Aircraft measurements of anthropogenic NO_2 with an imaging DOAS instrument

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Objectives

Objectives: Measuring the amounts and spatial distribution of tropospheric trace gases, e.g. for NO_2 pollution mapping, identification of source regions and source strengths, satellite data validation.

Why aircraft measurements and imaging DOAS?

- Aircraft observations form a link between ground based observations and satellite measurements.
- Good spatial resolution ~ 100 m, at useful spatial coverage.
- 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.

Status of the IUP Bremen iDOAS: The imaging DOAS instrument has been developed in 2011. Laboratory measurements have been performed to characterise the instrument, first test flights have been conducted during a flight campaign in June 2011. Latest work covers the determination of the corrected ground coordinates.

The Polar-5 aircraft

Polar-5

Registration	C-GAWI
Aircraft Type	Basler BT-67 / DC3
Length/Height/Span	21 m / 5.2 m / 29 m
Speed	50-105 m/s
Altitude	100-19000 ft
(no pressurised cabin)	

Owner: AWI, Germany
Operator: Kenn Borek Air Ltd., Canada

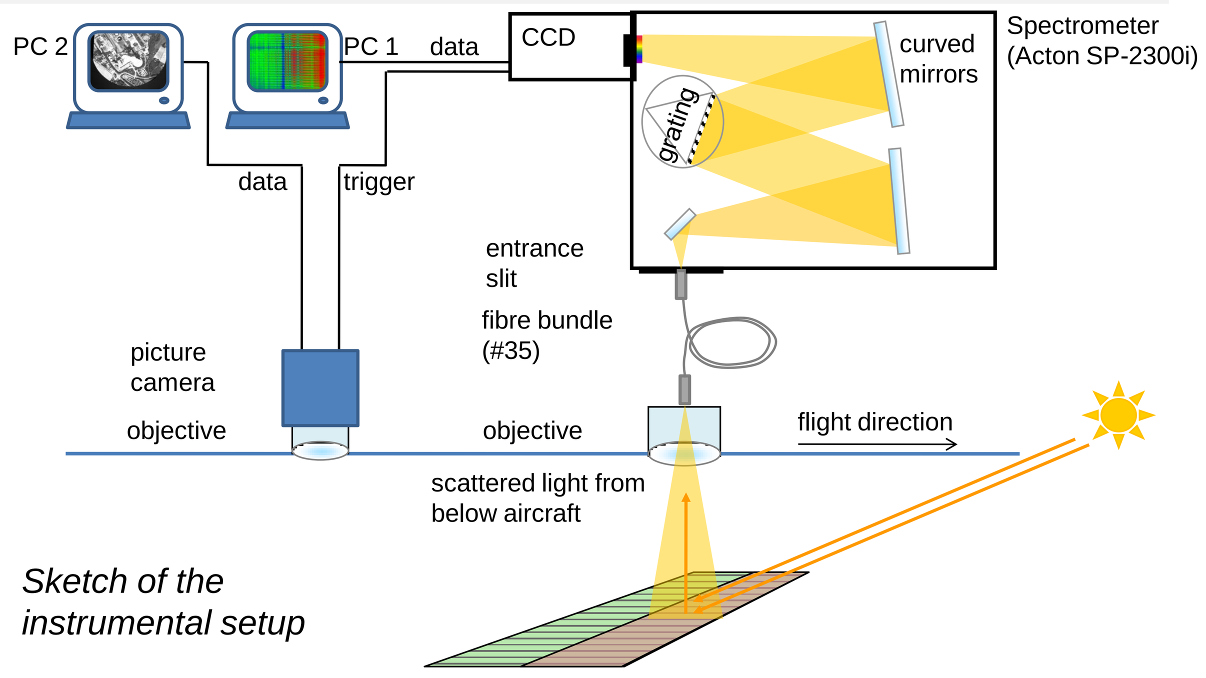
Polar-5 in Hangar at Bremerhaven Luneort airport

Instrumental setup

Technical information and special features

Spectral window/resolution:	420 - 460nm / 0.7-1.0nm
CCD Detector size:	512x512 pixels, 8.2x8.2 mm²
Detector type:	Frame transfer (FT) technique
Entrance optics:	Wide angle objective + fibre bundle
Fibre bundle:	35 sorted fibres imaged onto CCD

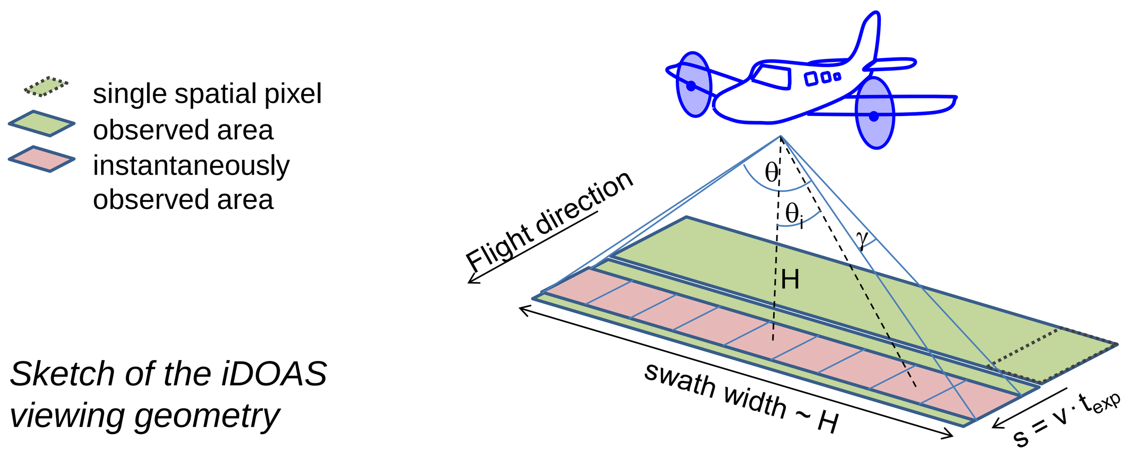
This special setup allows gap-free measurements (due FT CCD) and flexible positioning in aircraft (due to sorted fibre bundle).



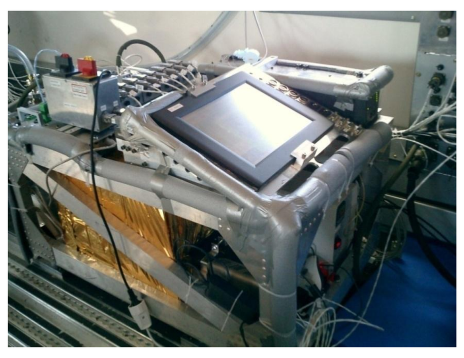
Sketch of the instrumental setup

Observation and viewing geometry

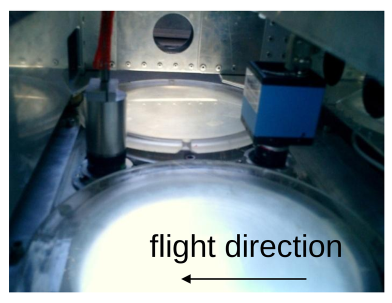
- Two nadir ports: spectrometer objective and picture camera
- Geolocation information: from GPS sensor and gyrometer
- Viewing directions: max. 35 LOS (line of sight) from 35 fibres
- LOS after averaging across track: fibres combined to 9 LOS (θ_i)
- Field of view: ~48° across track (γ), ~3° along track (θ)
- Swath width: on the order of flight altitude H
- Exposure time t_{exp}: typ. 0.5s
- Measurement sequence: no gaps between exposures
- Spatial resolution: ~100 m (at H=1km flight altitude, 9 viewing directions, depending on flight altitude and required SNR)



Sketch of the iDOAS viewing geometry



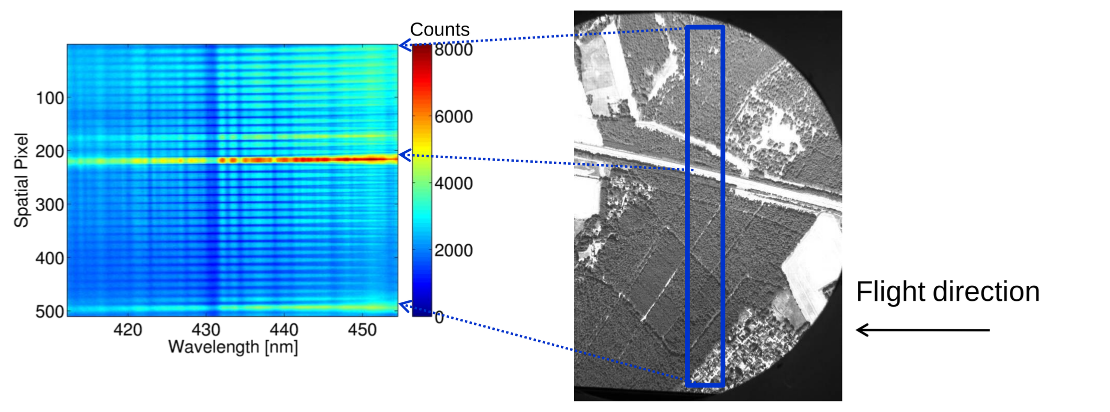
Imaging DOAS instrument rack in the Polar-5 aircraft



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

Measurement example

Spectrometer CCD image   Picture camera

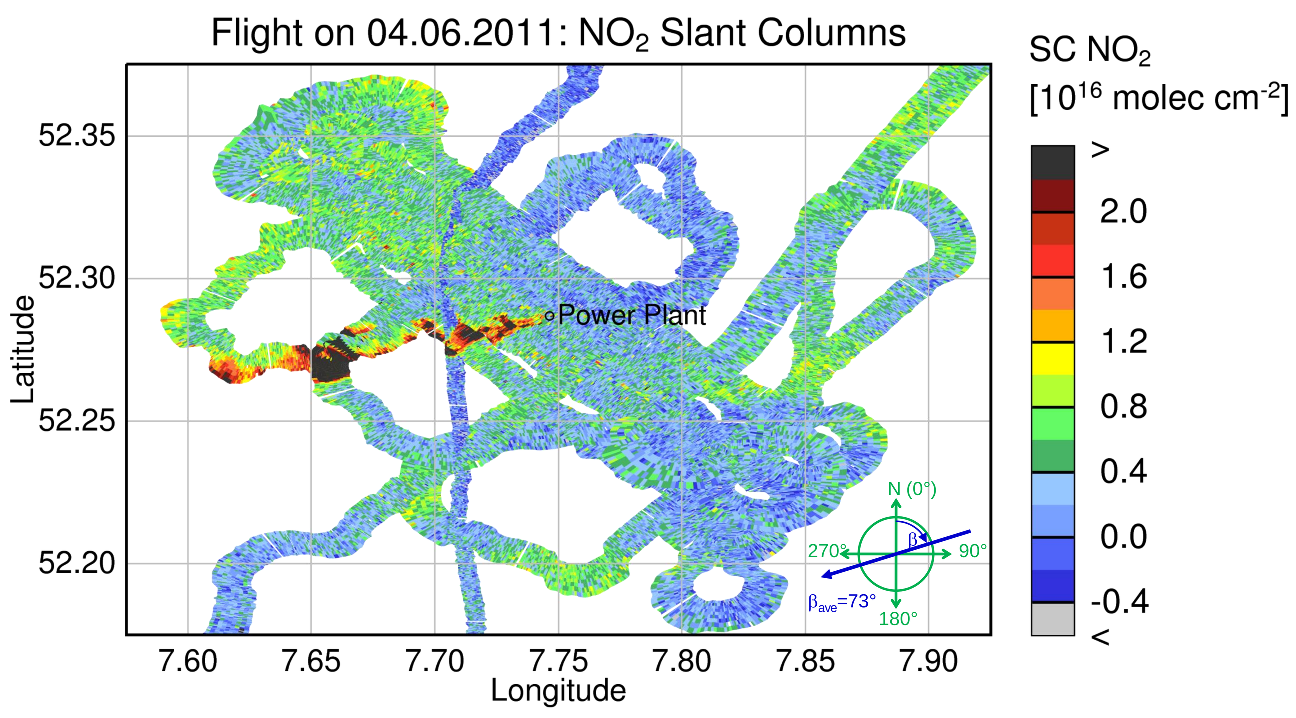


The blue box (right) marks the field of view of the spectrometer. Bright scenes such as roads are identified by higher intensity in single LOS on the CCD, demonstrating good spatial imaging.

Observation of NO_2 columns with corrected geolocation

NO_2 retrieval above a power plant

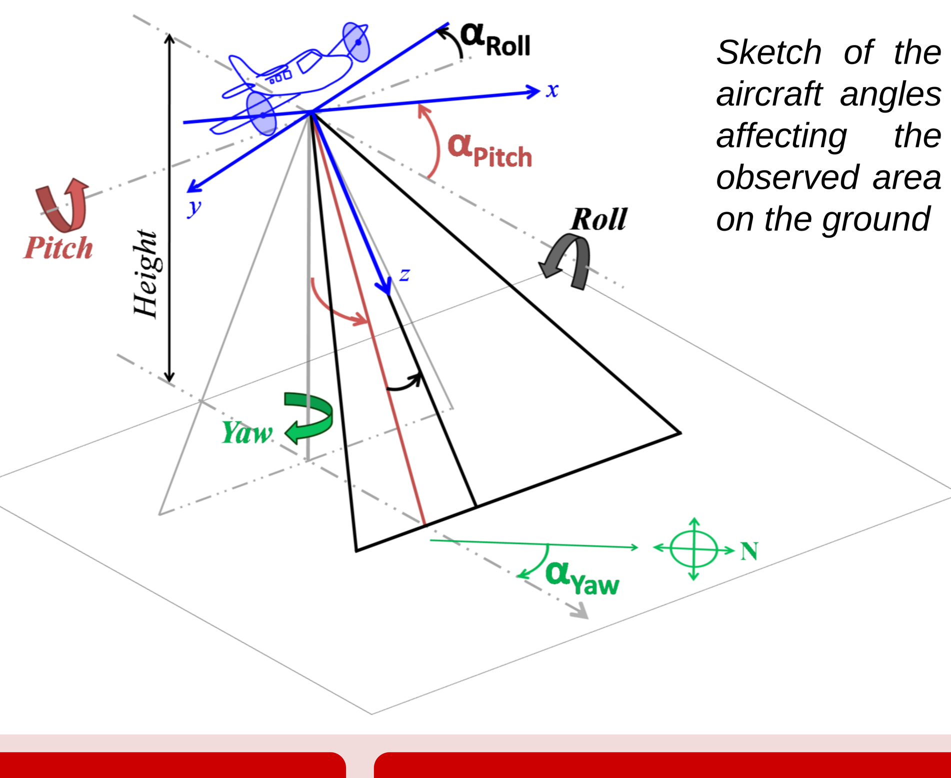
- Black coal power plant (848 MW) at Ibbenbüren (52° 17.2' N, 7° 44.8' E)
- The slant column of NO_2 is retrieved by DOAS (see settings below)
- Large variation of NO_2 amounts across and along track are observed
- The NO_2 in the exhaust plume of the power plant is clearly visible



NO_2 amounts along the flight track retrieved from the flight on 04.06.2011. Downwind from the power plant of Ibbenbüren, strong enhancement of NO_2 is visible (average wind direction was about East North-East). Enhanced NO_2 is on the order of 10^{16} molec/cm².

Computation of viewing geometry in flight

- Calculation of correct ground geolocation from the field of view is important
- Consideration of the aircraft angles (pitch, roll and yaw) is required in addition to GPS position
- The ground pixel centre and corner coordinates for each LOS are calculated for the start and end of each exposure to determine the pixel area



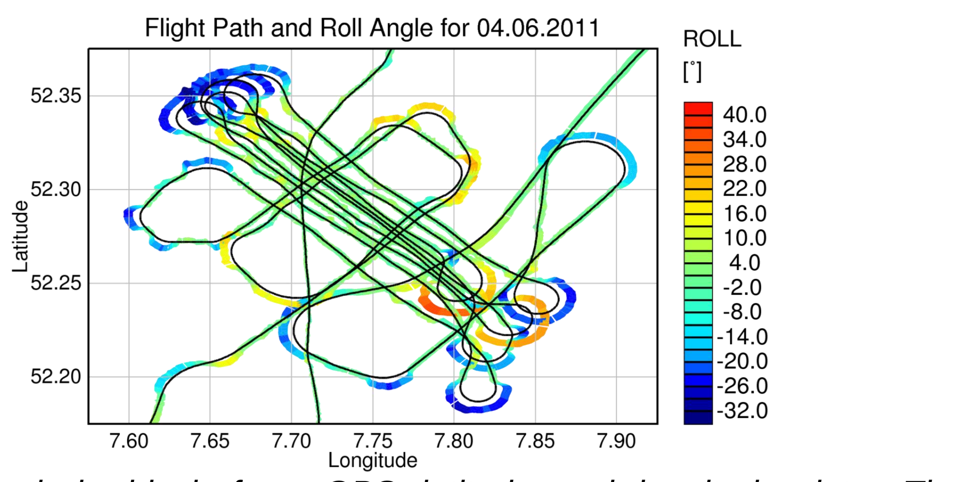
Sketch of the aircraft angles affecting the observed area on the ground

Influence of aircraft angles on geolocation

Aircraft movement changes the ground pixel geolocation significantly. The magnitude of the displacement additionally depends on flight altitude and LOS.

Displacements of the ground pixel at a flight altitude ~1km:

- during straight tracks: on the order of a few tens of metres
- during turns: typically on the order of 500 m with maximum distances larger than 1km
- average for central flight pattern on 04.06.11: around 160m



Flight track in black from GPS latitude and longitude data. The coloured track shows the roll angle within the corrected ground pixel area from the three central LOS. Positive turns (right wing down) are shown in red, negative turns are plotted in blue. Displacements during curved parts of the track are clearly seen.

NO_2 retrieval settings

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), intensity offset
Polynomial	quadratic
Reference I_0	from same LOS, rural scene, low NO_2 content, 1 min. average
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

Summary

- The newly developed airborne imaging DOAS instrument performed well during test flights in June 2011
- Good imaging quality; constant slit function along spectral axis; promising measurement quality
- NO_2 column amounts have been retrieved, pollution point sources can be observed
- Aircraft pitch, roll and yaw angles are fully taken into account, for correct ground geolocation
- Noise on the NO_2 amounts is quite large, data averaging may further improve SNR

Activities for the future

- Accurate consideration of air mass factor needs to be implemented
- Emission strength of sources may be determined and further dedicated campaigns will be conducted

Selected References

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