Airborne measurements of NO_2 shipping emissions using imaging DOAS

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1. Motivation

Why should NO_x be measured?

- NO_x (NO + NO_2) plays a key role in tropospheric chemistry
- It is harmful for health and ecosystems

Why are shipping emissions measured?

- Shipping emissions contribute substantially to global emissions of anthropogenic NO_x (approx. 13% , estimated for the year 2000)
- In coastal areas, they can be a relevant source of air pollution
- Global merchant fleet has doubled since 2000 → relative importance of shipping emissions is increasing

Why do we need airborne measurements of NO_2?

Airborne imaging DOAS (iDOAS) can fill the gap between :

- satellite (global long-term coverage, coarse spatial resolution)
- in-situ / ground based stations (high sensitivity, limited spatial coverage)

- With its good spatial coverage at a fine spatial resolution it can resolve spatial variability of NO_x and facilitates the separation of point sources close together

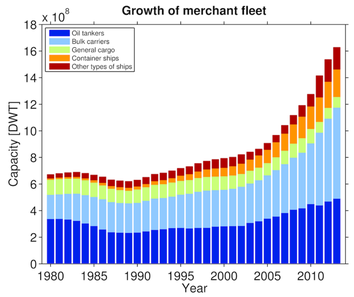

Fig. 1: Evolution of the global merchant fleet in the period 1980-2013
http://unctadstat.unctad.org

2. Instrumental setup and method

Technical information

- Wide angle objective and fibre bundle (35 fibres) as entrance optics
- Acton 300i imaging spectrometer
- Grating 600l/mm, blazed @500nm
- Spectral window 415 - 455nm
- Spectral resolution 0.7 - 1.0nm
- Frame transfer (FT) CCD Detector, 512x512 pixels, 8.2x8.2 mm²

→Gap-free measurements (due to FT CCD) and flexible positioning in aircraft (due to sorted fibre bundle)

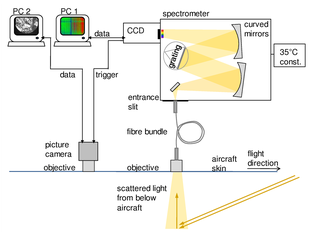

Fig. 2: Instrumental setup

Viewing geometry

- θ opening angle / FOV across track ~ 48°
- θ_i individual viewing angle of direction i (max. 35, typ. 9)
- γ opening angle/FOV along track ~ 1.5°
- s side length of pixel across track
- w side length of pixel along track
- H flight altitude ~ 1400m
- v aircraft speed (typ. 60m/s)
- t_{exp} exposure time typ. 0.5s

@alt=1400 m, ground speed=60 m/s	VD = 9 (typ.)	VD= 35 (max)
Ground pixel size	130 x 30 m²	36 x 30 m

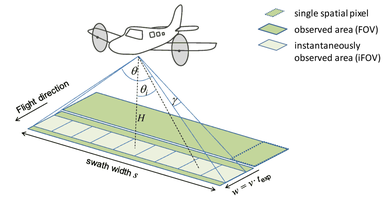

Fig. 3: The iDOAS viewing geometry

Method

- Differential optical absorption spectroscopy (DOAS)
- Imaging spectrometer retains spatial information
- NO_2 is retrieved in the visible spectral range
- Fitting window (425 – 450 nm)
- Reference spectrum taken in a rural scene with low NO_2
- Air mass factor applied assumes constant albedo of 5%, no aerosols

Instrument on aircraft

- Cessna 207 Turbo
- Operated by FU Berlin

Aircraft

Instrument rack

2 nadir ports

3. Observation of NO_2 over shipping lane

- High variability of NO_2 vertical column densities
- Shipping lanes north of Neuwerk can be clearly identified
- Vertical column densities (VCD) up to ~1 x 10^{16} molec / cm^2 above background

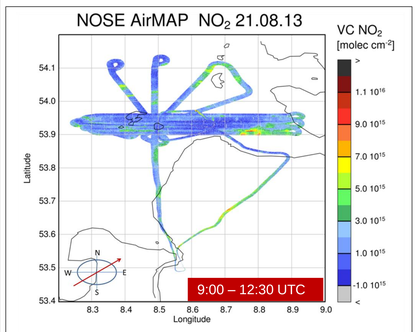

Fig.4: Overview over the whole flight on the 21.08.2013 around Neuwerk, a small island in the Elbe estuary, close to shipping lanes. Compass shows wind direction.

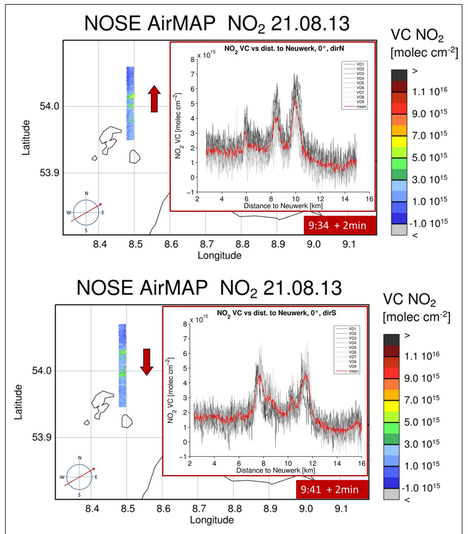

Fig.5: Two sequences of the flight over shipping lane. Flight in northern direction (top) and southern direction (bottom). Grey lines show the retrieved VCDs for individual viewing directions, red line is the mean over all viewing directions. Red arrow indicates the flight direction.

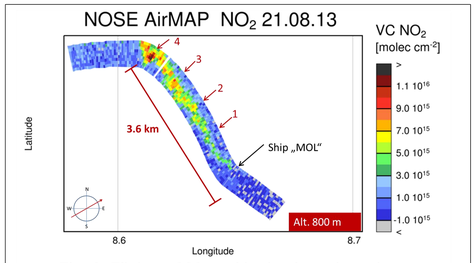

Fig. 6: Flight at 800 m altitude along the exhaust plume of an individual container ship

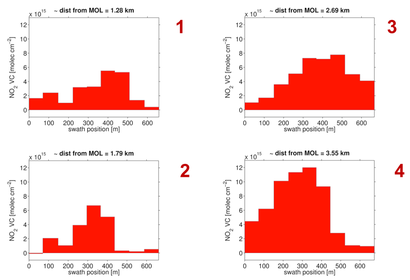

Fig. 7: Cross-sections of the plume at different distances as denoted in Fig. 6.

- Low level flight over an individual ship
- Flight track along the exhaust plume
- Plume almost fully covered over a distance of ~3.6 km
- NO_x is emitted as NO at the stack and subsequently converted to NO_2 in the atmosphere
- Evolution of the plume can be observed by the instrument
- Observed VCD increase up to 1.2 x 10^{16} molec / cm^2

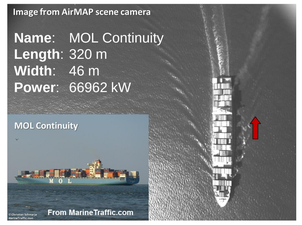

Fig. 8: Photographs of the ship, red arrow denotes the flight direction

4. Summary & Outlook

- Instrument operated successfully
- NO_2 from shipping emissions can be observed
- Measurements can contribute to better understanding of plume evolution and NO → NO_2 conversion
- Meteorological / AIS-ship data will be used to assign measured NO_2 VCD to emission sources
- Comparison with MAX-DOAS data from Neuwerk under way
- Improvement of instrumental setup to allow simultaneous retrieval of SO_2

Selected references

- Heue et. al.: „Direct observation of two dimensional trace gas distributions with an airborne Imaging DOAS instrument“. *Atmos. Chem. Phys* 8: 6707–17, 2008
- Berg, N. et.al.: „Ship emissions of SO_2 and NO_2: DOAS measurements from airborne platforms“. *Atmospheric Measurement Techniques* 5 (5): 1085–98, 2012
- Schönhardt et.al.: „A Wide Field-of-View Imaging DOAS Instrument for Continuous Trace Gas Mapping from Aircraft“. *Atmospheric Measurement Techniques Discussions* 7 (4): 3591–3644, 2014

Acknowledgements

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Related posters

- Schönhardt et. al.; today; Z182
- Wittrock et al.; 30 APR; Z115

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