A new airborne imaging DOAS instrument - development and first measurements

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Objective and Motivation

Objectives

Measuring and mapping of tropospheric trace gases, esp. NO_2 (pollution mapping), identification of source regions and source strengths, satellite data validation.

Why aircraft measurements?

Link between ground based observations and satellite measurements.
Good spatial resolution ~ 100 m, at useful spatial coverage.

Why imaging DOAS?

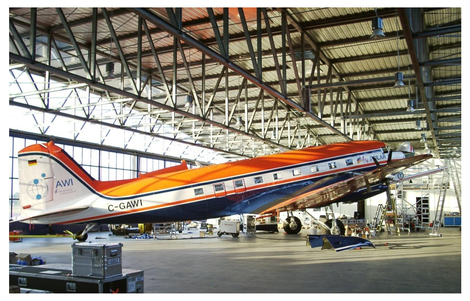
Several viewing directions are observed at the same time, i.e. a broad stripe below the aircraft.
Advantage: less data is lost as cp. to scanning instruments, adjacent regions are viewed simultaneously.
Disadvantage: reduction in signal-to-noise as the recorded light is divided into several individual spectra

Status: The imaging DOAS instrument has been developed very recently. Laboratory measurements have been performed to characterise the instrument, first test in flight have been conducted during a flight campaign in June 2011. Results are therefore early and preliminary.

The Polar-5 aircraft

Polar-5

Registration	C-GAWI
Aircraft Type	Basler BT-67 / DC3
Length	21 m
Height	5.2 m
Wingspan	29 m
Speed	50-105 m/s
Altitude	100-19000 ft
(no pressurised cabin)	
Flight duration	3-8 h
(depending on payload)	
Owner:	AWI, Germany
Operator:	Kenn Borek Air Ltd., Canada



Polar-5 in Hangar Bremerhaven, Luneort

Instrumental setup

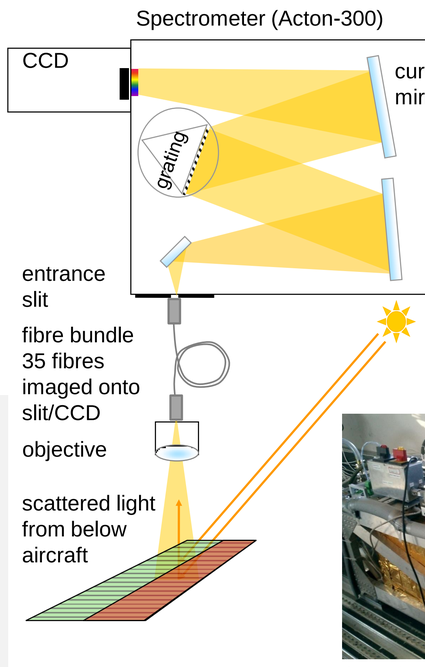
Imaging DOAS instrument – Technical Data

Spectral window	420 – 460 nm
Spectral resolution	0.7 – 1.0 nm
(smaller in central viewing direction, larger at the slant LOS)	
Grating	600 l/mm
Detector size	512x512 pixels, 8.2x8.2 mm²
Slit width	100 µm
Power consumption	< 400 W
Power Supply	230VAC via UPS
	or 28VDC via Inverter and UPS
Temperature stablised at	35 C (spectrometer unit only)

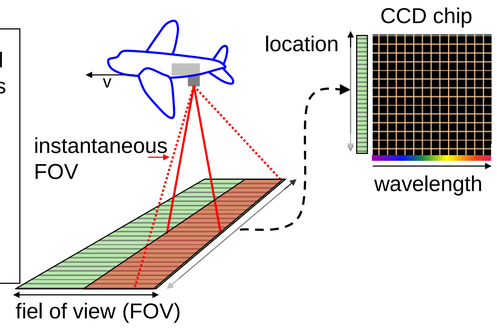
Observation and viewing geometry

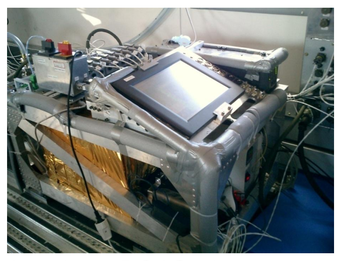
- Two nadir ports: spectrometer and 2nd port for picture camera
- Geolocation information from GPS sensor and gyrometer
- max. 35 viewing directions (LOS, line of sight), 35 fibres imaged onto CCD, here combined to 9 LOS
- Field of view ~48 across track, ~3 along track
- Spatial resolution e.g. ~100 m (at ~1km flight altitude and 9 viewing directions, depends on flight altitude and required SNR)

Schematic setup

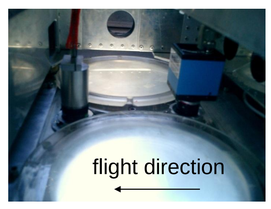


Viewing geometry



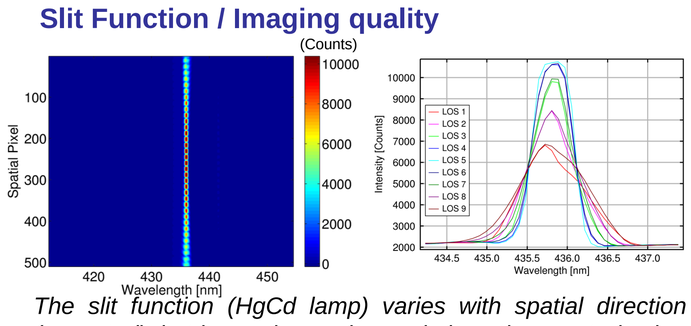


Imaging DOAS instrument rack in the Polar-5 aircraft



Nadir viewing ports: spectrometer objective (left) & picture camera (right)

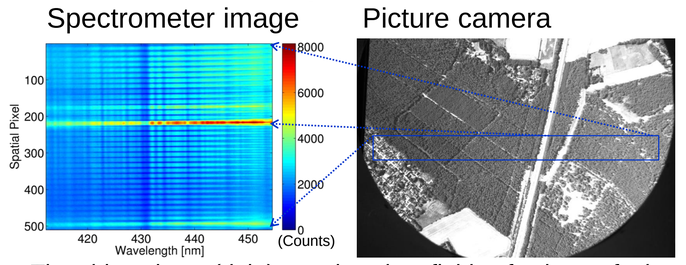
Slit Function / Imaging quality



The slit function (HgCd lamp) varies with spatial direction (expected), but it remains unchanged along the spectral axis.

Measurement example

Spectrometer image Picture camera

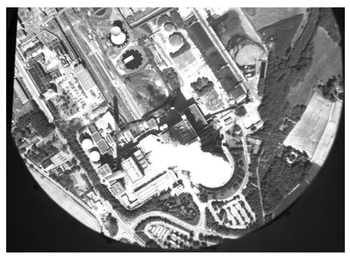


The blue box (right) marks the field of view of the spectrometer. Bright scenes such as roads can be identified by higher intensity in the spectrometer image, demonstrating good spatial imaging.

Sample flight and measurements

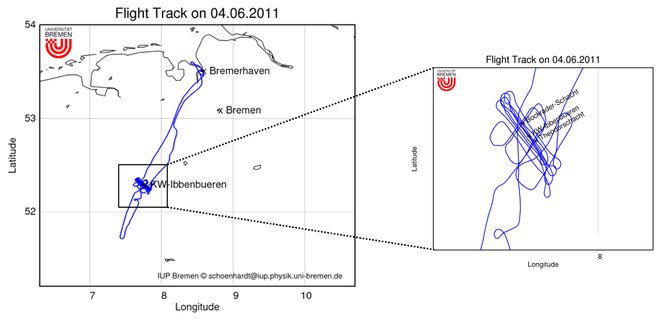
Target area:

Ibbenbüren (52° 17.2' N, 7° 44.8' E)
Coal mining area and
Black coal power plant
Power generated: 848 MW

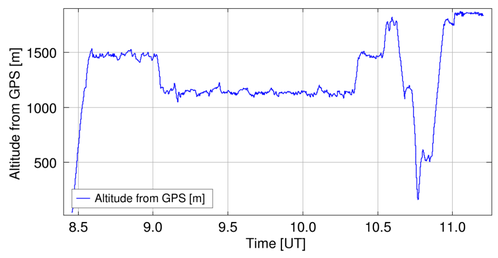


View of the power plant taken by the picture camera at overflight.

Viewing angles (w.r.t. nadir)	
LOS 1	-21.6
LOS 2	-16.5
LOS 3	-10.9
LOS 4	- 5.6
LOS 5	0.1
LOS 6	5.3
LOS 7	10.7
LOS 8	16.2
LOS 9	21.5

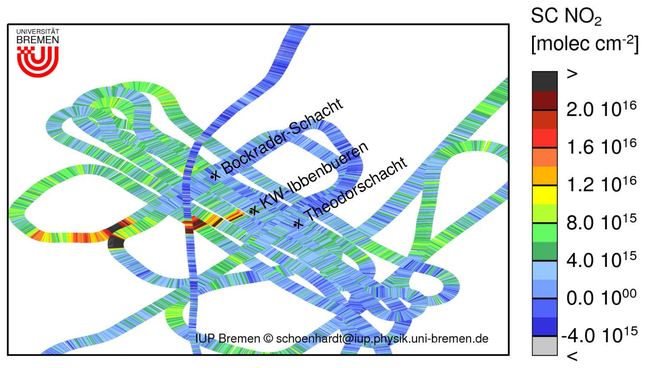


Flight track on the 04.06.2011, going from Bremerhaven to Ibbenbüren, tight flight pattern above target area and back.



Altitude profile of the flight, typical flight altitude was ~1100m.

Time series of NO_2 from entire flight (top) and for a selection (bottom). Spikes of NO_2 seen in the long time series are real enhancements as can be seen in the example. Large amounts, e.g. around 10.20h were captured when passing through the plume downwind of Ibbenbüren city and power plant.



NO_2 amounts along the flight track retrieved from the flight on 04.06.2011. Downwind from the power plant Ibbenbüren, strong enhancement of NO_2 is visible.
Enhanced NO_2 is on the order of 10^{16} molec/cm².
The width of the flight track depends on flight altitude, narrower lines correspond to lower flight altitude.

NO_2 retrieval

Retrieval Settings

Fitting window	425 – 450 nm
Trace gases	NO_2 (293K), O_3 (241K), O_4 (296K), H_2O (HITRAN)
Atmospheric effects	Ring (SCIATRAN calculated), constant stray light
Polynomial	quadratic
Reference I_0	from same viewing angle, rural scene with low NO_2 content
Slit function	individual slit function for each viewing direction

Detection Limit

- Depends on integration time (typ. 0.5 s exposure time, binning leads to slightly larger pixels)
- For 2s, the detection limit lies around 10^{15} molec/cm², optical density rms is on the order of 10^{-3}

→ Trade-off between ground spatial resolution and signal-to-noise ratio

Summary and Outlook

- A new imaging DOAS instrument for aircraft measurement has been developed and has been tested in some first technical flights. Performance was overall stable.
- Imaging quality is good, slit function remains consistent along spectral axis.
- Very early results from campaign in June 2011 show promising measurement quality.
- NO_2 column amounts have been retrieved, pollution sources can be seen.
- Scattering on the NO_2 amounts is quite large, data averaging may further improve SNR.

Activities for the future:

- Take pitch and roll angles precisely into account to improve geolocalisation of observations
- Create clean air sector reference spectrum as background I_0, instead of rural air sector currently used
- Accurate consideration of air mass factor
- Dedicated measurements, e.g., for pollution mapping will be planned as soon as flight options arise.

Selected References

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