Monitoring shipping emissions in the German Bight using MAX-DOAS measurements

André Seyler[1] (a.seyler@uni-bremen.de), Folkard Wittrock[1], Lisa Kattner[1,2], Barbara Mathieu-Üffing[1,2], Enno Peters[1], Andreas Richter[1], Stefan Schmolke[2], Andreas Weigelt[2] and John P. Burrows[1]

[1]Institute of Environmental Physics (IUP), University of Bremen, Germany
[2]Federal Maritime and Hydrographic Agency (BSH), Hamburg, Germany

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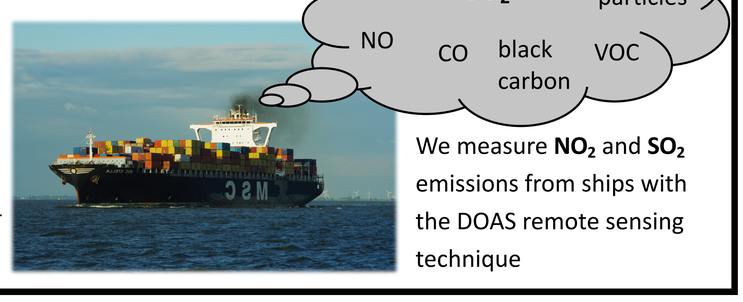
Why measure shipping emissions?

- Shipping is generally the most energy efficient transportation mode (per t per km)
- Shipping accounts for ≈ 80% of total merchandise worldwide trade volume
- Seaborne trade grows fast, despite the economic crisis
- Capacity of global merchant fleet doubled in the last decade

⇒ Shipping accounts for a significant part of the emissions from the transportation sector

- Emissions of NO_2 from high temperature combustion (nitrogen and oxygen from ambient air)
- Emissions of SO_2 directly linked to fuel sulfur content
- Local scale: affecting air quality and harmful for human health
- Global scale: changing atmospheric composition and impact on climate

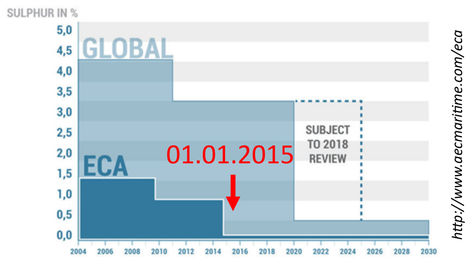


We measure **NO_2** and **SO_2** emissions from ships with the DOAS remote sensing technique

Important change in existing regulations

- International Maritime Organization (IMO): Convention for Prevention of Marine Pollution from Ships (MARPOL 73/78 Annex VI)
- Establishment of general Emission Controlled Areas (ECA)
- NOx emission limits for newly built engines
- Limitation of sulfur content in heavy oil fuels

⇒ since January 2015 only 0.1% sulfur is allowed (before: 1%) in ECAs like North Sea and Baltic Sea



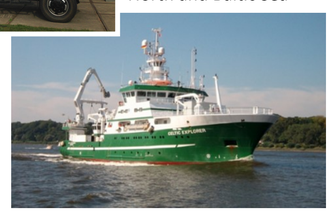
MeSMarT project

- "**M**easurements of **S**hipping Emissions in the **Mar**ine **T**roposphere" – a project coordinated by the University of Bremen with support of the German Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH) and the Helmholtz Zentrum Geesthacht (HZG)
- **MeSMarT measurement sites and platforms:**

MAX-DOAS on radar tower Neuwerk (see below)

MAX-DOAS Wedel

Measurement truck: mobile air quality monitoring station



RV Celtic Explorer: Several ship cruises on North and Baltic Sea

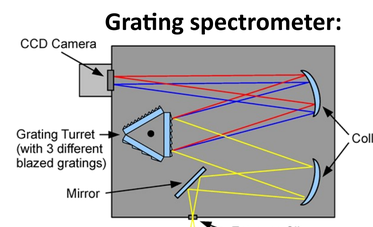
White numbers: Annual ship movements

Map: http://www.bing.com/maps/ (01.04.2014), Data: http://www.wsv.de/ (09.05.2014)

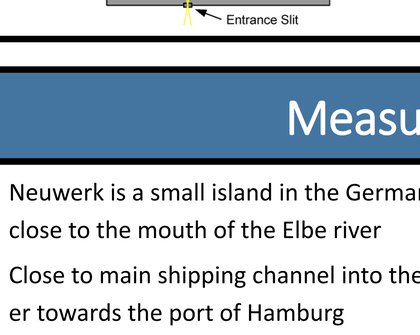
MAX-DOAS measurement geometry

- **DOAS** = **D**ifferential **O**ptical **A**bsorption **S**pectroscopy
- Measure spectra of back-scattered sunlight from the atmosphere, fit absorption cross sections of multiple absorbers (e.g. NO_2, O_3, H_2O, O_4) simultaneously to measured optical depth
- Retrieved quantity: Slant column density = Concentration of absorber integrated along the light path

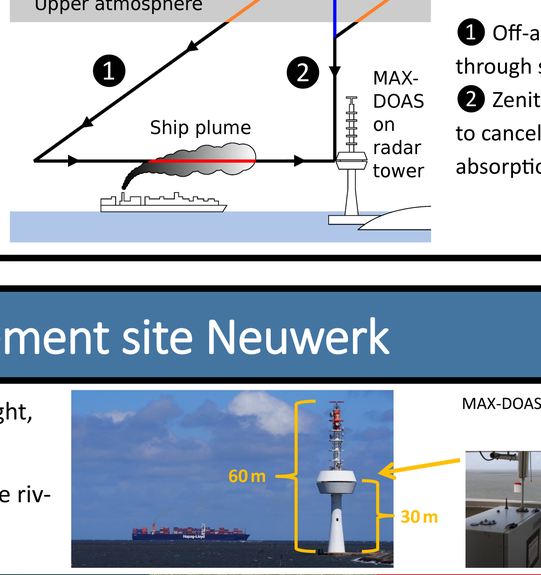
MAX-DOAS instrument setup:



Grating spectrometer:



Measurement geometry:

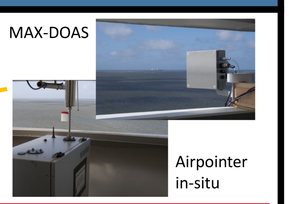


Light source: the sun

❶ Off-axis measurement through ship plume
❷ Zenith-sky reference to cancel out stratospheric absorption

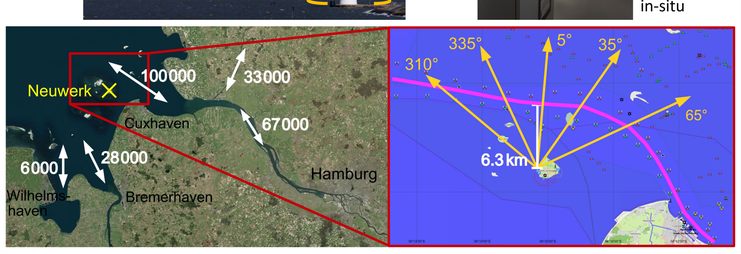
Measurement site Neuwerk

- Neuwerk is a small island in the German Bight, close to the mouth of the Elbe river
- Close to main shipping channel into the Elbe river towards the port of Hamburg
- From July 2013 until July 2016
- Two channel MAX-DOAS (UV, vis)
- Multiple azimuthal viewing directions to cover the region and main shipping lane



MAX-DOAS

Airpointer in-situ



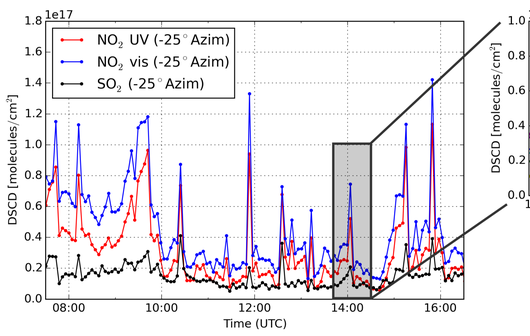
White numbers: Annual ship movements

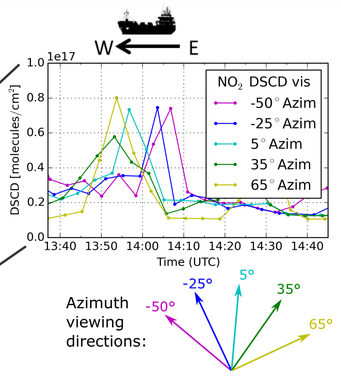
Map: http://www.bing.com/maps/ (01.04.2014), Data: http://www.wsv.de/ (09.05.2014)

Results

Measured slant column densities of NO_2 and SO_2:

- Slant column densities of NO_2 and SO_2 measured on Neuwerk on Wednesday, 23 July 2014 in 0° elevation and -25° azimuth
- High and sharp peaks: pollution plumes emitted from ships
- Enhanced coastal background pollution in the morning





- NO_2 Peaks in azimuthal viewing directions (zoom) show movement direction of ship (east to west)

Wind sectors:

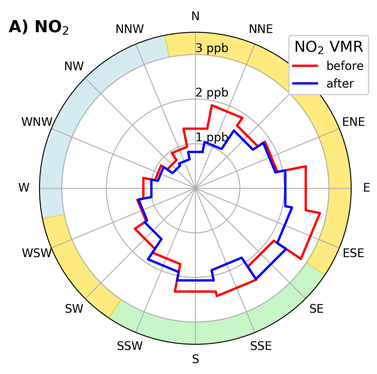
Classification:

- Blue sector: wind from open North Sea, shipping is the only pollution source
- Green sector: mainly land-based air pollution (traffic, industry, …)
- Yellow sector: air mass contains shipping emissions as well as land-based air pollution (mixed origin)

Dependence of NO_2 and SO_2 pollution levels on wind direction:

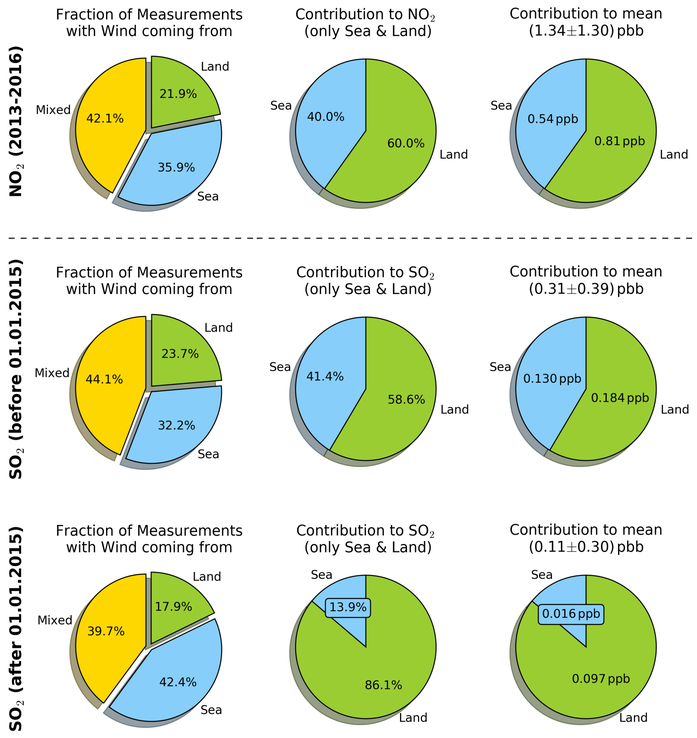
- Red curve: before 1 January 2015
- Blue curve: after 1 January 2015
- NO_2: No regulations → no significant change in emission
- SO_2: Allowed fuel sulfur content dropped from 1.0 % to 0.1 % (MARPOL 73/78 Annex VI)

  → significantly lower SO_2 emissions, especially from the open North Sea



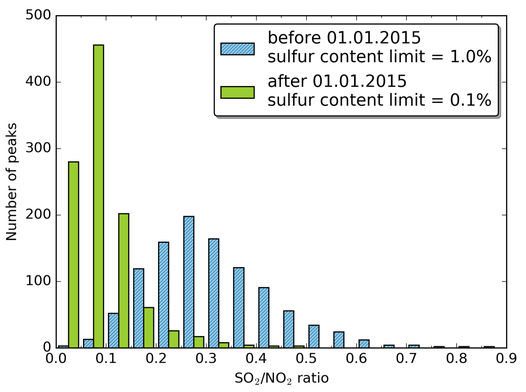
Contributions of ships vs. land-based pollution sources on coastal air quality on Neuwerk:

- To trade ship emissions off against land-based emissions (e.g. industry, road transport), two representative sectors of wind directions have been chosen (blue and green sectors in map above)
- Excluding data with mixed air mass origin, the contribution of shipping sources to pollution on Neuwerk is around 40% for both NO_2 and SO_2 in the years 2013 and 2014, a significant, but surprisingly small fraction
- Since January 2015, the relative contribution of shipping sources was reduced to 14%, the absolute amount decreased by a factor of 8
- Since 2015, the vast majority of SO_2 emissions can be attributed to land sources, ships play only a negligible role



SO_2 to NO_2 ratios in ship plumes

- Emission factors cannot be measured by MAX-DOAS directly
- Ratio of SO_2 to NO_2 in ship plumes gives a good estimate of the SO_2 to NO_x emission ratio of the ships
- More than 2000 individual ship plumes were identified in the data and analyzed for the SO_2 to NO_2 ratio
- Results varied between ships (different sulfur content in fuel) but on average yielded values of about 0.3 for the years 2013/2014 → good agreement with results from other studies (Diesch et al., 2013; McLaren et al., 2012)
- Implementation of stricter sulfur limits in shipping fuel lead to a large reduction in SO_2 to NO_2 ratios → good agreement with Kattner et al. (2015), who found that 95% of the ships are sticking to the new limits



Conclusions

- MAX-DOAS can measure emission peaks from single ships as well as background pollution
- The overall contribution of ship emissions to pollution levels at the measurement site is large but land based sources still dominate, even in the immediate vicinity of shipping lanes
- Fuel sulfur limit regulations are working: Significant reduction of SO_2 emissions since January 2015

For further information on shipping emission measurements: *Comprehensive study of NO_2 and SO_2 from shipping emissions measured with on-shore in-situ instruments,* talk by Lisa Kattner, UP 9.4, Wednesday 17:45, GW2 3009

Acknowledgements
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