Measurements of Shipping Emissions in the Marine Troposphere: an option to trigger a targeted MARPOL (VI) compliance monitoring?

Stefan Schmolke, Lisa Kattner, Barbara Mathieu-Üffing, Folkard Wittrock
The Member States shall take all necessary measures to **check by sampling** that the sulphur content of fuels used complies with the regulations. It shall be carried out periodically with **sufficient frequency** and quantities in such a way that the samples are **representative** of the fuel being used by vessels while in relevant sea areas and ports.
EU Implementing Act

The EU Commission is preparing implementing acts to enforce the sulphur directive 2012/33/EC

- Minimum sampling frequency
- Sulphur Inspection Guidelines (Sampling Guidelines)
- Rules concerning the content and format of the annual reporting obligations

➢ To achieve health and environmental benefits.
➢ To avoid competitive advantages by using high sulphur bunker oil
The challenge

What is a sufficient frequency?
How can we get a representative sample (information) of the fuel being used?

- **basic population**
  - 15 blue
  - 05 red
  - 25% red

- **Case 1**
  - 08 blue
  - 01 red
  - 11% red

- **Case 2**
  - 02 blue
  - 02 red
  - 50% red

As smaller the number of non compliant ships is, as more effort is needed to detect them.
Enforcement of MARPOL (VI) rules by targeted bunker oil monitoring (sampling)

The challenge is, to know the fuel (bunker oil) quality from as much ships as possible, just to find these ones which doesn’t comply to the current rules. What, if each ship would just carry a flag, indicating the bunker oil quality currently in use? In this case we could just pick out the black sheep!

The stack emission plume of each ship in operation carry this information. The only question is whether it is possible to read it.
The MeSmarT Project (2012 to 2015)

Measurements of shipping emissions in the marine troposphere

**satellite and land based remote sensing**
(MAX-DOAS) Multi Axis Differential Optical Absorption Spectroscopy

**ground based insitu measurements**
(+ meteorology, AIS)

**Eulerian transport and deposition modelling**

- $\text{CO}_2$
- $\text{NO}$, $\text{NO}_2$, $\text{NO}_x$
- $\text{SO}_2$
- $\text{O}_3$
Project Measurement sites and platforms

**RV Celtic Explorer**

**Neuwerk**
6-7 km to navigation canal

**Wedel (Hamburg)**
0.5 km to navigation canal

2012 to 2014

Diagram showing the locations of Neuwerk and Wedel in the context of navigation canals.
1. Insitu-Measurements

Just a brief view on the Insitu-Measurements

- CO$_2$
- NO, NO$_2$, NO$_x$
- SO$_2$
- O$_3$
Instrumentation Insitu-Measurements

**MLU** Messtechnik für Luft und Umwelt *Airpointer*

**Horiba** integrated trace gas monitor
One day of measurements in Wedel (15.6.2013)

well distinguishable individual ship stack emission peaks
Identification of individual ship emission

Association of exhaust plume signals to individual ships, via combination of AIS ship information and local meteorological data

<table>
<thead>
<tr>
<th>Name</th>
<th>type</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ciudad de Cadiz</td>
<td>Cargo</td>
<td>125x25</td>
</tr>
<tr>
<td>Conmar Avenue</td>
<td>Cargo</td>
<td>151x24</td>
</tr>
<tr>
<td>Leonie P</td>
<td>Cargo</td>
<td>139x24</td>
</tr>
<tr>
<td>CSCL Africa</td>
<td>Cargo</td>
<td>331x43</td>
</tr>
</tbody>
</table>

1.): (0,79 ± 0,11) %S in fuel
2.): (0,56 ± 0,08) %S in fuel
3.): (0,92 ± 0,13) %S in fuel
4.): (0,29 ± 0,04) %S in fuel
Stack plume measurement / bunker oil analysis

Stack plume measurement 30 days

<table>
<thead>
<tr>
<th>30 days in May/June 2013</th>
<th>Number [n]</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzed peaks (with sign. SO$_2$/CO$_2$)</td>
<td>458/166</td>
<td>100%</td>
</tr>
<tr>
<td>$&lt; 0,1$ % S</td>
<td>292</td>
<td>64%</td>
</tr>
<tr>
<td>$\geq 0,1$ and $&lt; 1,0$ % S</td>
<td>143</td>
<td>31%</td>
</tr>
<tr>
<td>$\geq 1,0$ % S</td>
<td>23</td>
<td>5%</td>
</tr>
</tbody>
</table>

Bunker oil analysis Hamburg 3 years

<table>
<thead>
<tr>
<th>2011 – April 2013</th>
<th>Number [n]</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of analyzed samples</td>
<td>271</td>
<td>100%</td>
</tr>
<tr>
<td>$\geq 0,1$ % S</td>
<td>154</td>
<td>57%</td>
</tr>
<tr>
<td>$\geq 0,149$ % S</td>
<td>104</td>
<td>38%</td>
</tr>
<tr>
<td>$\geq 1,0$ % S</td>
<td>13</td>
<td>5%</td>
</tr>
</tbody>
</table>

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2. The Remote sensing Method

Remote sensing: MAX-DOAS
Multi-Axis Differential Optical Absorption Spectroscopy

- Detection of column densities of trace gases for different optical path
- Vis spectrometer (400 – 570 nm) for NO₂ measurements
- UV spectrometer (315 – 385 nm) for SO₂ measurements
The Remote sensing Method

A short glance on the potential of the remote sensing techniques

**Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS)**

- Vis spectrometer (400 – 570 nm) for NO₂ measurements
- UV spectrometer (315 – 385 nm) for SO₂ measurements

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NO$_2$ measurement in Neuwerk

Comparison of in-situ and MAX-DOAS measurements: (wind direction equal to viewing direction of DOAS instrument)

NO$_2$–VMR (Neuwerk, 24.08.2013)

Time delay of in situ measurements due to transport of the air
Aircraft measurements (iDOAS)

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Online **ship emission monitoring** to trigger targeted fuel sampling.

Available tools and necessary further development

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Parameter</th>
<th>😊</th>
<th>😞</th>
</tr>
</thead>
<tbody>
<tr>
<td>in-situ measurement</td>
<td>SO₂, NO, NO₂, CO₂, O₃, PM</td>
<td>- independent of sunlight</td>
<td>- dependent on local meteorology and atmospheric transport processes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- almost standard instrumentation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- broad set off parameter possible</td>
<td></td>
</tr>
<tr>
<td>optical remote sensing (MAX-DOAS, iDOAS)</td>
<td>NO₂, SO₂, ...</td>
<td>- independent of local meteorology</td>
<td>- dependent on daylight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- aircraft measurements in elevated altitudes possible</td>
<td>- CO₂ detection not possible.</td>
</tr>
<tr>
<td>optical remote sensing active light source</td>
<td>NO₂, SO₂, ...</td>
<td>- as above, but also independent on sun light.</td>
<td>- CO₂ detection not possible.</td>
</tr>
</tbody>
</table>

Further effort is need to develop:

**Software** for quality assured automated trace gas signal processing and related ship identification (integrated local meteorological and AIS signal processing).

**IT-Infrastructure** for central data handling, interpretation and distribution.

**Monitoring network** stepwise graded extension (prioritized)

**Certified remote sensing system (Airborne Maritime Surveillance)**, may under the frame of the Co-operation on Aerial Surveillance over the North Sea Area (Bonn agreement).
Conclusion

- Ship emission surveillance monitoring can boost the efficiency of targeted sampling.
- There are currently a variety of complementary featured monitoring methods available.
- The operational service of a monitoring network needs further development of
  - quality assured automated signal processing software
  - advanced data management and network technology
  - extended monitoring network
  - data exchange/dissemination mechanism
- The current MeSMarT project could act as a nucleus of a future ship emission monitoring network. It is currently funded until 09/2015.
- Ship emission monitoring as an option to trigger a targeted MARPOL (VI) compliance monitoring is under intense discussion in German administration, but a final decision about its operational implementation has not been made so far.
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