Sulphur emission compliance monitoring of ships in German waters – results from five years of operation

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BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

Introduction, method & dataset

Since September 2014 a ship emission monitoring station is operated at the approach to the harbour of Hamburg, representing the world longest continuous MARPOL–VI compliance monitoring time series. In August 2017 and May 2018 additional monitoring stations were installed in Bremerhaven and Kiel following the setup at the pilot station in Wedel. Each station is equipped with a high sensitive in-situ trace gas monitor (Sniffer) to measure the concentration of NO, NO_2, NO_x, SO_2, CO_2 and O_3 with a temporal resolution of 5 to 10 seconds. A meteorological station and an AIS receiver is installed to allocate measured plumes to individual ships. The setup and operation of the German ship emission compliance monitoring network is described in detail on the Poster "Sulphur emission compliance monitoring of ships in German waters – The operational network" by S. Griesel.
For this study we analysed nearly 30 000 ship plume measurements until July 2019. Table 1 summarises the dataset and gives the average compliance rate found at the German monitoring stations.

Measurement site	Wedel	Bremerhaven	Kiel
Period	09/2014-07/2019	08/2017-07/2019	05/2019-07/2019
Analysed plumes	21059	5621	3210
Suspictions of non-compliance	190	15	91
Non-compiance rate	0.9%	0.3%	2.8%

Table 1: Number of analysed plumes within the German ship emission compliance monitoring network.

Distribution of FSC and trends

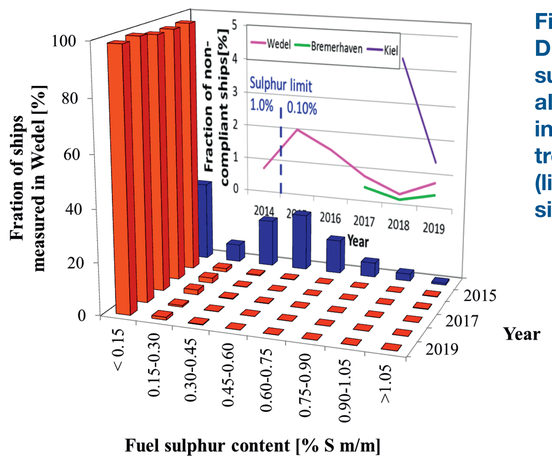

Figure 1: Distribution of ship fuel sulphur content derived from all Sniffer measurements in Wedel (histogram) and trends of non-compliance (line plot) for all monitoring sites.

- Significant decrease of observed FSC after tightening of SECA Sulphur limit in 2015 from 1.0 to 0.1% S m/m
- Observed non-compliance rate < 1% for Wedel and Bremerhaven (except 2015)
- Higher non-compliance rate in Kiel might be caused by difference in route section: ships measured in Kiel often do not call a German port but do pass the Kiel Canal

Plume aging

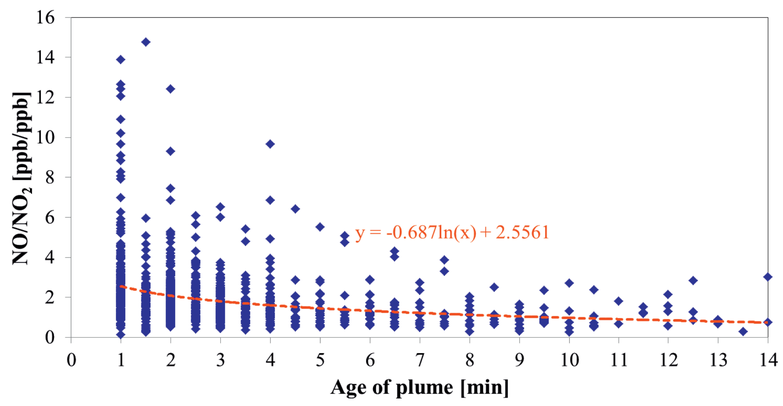

Figure 3: NO/NO_2 ratio plotted against the time the plume needs to be transported from the ship to the measurement site in Kiel.

- NO/NO_2 decreases with increasing age of plume due to oxidation of NO to NO_2
- Ratio seems to be most variable for plumes younger than 2 min and more or less stable if plume age is longer 8 min

SO_2/NO_2 ratio suitable for Sulphur compliance monitoring?

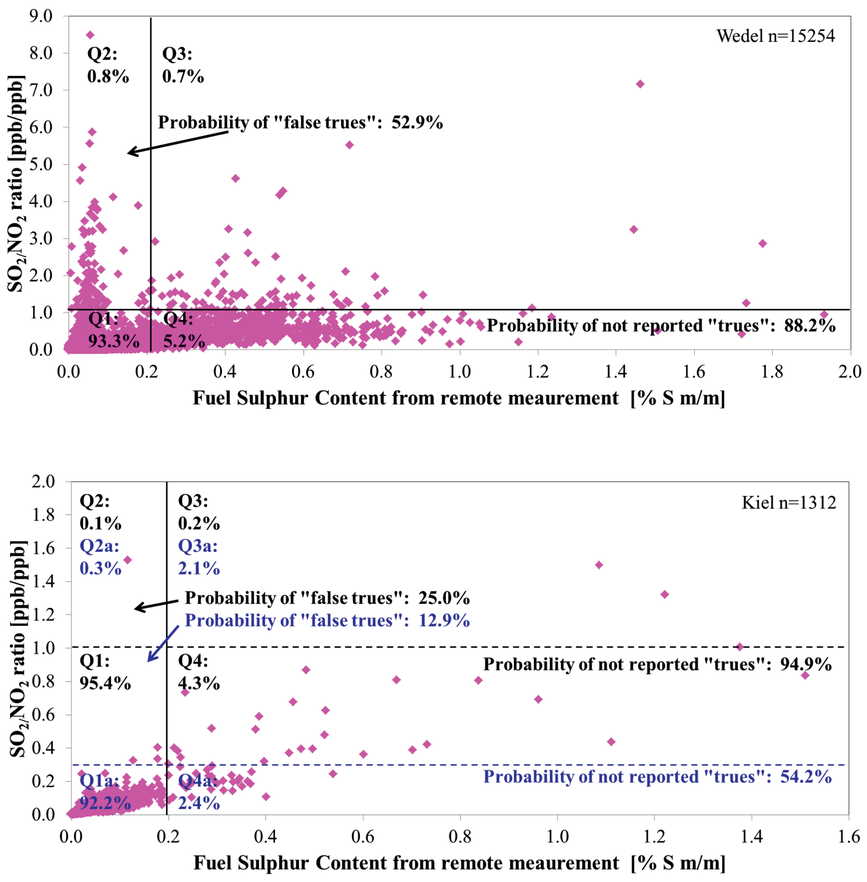

Figure 2: Scatter plot of all SO_2/NO_2 ratios as function of the calculated FSC (both based on Sniffer measurements) for Wedel (top) and Kiel (bottom). Q1-Q4 numbers give the relative fraction of data points in the certain quadrant. The probability of "false trues" is calculated by Q2/(Q2+Q3). The probability of not reported "trues" is calculated by Q4/(Q3+Q4).

- SO_2/NO_2 > 1.0 is often used as trigger to indicate non-compliance with MAX-DOAS measurements
- Significant correlation of SO_2/NO_2 with FSC (from Sniffer) in Kiel but not in Wedel
- Decreasing the SO_2/NO_2 trigger to > 0.3 would half the fraction of not reporting non-compliant vessels and the probability of reporting compliant vessels (false trues), when assuming Sniffer results are correct

NO_x/CO_2 ratio for NO_x compliance monitoring

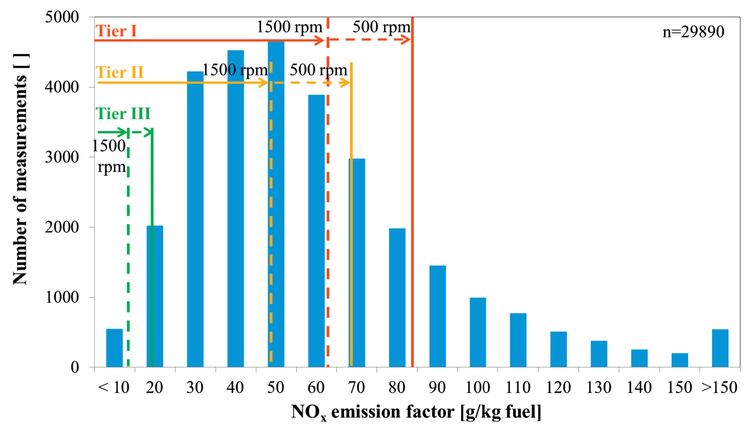

Figure 4: NO_x emission factors calculated from the NO_x/CO_2 ratio of all measured ship plumes in Wedel, Bremerhaven and Kiel since September 2014. The NO_x emission limits according to the Tier I, II and III (ships constructed after 2000, 2011 and 2016) are calculated for engine rated speed of 500 and 1500 rpm and are given as solid and dashed lines in red, yellow and green, respectively.

- More than 80% are measured to be compliant with the Tier I upper limit but only 9% are compliant with Tier III
- From 2021 it is expected the histogram will shift to smaller emission factors with time

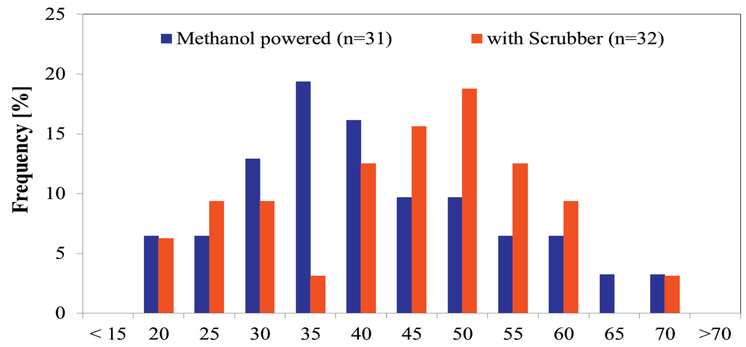

Figure 5: Comparison of NO_x emission factors for two similar ferries operated in the Baltic Sea passing regularly the measurement site in Kiel. One ferry is methanol powered and the other one is operated with HFO and Scrubber.

- NO_x emissions from a methanol powered ferry are significantly lower than from a HFO powered ferry with Scrubber

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