High resolution mapping of the tropospheric NO_2 distribution in three Belgian cities based on airborne APEX remote sensing

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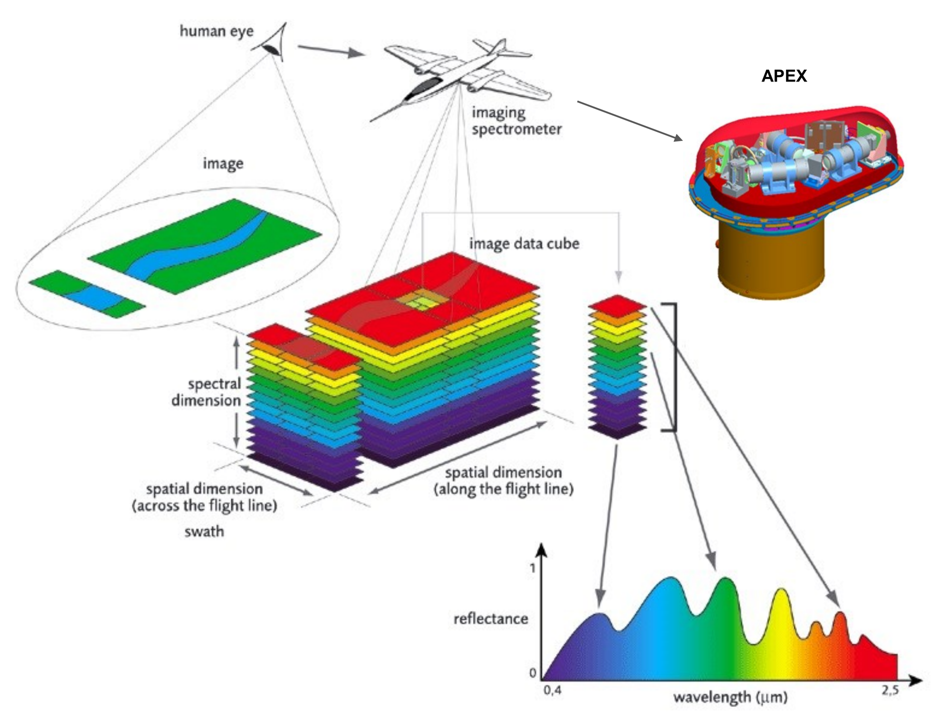
1 Introduction

- An algorithm is presented to retrieve **tropospheric nitrogen dioxide (NO_2)** vertical column densities (**VCDs**) and to map the NO_2 spatial distribution at high resolution, based on APEX observations
- This study is done in the framework of the **BUMBA project** (Belgian Urban NO_2 Monitoring Based on APEX hyperspectral data - **www.bumbair.be**) started in 2015
- Main objectives: (1) Assess the operational and technical capabilities of APEX to map the NO_2 field at high spatial and spectral resolution, (2) Use the retrievals for validation and improvement of the recently developed **RIO-IFDM air quality model** (Lefebvre et al., 2013)

2 APEX instrument

- **Airborne Prism Experiment (APEX)** → pushbroom hyperspectral imager (Schaepman et al., 2015)
- Mounted on Dornier DO-228 plane, operated by DLR
- APEX observed spectra → **solar radiation** backscattered by atmosphere or ground surface

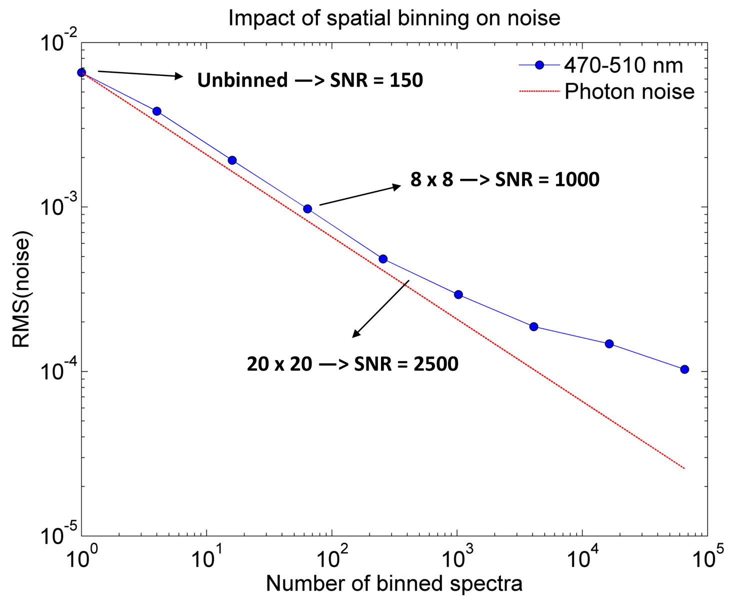


Spectral performance for NO_2 analysis window	
Spectral range	370 - 600 nm
Spectral bands	249 (in unbinned mode)
Spectral sampling rate	0.9 nm
Spectral resolution (FWHM)	2.5 nm
Spatial performance under typical flight conditions	
Spatial CCD	1000 detectors
FOV (across-track)	28°
Swath width (at 6000 m AGL)	3000 m
IFOV (across-track)	0.028°
Spatial resolution (at 6000 m AGL)	3 m
Other	
Plane speed	72 mps
Integration time	58 ms
APEX total mass	354 kg

3 NO_2 retrieval algorithm

3.1 Preprocessing and signal enhancement

- Spatial and spectral data selection
- **Spatial aggregation** to increase **signal-to-noise**
- Trade-off: spatial binning of 20 pixels (50 binned columns across-track) → **optimal SNR of 2500 but spatial resolution reduced to 60 m**



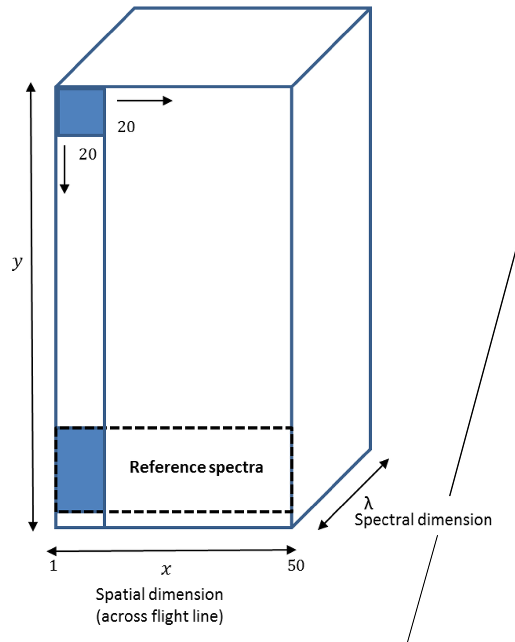
3.2 Differential Optical Absorption Spectroscopy

- DOAS equation based on Lambert-Beer's law:

$$\ln\frac{I_o(\lambda)}{I(\lambda)} = Q_{(a)}(\lambda) + \sum_i \sigma_i(\lambda) SCD_i$$

- **Spectral calibration** of each column based on high resolution solar spectrum → fit and detect narrow spectral absorption features
- APEX spectra analysed by **QDOAS spectral fitting tool** (Danckaert et al., 2014)
- NO_2 fit analysis settings
  - Fitting window → 470 – 510 nm
  - Fitted species → NO_2 (298 K), O_3, O_4, H_2O and Ring effect correction
  - Polynomial → order 5
- Direct product: NO_2 diff. slant column densities (**DSCD**s)

APEX image cube



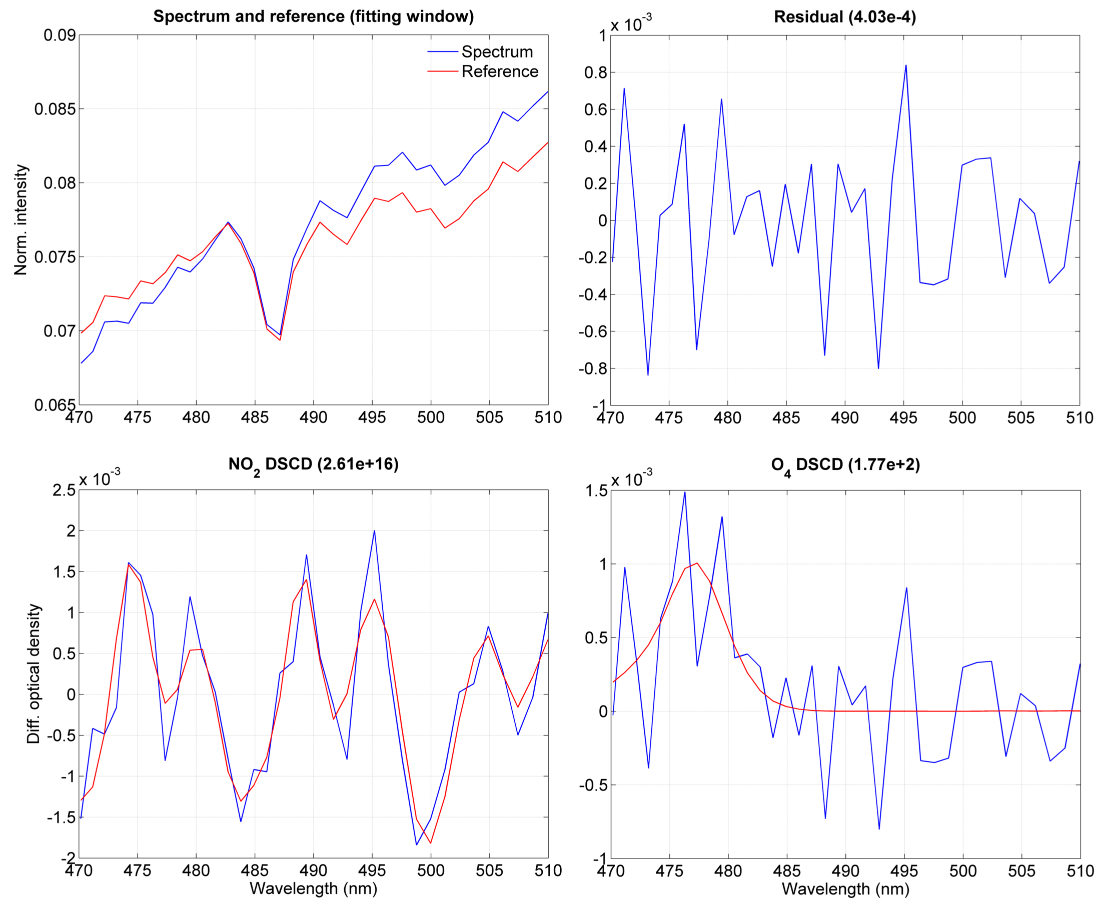
3.4 Reference slant column density

- DOAS analysis with respect to reference spectrum (**RSCD**) per binned column
- RSCDs must be chosen in **clean and homogeneous area**
- Estimation of residual NO_2 in reference based on ground-based observations or model data

3.4 Air mass factor calculation

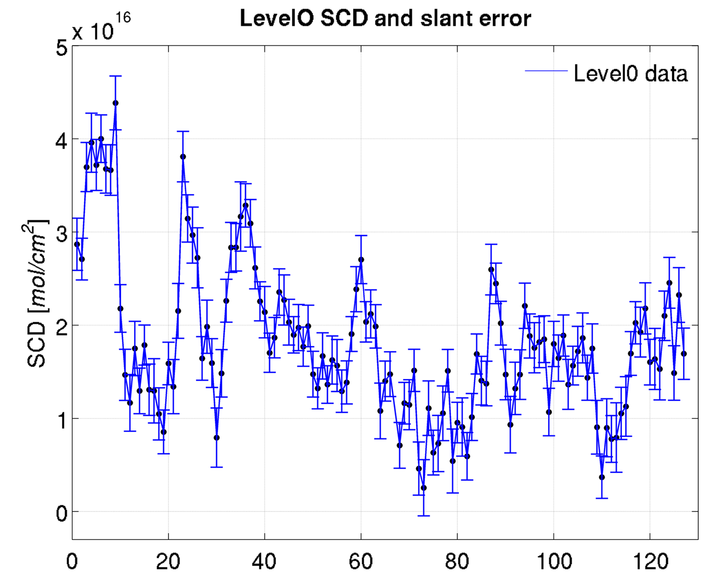
- **Radiative transfer modeling** of atmospheric lightpath with **LIDORT RTM** (Spurr, 2008)
- Accounting for surface reflectance (APEX L2 product), aerosol and NO_2 profile shapes
- Calculation of appropriate **AMF**s

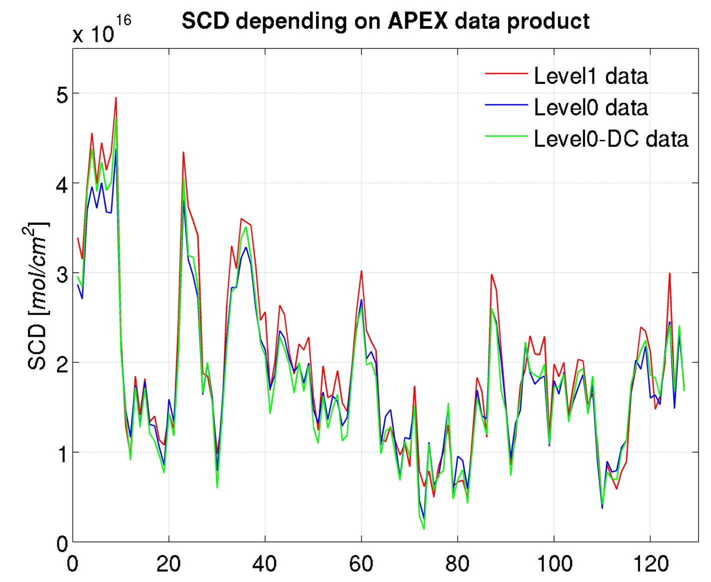
$$VCD = \frac{DSCD + RSCD}{AMF}$$

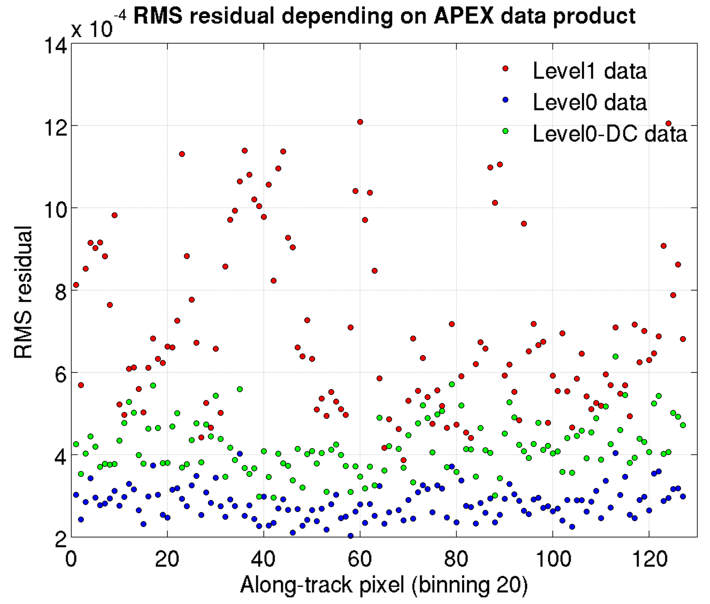


DOAS spectral fit analysis

4 Preliminary results





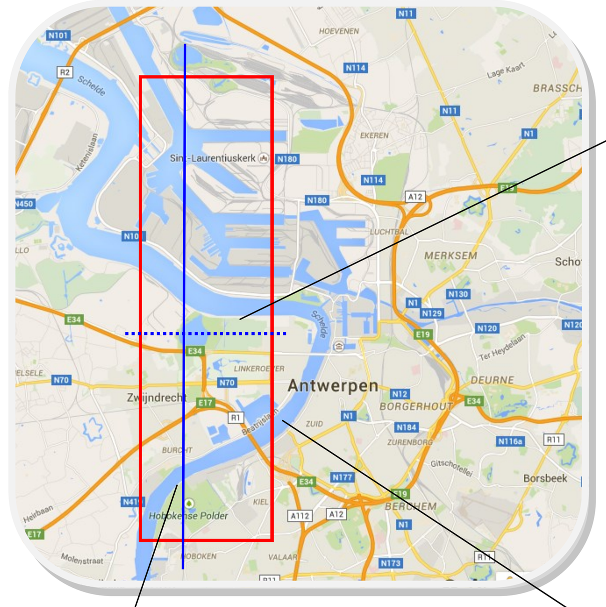


4.1 Future data sets

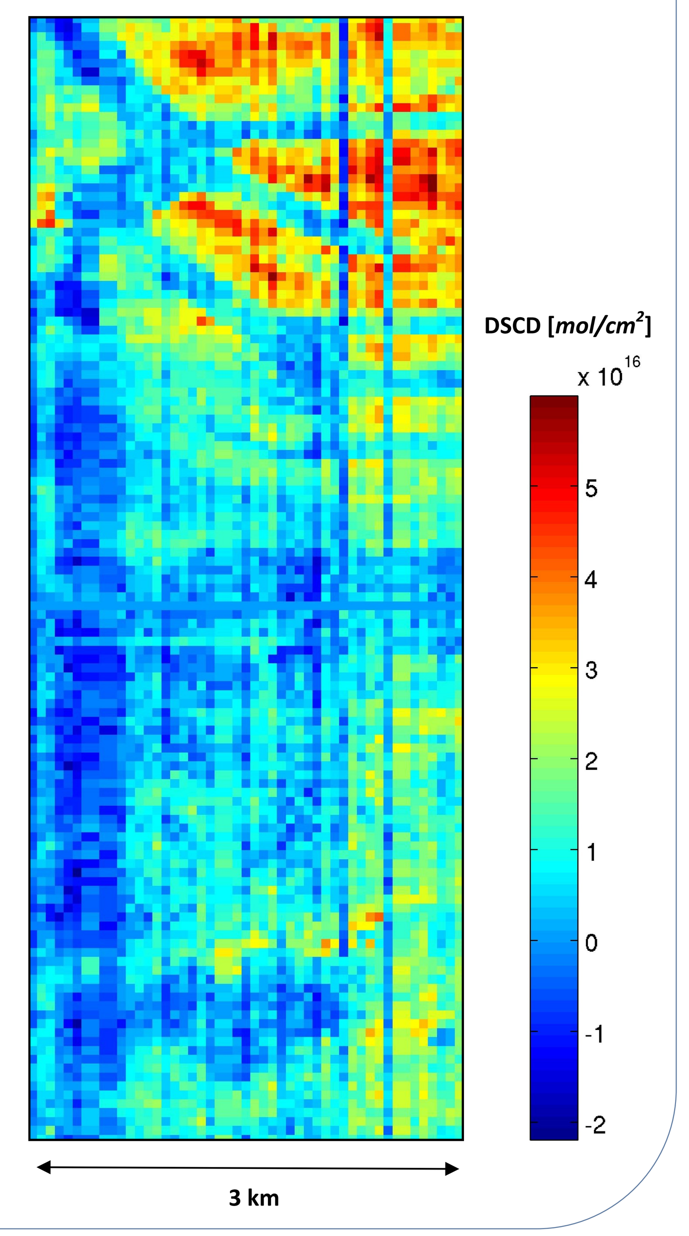
- Campaign flights are planned in spring - summer 2015 above the three largest and most heavily polluted Belgian cities: **Brussels, Antwerp and Liège**
- **Validation** of NO_2 retrievals will be done based on correlative datasets from **car mobile-DOAS systems and mini MAXDOAS**

4.2 Test data set

- Preliminary results are based on a test flight acquired in unbinned mode above Antwerp in 2012
- This flight was not yet optimized for NO_2 retrieval! Furthermore no clean reference area was acquired or simultaneous ground based measurements were performed



Reference spectra



Analysed binned column

- Left three plots show output for the DOAS analysis, applied on a binned column → RMS of the noise and retrieved NO_2 slant columns
- SCD retrieval seems to be stable for different APEX data products
- **Detection limit** is around 2.5×10^{15} on SCD and around **1.4×10^{15} on VCD**

Analysed flightline

- Preliminary map (50 binned columns, 127 binned rows) of the **NO_2 distribution**, West of Antwerp city center
- Clear **patterns of enhanced NO_2** can be identified

References and acknowledgements

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5 Perspectives

- Retrieval of clear NO_2 signals and spatial patterns of enhanced NO_2, based on APEX observations, is demonstrated here
- Short term planning
  - Optimalisation of DOAS analysis settings & conversion of SCDs to VCDs based on AMF calculations
  - Georeferencing and proper mapping of the retrieved VCDs
- Long term planning
  - Implementation of an operational NO_2 retrieval algorithm, based on APEX data, and application on optimal data sets that will be acquired above Brussels, Antwerp and Liège
  - Quantitative and qualitative assessment of retrieved NO_2 columns
  - Conversion of retrieved NO_2 columns to high resolution surface concentrations for spatial validation of the RIO-IFDM air quality model