# Monitoring Shipping Emissions with MAX-DOAS Measurements of Reactive Trace Gases

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## 1. Motivation

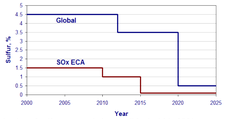
**Shipping emissions**:

- 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**

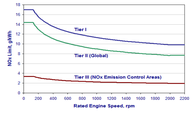
**Political Measures**:

- 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), starting Jan 2015 only 0.1% sulfur is allowed**
- Establishment of general Emission Controlled Areas (ECA)
- Regulation of $NO_x$ emissions from newly built marine engines

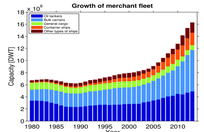
ECA zones around the world




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)




Growth of merchant fleet (from 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
- **Establishment of remote sensing instruments like MAX-DOAS to support the surveillance of international emission regulations**
- 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**

## 3. Operational area and platforms

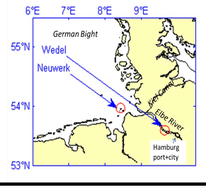
**German Bight and Baltic Sea**:

- 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

**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, the biggest German harbor

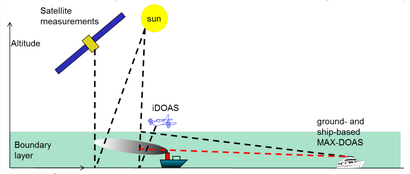



**Ship** (routinely used by BSH):

RV Celtic Explorer (Marine Institute, Galway, Ireland) Up to now three camapigns in the German Exclusive Zone

## 4. Methods

**A. Passive remote sensing with Differential Optical Absorption Spectroscopy (DOAS) using different platforms**
here only MAX-DOAS results from the ground are presented




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

**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:**

Using $O_4$ and $H_2O$ as proxys for the effective light path to calculate **profile information (VMR) for $NO_2$ and $SO_2$**

Detection limits $NO_2$ ~100 ppt, $SO_2$ ~200 ppt for typical viewing conditions, time resolution 1 to 5 min

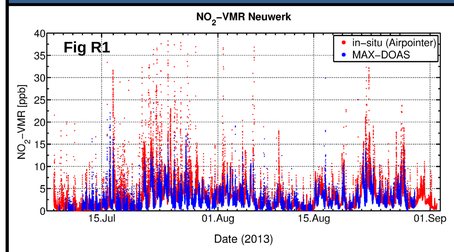
**B. Continuous in situ measurements**: with trace gas monitor in ambient air

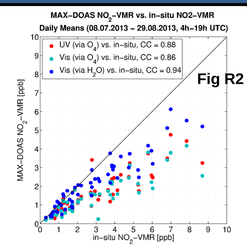
| | $SO_2$ | NO, $NO_2$, $NO_x$ | $O_3$ | $CO_2$ |
|---|---|---|---|---|
| Measuring principle | UV-fluorescence (EN 14212) | Chemiluminescence of NO (EN 14211) | UV-absorption (EN 14625) | Non-dispersive IR-spectroscopy LI-COR LI820 |
| Detection limit | 0.25 ppb | 0.4 ppb | 0.5 ppb | 1 ppm |
| Measuring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

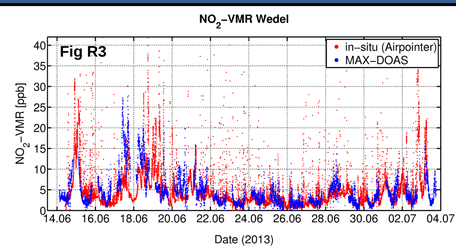
**Complementary data:**

- In situ observations of $SO_2$, $NO_x$, $O_3$, and $CO_2$ – see poster Kattner et al. for details
- Meteorological data (wind speed, direction), precipitation, temperature, humidity, total radiation
- AIS (Automatic Identification System) data are recorded locally at each site to get detailed information (e.g. position, velocity, course, size) on passing ships

## 5. Selected Results and Discussion



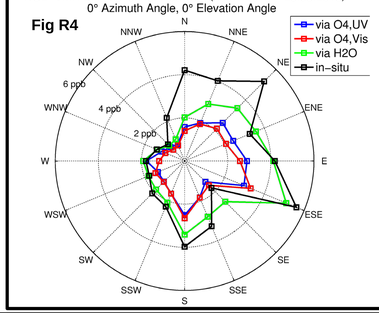




**Further interpretation of data:**

- Figure R6 illustrates exemplarily how the MAX-DOAS measurements can be used to estimate emissions from single ships
- AIS and meteorological data are used to assign single peaks in the $SO_2$ time series to specific ships passing the measurement site, the $NO_2$ to $SO_2$ ratio (numbers close to the peaks) together with information on the engine load (speed) of the ships allows to estimate the fuel quality
- For the ships monitored on that day sulphur contents of 0.2 (Maersk Taurus) to 2% (Frederik) are assessed
- Changing numbers for one ship reflect the NO to $NO_2$ conversion within the plume

NO2–VMR Distribution for Neuwerk (09.07.2013 – 29.08.2013)
0° Azimuth Angle, 0° Elevation Angle




**MAX-DOAS vs. in situ data:**

- Figures R1 to R5 show comparisons of MAX-DOAS with in situ data both for $NO_2$ and $SO_2$
- In particular for the Neuwerk site the best agreement was found when using water vapour as a proxy for the effective light path
- Since ship plumes usually never cover the whole light path very high peaks are usually underestimated (notably for Wedel where the distance to passing ships is ~500m, Figure R3)
- The distribution of $NO_2$ and $SO_2$ depending on the wind direction (Figures R4 and R5) illustrate nicely the impact of the shipping lanes north and east/southeast of Neuwerk

SO2–VMR Distribution for Neuwerk (03.08.2013 – 29.08.2013)
0° Azimuth Angle, 1° Elevation Angle

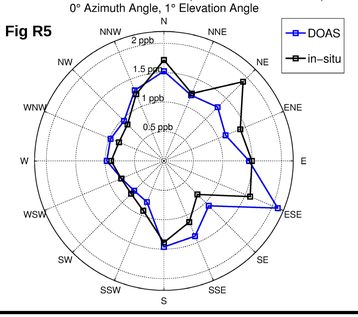
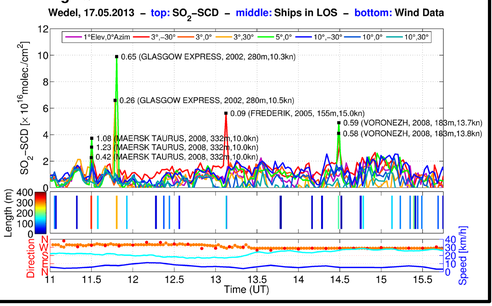



**Fig R6**




## Further information

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

Here on the EGU: Poster
EGU2014-11100 "Monitoring shipping emissions with in situ measurements of trace gases" by Lisa Kattner et al.
and
EGU2014-4334 „Airborne measurements of NO2 shipping emissions using imaging DOAS" by Andreas C. Meier et al.

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## Selected references

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