Impact of Sulfur Regulations of Shipping Fuels on Coastal Air Quality

André Seyler[1], 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

Contact: aseyler@iup.physik.uni-bremen.de

EGU 2016
Session: AS 3.9
Poster: X2.422

③ MeSMarT project

= "Measurements 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 (BSH) and the Helmholtz Zentrum Geesthacht

- **Aims:**
  - Measure ship emissions in the marine environment, comparison with satellite and model data
  - Investigate their impact on the atmospheric boundary layer
  - Development of a concept for controlling ship emissions
- **Operational area:** German Bight and Baltic Sea
- **Stationary measurement sites:**

Neuwerk: ≈6 km to navigation channel in the mouth of Elbe

Wedel: ≈0.5 km to navigation channel of Elbe river close to Hamburg

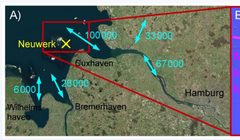
Mobile measurements:

RV Celtic Explorer
(Marine Institute, Galway, Ireland)
Several campaigns in the German Exclusive Zone

Monitoring car:
Mobile measurement station equiped with MAX-DOAS and in-situ devices

④ 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 (passes the island in the north)
- Instruments installed on a radar tower in a height of 30m
- Two channel MAX-DOAS (UV, visible), viewing towards the main shipping lane
- In-situ measurements of SO_2, NO_x, O_3, and CO_2 with trace gas monitor in ambient air
- Weather and wind data
- Automatic Identification System (AIS) signal, broadcasted from ships

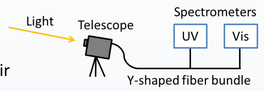


Numbers: Annual ship movements
Map: http://www.bing.com/maps/ (01.04.2014), Numbers. http://www.wsv.de/ (09.05.2014)

Azimuthal MAX-DOAS viewing directions covering the shipping lane
http://www.freie-tonne.de, based on OSM data

Radar tower with installed MAX-DOAS and Airpointer in-situ instrument

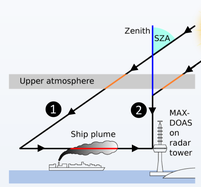
- Setup of ground-based Multi-Axis-DOAS (MAX-DOAS) instrument:



- Pan/Tilt head: Allows vertical and horizontal scanning

⑤ MAX-DOAS measurement geometry

- **DOAS = D**ifferential **O**ptical **A**bsorption **S**pectroscopy
- Idea: 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 (SCD)
  = Concentration of the absorber integrated along the light path



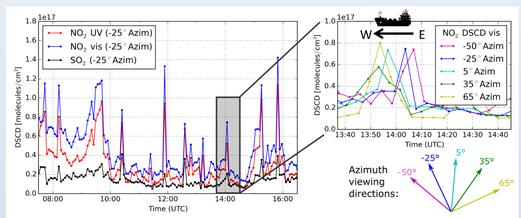
❶ Off-axis measurement through ship plume
❷ Zenith-sky reference to cancel out stratospheric absorption

MAX-DOAS measurement geometry

- SCD to volume mixing ratio (VMR): Use oxygen collision complex O_4 as a tracer for the effective horizontal light path length (Gomez, 2014)
- Result: Horizontal path-averaged volume mixing ratio

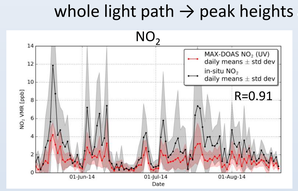
⑥ Measured slant column densities of NO_2 and SO_2

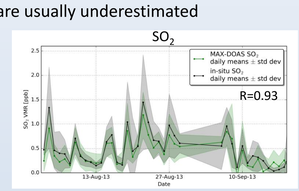
- Slant column densities of NO_2 and SO_2 measured on Neuwerk on Wednesday, 23 July 2014 in 0° elevation (left): High and sharp ship emission peaks, enhanced coastal background pollution in the morning
- NO_2 Peaks in azimuthal viewing directions show movement direction of ship (right)



⑦ Daily means: Comparison of MAX-DOAS with in-situ volume mixing ratios

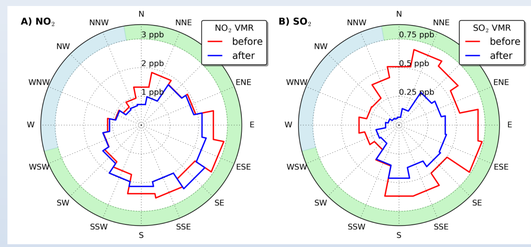
- Good agreement in progression of curves
- In-situ values systematically higher → expected, because MAX-DOAS averages over long light path and plumes usually never cover the whole light path → peak heights are usually underestimated





⑧ Mean VMR depending on wind direction

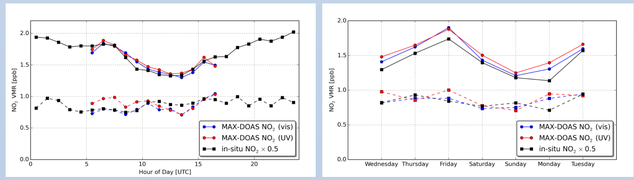
- Red curve: before 1 January 2015
- Blue curve: after 1 January 2015
- Blue sector: Wind from open North Sea, shipping is the only source
- Green sector: Wind from the coastline, air mass contains shipping emissions as well as land-based air pollution (traffic, industry, …)



- **NO_2: No regulations → no 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 sector

⑨ Impact of land-based pollution on air quality in the German Bight

- All NO_2 measurements (solid line): Clearly visible diurnal (left) and weeky cycle (right)
- Ship traffic should not depend on weekday and hour of day → it has to be road traffic emissions from land

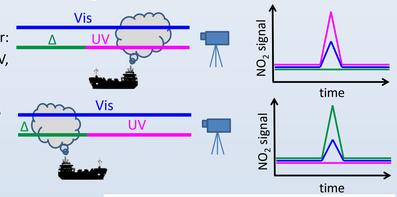


- Only wind from open North Sea (dashed): Cycle vanishes, significantly lower values
- Although Neuwerk is 8 km away from the coast, land-based air pollution strongly influences air quality on the island

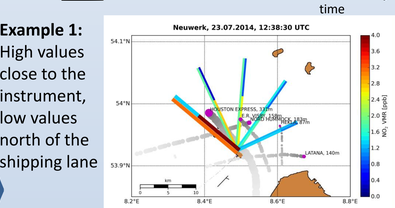
⑩ Horizontal distribution of plumes

- Light path length in the atmosphere depends on wavelength: Shorter light path in UV, longer light path in visible
- Typical horizontal light path length: ≈10 km in UV, ≈15 km in vis
- Idea: Retrieve information on spatial distribution and movement of ship plumes (so called "onion peeling approach")
- Calculate ΔVMR of NO_2 from ΔSCD and ΔPath

Plume close to the radar tower:
High peak in UV, no signal in Δ

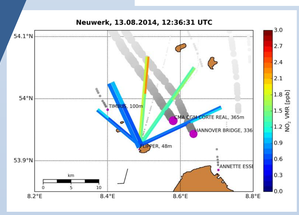


Plume 10 to 15 km away: High peak in Δ, no enhancement in UV data



Example 1:
High values close to the instrument, low values north of the shipping lane

Example 2:
- High NO_2 concentrations 10 to 15 km away from our instruments
- In-situ device cannot see plumes



⑪ Conclusions

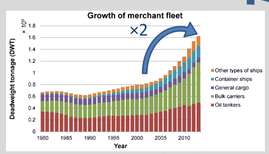
- **MAX-DOAS can measure emission peaks from single ships as well as background pollution**
- **Good agreement with in-situ measurements**
- **Fuel sulfur limit regulations are working: Significant reduction of SO_2 emissions since January 2015**
- **Land-based air pollution has a strong influence on AQ**
- **Retrieval of horizontal distribution of plumes possible**

① Motivation: Shipping emissions

- Shipping
  - is the most energy efficient transportation mode (per t & km)
  - 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

→ Significant contribution to emissions from transportation sector

- Emissions of CO_2, CO, NO_x (= NO+**NO_2**), **SO_2**, black carbon (BC), volatile organic compounds (VOC) and particulate matter (PM)
- Emissions of NO_2 from high temperature combustion (nitrogen and oxygen from ambient air)
- Emissions of SO_2 directly linked to the fuel sulfur content
- Local scale impact: affecting air quality and human health
- Global scale impact: changing atmospheric composition and climate

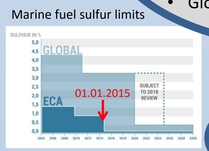


Data: http://unctadstat.unctad.org

② 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)
- Limitation of sulfur content in heavy oil fuels, in ECAs since January 2015 only 0.1% sulfur is allowed
- NO_x emission limits for newly built engines (up to now: only USA)

Marine fuel sulfur limits



http://www.aecmaritime.com/eca

http://www.green4sea.com/

Sector with wind from the open North Sea, where ship emissions are the only source of air pollution

https://commons.wikimedia.org/wiki/File:North_Sea_relief_location_map.jpg

Further information: visit www.mesmart.de and www.iup.uni-bremen.de/doas/

Acknowledgements
This project is funded by the "Federal Ministry of Transport and Digital Infrastructure", part of the instruments have been funded by the University of Bremen.
The authors thank the staff of the BSH Laboratory in Hamburg-Sülldorf for their assistance and their great support.
Many thanks also The „Wasser- und Schiffahrtsamt Cuxhaven and Hamburg" and the Hamburg Port Authority (HPA).

Selected references

Gomez, L. et al, Long-path averaged mixing ratios of O_3 and NO_2 in the free troposphere from mountain MAX-DOAS, Atmos. Meas. Tech., 7, 3373-3386, 2014.
Eyring, V., et al., SeaKLIM (Impact of Ship Emissions on Atmosphere and Climate), Final Report (2010)
Kattner, L. et al., Monitoring compliance with sulphur content regulations of shipping fuel by in-situ measurements of ship emissions, ACP, 15.17, pp. 10087–10092, 2015.

This poster as PDF: