Remote measurements of gas and particle emissions to air from ships in open sea and harbors

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Background

- Special environmental zones (ECA) have been established in northern Europe, the US and near to the shores of China requiring the usage of lower fuel sulfur content (0.1-0.5%) and NOx abatment in new ships
- In 2020 it will be required to operate with fuel sulfur content <0.5% worldwide and ships to reduce NO_x by 90% in special areas by 2021
- Chalmers University of Technology has developed and applied automatic systems for sulfur and NOx compliance control for usage from airplanes, ship platforms and fixed stations since 2006. Also particles are measured.
- Remote measurements can be used to investigate real emissions and GUIDE on board inspection and monitor whether ships comply with the legislation on the open sea.
- Funding through several EU projects (Envisum, Compmon) , Swedish environmental protection and innovation agency, Danish environmental protection agency, port of Gothenburg and South Coast Air quality management district (California)

Compliance monitoring 2020

- Today there exists operational techniques for remote sulfur compliance monitoring within 500 nautical miles from shore:
  - Solution is based on sniffer and optical technique operated from airborne and fixed stations.
  - UAV solutions with small sensors not operational due to legislative and technical issues. EMSA is running a drone program

- Ship monitoring at more than 500 nautical miles distance is difficult (Atlantic ocean) and requires other solutions:
  - On board monitoring in stack OR autonomous sniffer on deck
  - Advanced fuel control (fuel calculator)
  - Long duration UAVs at medium altitude utilizing optical measurements

- Satellite monitoring is no option for single ship identification due to the large light scattering in the atmosphere and imaging requirements. But may be used for yearly averages

ENVISUM project, WP 2 Emission data and modelling

- Create detailed emissions data of sulphur, NO_x and particles (mass, number, size distribution, black carbon) of ships in real traffic
  - Fixed measurements from Älvsborg site/Gothenburg, Great Belt bridge/Denmark and Gdynia/Gdansk.
  - Airborne measurements middle of Baltic
  - On board measurements particle emissions scrubbers, methane slip LNG, other (MUS, FMI)
  - Inventory of sulfur fuel (MUS)

- Use measured emission data
  - To validate and improve ship emission modelling
  - Compliance monitoring

- Generate modelled emission data of Baltic sea area
  - As input for regional/local air quality studies

- Improve modelling tools for alternative fuels (LNG) ar technique (scrubber)

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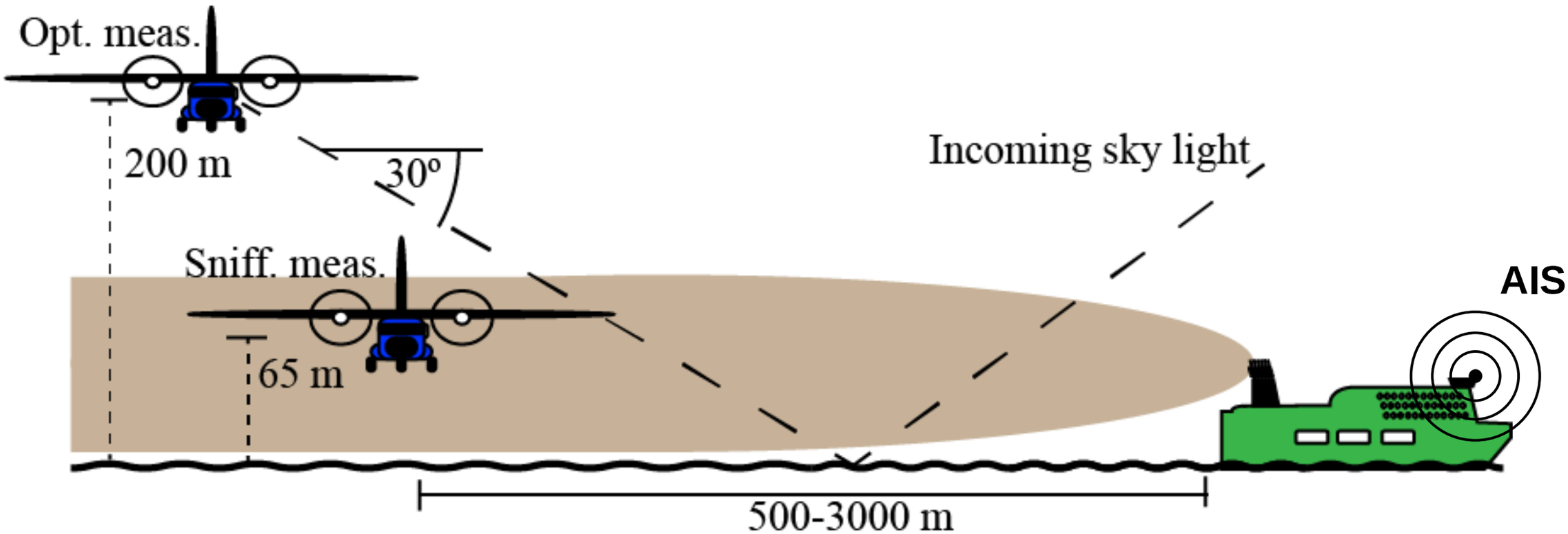
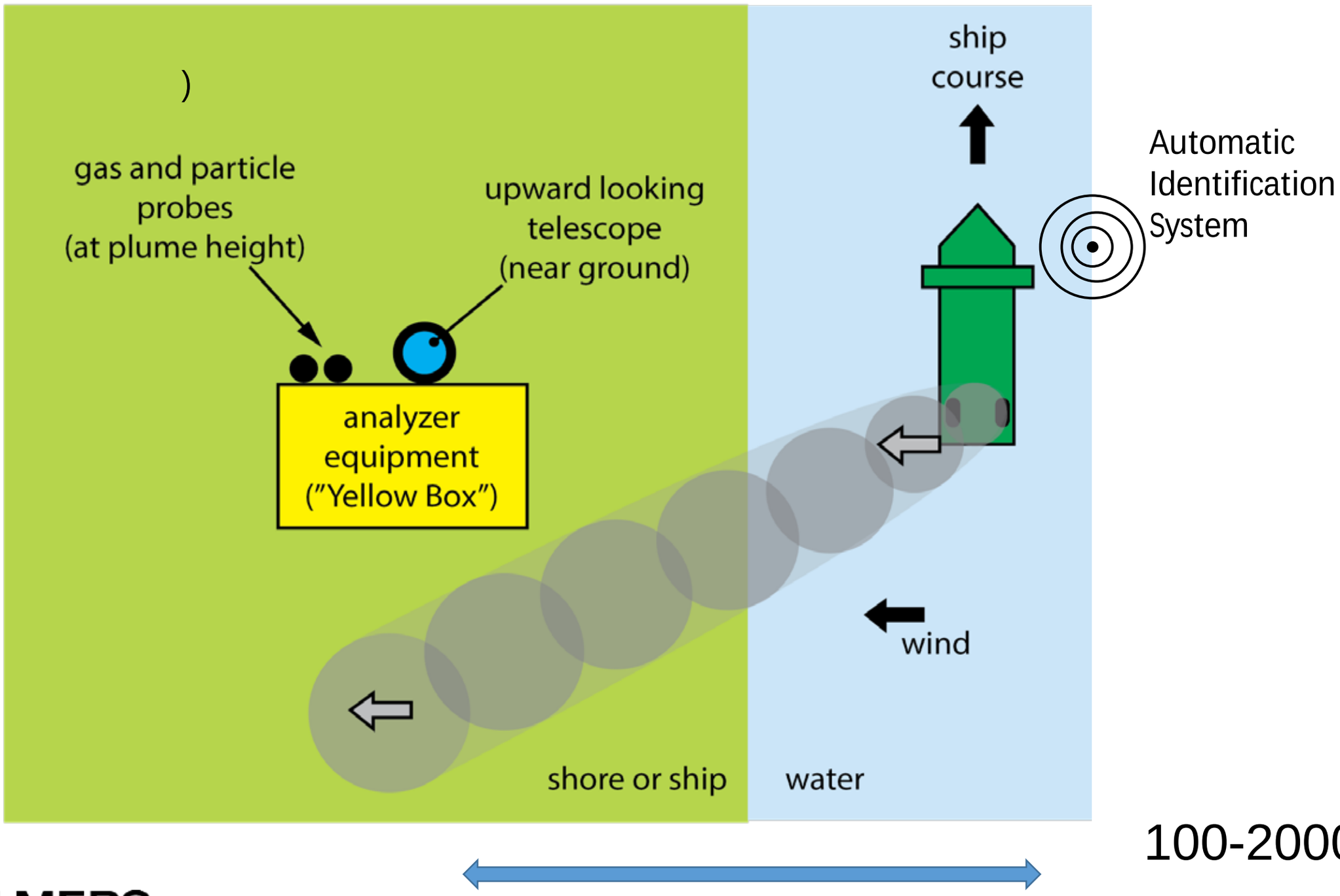
Airborne measurements (combination of optical and sniffer technique)



Aircraft crosses above or through plume. First **optical** measurements are done at higher altitude. If sulfur measurement is high, a **sniffer** measurement of SO2 is done at lower altitude

Fixed measurement.

The ship emission plume drifts over the site and the smoke is analyzed using a sniffer and sometimes optical sensor



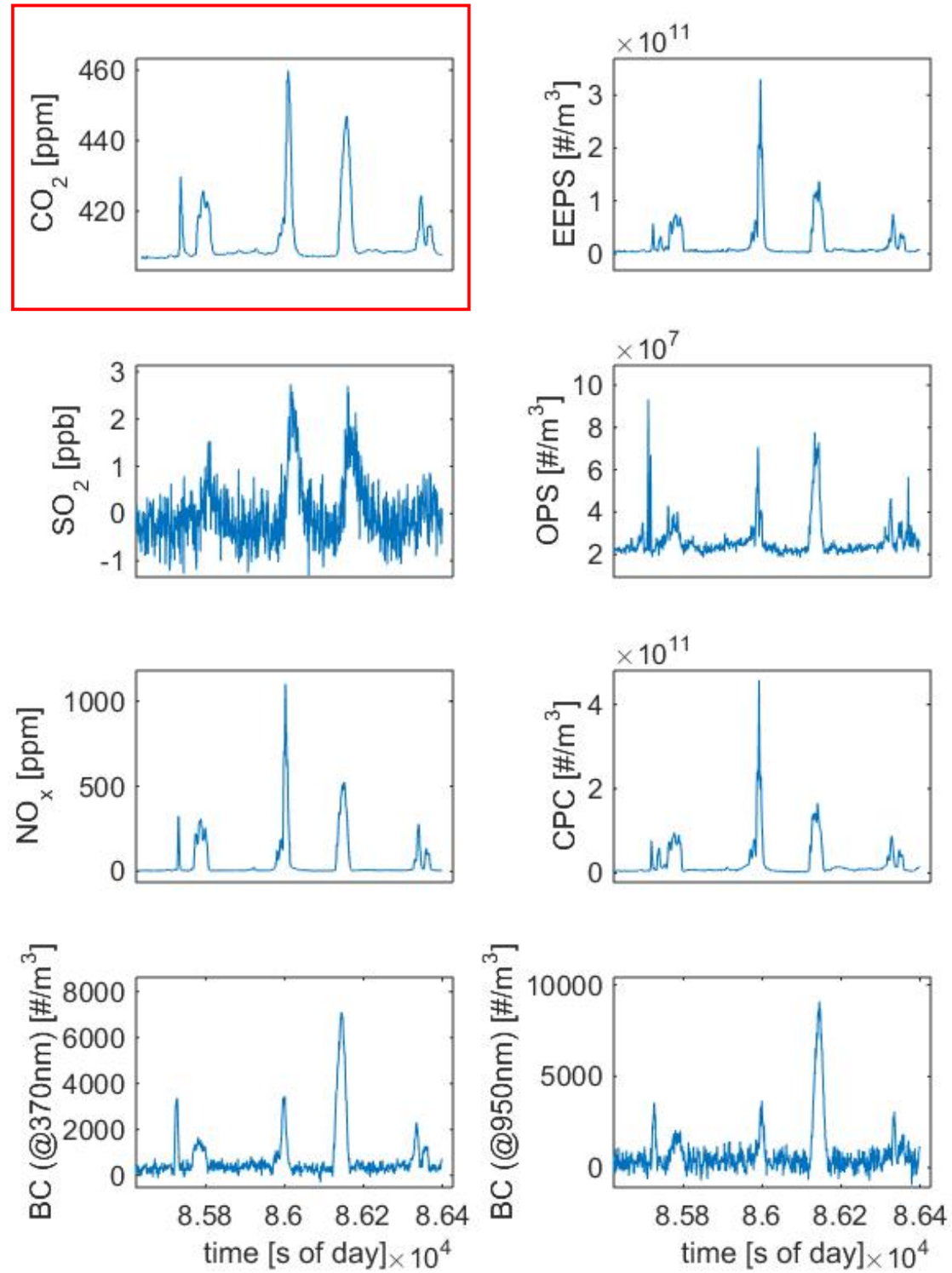
Calculation of emission factors from sniffer measurements

- Measurements of SO2, NOx, CO2, PM, PN, BC using conventional techniques.

- CO_2 emission is directly related to the amount of combusted fuel
- The fuel specific emission factor is proportional to the ratio of the pollutant versus CO_2 for each plume

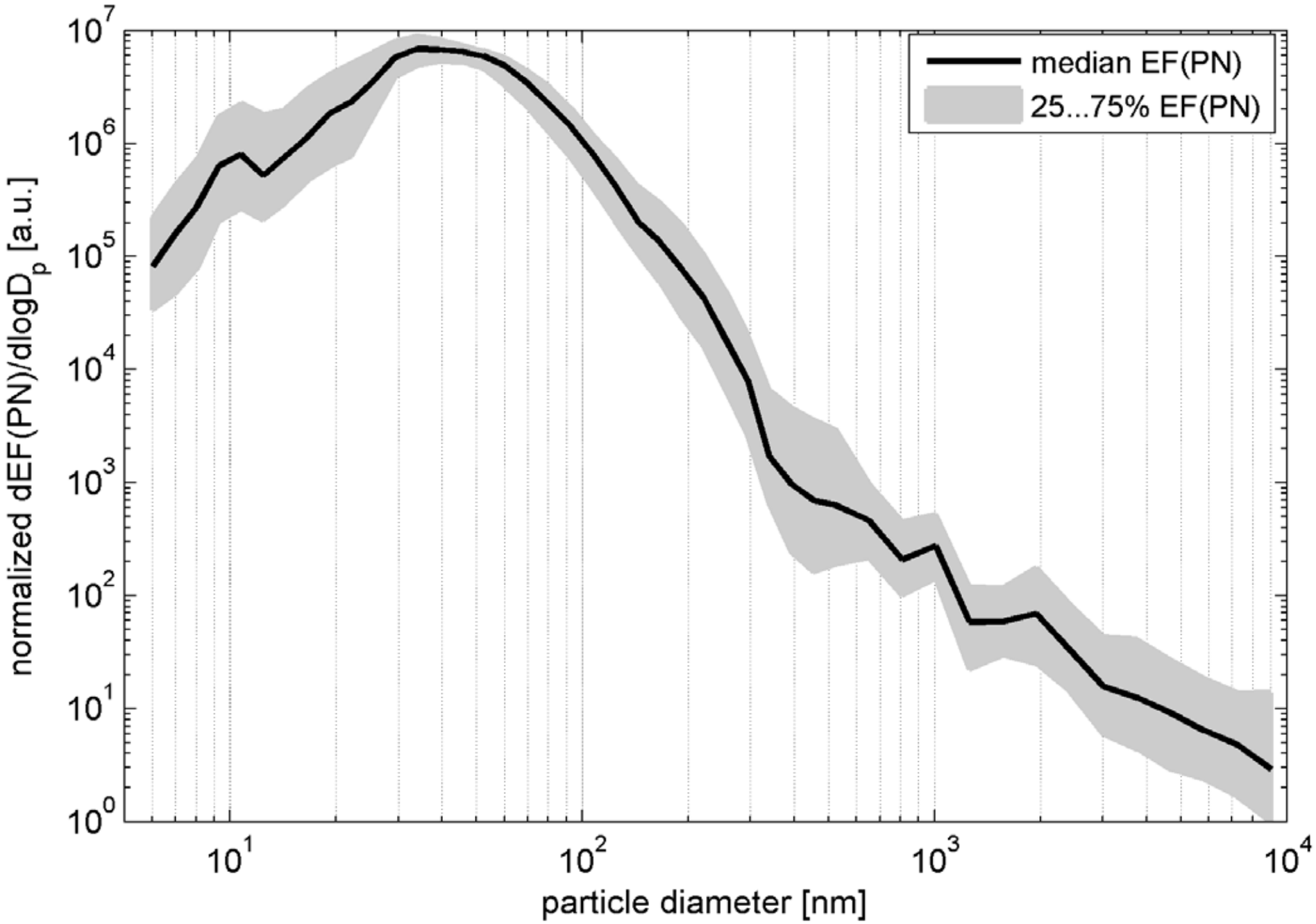
$$\mathrm{EF(X)}_{(\mathrm{g \cdot kg_{fuel}^{-1}})} = \frac{\mathrm{M(X)} \cdot \sum(\mathrm{X_{ppb}})}{\mathrm{M(C)} \cdot \sum(\mathrm{CO_{2,ppm}}) / 0.87}$$

$$\mathrm{EF}\left(\mathrm{PN}_{(\#\cdot \mathrm{kg_{fuel}^{-1}})}\right) = \frac{\sum\left[\mathrm{PN}_{(\#\cdot \mathrm{m^{-3}})}\right]}{\sum\left[\mathrm{CO_{2,(kg \cdot m^{-3})}}\right]} \cdot \mathrm{EF(CO_2)}$$



Particle size distribution is measured. Below is shown typical average measurements

number-size distribution



Fixed measurements using sniffers (smoke drifts over station)

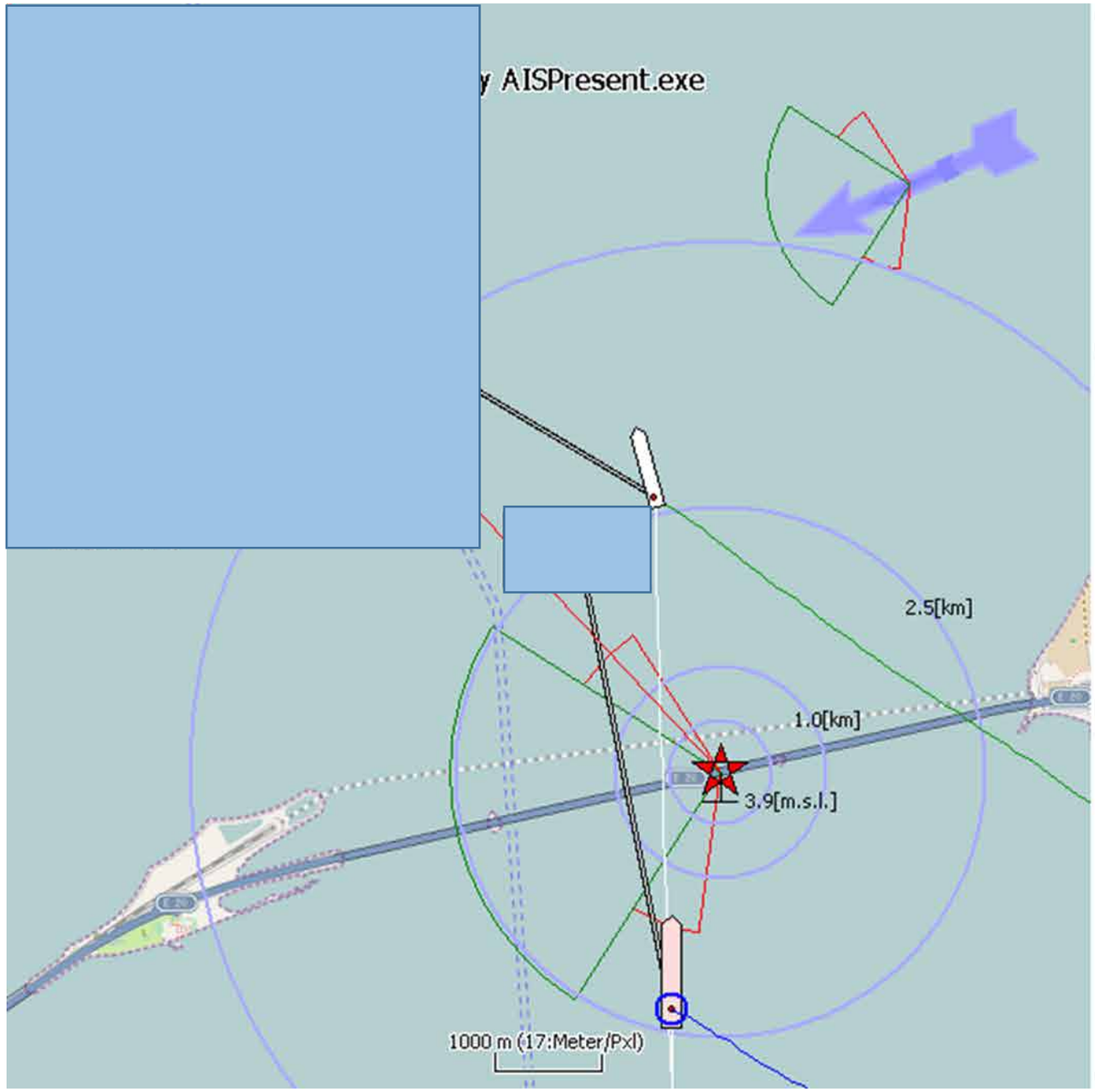
Ship channel of Göteborg since 2014,
4000 inspection per year

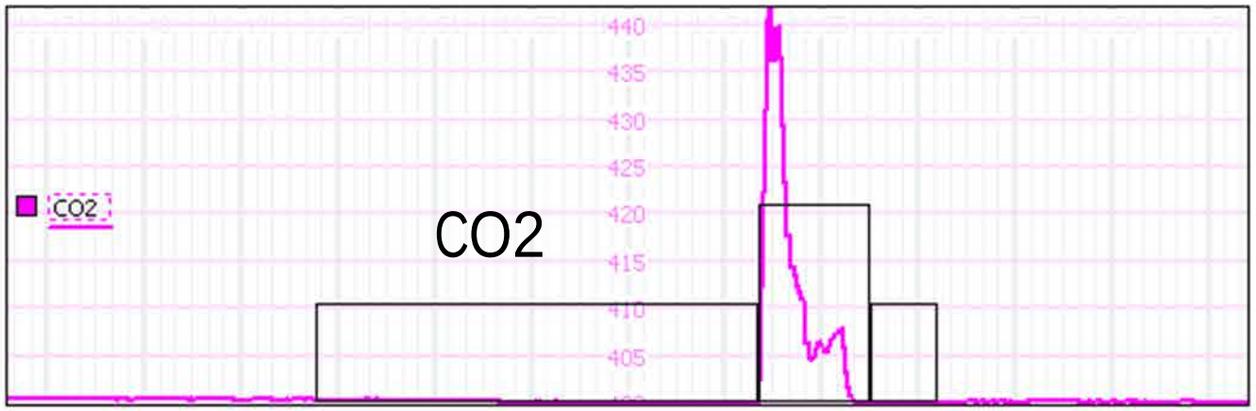
Great Belt bridge, since 2015,
4000 inspections/month

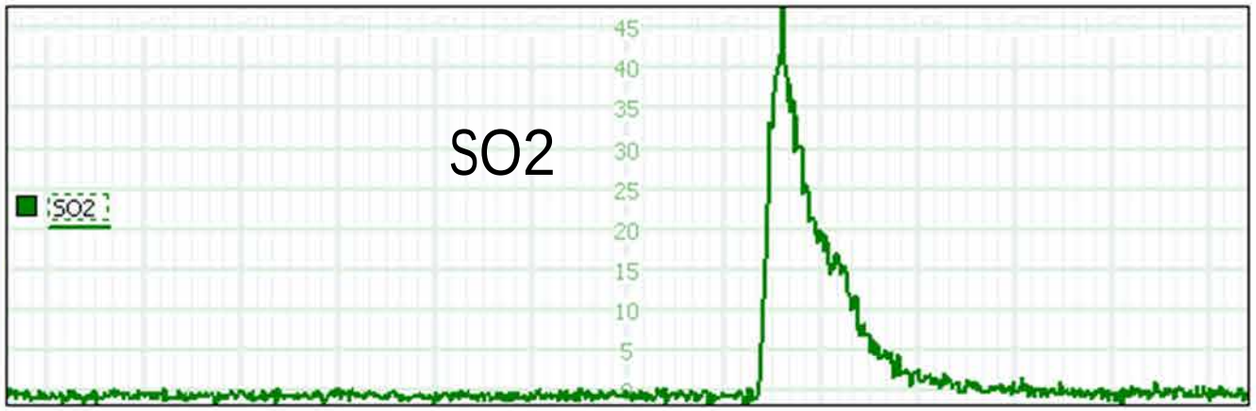
Öresund bridge, since Dec 16

Automatic measurements

A special software communicates with instruments, identifies ships and calculates fuel sulfur content and NOx emissions per kWh and sends the data to a webdatabase and creates mail-alerts



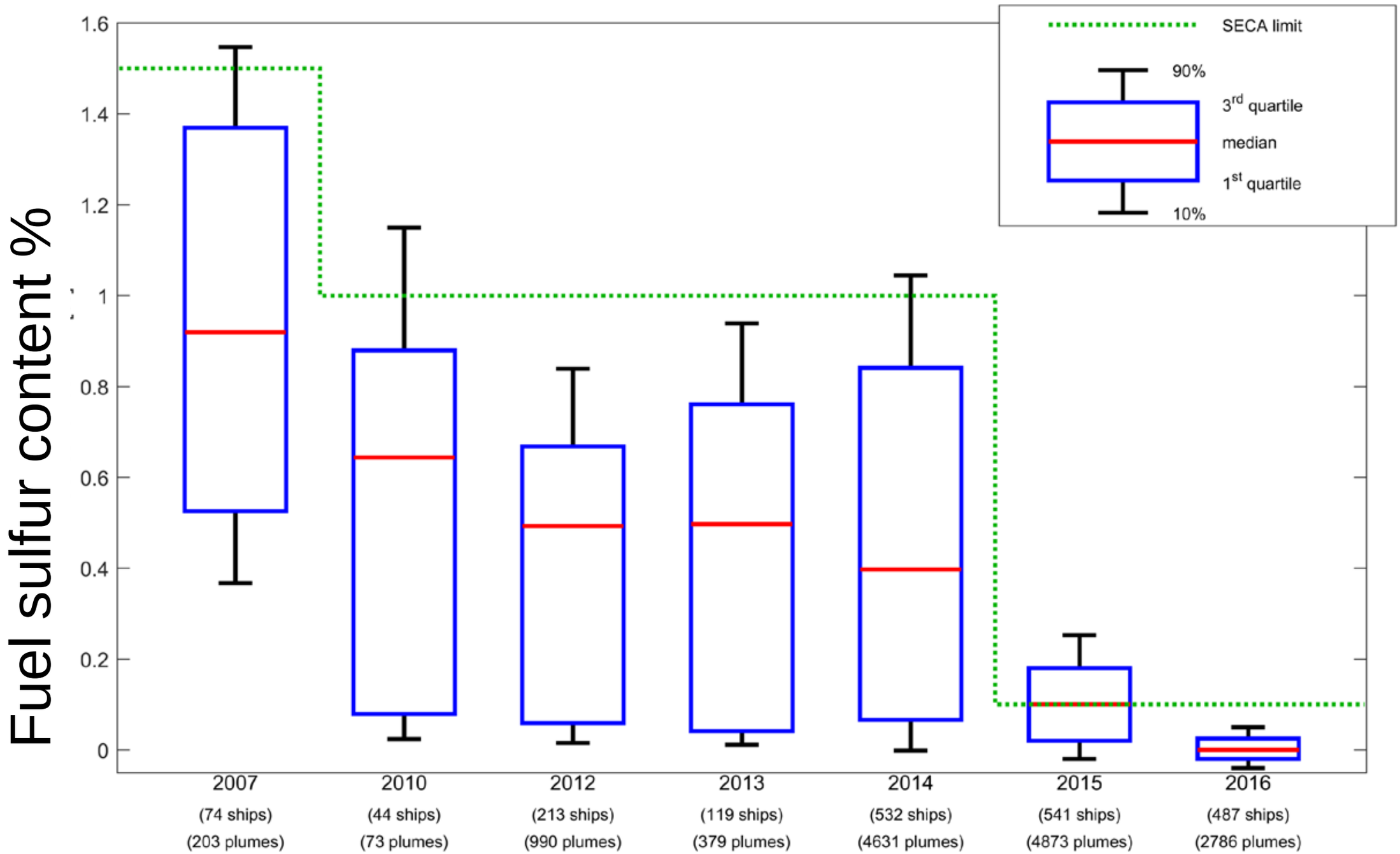




The data with is sent in realtime to a web database. If high it is put in Thetis-EU for further port state control

Date	Record type	Value	Quality tag	Quality control	Platform	Platform type	S
05/10/2017 - 08:35	SC	0.04	Medium	Automatic	SE Älvsborg	Stationary	S
05/10/2017 - 08:16	SC	-0.03	High	Automatic	SE Älvsborg	Stationary	S
05/10/2017 - 08:01	SC	-0.02	Medium	Automatic	DK Storabält	Stationary	S
05/10/2017 - 07:49	SC	-0.01	Medium	Automatic	SE Älvsborg	Stationary	N
05/10/2017 - 07:39	SC	-0.02	Medium	Automatic	SE Älvsborg	Stationary	A
05/10/2017 - 07:37	SC	0.02	High	Automatic	DK Storabält	Stationary	H
05/10/2017 - 06:44	SC	0.01	Poor	Automatic	SE Älvsborg	Stationary	S
05/10/2017 - 06:23	SC	-0.04	High	Automatic	DK Storabält	Stationary	F
05/10/2017 - 06:21	SC	0.03	Poor	Automatic	DK Storabält	Stationary	V
05/10/2017 - 06:08	SC	-0.01	Poor	Automatic	SE Älvsborg	Stationary	F
05/10/2017 - 05:58	SC	-0.17	Poor	Automatic	SE Älvsborg	Stationary	E
05/10/2017 - 05:53	SC	0.07	Poor	Automatic	SE Älvsborg	Stationary	T
05/10/2017 - 05:19	SC	-0.04	Medium	Automatic	DK Storabält	Stationary	C

Automatic estimation of fuel sulfur content from sniffer measurements at the inlet channel of Göteborg during several years



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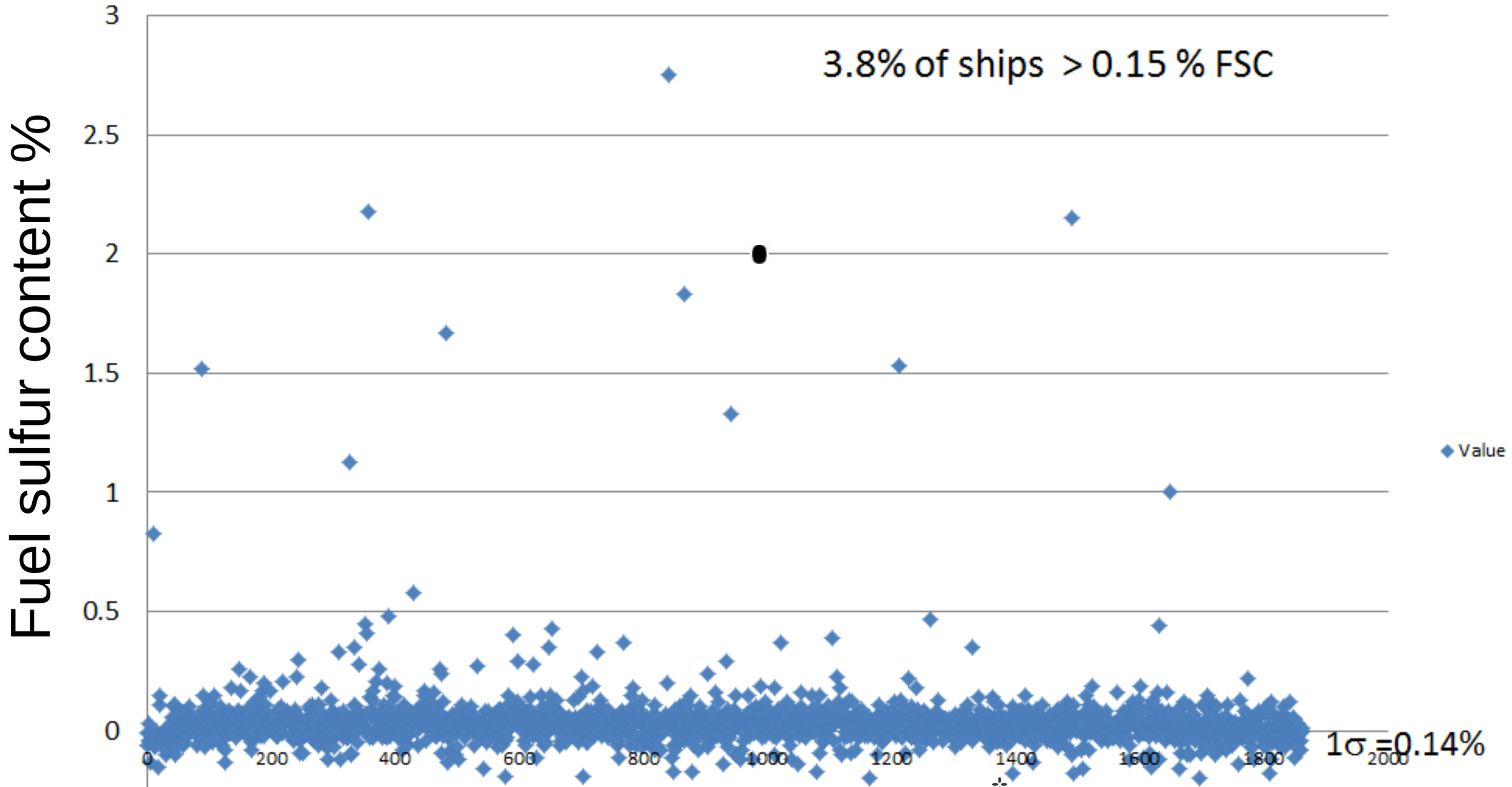
Automatic estimation of fuel sulfur content from sniffer measurements at the Great Belt bridge (Denmark) between May and October 2016

360 good measurements/month. Here 3.8% were above the sensitivity threshold of 0.15% in fuel sulfur content



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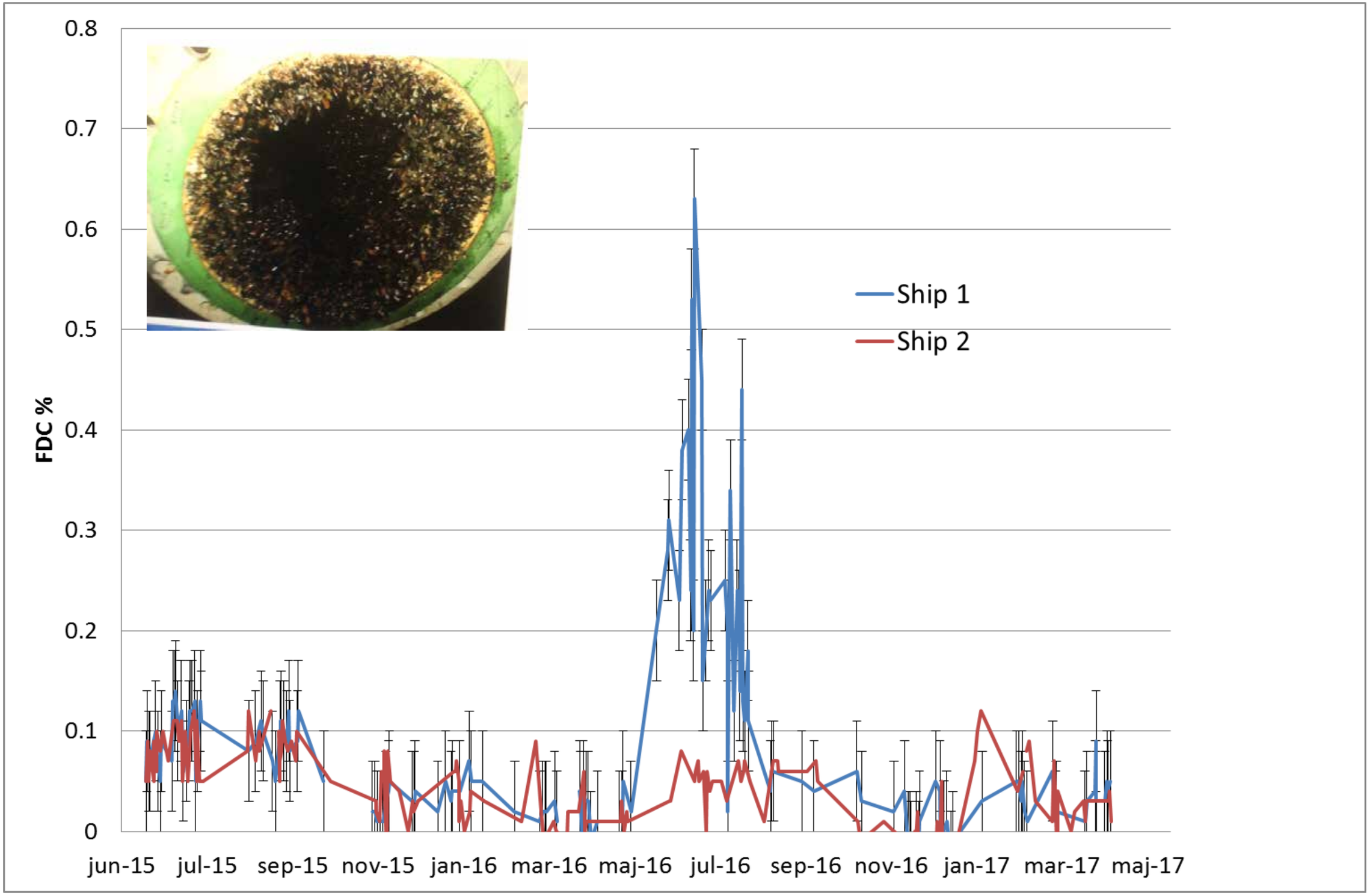
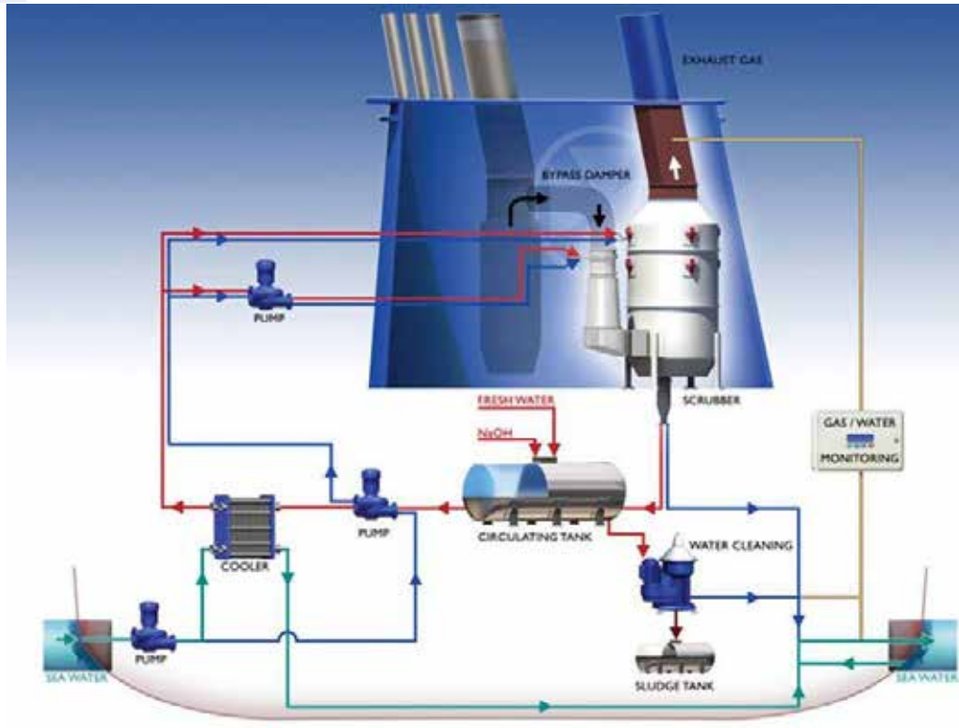
Miljø- og Fødevareministeriet
Miljøstyrelsen

Malfunctioning scrubber has been encountered on several occasions. Here two scrubber ships measured at Great Belt. One of then had problems with antifouling.



Example of equivalent fuel sulfur content in wet scrubber ship measurements, Gothenburg 2015

Ship	FSC average	FSC standard deviation	FSC 90th percentile	Meas
#1	0.16	0.09	0.26	51
#2	0.07	0.07	0.13	11
#3	0.10	0.05	0.17	48
#4	0.09	0.08	0.21	26
#5	0.13	0.18	0.22	36
#6	0.14	0.08	0.25	23



Surveillance aircraft in Roskilde, Denmark

- Dedicated aircraft for ship emission monitoring of sulfur and other species
- Instruments based on **optical** and **sniffer** technique.
- EASA certified installation
- Operated last 2 years routinely in Danish full scale pilot (240 h)
- Operated at SECA border and north sea as part of the CompMon project
- 6-10 ships/h

Sulfur sniffer

Logging Computer
AIS and GPS reciever
Calibration gas
CO_2 sensor
SO_2 sensor
Power converters, TCP
47 kg, 15 A @ 28 V DC
19” dimension

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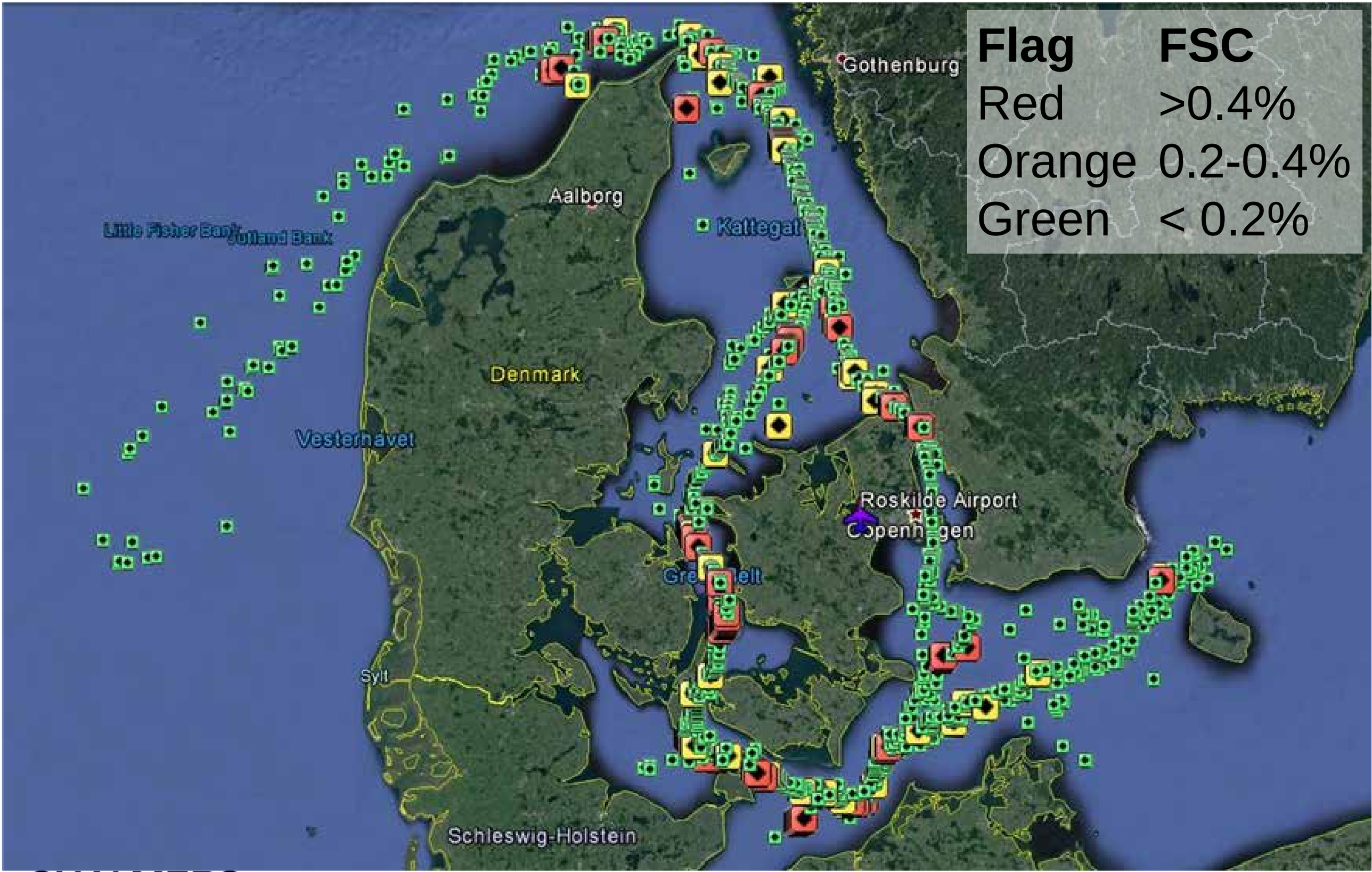
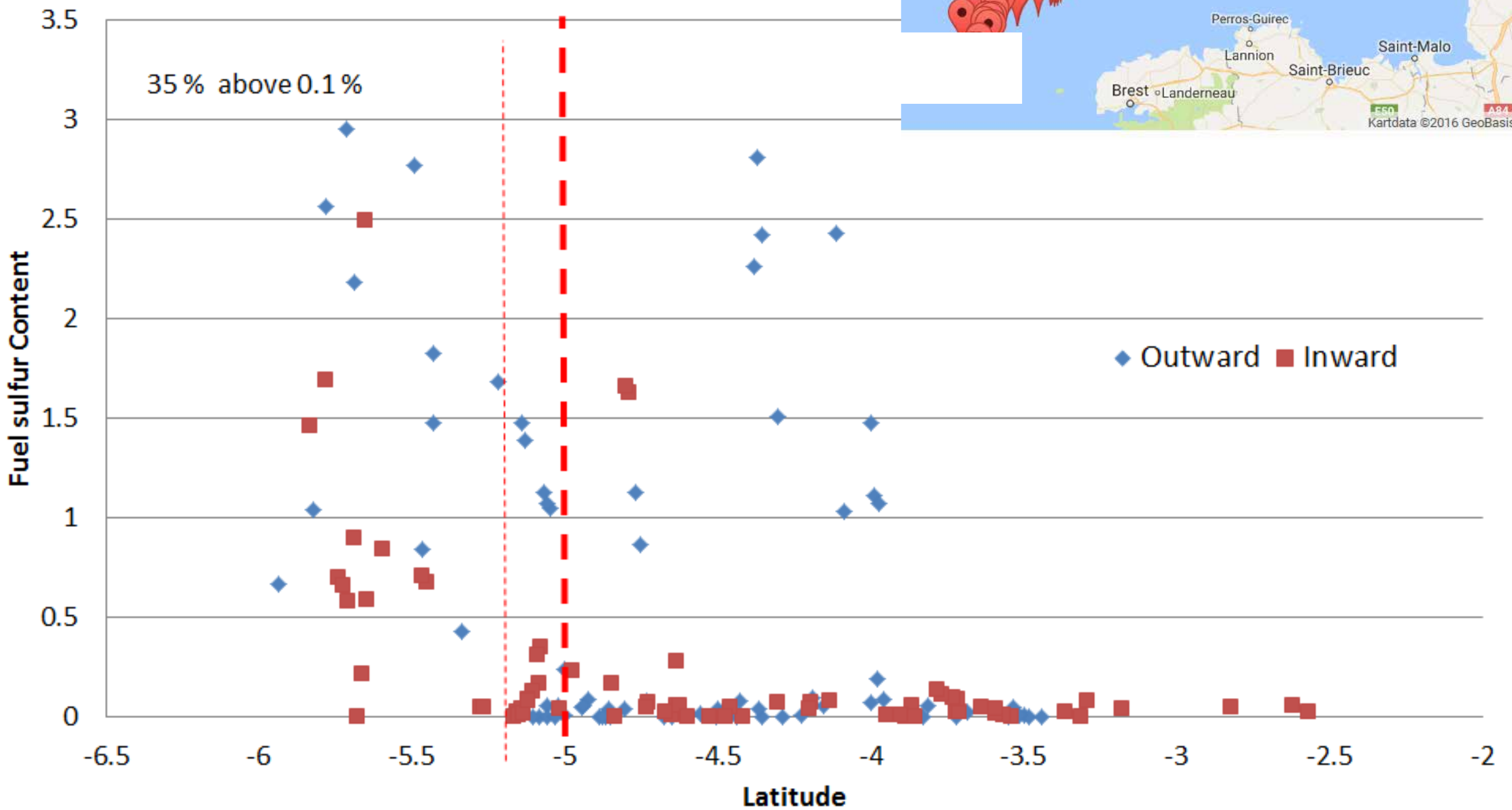
Airborne sniffer measurements of fuel sulfur content 2015-2016



Airborne sniffer measurements at SECA border (5 W). 84% compliance out of 74 ships



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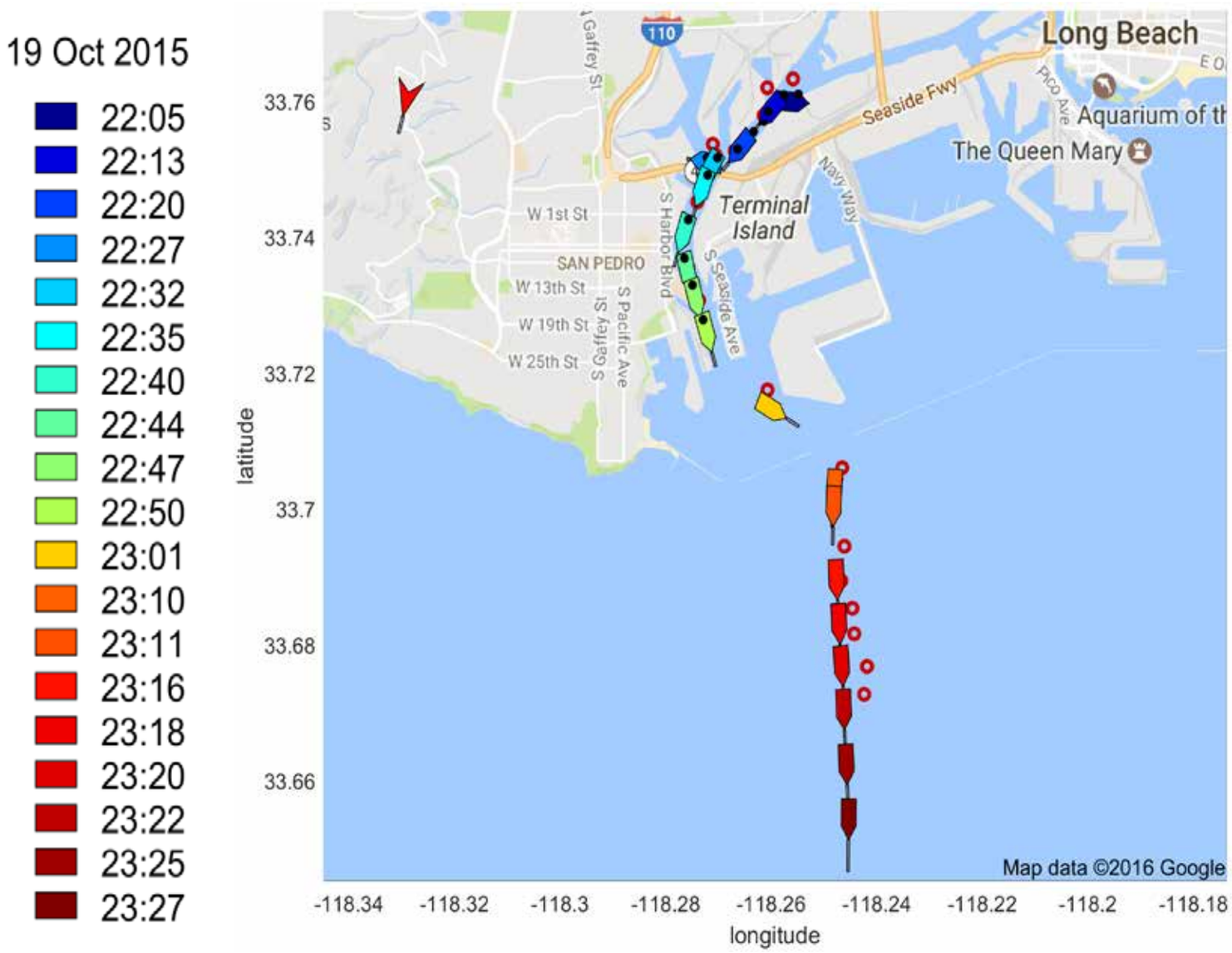
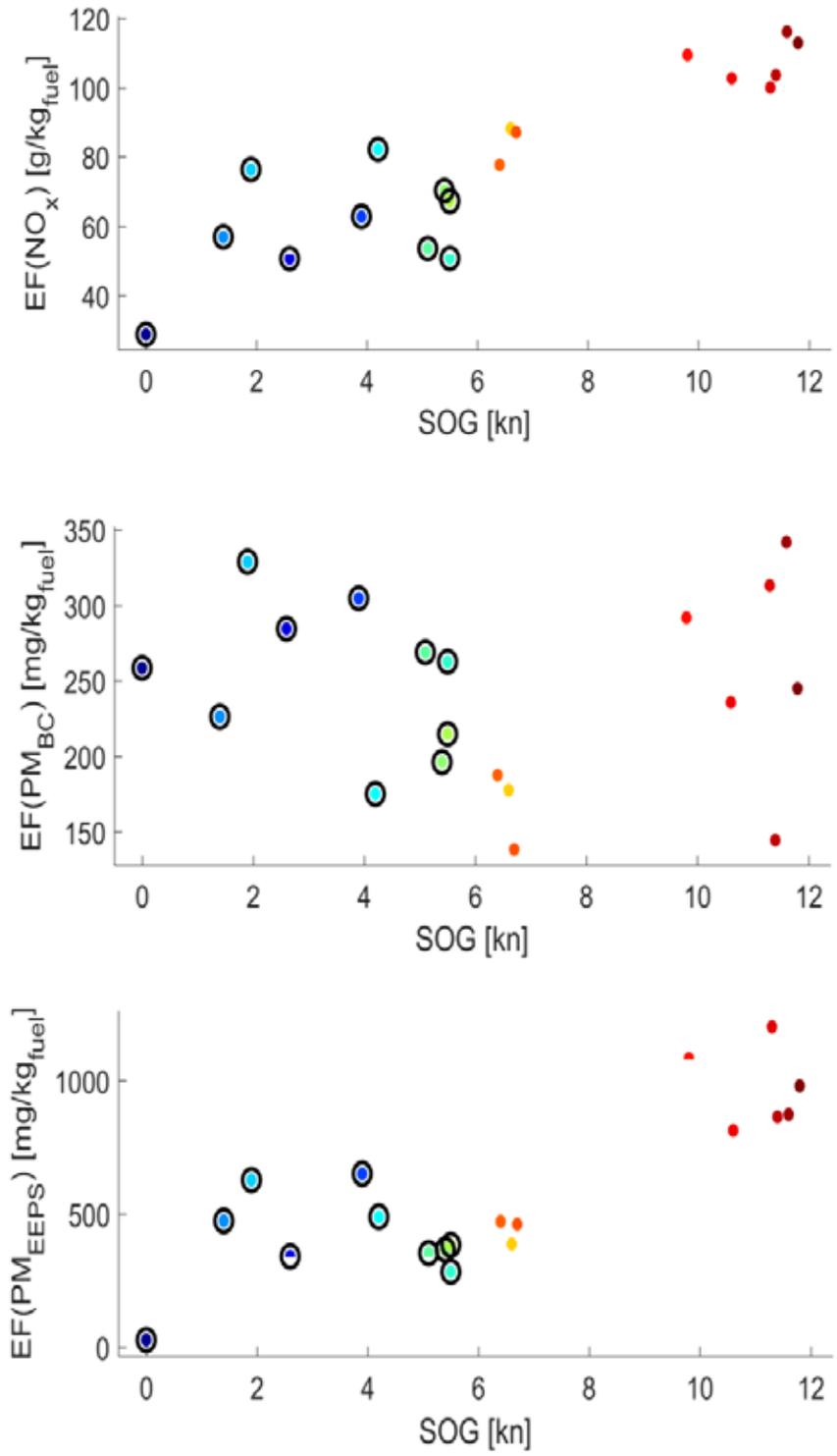
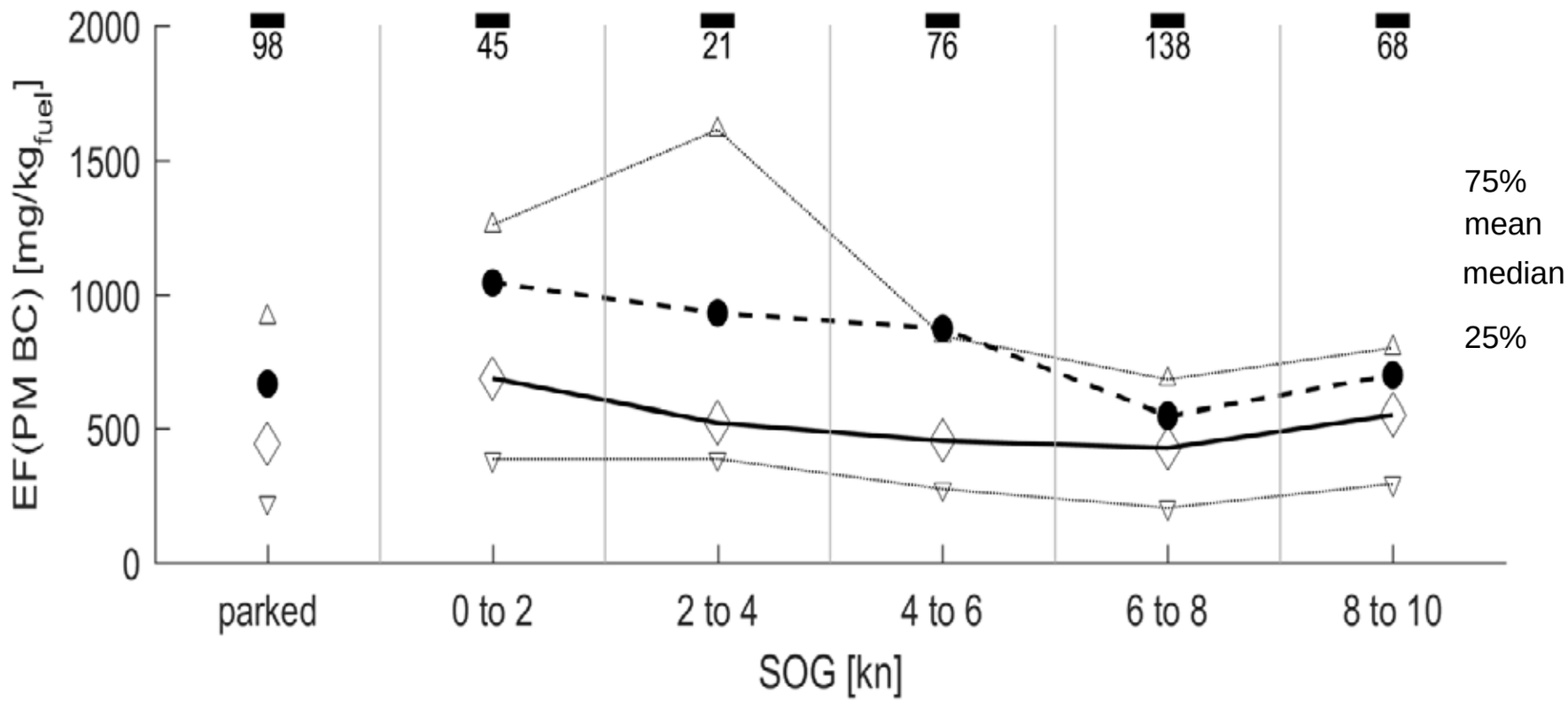
Chase experiments in port of LA from the research vessel, Yellow Fin.

Chase studies - example



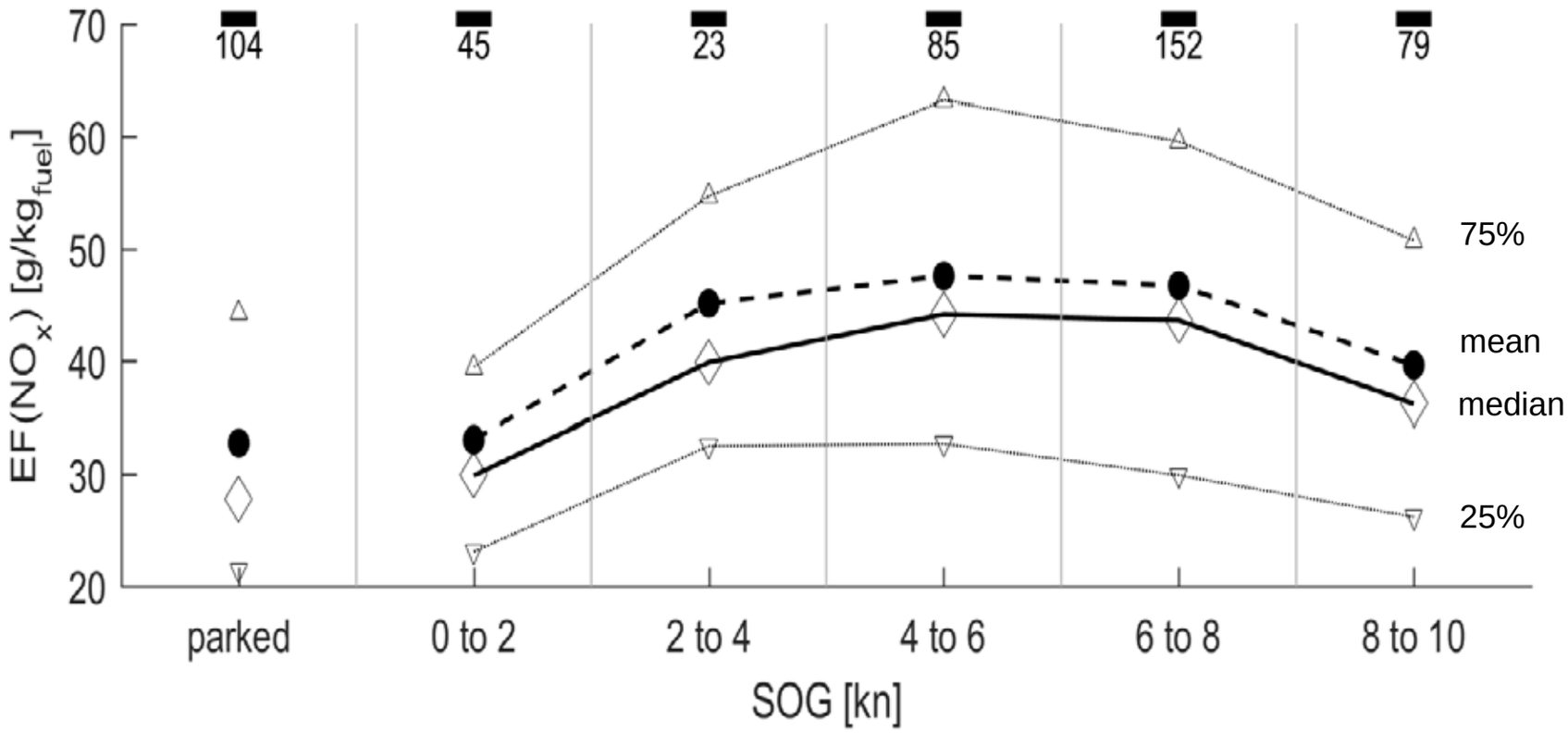


Emissions of black carbon (BC) at different speed (690 ships)



- Maximum emission for slow speeds at 2 to 4 kn – decrease with higher speed
- Maximum probably caused by intensive work by tugs and also incomplete combustion at low load

Emissions of nitrogen oxides (NO_x)



- NO_x emission is about half of what is reported in inventories
- Emission increases with speed by a factor of about 2 – contrary to what was assumed in the inventories
- 20 to 30% lower emissions than reported in literature – more maneuvering vessels at lower speeds in this study as compared to others
- Individual ships emit in the order of 20 to 45 kg(NO_x)/h

Some results

- Envisum project (in progress):
  - Ship specific emission factors of sulphur, NOx, Particulate matter, particulate number and Black carbon measured in harbors and open sea
  - Special analysis will be made wrt ships with abatement equipment and running alternative fuels (scrubber, SCR, LNG, methanol)
  - Compliance levels on Baltic sea, Gdansk, Göteborg
- Other projects
  - On the English Channel 13 % of the ships were doing too early fuel switching starting at 4W when leaving the SECA .
  - Around Denmark and southern Baltic and North sea there is in general good compliance rate, 96 % at great Belt bridge, 94 % from airborne.
  - Some specific shipowners/lines are often encountered high (flag less important)
  - Several ferry lines have been operating with malfunctioning scrubbers. Some cruiser lines makes long term tests with permission from non SECA flagtest.

References

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