recorded with highly elevated FSC values compared to previous years. At the same time, the introduction of scrubbers on ocean-going vessels appears to be having a positive impact on the overall maritime sulphur emissions.

2.1 Dataset

The full dataset for the 2019 Campaign consists of 615 independent ship observations. Due to their frequent operation in Danish waters, some vessels were measured multiple times during the year, however at a maximum on four occasions.

Ships were observed throughout Danish waters with an emphasis on the international shipping lanes and areas with the highest maritime traffic density. Except for 7 anchored vessels, all ships were observed while underway. The map in Figure 1 depicts the location of all measurements including vessel headings and corresponding FSC levels.

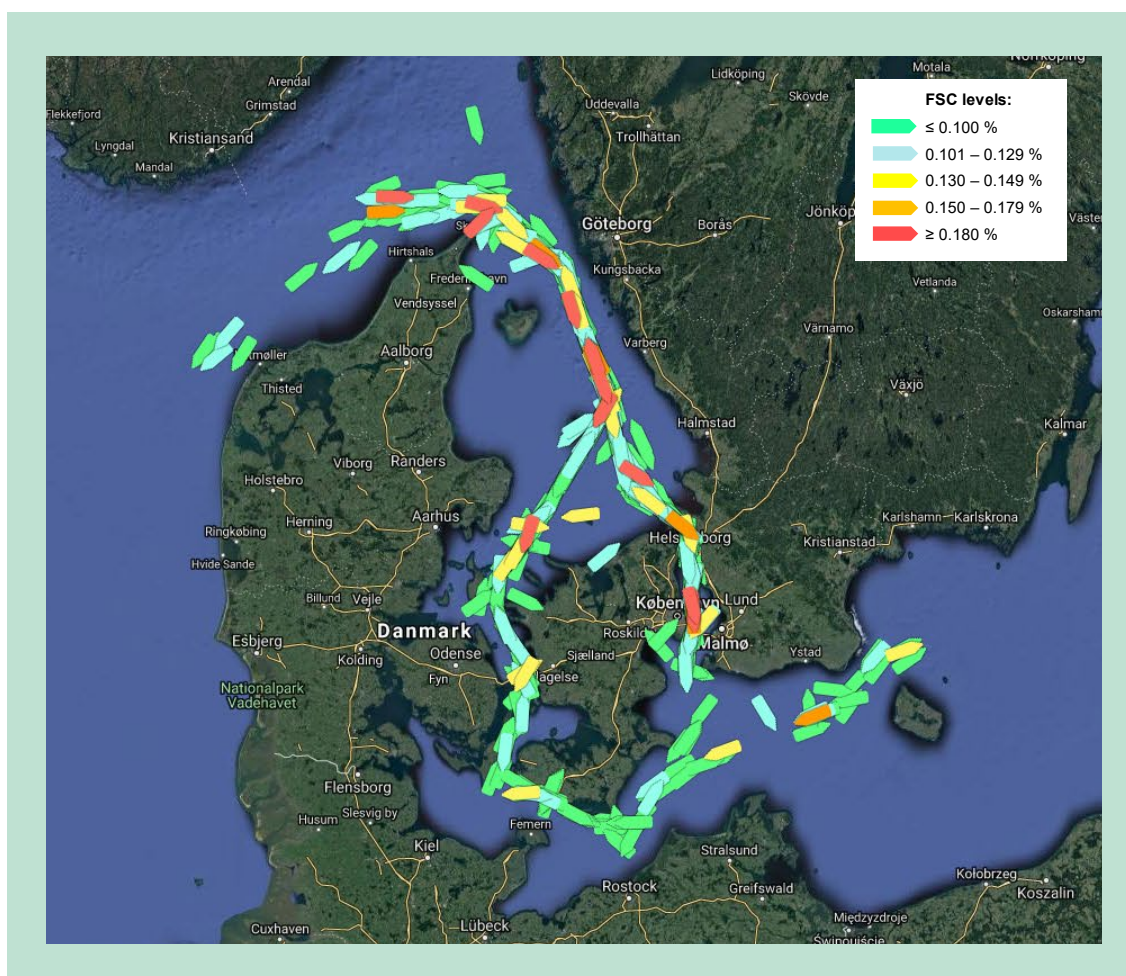


FIGURE 1. Geographical map of all measurements.



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

Type	Cargo	Tanker	Passenger	Other	Not available	Total
Measurements	354	212	27	18	4	615
% of total	57.6 %	34.5 %	4.4 %	2.9 %	0.7 %	100 %

2.1.1 Measurement quality

Overall, the campaign was able to demonstrate – as has been the case all along – a consistently high-quality level. Of the 615 ship observations, 576 measurements (94 %) 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.

Unlike the uncertainty, which assigns an error margin to a given FSC output (the lower the FSC, the higher the uncertainty), the quality score allows users to evaluate the position in the plume, i.e. the pilot's ability to successfully capture the exhaust gasses. The higher the quality score, the better the sampling position was in the plume.

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	17	22	576	615
% of total	2.8 %	3.6 %	93.7 %	100 %

2.2 Observed FSC levels

The measurement distribution by FSC level is presented in Figure 4. When analysing the distribution of the measurements on different FSC levels, the 2019 data corresponds to the pattern observed in previous years with an approximate normal distribution peaking in and around the 0.10 % regulatory threshold applicable within the SECA.

However, a few notable differences appear in this year’s dataset, most importantly the absence of any observations above >0.64 % FSC. The lack of gross non-compliance is consistent with other remote monitoring findings reported by other campaigns and PSC authorities in 2019 and thus not specific to this dataset.

Another notable difference is the significant shift in observations at or below the SECA 0.10 % FSC threshold. Over the past 3 years, the number of observations in this range (= green ships on the map) has increased from 48.5 % of the total dataset (2017) to 71.5% this year. Since there has been no changes in the sensor system or monitoring pattern, this shift can only be explained by a general improvement in sulphur emissions from ships in Danish waters, a conclusion which is further supported by the lowering in ambient sulphur levels in the atmosphere in and around Denmark reported by DEPA.

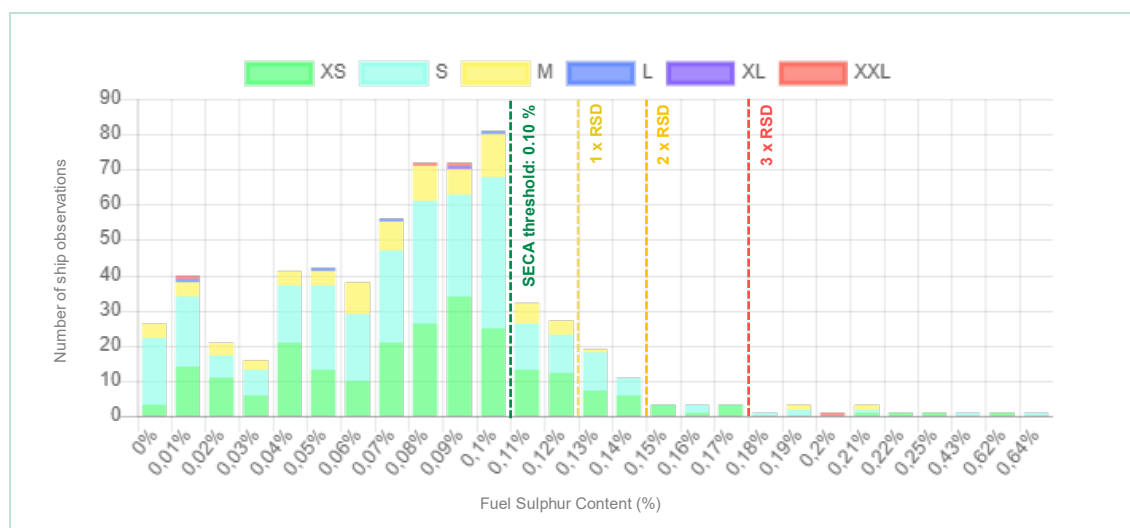


FIGURE 4. Distribution of measurements by measured FSC. Note: The colours indicate difference in vessel sizes according to their length¹. The dotted lines indicate the various compliance cut-off levels for 1xRSD, 2xRSD and 3xRSD respectively.

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

The data also reveals a significant increase in observations at the lowest end of the spectrum where a new “peak” around 0.01 % FSC has emerged consistent with the increased use of scrubbers, particularly on ocean-going vessels preparing for the upcoming 2020 global sulphur cap of 0.5 % FSC. This finding is supported by visual observations by the flight team who report an increase occurrence of ‘white plumes’. Unlike “normal” exhaust plumes, exhaust gases that have passed through a scrubber contain high amounts of water vapour which colour the otherwise invisible emissions white. (An example of this phenomenon can be seen in the cover image of this report.) The increased use of scrubbers, while presumably motivated primarily by the global sulphur cap and not the SECA itself, thus appears to be having a derived positive impact inside the SECA as well.

Whether the disappearance of the gross non-compliant cases is also linked to the increased use of scrubbers is harder to conclude. In some cases, scrubbers are undoubtedly helping ships otherwise struggling with long-lasting residual effects of fuel changeovers to more effectively clean up their emissions. In other cases, the risk of detection may also play a role in compliance behaviour. Denmark has deployed airborne surveillance of maritime emissions since January 2015, when the 0.10 % SECA cap was introduced, and so ships operating here are increasingly aware of the regular airborne ‘sulphur checks’ increasing the preventive effect of these checks.






This year’s overall distribution profile shows a median FSC value of 0.083 % with a peak value at 0.100 % FSC. This result is in line with the previous reported levels and goes to confirm that the data shows no immediate bias vis-a-vis known bunkering patterns.

A breakdown of the distribution is presented below. Where relevant, the data is compared to the results of the 2017 and/or 2018 Campaigns.

2.2.1 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 regulator compliance threshold 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		440	71.5 %
0.101 – 0.129 %	N/A		127	20.7 %
0.130 – 0.149 %	1 x RSD		26	4.2 %
0.150 – 0.179 %	2 x RSD		9	1.5 %
≥ 0.180 %	3 x RSD		13	2.1 %
Total			615	100 %

At the 95% coefficient level (2xRSD) – the recommended level used when interpreting fuel analysis results according to ISO 4259 – the number of vessels measured with elevated FSCs indicating non-compliant fuel was 22 or 3.6 % of the total. This is a significant decrease from



Visibility of ship exhaust plumes






While exhaust plumes under normal cruising operations are not visible typically – not even if they contain high levels of sulphur – sometimes certain procedures such as engine startup, maneuvering, etc. can cause residuals from the combustion process to be released to the air creating a clearly visible smoke trail. This is however not necessarily an indication of sulphur non-compliance, but is most often caused by particulate matter or other exhaust substances.

last year where 7.3 % of all observations were found to be ≥ 0.15 % FSC, but less of a difference from 2017 where 5.4 % of vessels were found to be ≥ 0.15 % FSC. For ship observations ≥ 0.18 % FSC, the share has fluctuated over the past three years from 2.7 % (2017) to 3.9 % (2018) to 2.1 % recorded in 2019. The exact cause of the year-of-year change is unknown and may likely be due to annual fluctuations.

2.2.2 Distribution of FSC values by vessel type

In table 4, the FSC distribution is broken down by vessel type focusing only on cargo and tanker ships. These represent more than 90 % of the total dataset while the number of passenger and other types have been omitted due to their low number of measurements.

TABLE 4. FSC distribution by vessel type and level of uncertainty

FSC	RSD	Colour	Cargo		Tanker	
			No.	% of total	No.	% of total
≤ 0.100 %	N/A		244	69.9	159	75.0
0.101 – 0.129 %	N/A		79	22.3	38	17.9
0.130 – 0.149 %	1 x RSD		17	4.8	8	3.8
0.150 – 0.179 %	2 x RSD		6	1.7	3	1.4
≥ 0.180 %	3 x RSD		8	2.3	4	1.9
Total			354	100	212	100

While tankers in the past two years have shown a slightly higher occurrence of non-compliance than cargo ships, this picture has changed in 2019. This year, only 3.3 % of tanker observations were found to be non-compliant (≥ 0.15 % FSC) compared to 4 % of cargo ships. This is a significant change from 2018 when 9.2 % of all tankers were found to display non-compliance.

Whether the shift is due to a permanent change in the emissions patterns, or simply caused by annual fluctuations, is too early to tell without more data track record. Continued surveillance will help determine the endurance of some of these changes.

A year-on-year comparison of the FSC values ≥ 0.15 % is shown in Figure 5.

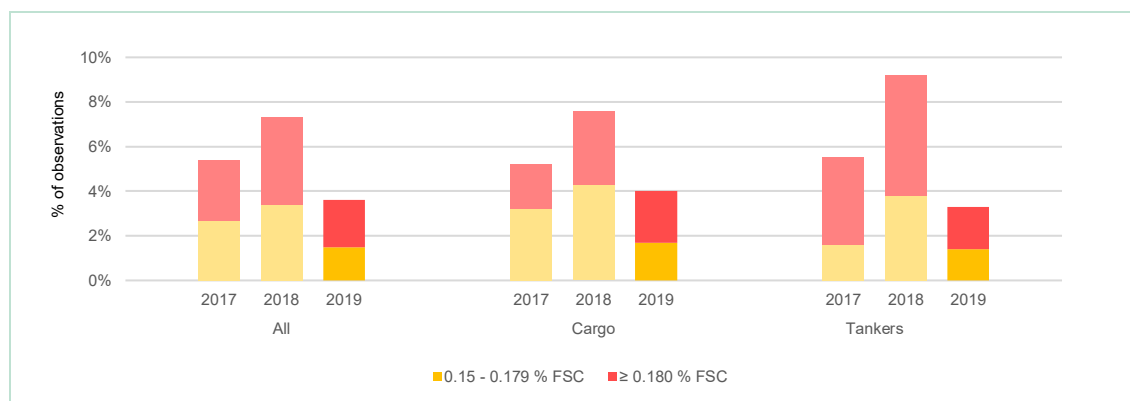


FIGURE 5. Observations with FSC values at or above 0.15 % FSC as a percentage share of the total number of measurements in a group (all, cargo or tankers).

2.2.3 Distribution of FSC values by geographical location

In a change from previous years, in 2019 all cases of non-compliance except for one observation were found North of the Great Belt and Øresund bridges, as illustrated on the map in Figure 1. This year, the tendency towards more non-compliance in Kattegat and Skagerrak is thus clearer.

While the Northern waters this year showed a higher risk of non-compliance, 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

Like last year the 2019 Campaign also collected indicative data on vessel NO_x emissions. While NO_x emissions are not a subject to this report, the data has been provided to DEPA for possible further analysis. The full dataset has further been polluted with built-year in order to enable a future NO_x analysis according to tier-levels.

No other observations have been made regarding the dataset. For details on the operations, please see chapter 1.

Airborne Monitoring of Sulphur Emissions from Ships in Danish Waters - 2019

Campaign Results

This report has been written by the Danish Environmental Protection Agency (DEPA) hired player Explicit. Explicit is hired by DEPA to survey ships exhaustings plumes from ships for Sulphur by sniffing (reading) the content of Sulphur in these gasses. It has been done to detect if ships are in compliances with the Danish legislations of Sulphur content in ships fuels.

Readings from the content of Sulphur in the plumes can indicate if there are breaches in the legislations concerning the maximum Sulphur content in ships fuels.

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

This report present the results for the campaign for the year of 2019 and how the survey has been carried out.

The survey contains of 615 measured ships from the period of March to December.

Denne rapport er skrevet af Miljøstyrelsens hyret aktør Explicit. Explicit er hyret af Miljøstyrelsen til at overvåge skibes udstødningsgasser for svovl ved måling. Det foretages for at detektere om skibe overholder de danske regler mht. svovlindhold i skibsbrændstoffer.

Svovlindholdsmålingerne fra røgfanerne kan indikere om der sker overtrædelser af lovgivningen mht. svovlindholdet i skibsbrændstoffer.

Arbejdet der er beskrevet i rapporten er en del af Miljøstyrelsens tilsynsopgave inden for området.

Rapporten præsenterer resultater for 2019 kampagnen hvor overvågningen er foretaget.

Overvågningen indeholder 615 målte skibe for perioden marts til december.

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