Remote sulfur compliance monitoring in environmental control areas and on the open sea

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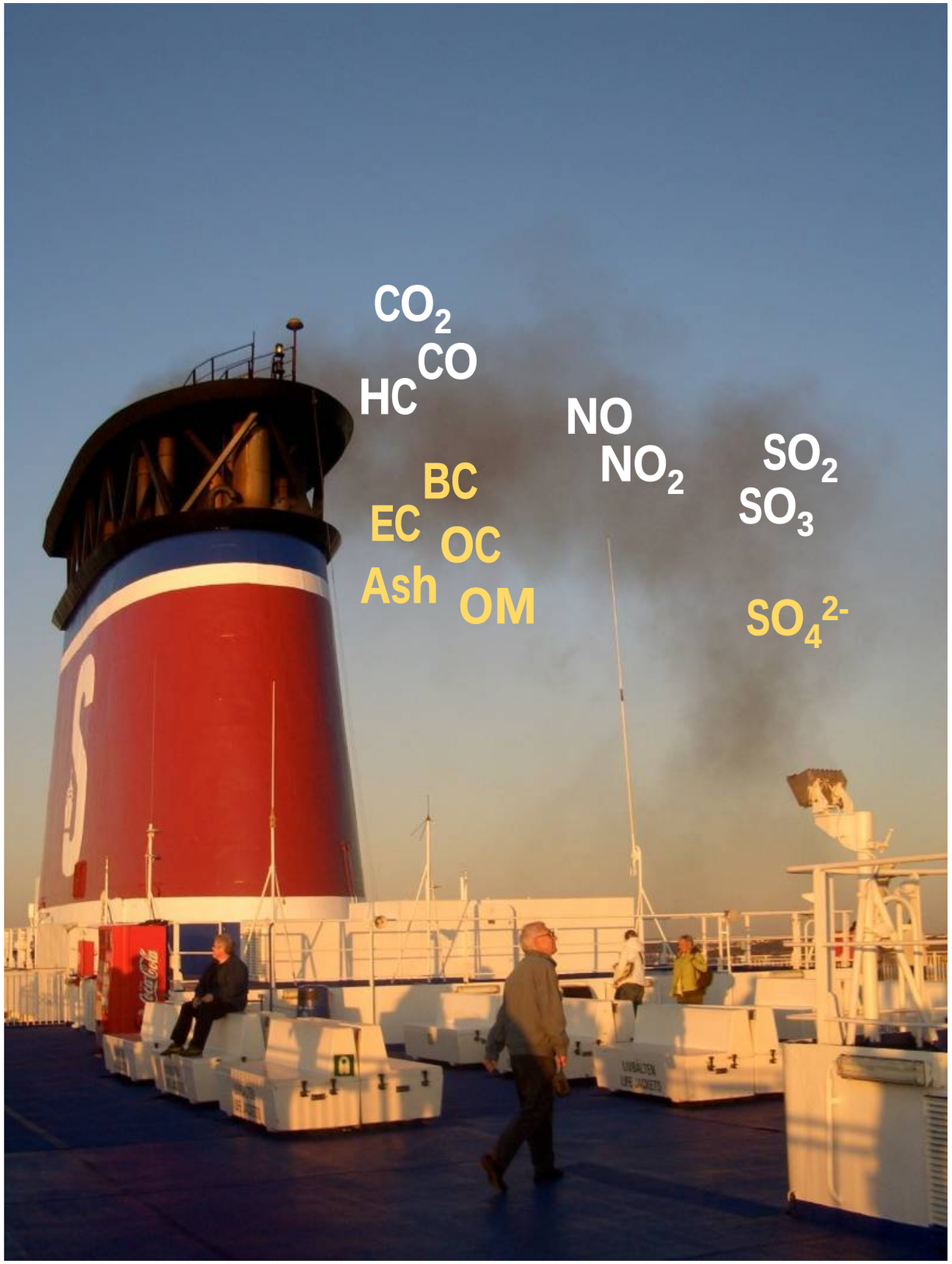
Major pollutants in ship exhaust



Climate
- radiative forcing

Environmental
- acidification
- nitrification
- ground-level ozone

Health
- lung and cardiovascular diseases

It has been acknowledged that ships have significant impact on air quality (SO2, NOx and particles), climate (BC and SO2) and nitrification (NOx)

SO2 and NOx are regulated but particles are not. Black carbon for arctic sailing is being discussed in IMO.

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%)
- In 2020 it will be required to operate with fuel sulfur content <0.5% worldwide.
- 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.
- Remote measurements can be used to GUIDE on board inspection and monitor whether ships comply with the legislation on the open sea.
- Funding through several EU projects, Swedish environmental protection and innovation agency and the Danish environmental protection agency

CompMon
Compliance Monitoring for Marpol Annex VI

Miljø- og Fødevareministeriet
Miljøstyrelsen

IGPS

VINNOVA

Interreg
Baltic Sea Region

EUROPEAN REGIONAL DEVELOPMENT FUND
EUROPEAN UNION

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Status on remote measurements of ship exhaust

- 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

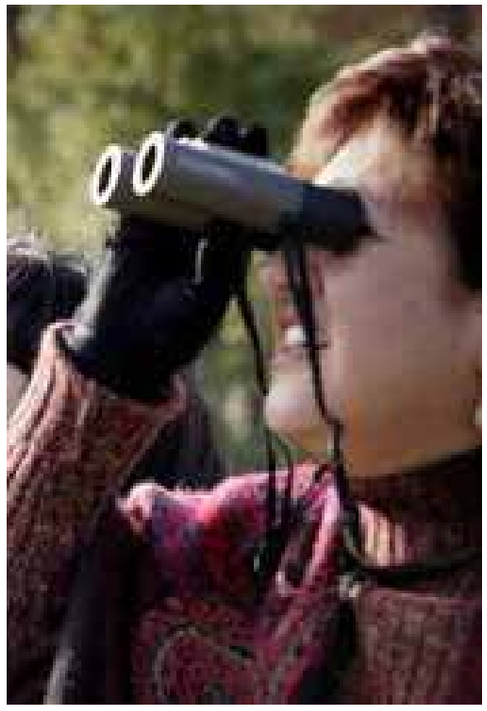
- Ship monitoring at more than 500 nautical miles distance is difficult (Atlantic ocean) and requires other solutions:
  - On board monitoring in stack OR autonomous sniffer on deck
  - Advanced fuel control (fuel calculator)
  - Long duration UAVs at medium altitude utilising optical measurements

- 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

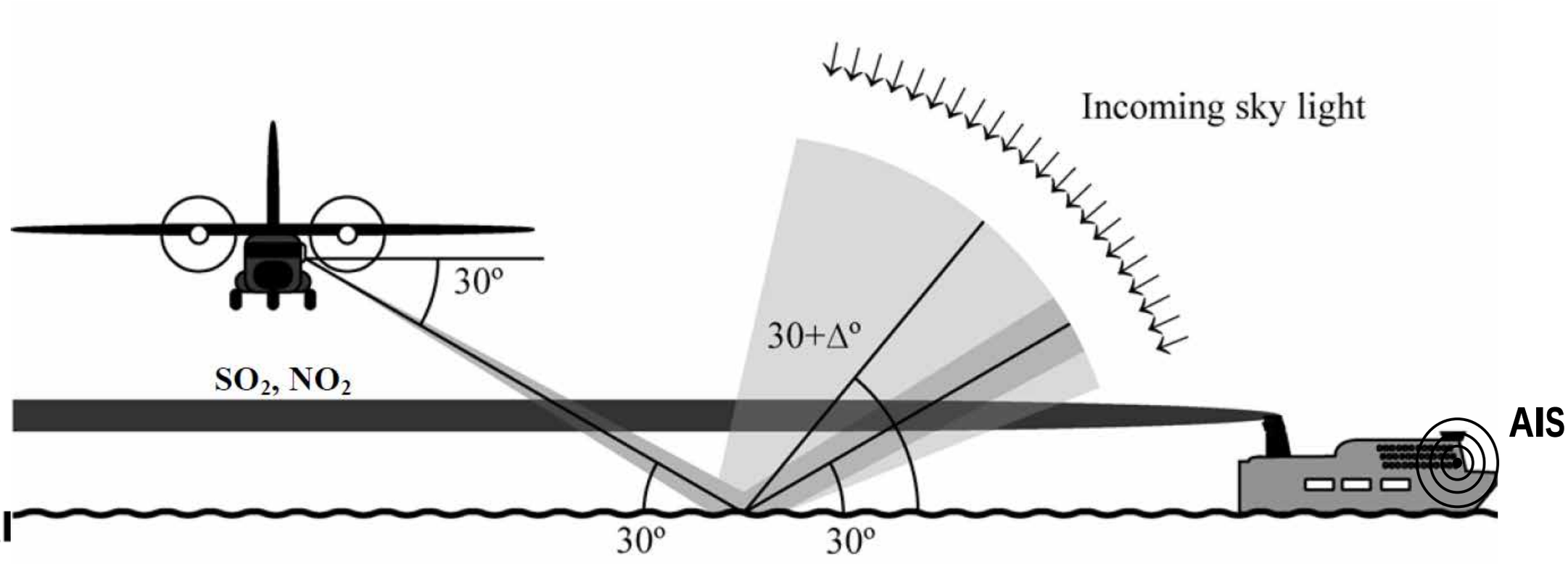
Sniffer Instruments

	Sniffer	Mini sniffer
	Conventional/ scientific	Coated Semiconductors
Species	SO2/CO2/NOx/PM/BC	SO2/CO2/NO2
Weight	50 kg	1 kg
Size	40*50*40 cm	5*5*5 cm
Power	500 W	20 W
Response	1 s	60 s
Sensitivity	ppb (µg/m3)	ppm (mg/m3)
Quality assurance	In field calibration	Laboratory calibration
Abs accuracy at 0.1% FSC	0.05% FSC	0.05% FSC
Platform	Aircraft, fixed	Helicopter, UAV
Experience	10 years, 10000 ships	5 years, 300 ships
Distance to ship	0.5-3 km	75 m
Time in smoke	1 s	>30 s
Price	100 kEuro	10 kEuro

Optical measurement



- An optical sensor measures the concentration of **SO2** and **NO2** in the ship plume by spectroscopic analysis of reflected solar light that passes through the smoke
- This sensor is a first alert system, distinguishing high sulfur (1%) from low sulfur ships (0.1%) remotely.
- Can be used for guided control and potentially on long duration UAVs



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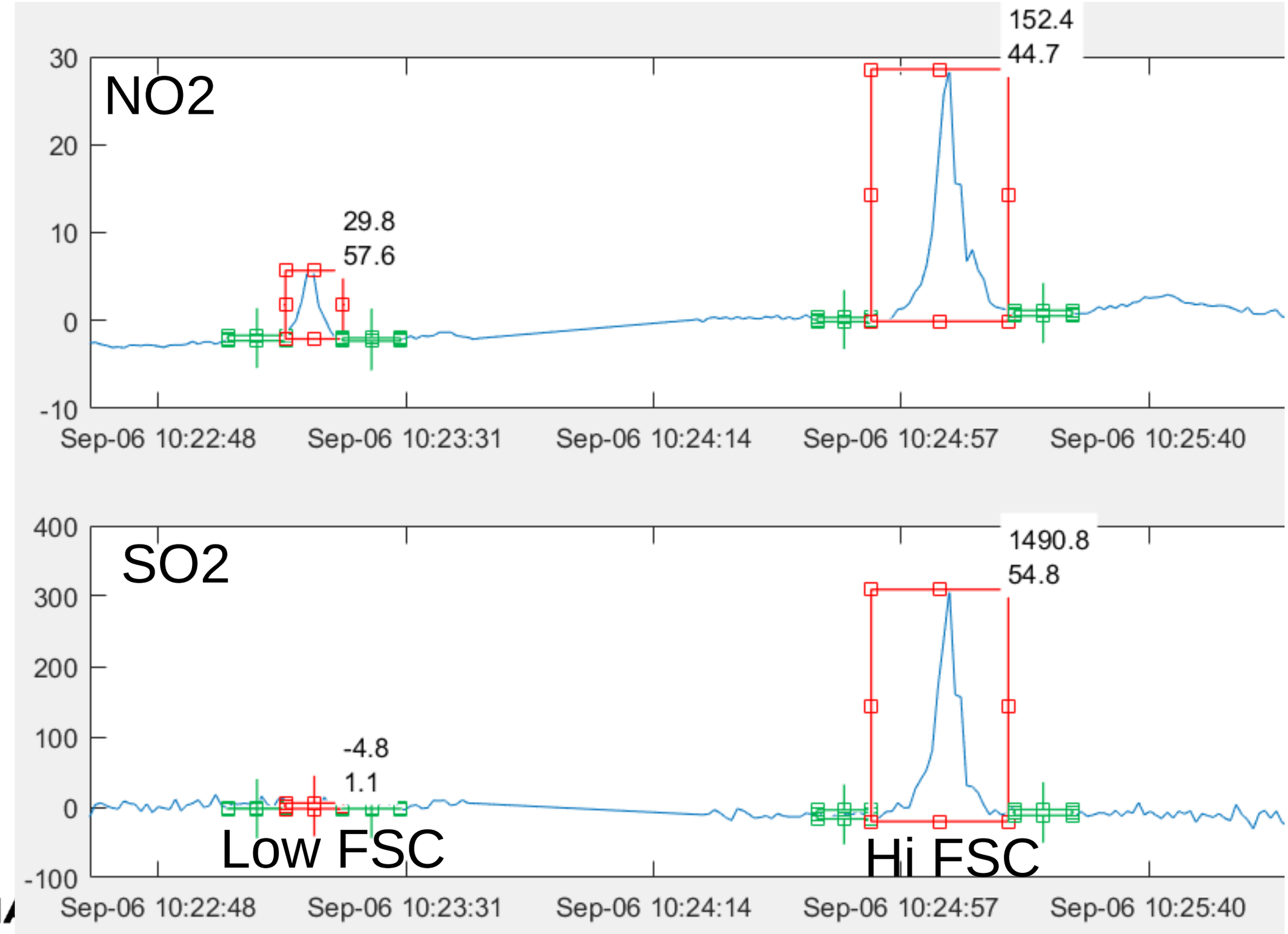
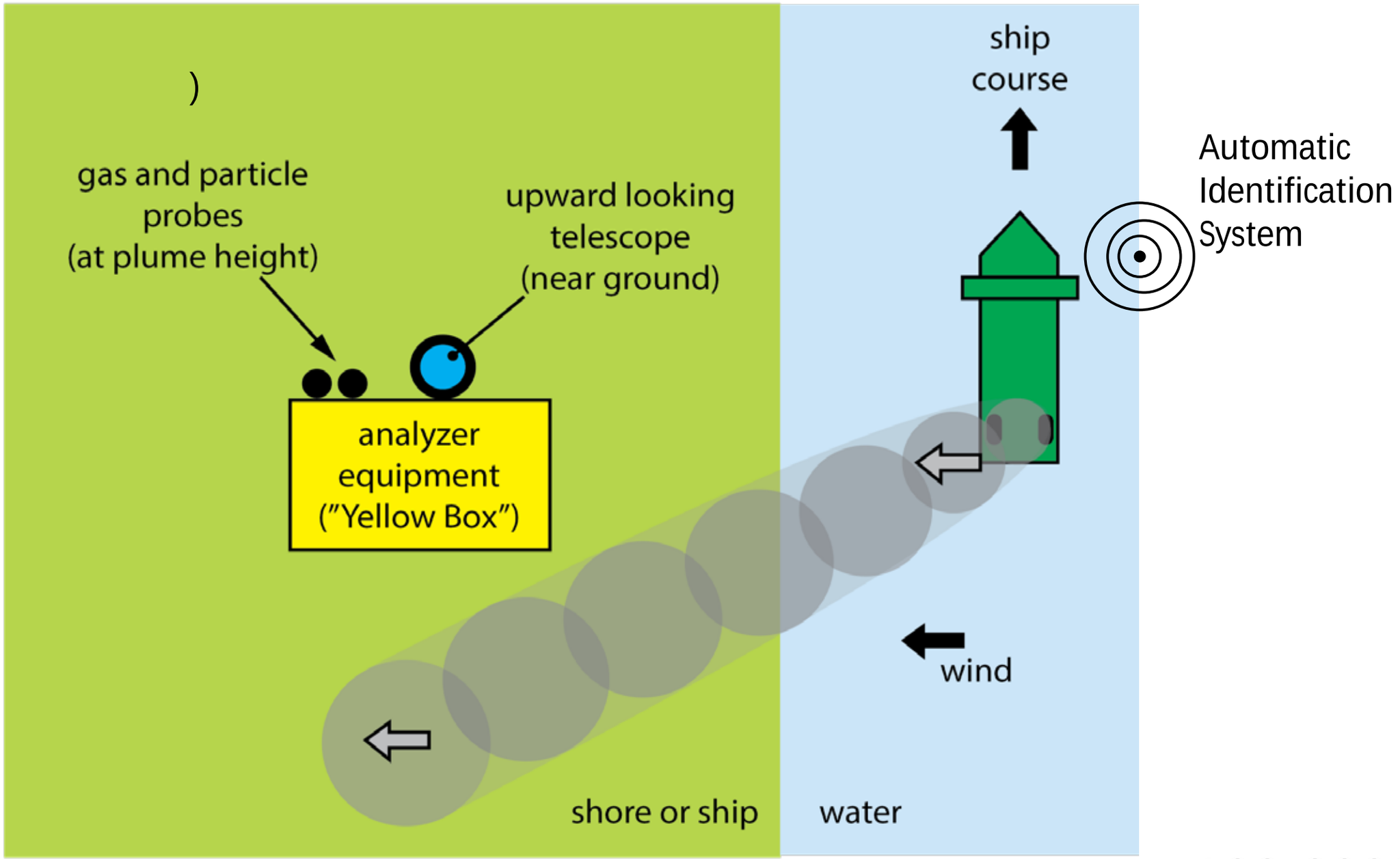
Optical measurement of SO2 and NO2 in the plume of two ships with different Fuel sulfur content. SO2/NO2 ratio is used as indicator.



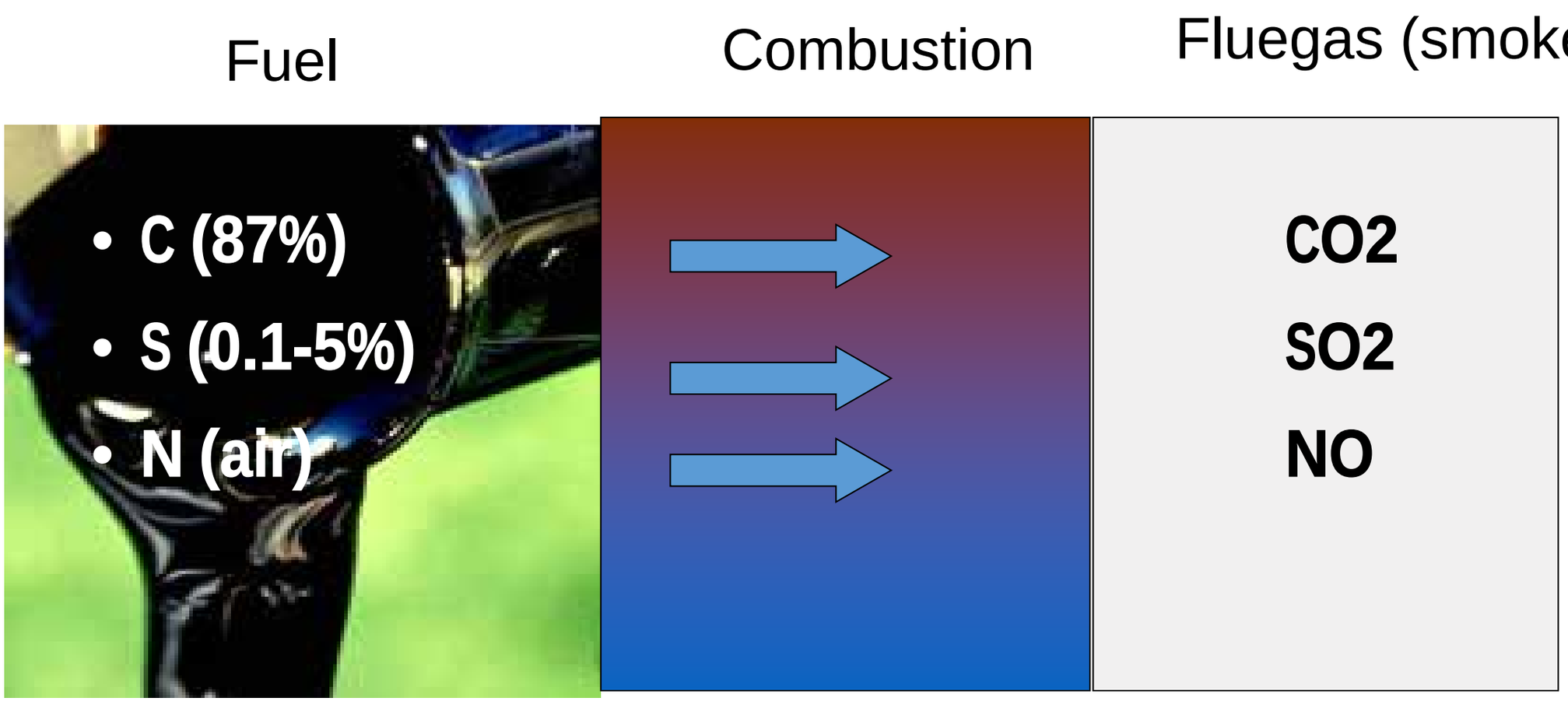
Fixed measurement.

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



Principle of sniffer measurements to obtain the fuel sulfur content

- **The concentration ratio of SO2 and CO2 in the smoke tells the fuel sulfur content ! Also NOx and particle emission can be measured in the same manner**

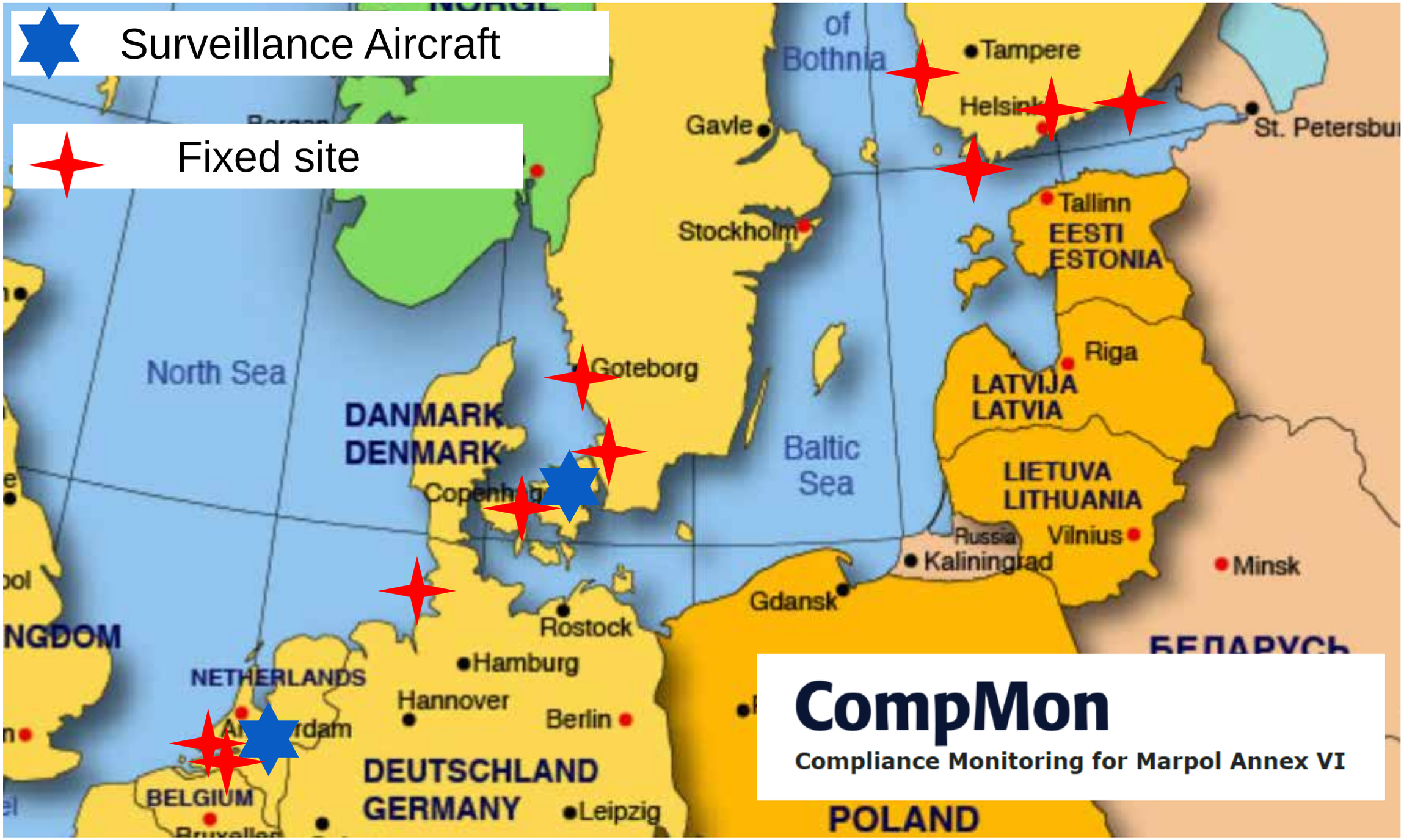


$S_{fuel\ \%} = SO2/CO2*Mass\_sulfur/Mass\_carbon*C\_content = SO2/CO2*232$

CompMon (European CEF project)

EU Sulfur Compliance monitoring pilot for MARPOL Annex VI 2014-2016

(Finland, Sweden, Belgium, Netherlands, *Denmark, Germany)*



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Fixed measurements using sniffers (smoke drifts over station)

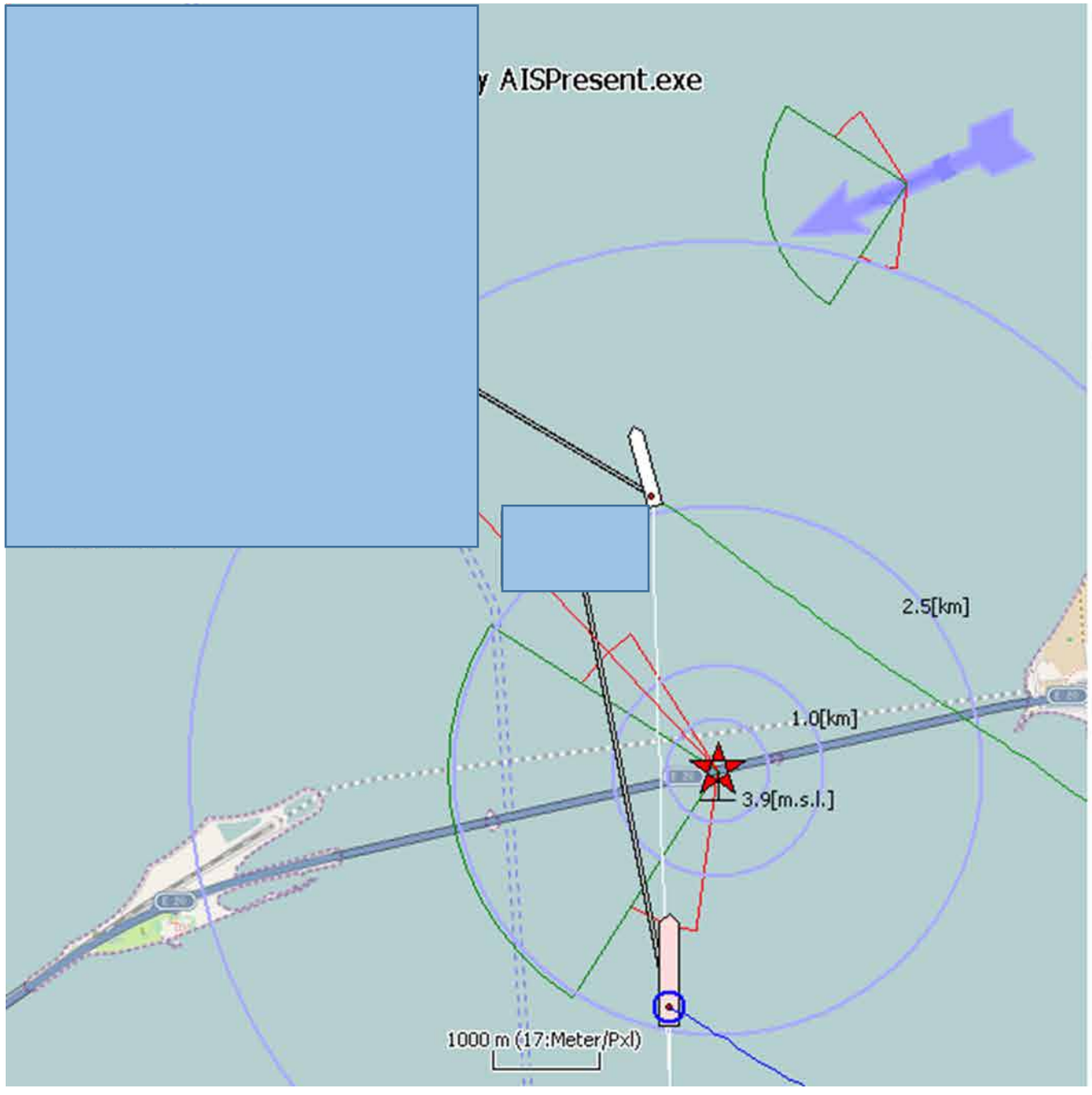
Great Belt bridge, since 2015,
4000 inspections/month

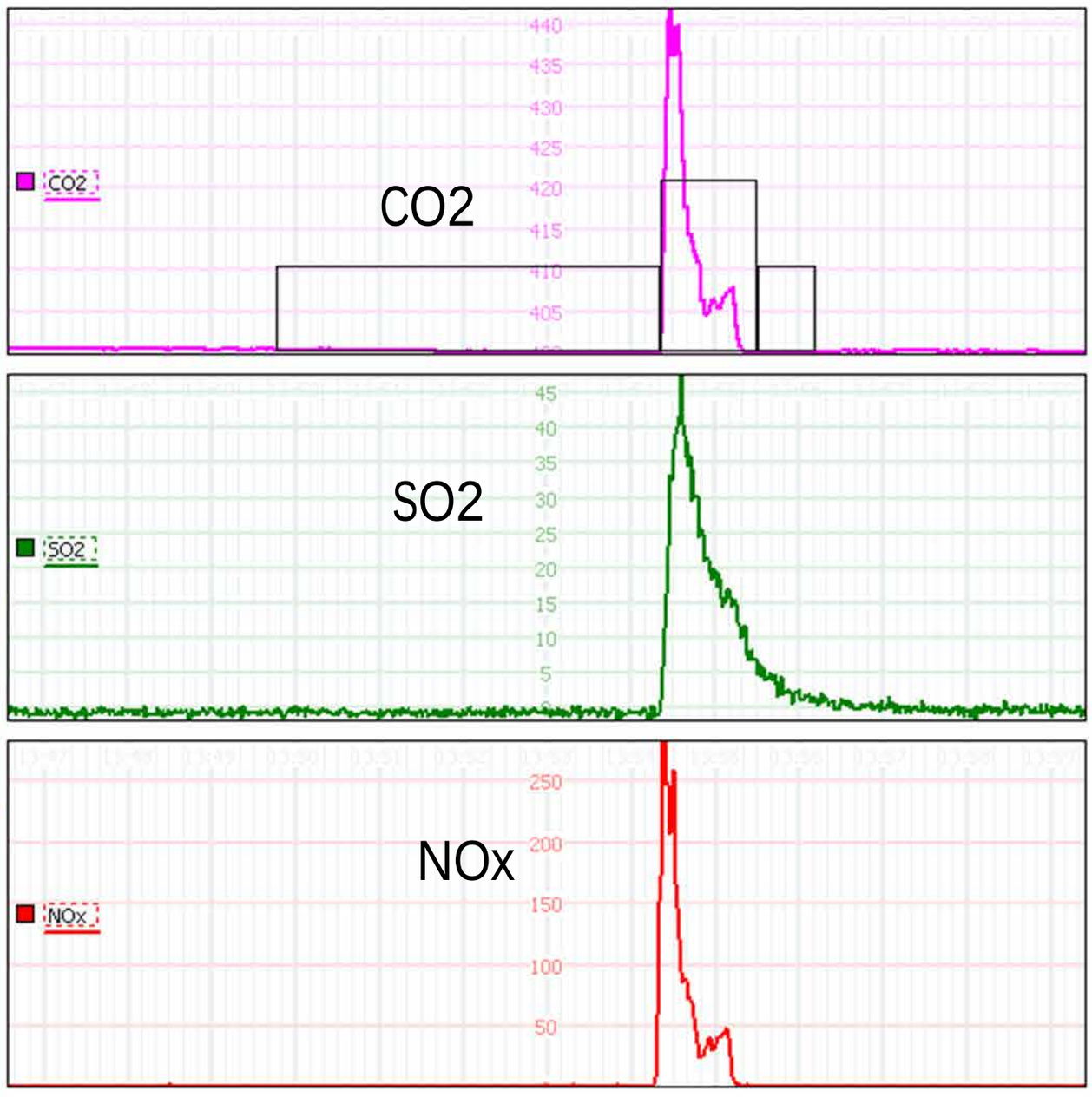
Ship channel of Göteborg since 2014,
4000 inspection per year

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

The MPI-Mainz UV-VIS Sp... Workpackages IMPRESS Infrared Working Group R... http--vpl.astro.washington... Sök - Göteborgs Stad (2) Sök - Göteborgs Stad Google

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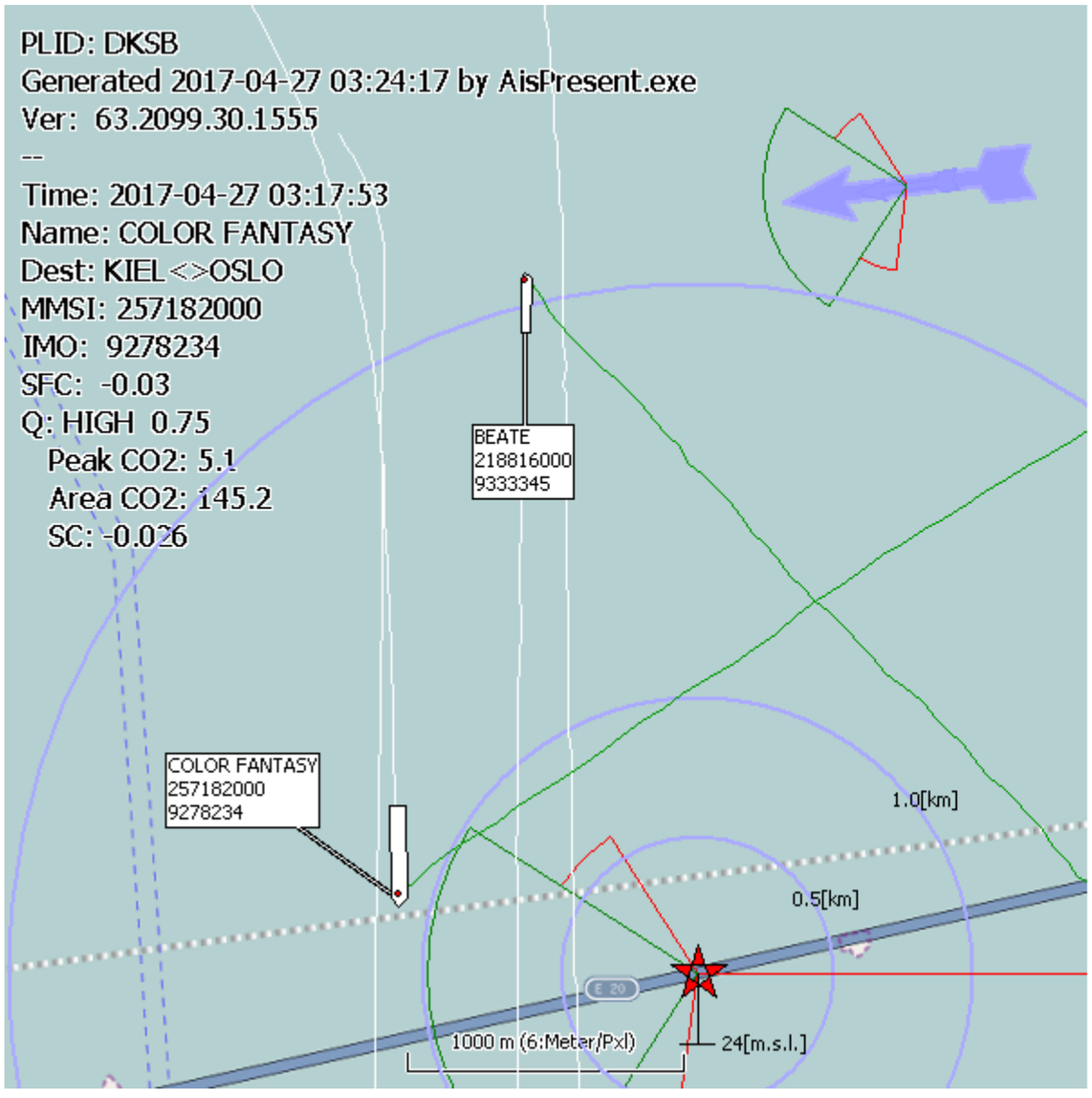
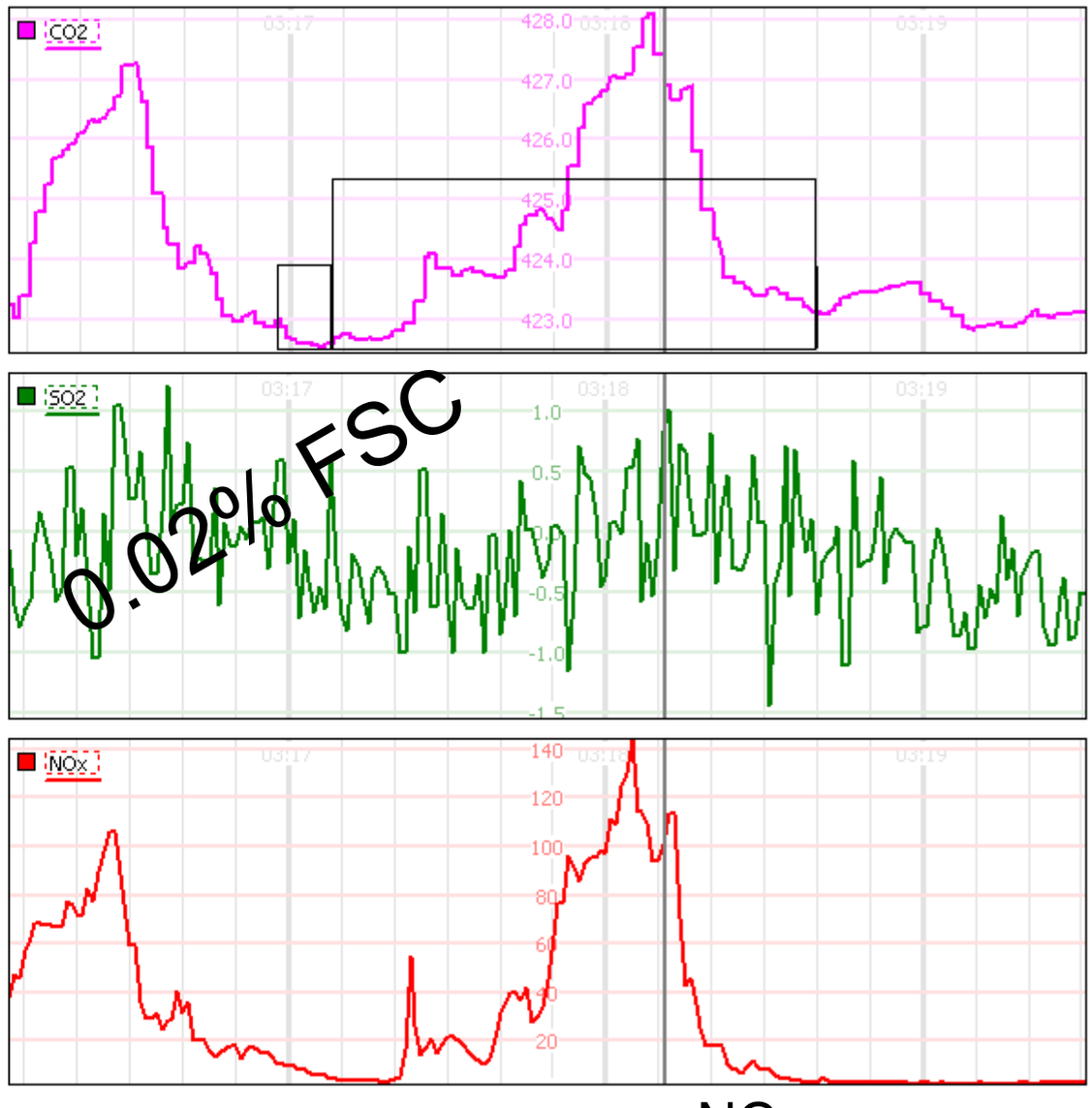
Date	type	Value	Quality tag	Quality control	Platform	Platform type	Ship name	Ship type	IMO	MMSI
03/09/2016 - 10:56	SC	0.00	Poor	Automatic	Älvsborg	Stationary	HANS	Other Type	8996956	230034540
03/09/2016 - 10:49	SC	0.06	High	Automatic	Älvsborg	Stationary	ICE STAR	Cargo	9142631	244264000
03/09/2016 - 10:25	SC	0.02	Medium	Automatic	Älvsborg	Stationary	GEORGE	Other Type	8634077	230034510
03/09/2016 - 09:44	SC	0.04	Medium	Automatic	Älvsborg	Stationary	STENA DANICA	Passenger	7907245	265177000
03/09/2016 - 09:18	SC	0.02	Medium	Automatic	Älvsborg	Stationary	ASTINA	Tanker » Hazardous category A	9320063	266220000
03/09/2016 - 08:56	SC	-0.15	Poor	Automatic	Älvsborg	Stationary	DELFIN	Tanker	0	265505100
03/09/2016 - 08:44	SC	0.02	Poor	Automatic	Älvsborg	Stationary	STENA SCANDINAVICA	Passenger » No additional information	9235517	266343000
03/09/2016 - 08:40	SC	-0.04	High	Automatic	Älvsborg	Stationary	STENA SCANDINAVICA	Passenger » No additional information	9235517	266343000
03/09/2016 - 08:17	SC	0.07	High	Automatic	Älvsborg	Stationary	THUN GLOBE	Tanker	9229051	245573000
03/09/2016 - 08:08	SC	-0.02	Medium	Automatic	Älvsborg	Stationary	HANS	Other Type	8996956	230034540
04/27/2017 - 05:17	SC	-0.03	High	Automatic	DK Storabält	Stationary	COLOR FANTASY	Passenger » Hazardous category B	9278234	2571820

Automatic measurements of Color Fantasy last night (26/4 5:17)





NOx

Quality assurance and control

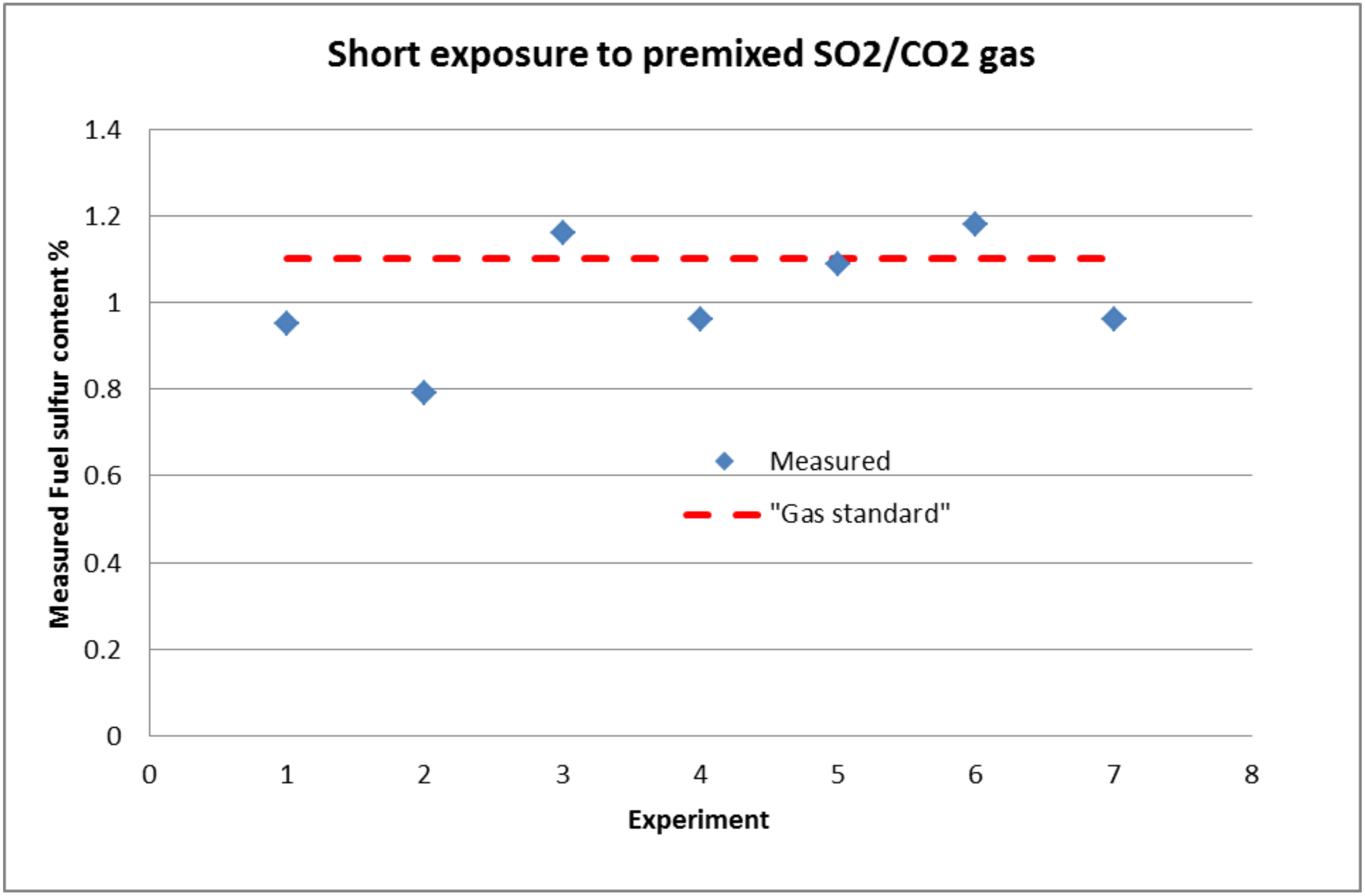
- Validation campaign in 2008, side by side measurement and on board comparison (Alfoldy 2013 , Balzani 2013...)

- Frequent field calibration using certified gas standards. As an option permeation tubes can be used.

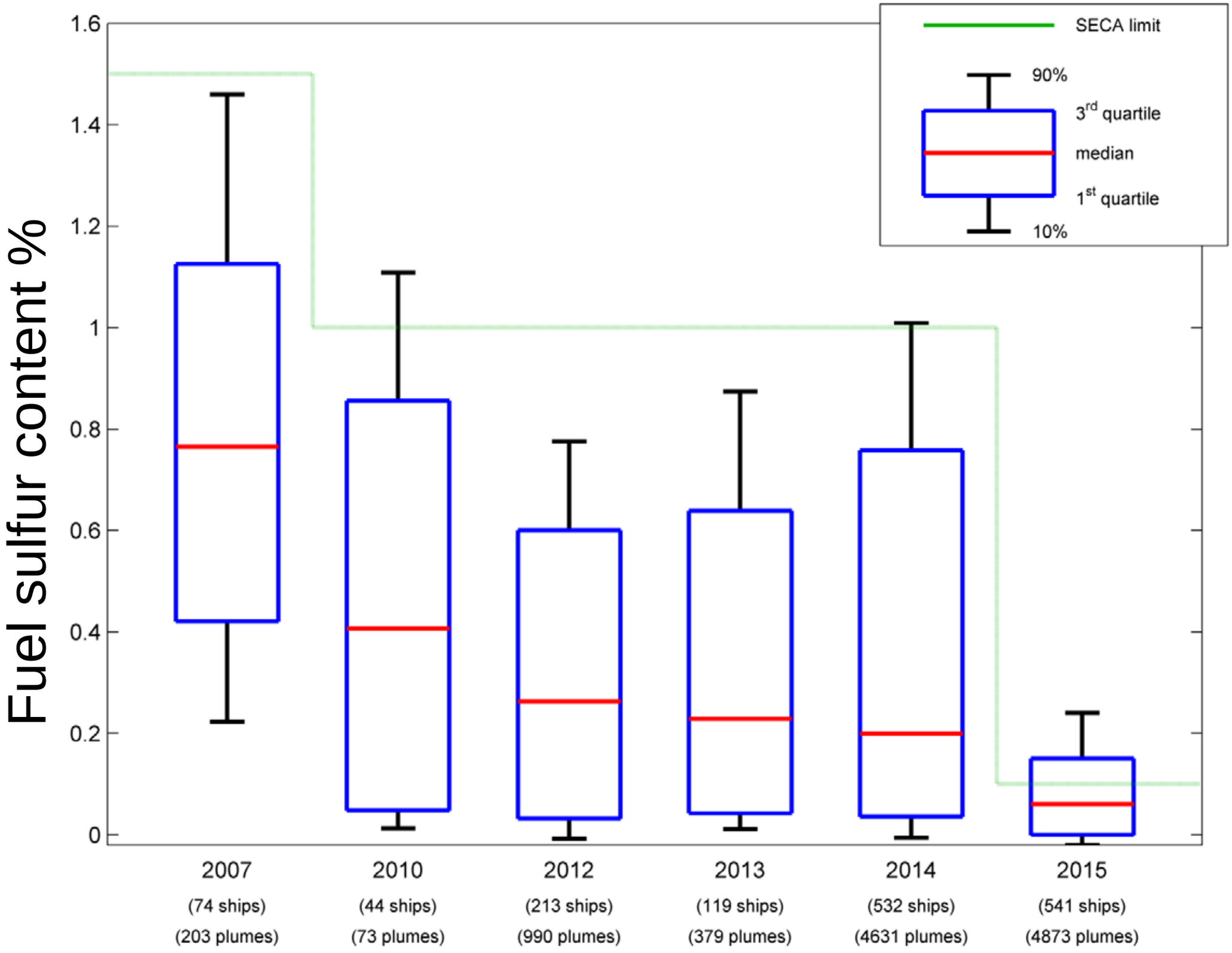
- Use of high concentration mixture of SO2 and CO2 wich corresponds to 1 % ship. This is used to simulate ship plumes and validate the behavior of time response and drift.

- Typical rel uncertainty of 20 % at 1% FSC level and 50% at 0.1% level yields compliance level thresholds of 0.15% for fix and 0.2-0.3% for aircraft

Quality assurance test measurement of premixed gas



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



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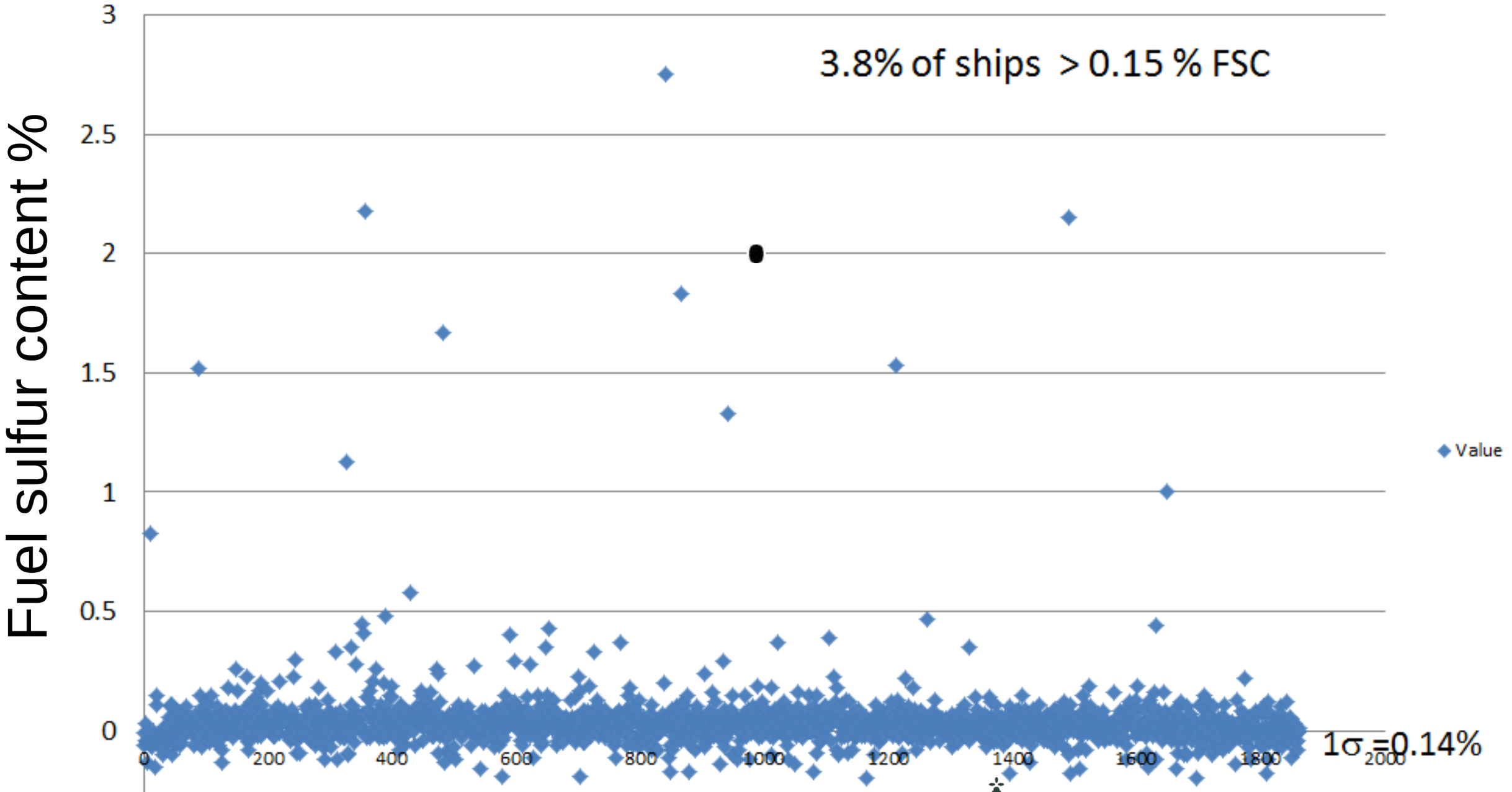
Automatic estimation of fuel sulfur content from sniffer measurements at the Great Belt bridge (Denmark) between May and October 2016

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



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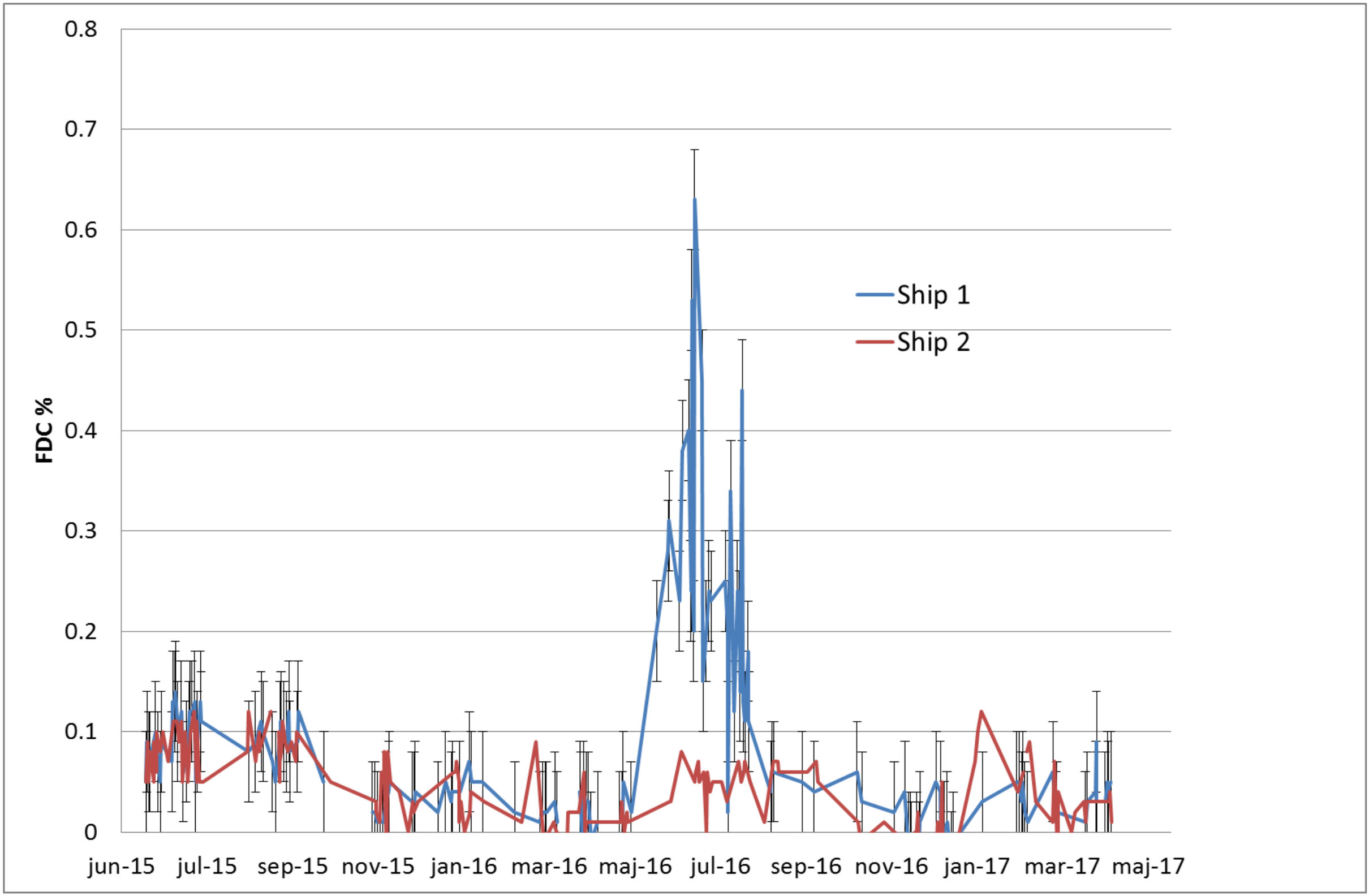
Miljø- og Fødevareministeriet
Miljøstyrelsen

occasions. Here two scrubber ships measured at Great Belt -0-01%-0.02%



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
CO2 sensor
SO2 sensor
Power converters, TCP
47 kg, 15 A @ 28 V DC
19” dimension

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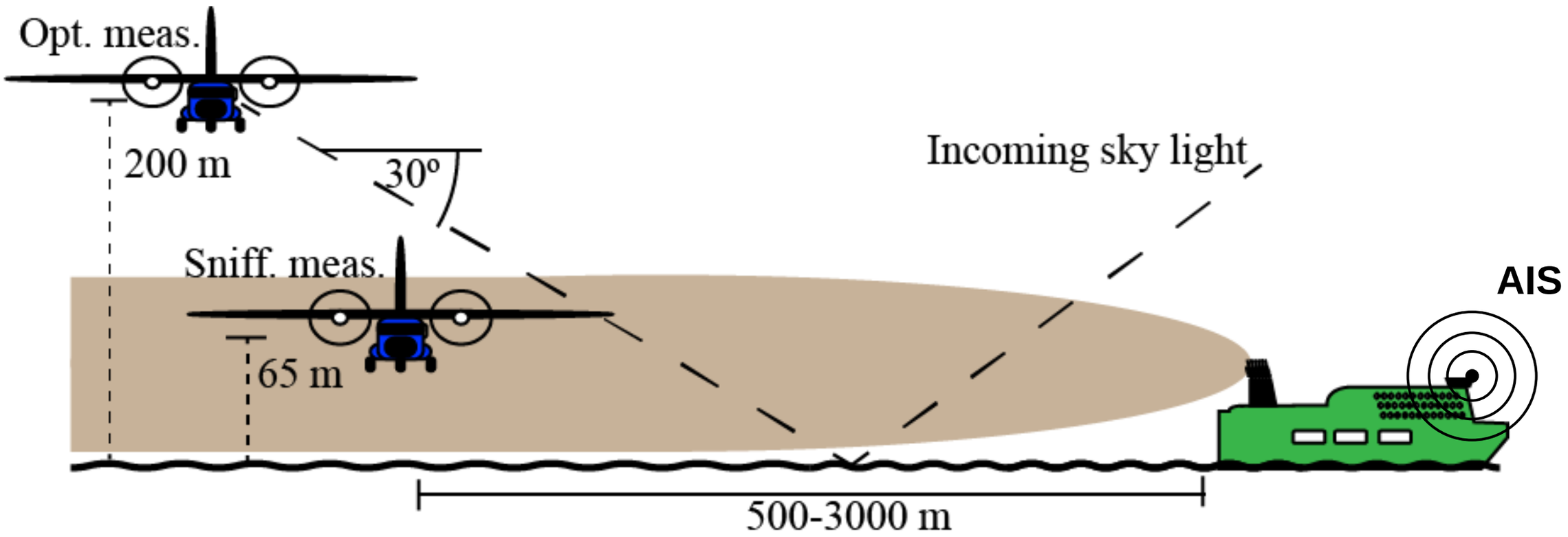
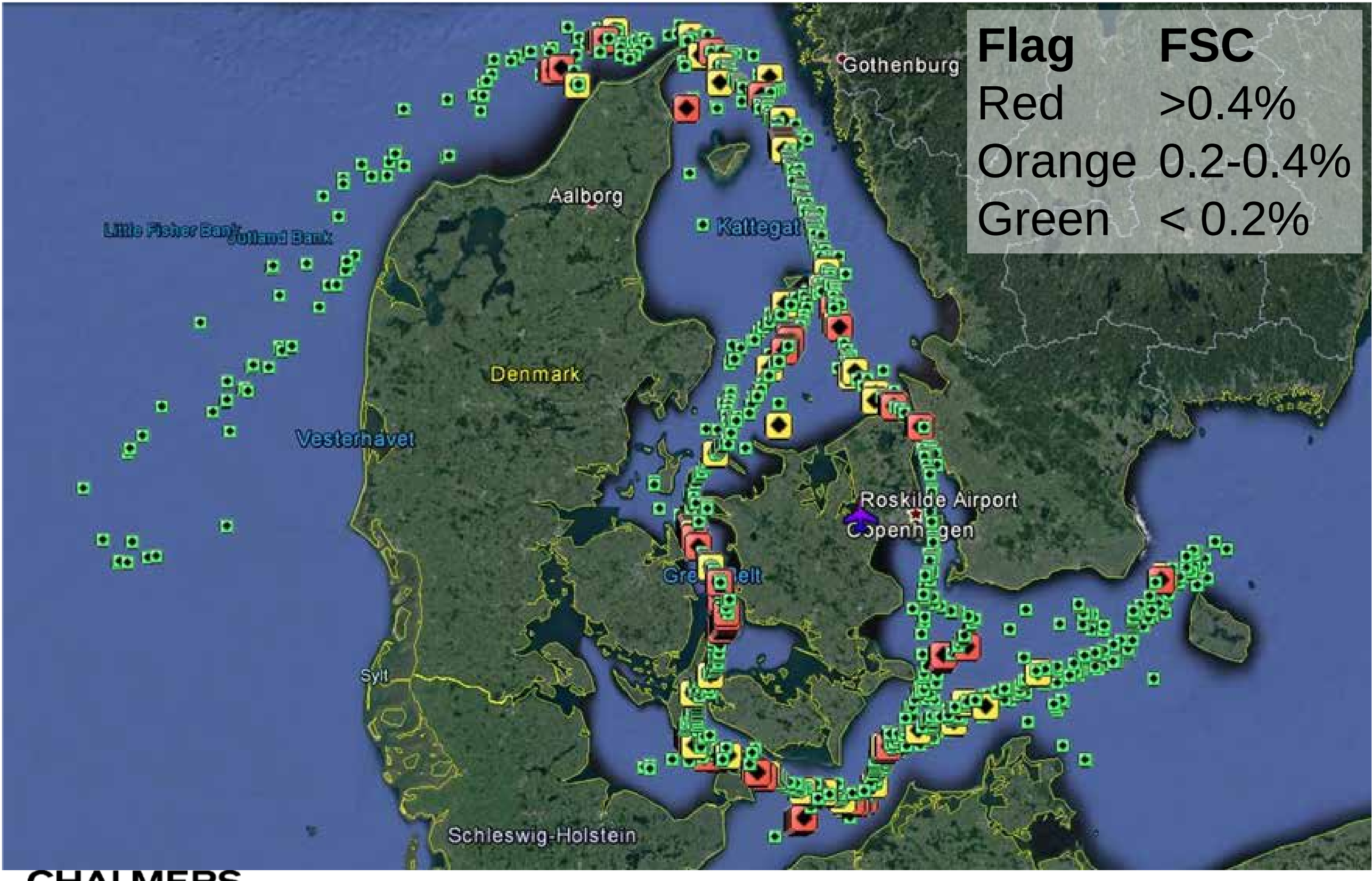
Airborne measurements (combination of optical and sniffer technique)

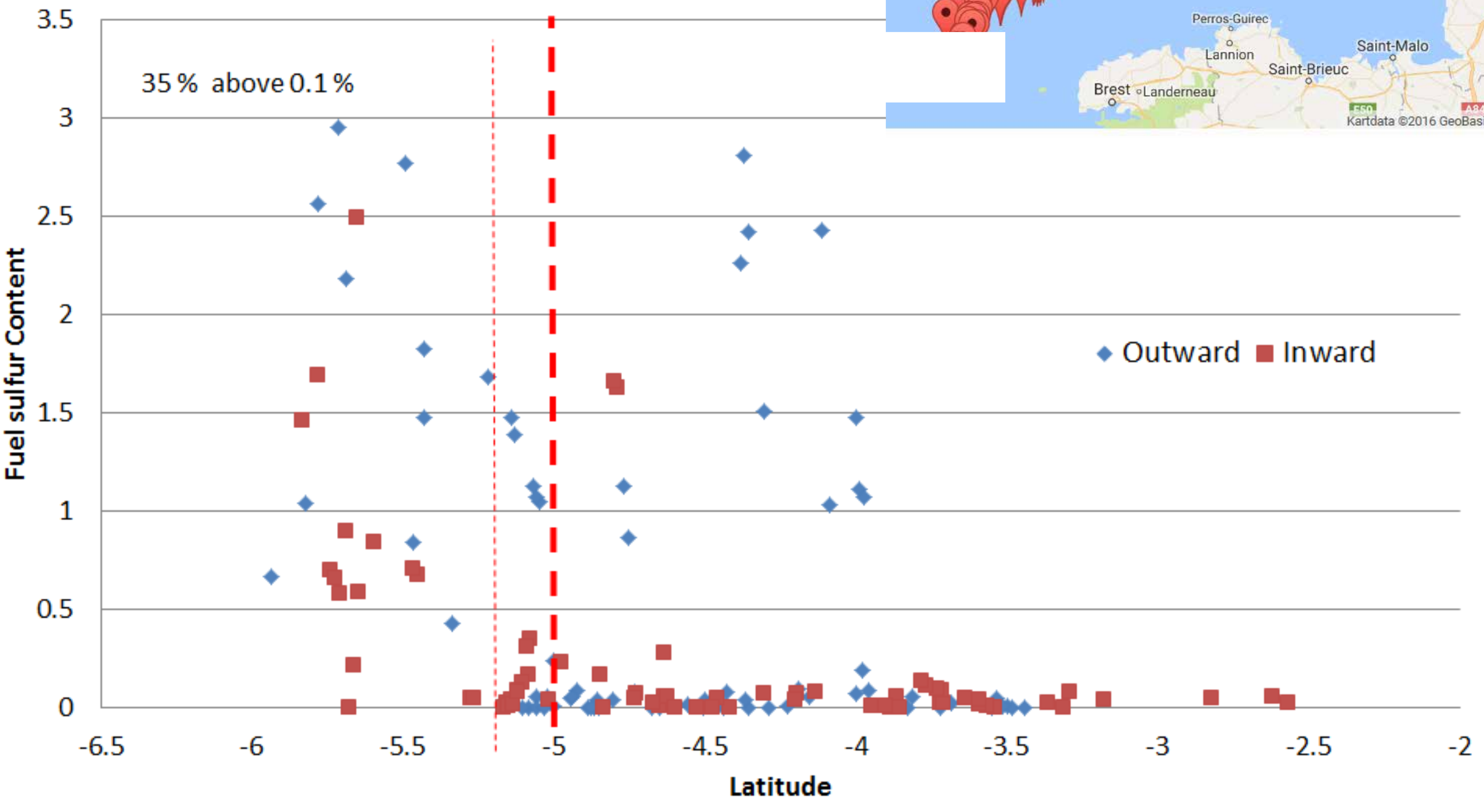


Aircraft crosses above or through plume. First **optical** measurements are done at higher altitude. If sulfur measurement is high, a **sniffer** measurement of SO2 is done at lower altitude

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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Some results

- The sniffer method is fully operational – demonstrated for fixed sites and airborne measurements also in the coldest winter.
- 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.
- Important with further QA and R&D work and future standardisation to improve assessment and homogenisation of errors
- Measurements will be avaialble within a few months in several reports (CompMon website) and from Danish EPA.

References

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