Monitoring Shipping Emissions with In-situ Measurements of Trace Gases

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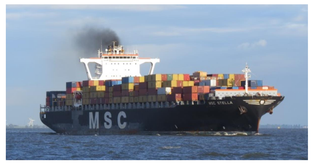
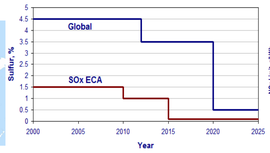


1. Motivation

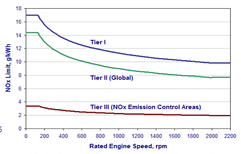
The dangers of shipping emissions:

- Impact on marine tropospheric chemistry, ecology and climate (formation of ozone and aerosols, acidification, albedo)
- Strong health effects on people living in harbor cities and coastal regions
- Especially dangerous with combustion of heavy oil fuels, with high sulfur content and strong soot emission

ECA zones around the world



Reduction of sulphur content in heavy oil fuel within SECA zones and globally as determined by MARPOL Annex VI



Limitation of NOx emission by engines, built after 2000 (Tier I), 2011 (Tier II), and 2016 (Tier III)

Political Measures:

- Convention of the International Marine Organization (IMO) for Prevention of Marine Pollution from Ships (MARPOL 73/78 Annex VI)
- Limitation of sulfur content in heavy oil fuels in Sulfur Emission Controlled Areas (SECA)
- Establishment of general Emission Controlled Areas (ECA)
- Regulation of NO_x emissions from newly built marine engines [4)]

2. Objectives

MeSMarT – a cooperation between University Bremen, Federal Maritime and Hydrographic Agency, and Helmholtz Zentrum Geesthacht

- How is the actual situation of air pollution over the North and Baltic Sea and what is the contribution of shipping emissions?
- How do the political regulations influence the air quality?
- Which methods are suitable for long term monitoring of shipping emission?
- Is it possible to reproduce measured data with state-of-the-art modelling?
- How can we observe and controll the compliance of the shipping emission regulations?

3. Measurement technique

Airpointer from MLU

	SO_2	NO, NO_2, NO_x	O_3	CO_2
Measuring principle	UV-fluorescence (EN 14212)	Chemilumine-scence of NO (EN 14211)	UV-absorption (EN 14625)	Non-dispersive IR-spectroscopy LI-COR LI820
Detection limit	0.25 ppb	0.4 ppb	0.5 ppb	1 ppm
Measuring range	< 10 ppm	< 20ppm	< 200 ppm	< 20000 ppm
Time period	< 90 s	< 60 s	< 30 s	1 s

The Airpointer is a comercially available system, combining four different instruments in a compact, climatized housing.

How to estimate the sulfur fuel content of passing ships with insitu measurements:

$$\%S\ in\ fuel = \frac{S\ [kg]}{fuel\ [kg]} = \frac{\Delta SO2\ [ppb] \cdot A(S)}{\Delta\ CO2\ [ppm] \cdot A(C)} \cdot 87\ \%$$

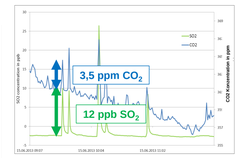
$$= \frac{\Delta\ SO2}{\Delta\ CO2} \cdot 0{,}232$$

with A(S), A(C) = atomic mass of sulfur, carbon

Assumptions:

- 87% of carbon in fuel
- 100% of carbon and sulfur is converted to CO_2 and SO_2

Example:



Ciudad de Cadiz:

$$\%\ S\ in\ fuel = \frac{12\ ppb}{3{,}5\ ppm} \cdot 0{,}232 = 0{,}79\ \%$$

(Caution: Measurement uncertainity : 15% according to Berg et. al. 2012)

If peaks have the same width, the height difference is enough for the calculation, for more complicated peaks, the peak area is needed

4. Wedel

Site: Wedel

- Next to the river Next to the river Elbe at the entrance of Hamburg harbour, about 500 m away from passing ships

http://www.marinetraffic.com/ais/de/

Comparison between bunker oil analysis by BSH and exhaust peak analysis

Bunker Oil analysis by BSH

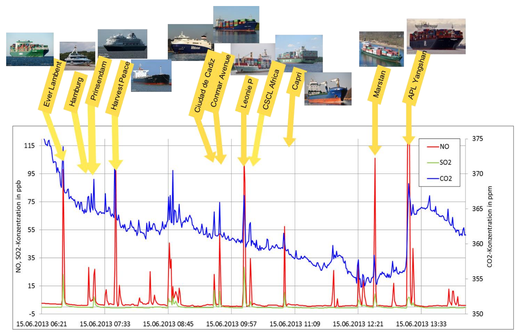
2010 until April 2013	number [n]	% of total
Analyzed samples:	271	100%
< 0,1 % S	117	43 %
≥ 0,149 % S	104	38 %
≥ 1,0 % S	13	5 %

Exhaust plume analysis

30 days in May/June 2013	number [n]	% of total
Analyzed peaks: (with sign. SO_2/CO_2)	379 147	100%
< 0,1 % S (no SO_2 detectable)	232	57 %
≥ 0,149 % S	145	45 %
≥ 1,0 % S	18	4 %

0.1 % S in fuel allowed during berth, according to harbour guideline, soon limitation for the whole North and Baltic Sea – actual limit is 1%

- Within 3 years the BSH analyzed 270 bunker oil samples to check compliance with harbour guiedelines, ships were chosen due to irregularities in fuel log books
- Within 30 days, 380 ships could be controlled by exhaust plume measurements



Peak analysis in Wedel

- At good conditions easily distinguishable peaks with similar shape, easy to associate to passing ships via AIS information (AIS = Automatic Identification System)
- Problem: high and strongly varying CO_2 background due to vegetation

Conclusion Wedel

- ✓ Perfect location for observing incoming and outgoing ships from Hamburg harbour and estimating their sulfur fuel content
- ✓ Could be used as a guidance for official control agencies wether to take fuel samples
- Needs to be further automatized to be useful – online data access and real time output
- – Ships are already on the Elbe river, no control in open water on the North Sea
- – Large background signals from traffic, harbour, airport and vegetation

5. Neuwerk

Site: Neuwerk

- Northeast of Cuxhaven, in the Wadden Sea, close to the main shipping route through the German Bight

http://www.marinetraffic.com/ais/de

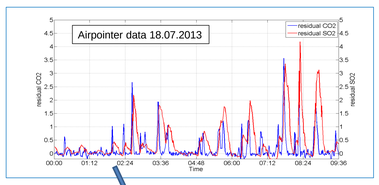
More challenging conditions on Neuwerk:

- Ships are 6 to 10 km away from measurement stations
- Few times with northerly winds during measurement period

Restrictions on wind for successful measurements:

- Wind direction between 300° and 90°are the only ones with ships and without land influence
- wind speed between 3 and 20 m/s, too slow wind leads to accumulation, too fast wind dilutes the peaks

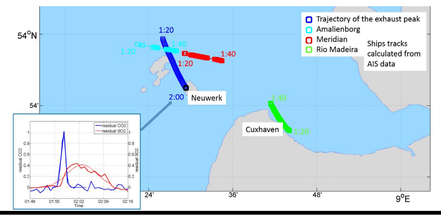
A thick brown layer of exhaust above the main shipping route, seen on Neuwerk



Peak analysis in Neuwerk:

- Peak area has to be estimated for calculation instead of peak height
- Trajectories are needed to find the ship
- Transport of plume up to 45 min to reach measurement station
- Possible mixing of different plumes

Peaks have to be analyzed carefully with peak fitting – Different shape because of signal broadening due to transport and different temporal resolution of instruments



Conclusion Neuwerk

- ✓ Good location to observe ships on the open water, but still close enough to the coast
- ✓ Scientifically interesting for studying the behaviour of ship exhaust plumes in a clean environment without other sources
- More complicated analysis is needed
- – If the exhaust peak cannot be associated with a single ship due to long transport and mixing, sulfur fuel analysis is not possible
- – Few good days of data collection because of the strong dependance on good wind conditions and lack of northerly winds

Further information

For more information aobut the project MeSMarT: www.mesmart.de

Here on the EGU: Poster in Session AS3.12/GI2.10:
EGU2014-12919 "Monitoring shipping emissions with MAX-DOAS measurements of reactive trace gases" by Folkard Wittrock et al.
Session AS4.5/GI2.2:
EGU2014-4334 „Airborne measurements of NO2 shipping emissions using imaging DOAS" by Andreas C. Meier et al.

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Selected references

- International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005) *http//:www.imo.org/…regulation-13* http://www.imo.org/blast/mainframe.asp?topic_id=1709&doc_id=10262
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- Moldanovà, J. et al., 2009. Characterisation of particulate matter and gaseous emissions from a large ship diesel engine. Atmospheric Environment 43, 2632–2641.
- Berg, N. et al., Ship Emission Measurements by the Chalmers IGPS System during the Rotterdam campaign 2009, Report