MeSMarT – Measurements of Shipping Emissions in the Marine Troposphere

Universität Bremen EXZELLENT
BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

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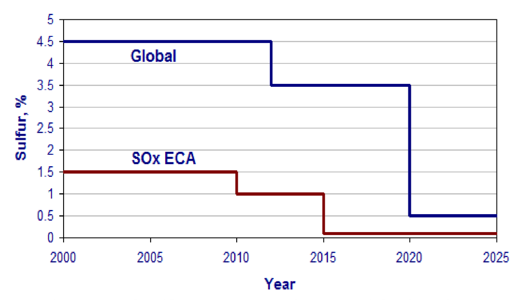
www.mesmart.de

1. Motivation

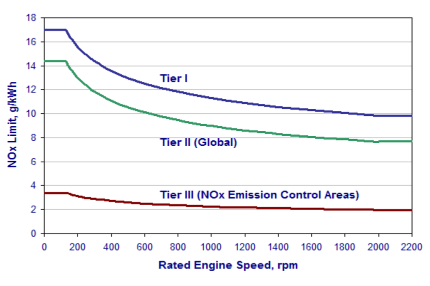
Shipping emissions:
- Pollution components: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs), black carbon (BC), polycyclic aromatic hydrocarbons (PAH), particulate matter (PM)
- Impact on marine tropospheric chemistry, ecological and climatic effects (formation of ozone and aerosols, acidification, albedo)
- Health risk (pulmonary/cardiovascular) for people living in harbor cities and coastal regions
- Especially dangerous due to combustion products from heavy oil fuels with high sulfur content and strong soot emission
- **Capacity of global merchant fleet has doubled since 2000 -> fraction of shipping emissions on global emissions is increasing**

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

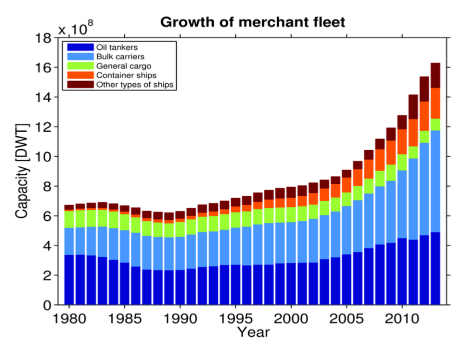
ECA zones around the world



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



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



Source: http://unctadstat.unctad.org

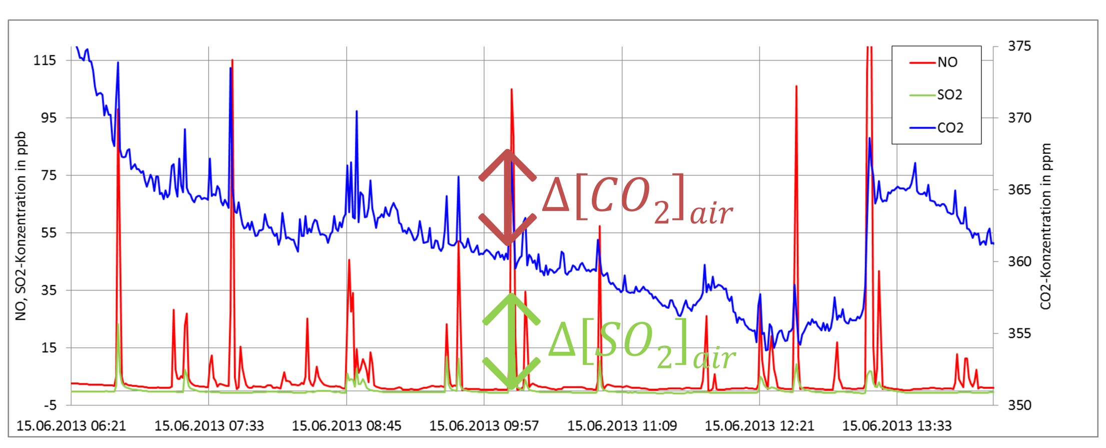
2. Objectives

MeSMarT – a projected coordinated by the University Bremen with support of the Federal Maritime and Hydrographic Agency and the Helmholtz Zentrum Geesthacht

- Assessment of different measurement systems such as remote sensing, in-situ, and passive sampling measurements as methods for long-term monitoring of shipping emissions in the North and Baltic Sea
- Improvement of ship emission data bases by measurements of the actual distribution of trace gases and aerosols related to ship emission
- Validation of satellite measurements and model data
- Description of the influence of ship emissions and its secondary products on the marine environment
- **Development of a concept for controlling ship emissions**

5. Determination of sulfur content in fuel

1. In situ measurements of distinct emission peaks of individual passing ships (here exemplarily shown for one day in June 2013 for the site on the right bank of Elbe in Wedel)

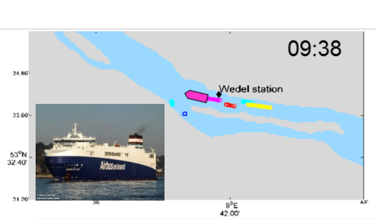


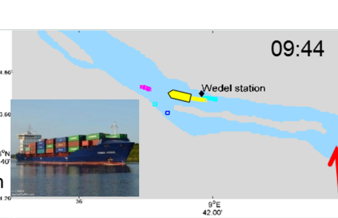
2. Calculation of fuel sulfur content [%]:

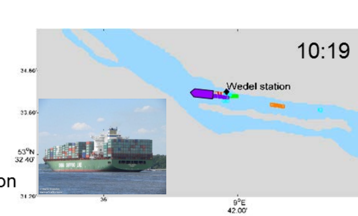
$$[S]_{fuel} = \frac{\Delta[SO_2]_{air}}{\Delta[CO_2]_{air}} \cdot 0{,}232$$

according e.g. to Cooper et al., 2005

3. Analysis of wind situation and identification of emitting Ships by AIS



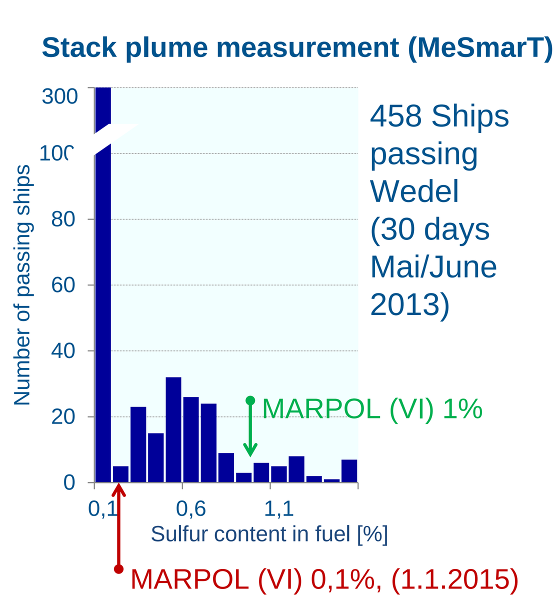




Ciudad de Cadiz (built 2009)	Conmar Avenue (built 2012)	Leonie P (built 1997)	CSCL Africa (built 2005)
RoRo Cargo Ship, L: 125 m	Container ship, L: 151 m,	Container Ship, L: 139 m	Container ship, L: 331 m
0,87 ± 0,17 %S in fuel	0,58 ± 0,11 %S in fuel	1,11 ± 0,22 %S in fuel	0,42 ± 0,08 %S in fuel

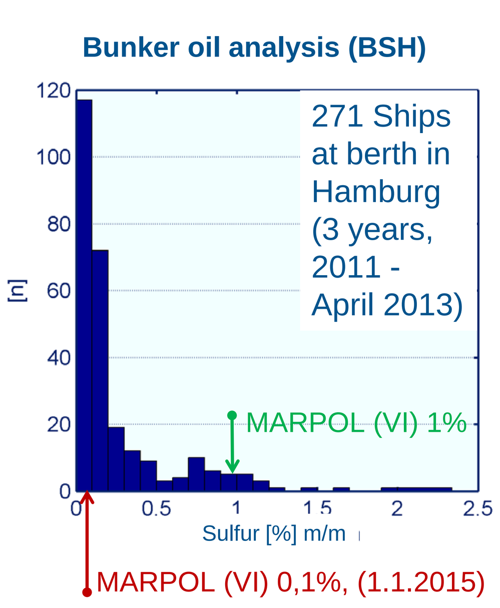
Statistics for Wedel site (close to Hamburg harbor):
- More than half of these ships apparently use fuel with <0.1% Sulfur and therefore stick to regulation for ports.
- However 30-40% of the analyzed ships won't pass the controls after January 2015
- About 5% violate the existing regulation.
- Calculation results are statistically compliant with analysis results of bunker oil samples from single ships at berth taken by port authorities during the last three years.
- With an uncertainty of ca. 20% the FSC can be calculated for an individual passing ship. Preconditions are:
  - significant peaks for CO_2 and SO_2
  - wind from direction of the ships for the in situ measurements or
  - daylight for DOAS measurements.
- So both methods together provide a possibility to get information about the emissions of many vessels and not at berth but with engines at work.

Stack plume measurement (MeSMarT)



30 days in May/June 2013	Number[n]	% of total
Analyzed peaks (with signif. SO_2/CO_2)	458 166	100%
< 0,1 % S	292	64 %
≥ 0,1 to < 1,0 % S	143	31 %
≥ 1,0 % S	23	5 %

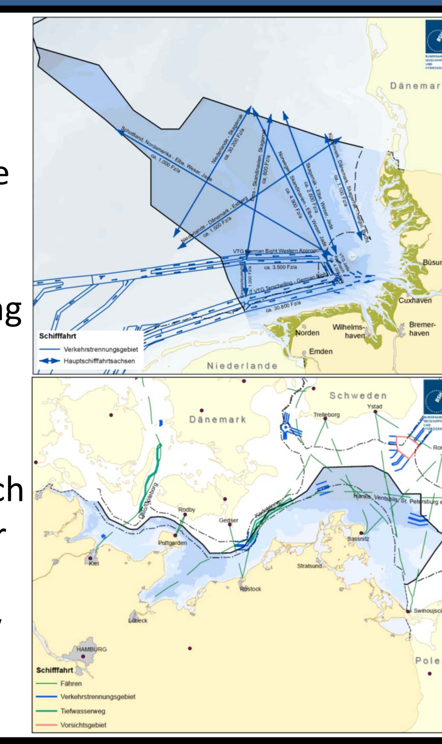
Bunker oil analysis (BSH)



2011 – April 2013	Number [n]	% of total
Total number of analyzed samples	271	100%
≥ 0,1 % S	154	57 %
≥ 0,149 % S	104	38 %
≥ 1,0 % S	13	5 %

3. Operational area and platforms

German Bight and Baltic Sea:
- German Exclusive Economic Zone, with 12-nm-zone und main shipping routes
- An area already covered with extensive research concerning water quality and oceanography by BSH



Ship (routinely used by BSH):

RV Celtic Explorer

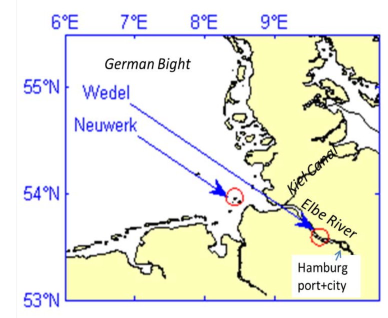
Airplane (on campaign basis only):

Cessna 207 Turbo (operated by FU Berlin)

Stationary Platforms:

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

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

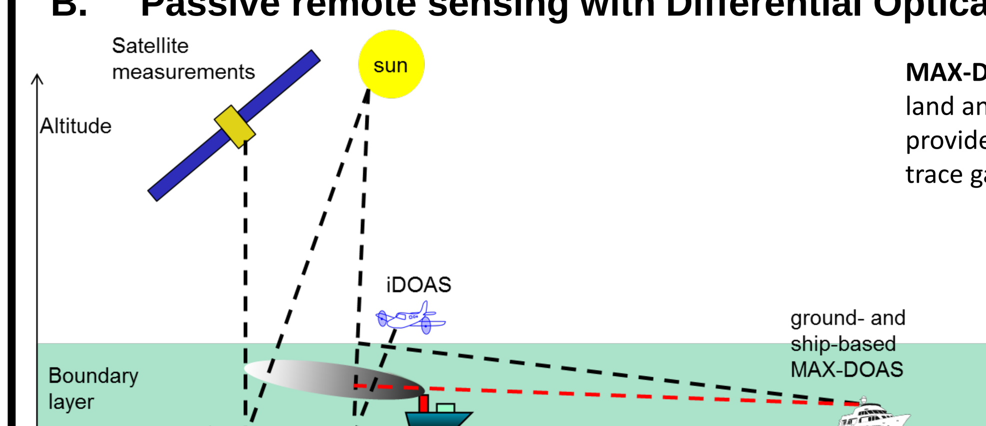


4. Methods

A. Continuous in situ measurements: with trace gas monitor in ambient air

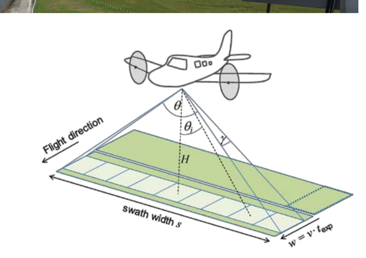
	SO_2	NO, NO_2, NO_x	O_3	CO_2
Measuring principle	UV-fluorescence (EN 14212)	Chemiluminescence of NO (EN 14211)	UV-absorption (EN 14625)	Non-dispersive IR-spectroscopy LI-COR LI820
Detection limit	0.25 ppb	0.4 ppb	0.5 ppb	1 ppm
Measuring range	< 10 ppm	< 20ppm	< 200 ppm	< 20000 ppm
Time period	< 90 s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

B. Passive remote sensing with Differential Optical Absorption Spectroscopy (DOAS)



MAX-DOAS: Multi-axis observations from land and ship – different lines of sight provide a 3-dimensional picture of the trace gas of interest

AirMAP (iDOAS): Airborne imaging DOAS provides good spatial coverage at a fine spatial resolution (up to 30x70 m²), facilitates separation of NO_x sources close together



Detection:

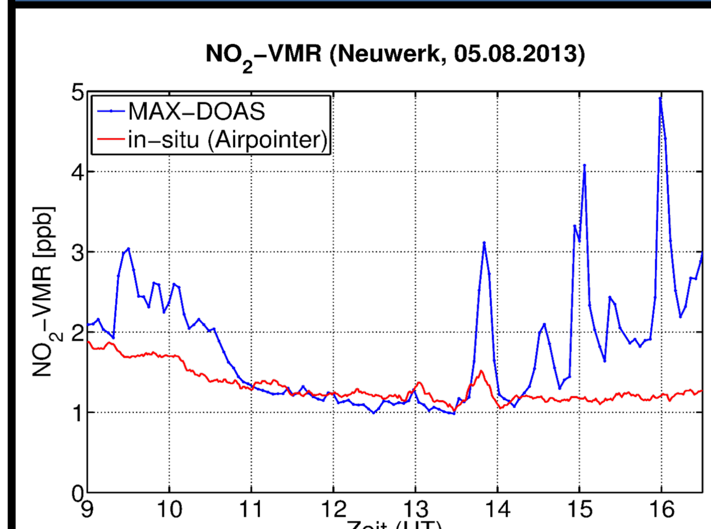
UV/vis (300 to 570 nm) measurement of scattered sunlight, Differential Optical Absorption Spectroscopy – DOAS to get the averaged absorption along all contributing light paths -> Slant Column

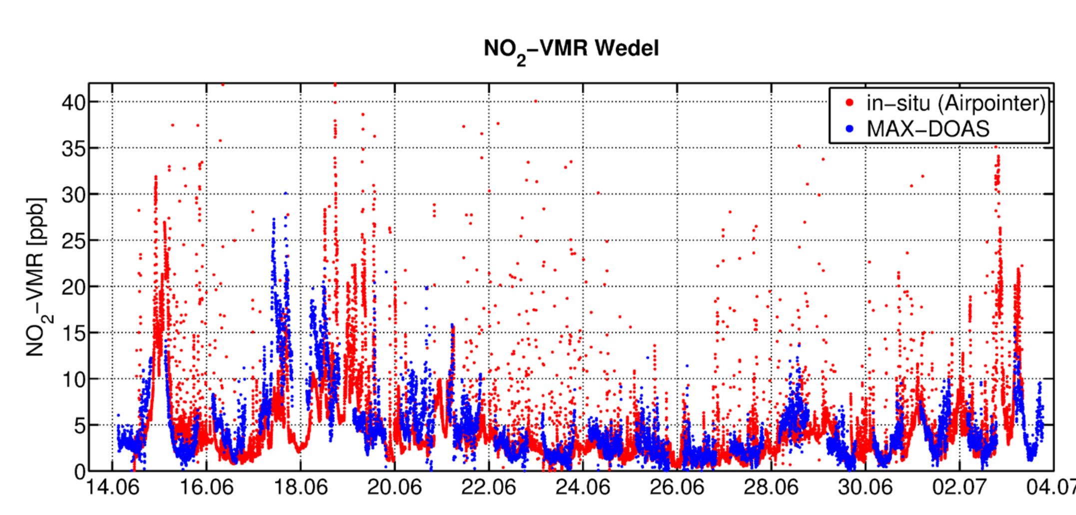
Further retrieval:

Radiative transfer calculations depending on several meteorological parameters (e.g. albedo, aerosol) to calculate **vertical columns and profile information (VMR) for NO_2 and SO_2**

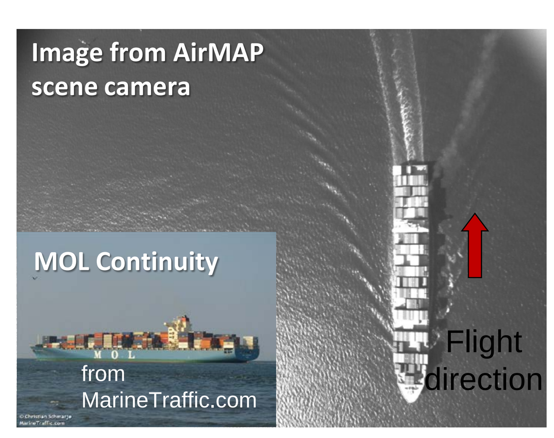
Detection limits (MAX-DOAS) NO_2 ~50 ppt, SO_2 ~200 ppt for typical viewing conditions, time resolution 1 to 5 min

6. Further exemplary results

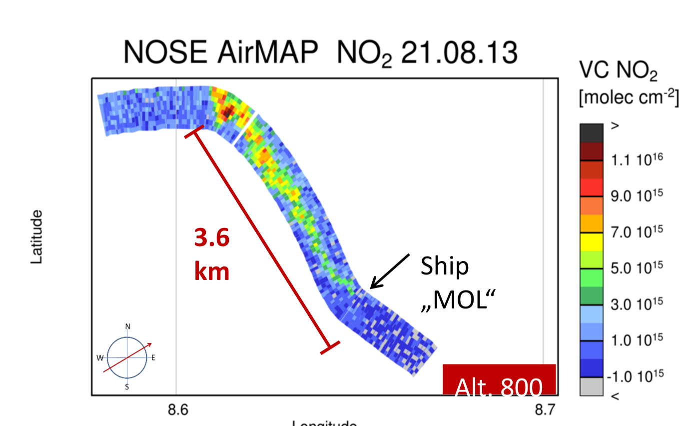




- Upper figures show comparisons between MAX-DOAS and in situ observations of NO_2
  - Left figure illustrates the capability to observe single ship peaks with MAX-DOAS even for a situation when the wind direction prevails the detection with the in situ instrument
  - In contrast the right figure shows the very good correlation between both methods for favorite conditions



- Figures to the left and right:
- Individual ship plumes can be observed with the AirMAP
- Measurements can contribute to a better understanding of plume evolution and NO -> NO_2 conversion



6. Conclusions and outlook

- Optimization of measuring conditions to calculate the sulfur content in the fuel (distance to ships, position concerning wind situation and other emission sources, time resolution)
- Validation of calculated sulfur content by comparison with bunker oil analyses
- Quality assurance by comparison to other state-of-the-art methods
- establishing a control system /"distant early warning system" for port authorities with sequencing sampling on board from ships suspected to use high sulfur fuel
- Efforts to better understand and control NO_x emission from ships
- Validation of chemical and transport models for simulation of the influence of shipping emissions (in cooperation with the Helmholtz Zentrum Geesthacht)
- Building up a network of remote sensing and in situ instruments nearby shipping lanes at German coast to control future emission regulations.

Acknowledgements

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Selected references

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