Experimental imaging DOAS observations over Bremen

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Introduction

Measurement principle: Differential Optical Absorption Spectroscopy (DOAS)

- Based on Lambert-Beer's law
- High-frequency part of (known) absorption structures σ are fitted to optical depth τ
- DOAS equation (I and are I_0 are measured):

$$\tau_{meas} = \ln\left(\frac{I_0}{I}\right) = \sum_i \sigma_i(\lambda)\cdot SC_i + polynomial + residual$$

- Result: Slant columns $SC_i = \int \rho_i \cdot ds$ (absorber concentration ρ integrated over light path s)

- I_0 measured usually in zenith direction
- Current Multi-Axis (MAX-DOAS) instruments are able to point in any direction allowing several elevation and azimuth directions

Limitations of current MAX-DOAS instruments:

- Only one measurement in a certain pointing direction per time
- Full hemispheric coverage not possible as being too time-consuming

→ Vertical scans (sequence of different elevations) performed in limited azimuthal directions only, or horizontal scan (sequence of different azimuths) performed in limited elevations

Aim of this work:

- Using an imaging spectrometer to perform measurements in multiple viewing directions simultaneously
- In addition: Mounting the entrance optics on a pan-tilt-head

→ Full hemispheric coverage on the time scale of minutes

Instrument

Instrument characteristics:

- Adaptation from an air-borne DOAS instrument [1].
- Outdoor parts: Entrance optic (Camera objective, 48° FOV) mounted on commercial ENEO VPT-501 pan-tilt-head, 100°/s)
- Optical fiber bundle consisting of 38 single glass fibers vertically aligned in the same sequence at either end (35 mapped on CCD)

→ allows optical imaging and flexible positioning of the instrument

- Indoor parts: Acton SP-2300i imaging spectrograph (temperature stabilized to 35°C, 413-499 nm, 0.7-1 nm resolution) in combination with a frame-transfer CCD (PhotonMAX) camera (cooled), electronics, computers.

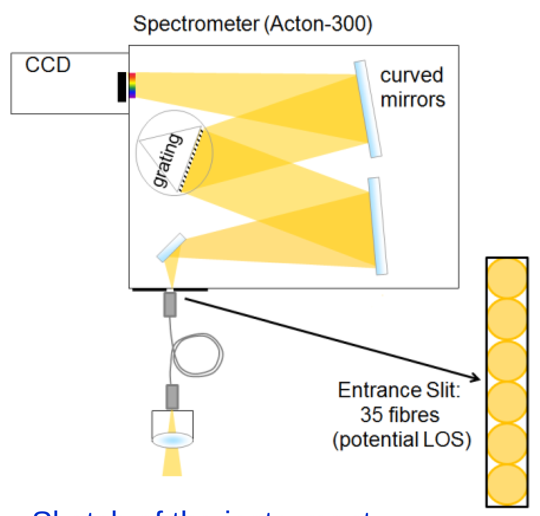

Fig 1: Sketch of the instrument comprising entrance optic (outdoor), optical fiber, and spectrometer (indoor) [3].

Advantage of the instrument:

- Due to the combination of special fiber bundle and imaging spectrometer the spatial information of the radiance is retained

→ 35 equally spaced vertical viewing directions (elevation angles) of 1.2° each

- Pan-tilt-head allows azimuthal changes while 35 elevations are measured simultaneously

→ Full hemispheric coverage each 6 minutes.

- Installed at roof of IUP-Bremen building from June to July 2014.

Fig 2: Entrance optic providing 35 elevations simultaneously mounted on pan-tilt-head for azimuthal movement.

Azimuthal NO_2 distribution over Bremen

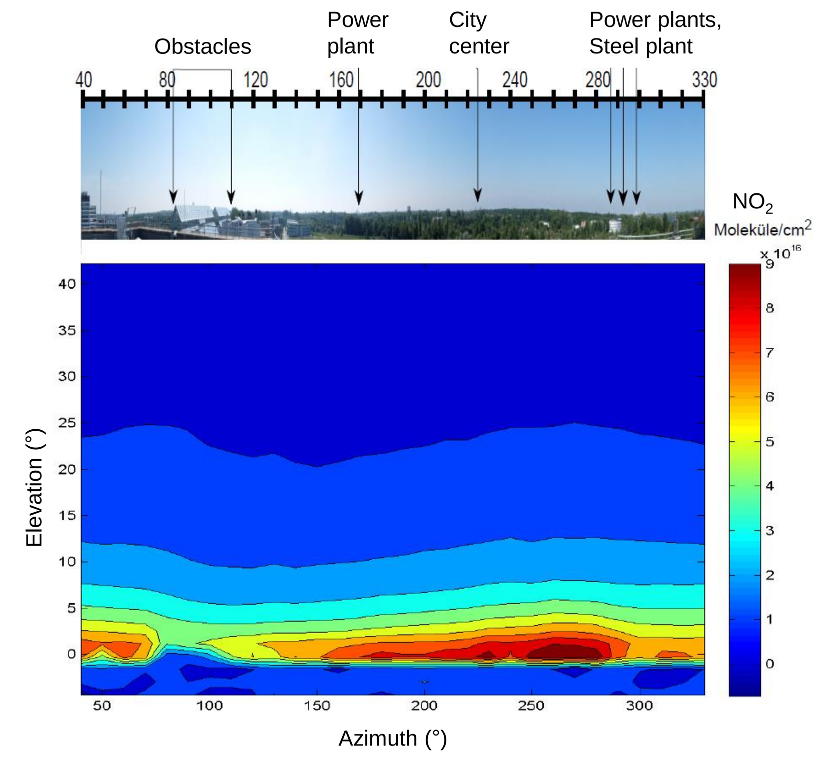

Fig 3: Top: Panorama view from IUPB roof. Bottom: Mean NO_2 SCs on 23 July 2014 [2]. (Negative elevations obstructed by building)

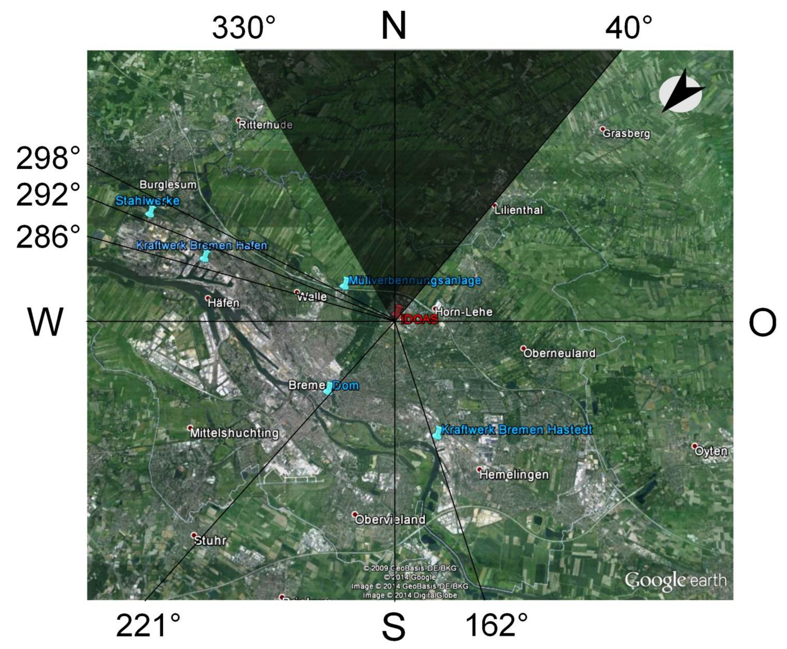

Fig 4: Aerial view of Bremen. Azimuthal viewing directions and possible point sources are Indicated [2].

- Azimuthal scans from 40° N to 330° N in 10° steps, integration time: 10 s
- No measurements between 330° and 40° N due to obstruction by building
- Pan-tilt-head allows recording zenith spectra after each azimuthal scan
- Using closest zenith spectrum as reference I_0
- NO_2 DOAS fits: 425-450 nm, resp. 425-490 nm (O_3, NO_2, O_4, H_2O, Ring, intensity offset)

- Wind direction at 23 July 2014 (Fig. 3 and 5): North-East (as indicated in Fig. 4)
- Generally larger NO_2 in direction of the city
- Largest NO_2 pollution from near-by power and steel plants (in Fig. 3 shifted because of wind direction)
- No enhanced NO_2 detected for power plant further away (see Fig. 4)

- Azimuthal distribution of other trace gases (O_4, H_2O) demonstrate influence of measurement geometry (position of the sun)

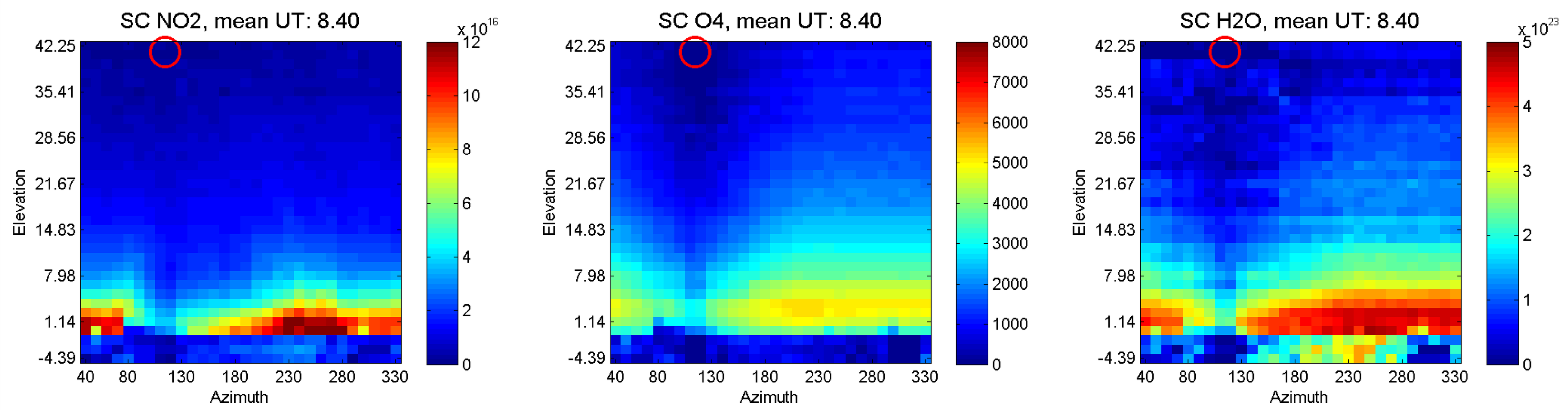

Fig 5: Example of a single 6 min azimuthal scan from 23 July 2014 (morning). Left: NO_2, middle: O_4, right: H_2O. Cloud-free sky. The position of the sun is indicated by a red circle. (DOAS fit here: 425-490 nm).

References

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Intercalibration & Outlook

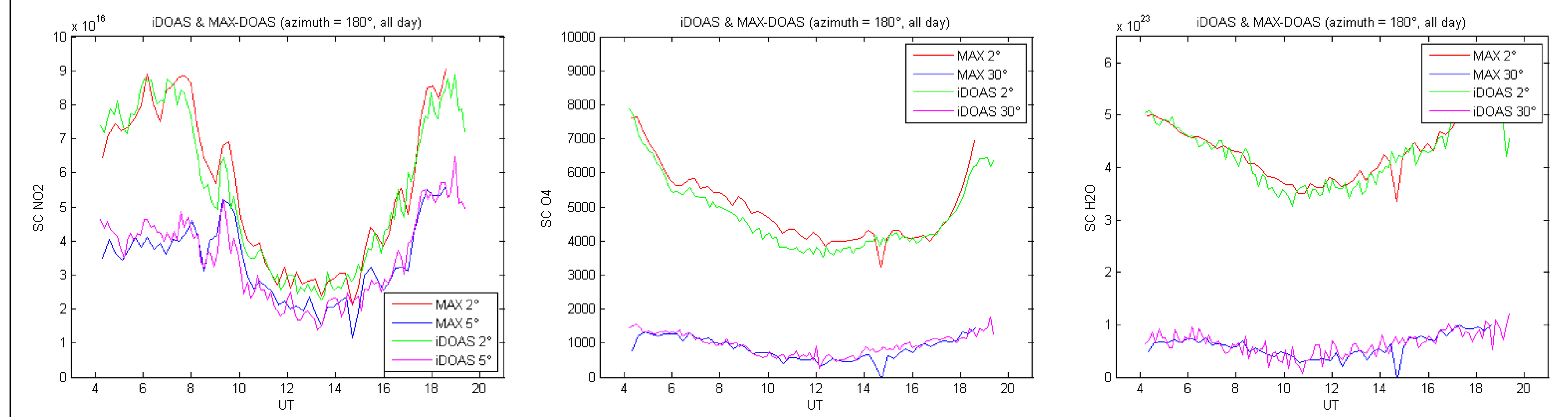

Fig 6: Intercomparison of the resulting slant columns of NO_2 (left), O_4 (middle) and H_2O (right) in 180° azimuth and different elevation angles between the imaging DOAS instrument and a MAX-DOAS instrument operated close-by.

Intercalibration results:

- Intercalibration was possible with a close-by MAX-DOAS instrument operated routinely
- Generally good agreement between MAX-DOAS and experimental imaging DOAS instrument was found for all trace gases
- MAX-DOAS and imaging DOAS did not point at exactly the same time in the same direction
- MAX-DOAS spectra were recorded using full vertical (software) binning of the CCD rows (expected to yield better results due to averaging)

Possible further applications:

- Measurements of O_4 could be used to study the effect of viewing geometry and aerosols on the resulting slant columns
- Retrieving aerosol information simulating O_4 via radiative transfer model (here: SCIATRAN)
- Possibly cloud flags could be elaborated when investigating cloudy days

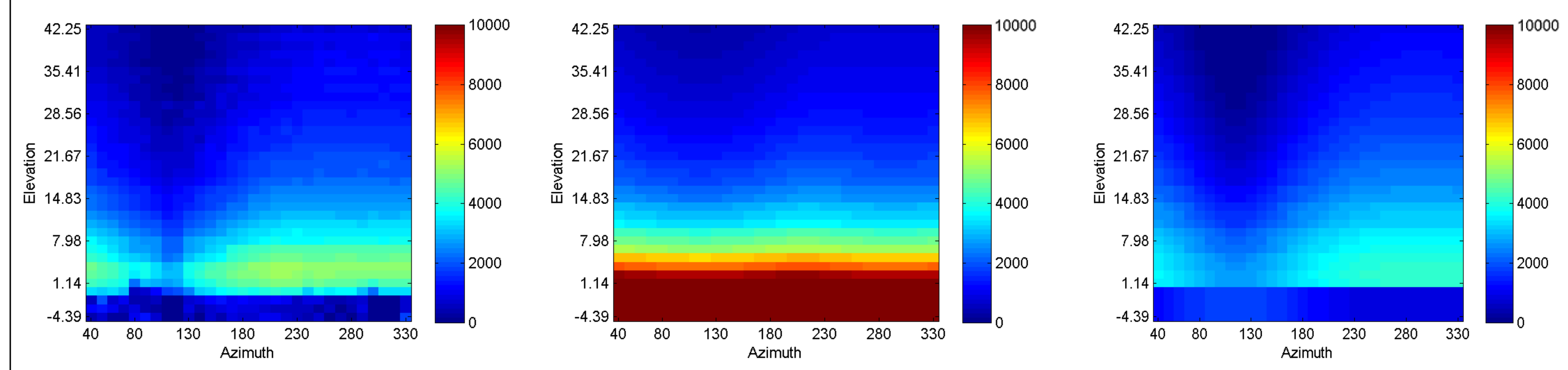

Fig 7: Left: Measured O_4 slant columns at 23 July 2014, 8.40 UT. Middle: Simulated O_4 slant columns for Rayleigh atmosphere and same viewing conditions (only positive elevations). Right: Same simulations including aerosols.

Conclusions

- Good vertical and horizontal coverage achieved at high speed (6 minutes) overcoming the limitation of current ground-based MAX-DOAS instruments
- Full hemispheric detection, i.e. vertical as well as azimuthal distribution, of tropospheric NO_2 over Bremen possible, identification of emission sources
- Good agreement found for coinciding viewing directions with close-by MAX-DOAS instrument
- Temporal evolution of NO_2 pollution can be monitored (duration of complete hemispheric scan ca. 6 minutes → much faster than NO_2 lifetime)
- Demonstrating effects of viewing geometry on retrieved slant columns in different directions
- Outlook: Comparing measured and simulated O_4 → adjusting (i.e. retrieving) aerosol scenario

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www.iup.uni-bremen.de/doas