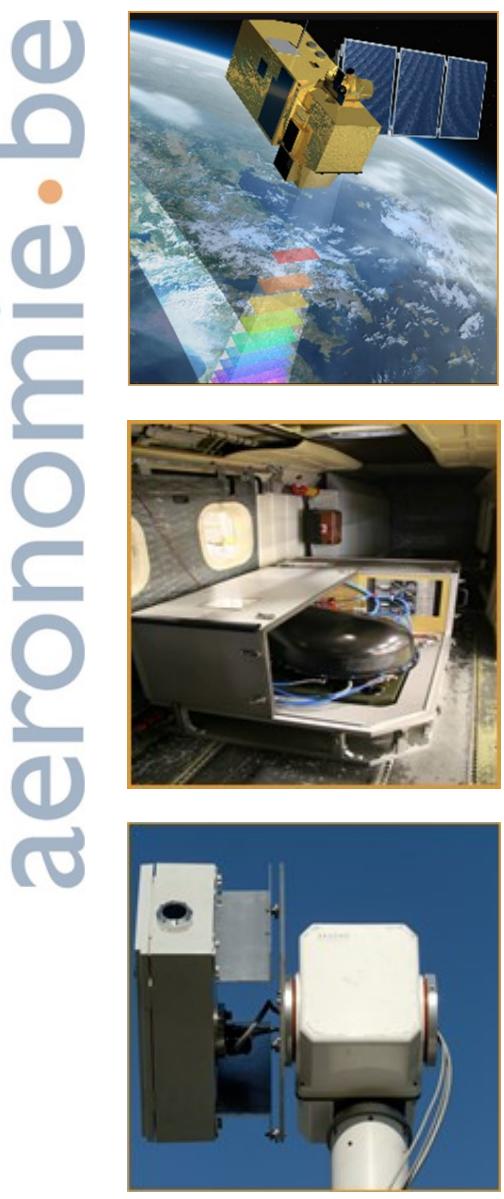


High resolution mapping of the tropospheric NO₂ distribution in three Belgian cities based on airborne APEX remote sensing

F. Tack¹, A. Merlaud¹, T. Danckaert¹, C. Fayt¹, G. Pinardi¹, M.-D. Iordache², K. Meuleman², and M. Van Roozendael¹

⁽¹⁾ BIRA-IASB, Belgian Institute for Space Aeronomy, Brussels, Belgium, Frederik.Tack@aeronomie.be

⁽²⁾ VITO-TAP, Flemish Institute for Technological research, Mol, Belgium

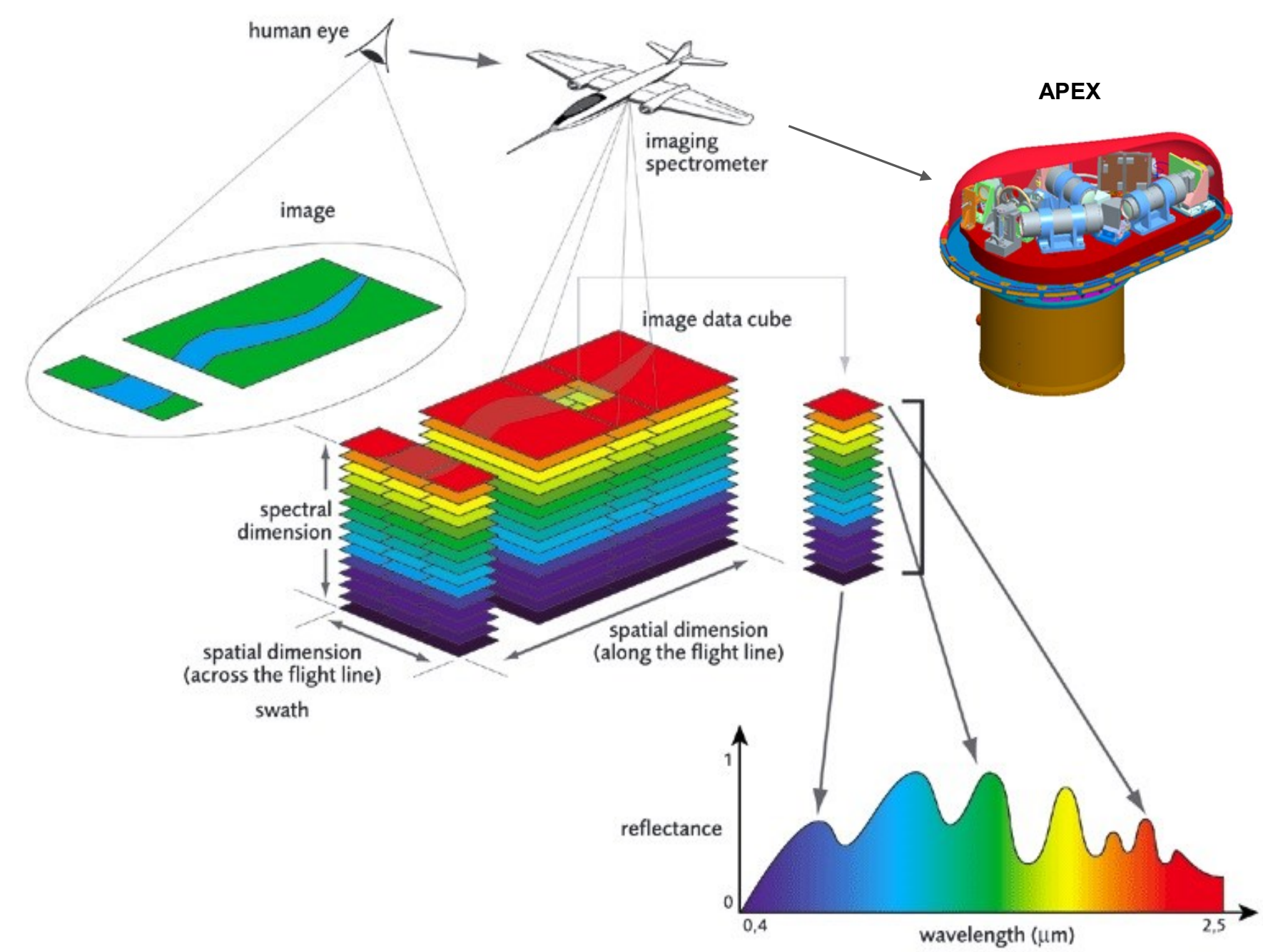


1 Introduction

- An algorithm is presented to retrieve **tropospheric nitrogen dioxide (NO₂)** vertical column densities (VCDs) and to map the NO₂ spatial distribution at high resolution, based on APEX observations
- This study is done in the framework of the **BUMBA project** (Belgian Urban NO₂ 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 NO₂ 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 (Schaeppman 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 NO₂ 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

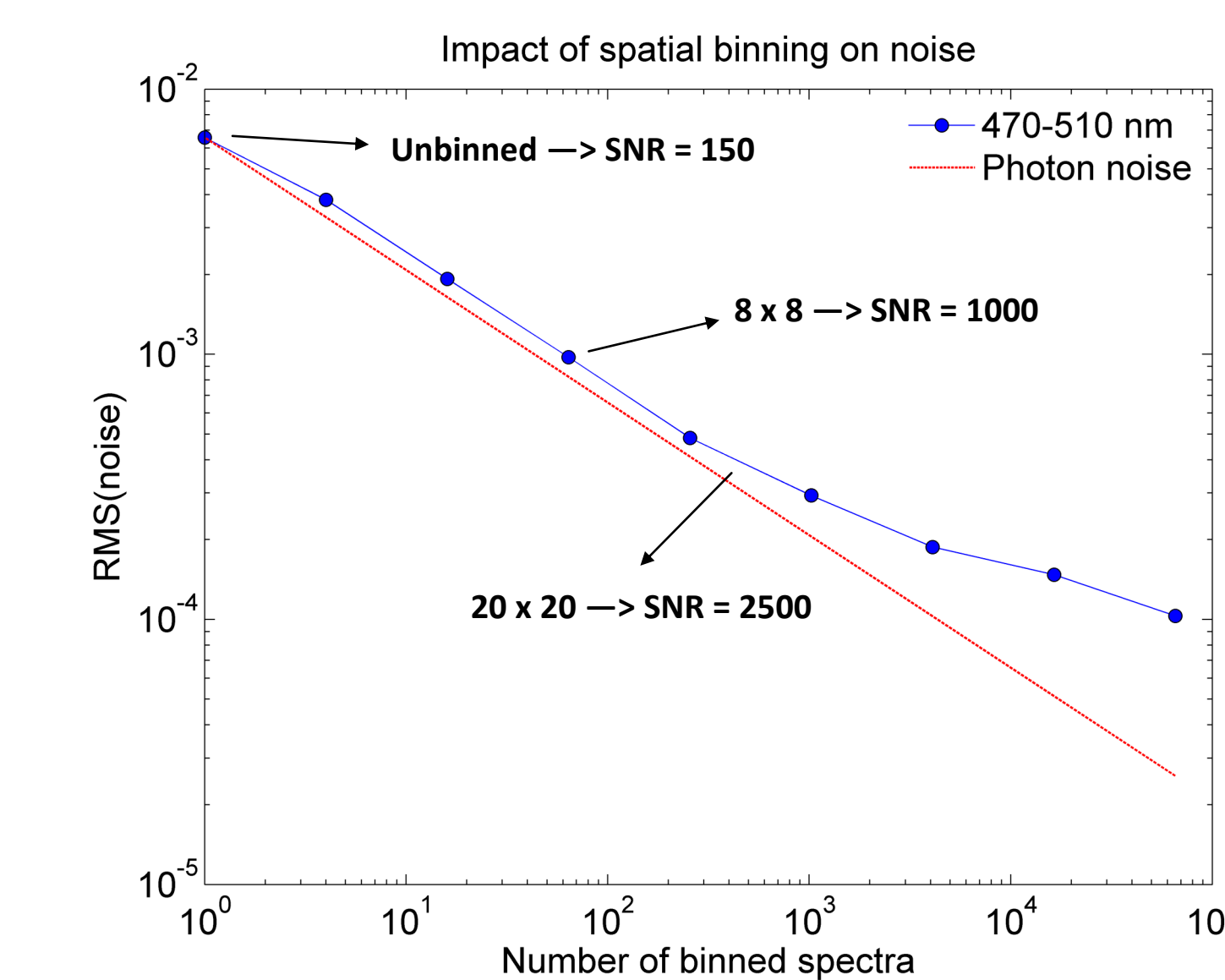
Other

Plane speed	72 mps
Integration time	58 ms
APEX total mass	354 kg

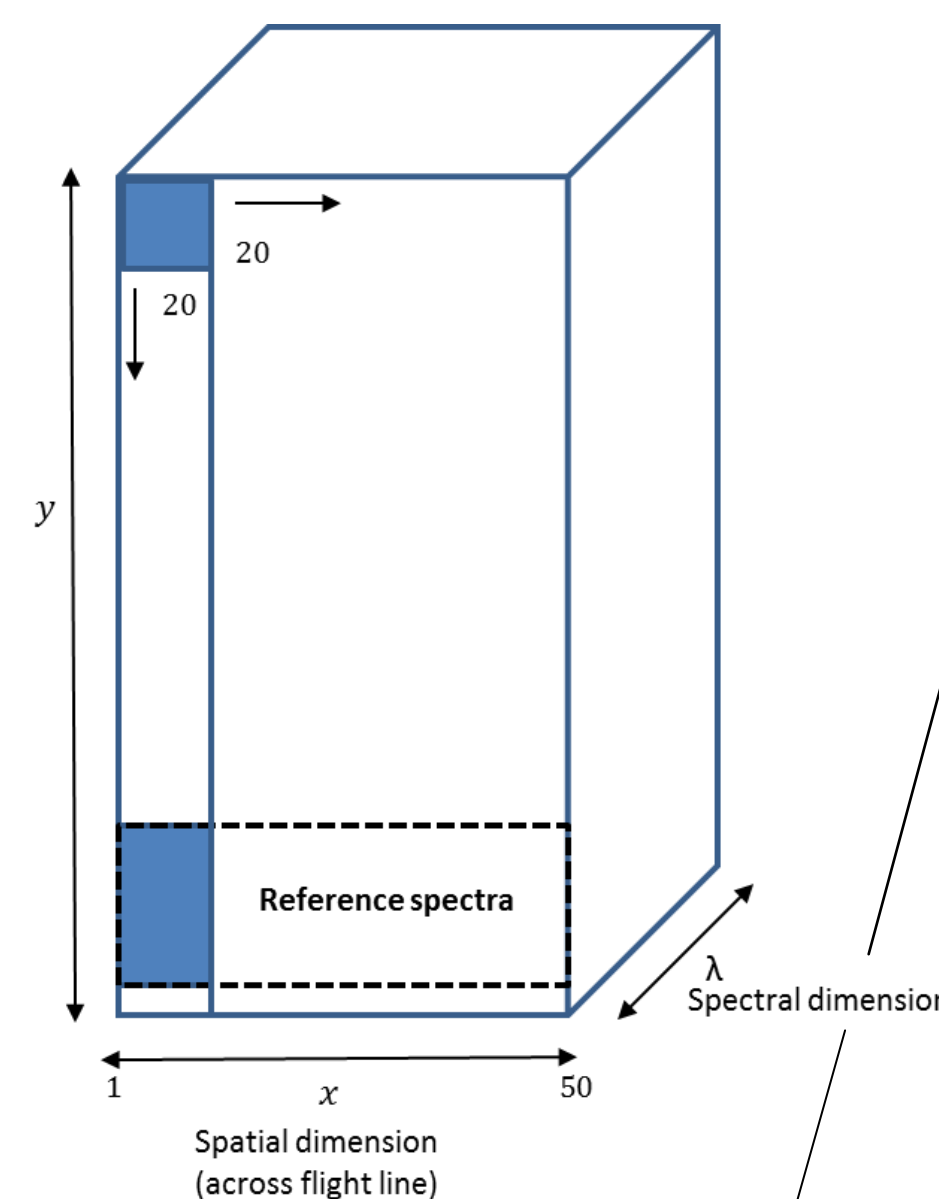
3 NO₂ retrieval algorithm

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**



APEX image cube



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

3.3 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 NO₂ 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 NO₂ profile shapes
- Calculation of appropriate **AMFs**

3.2 Differential Optical Absorption Spectroscopy

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

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

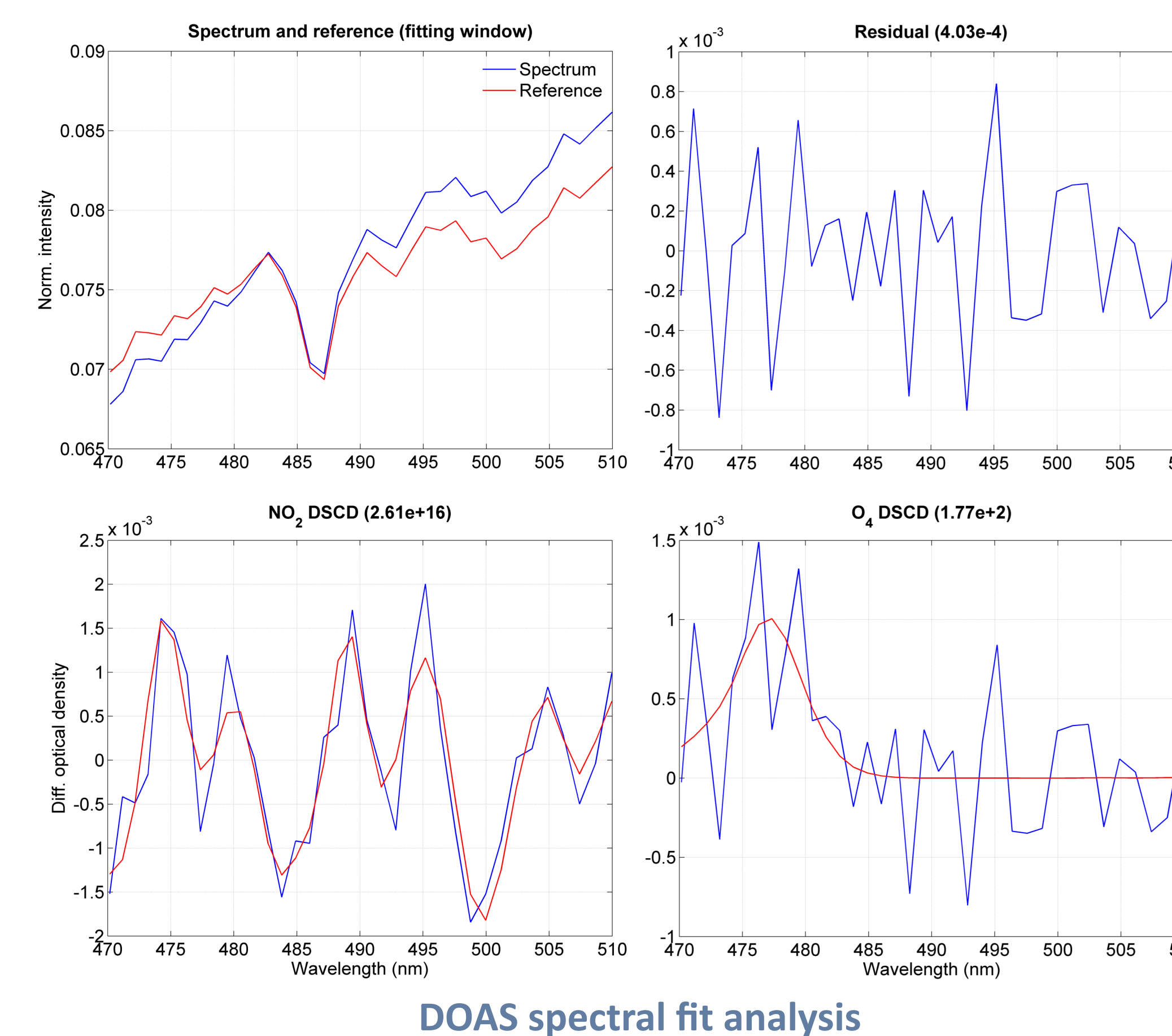
- Spectral calibration** of each column based on high resolution solar spectrum → fit and detect narrow spectral absorption features

- APEX spectra analysed by **QDOAS spectral fitting tool** (Danckaert et al., 2014)

- NO₂ fit analysis settings

- Fitting window → 470 – 510 nm
- Fitted species → NO₂ (298 K), O₃, O₄, H₂O and Ring effect correction
- Polynomial → order 5

- Direct product: NO₂ diff. slant column densities (**DSCDs**)

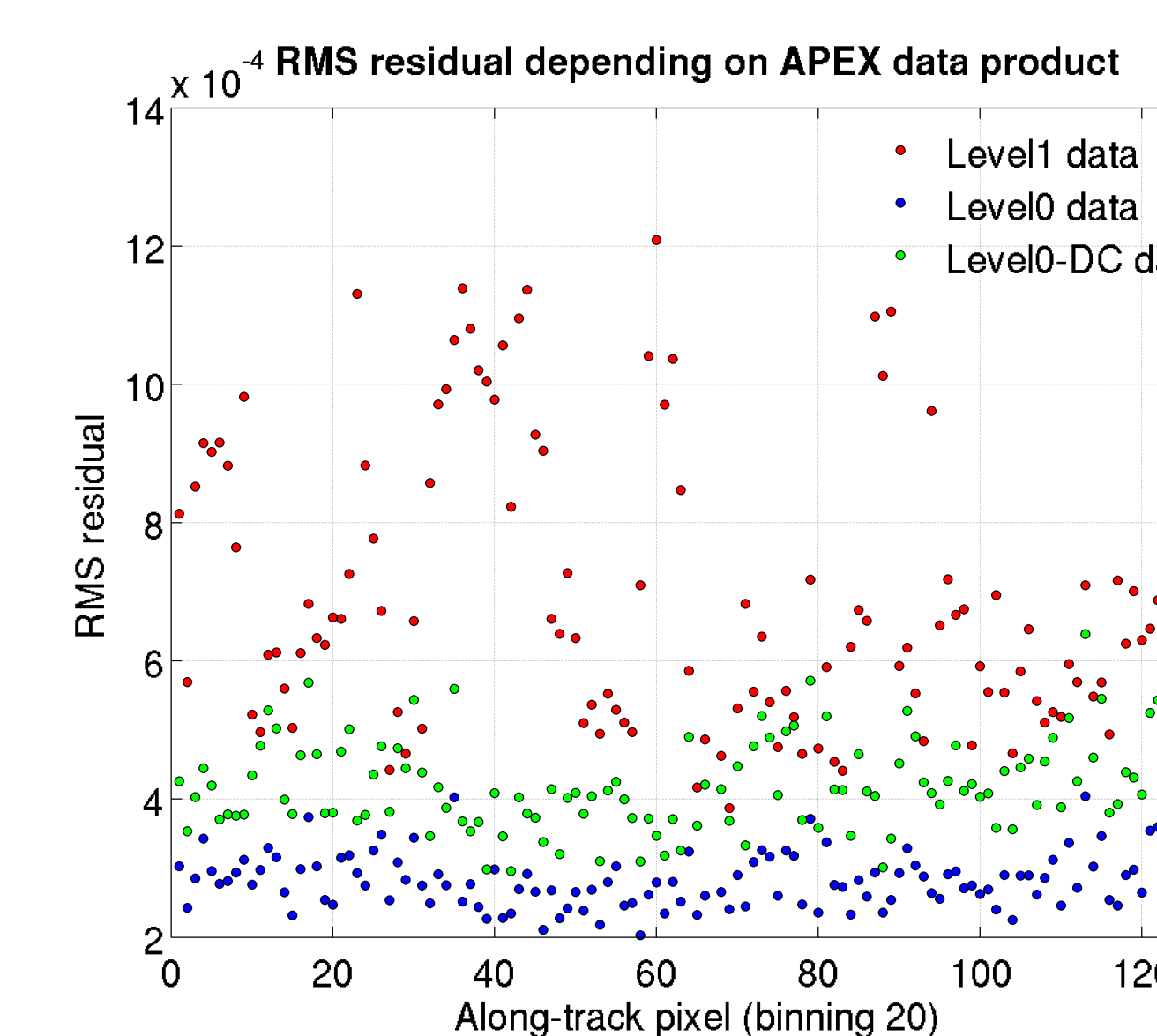
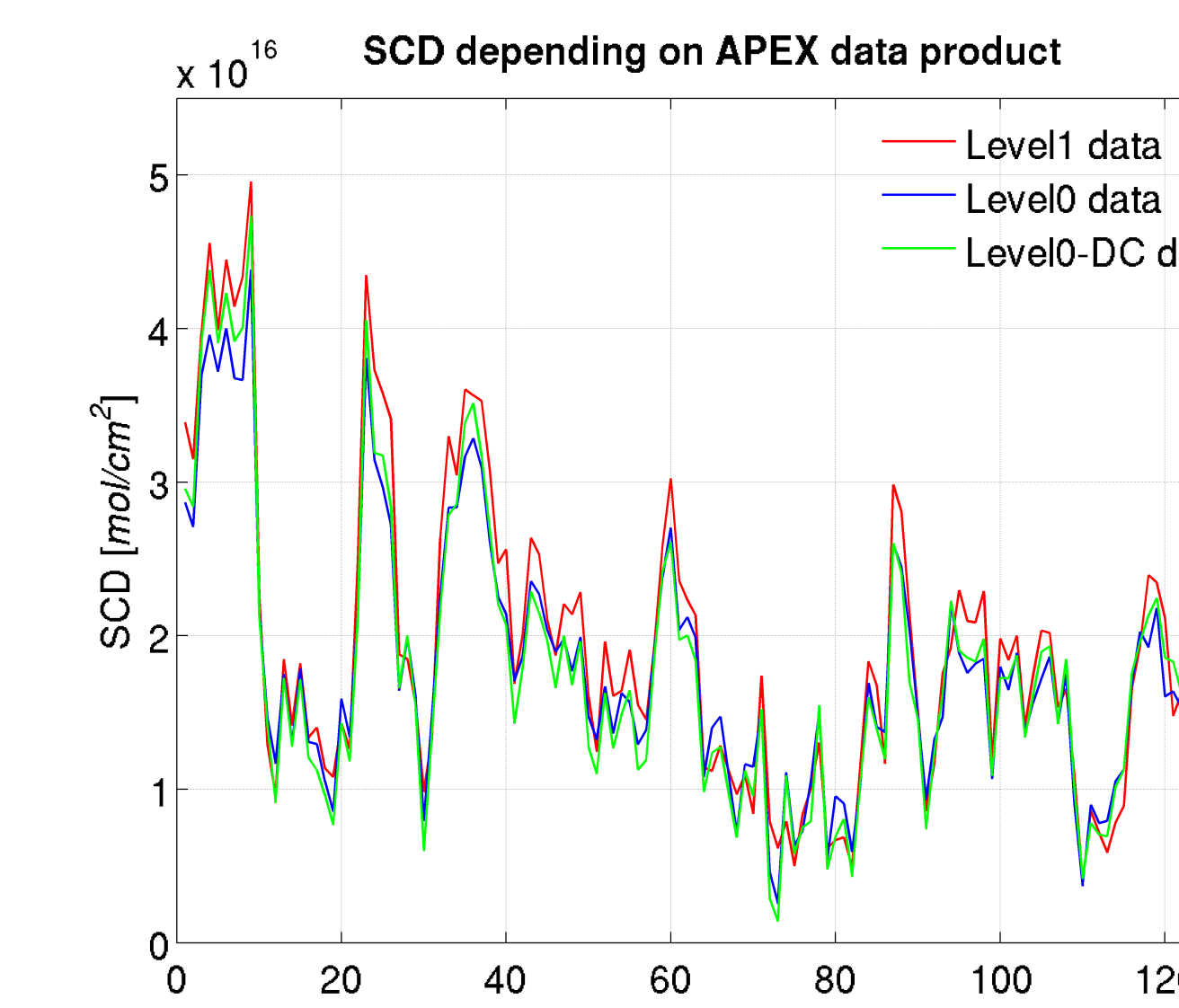
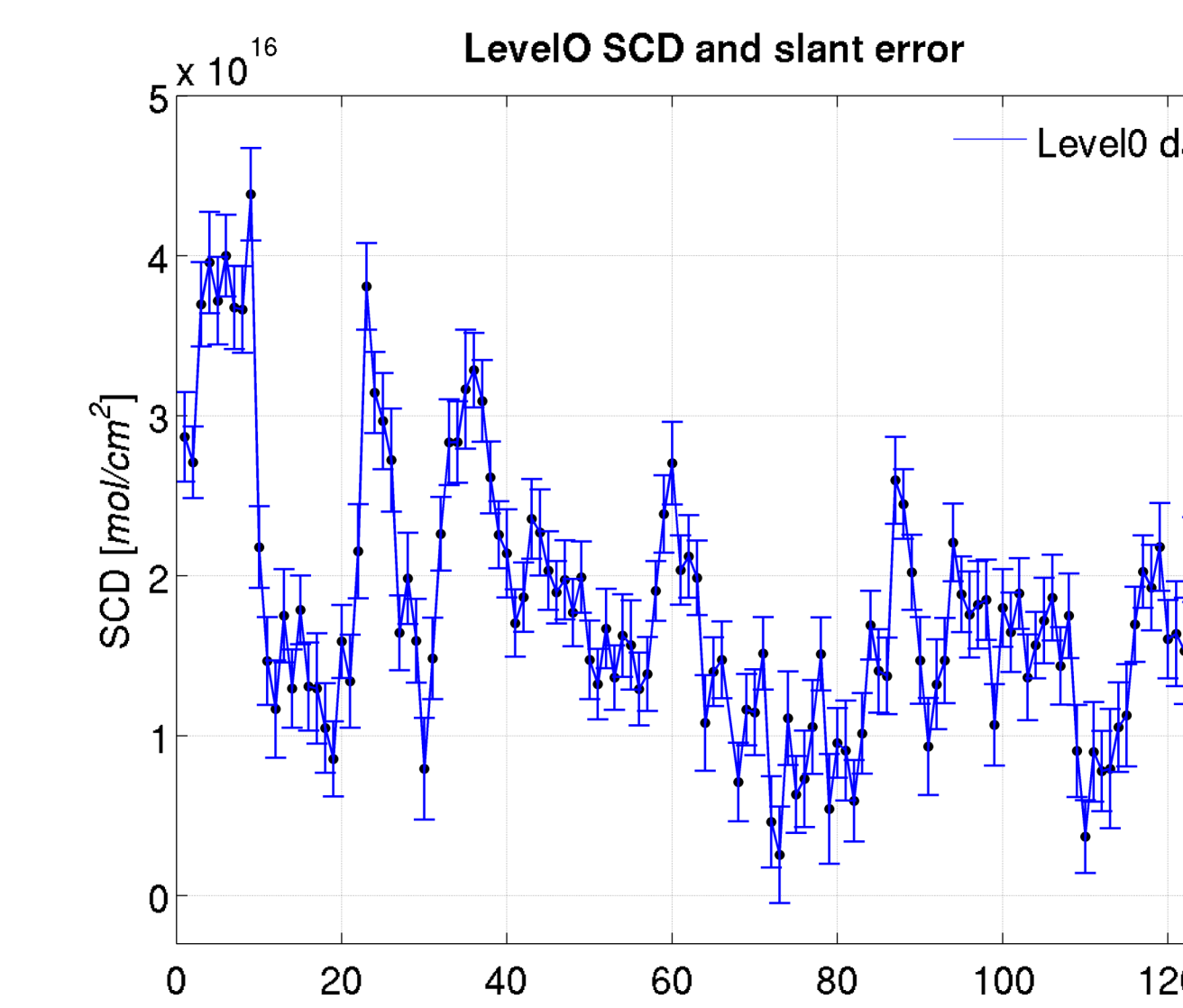


DOAS spectral fit analysis

References and acknowledgements

- Danckaert, T., Fayt, C., and Van Roozendael, M.: QDOAS software user manual 2.108, IASB/BIRA, Uccle, Belgium, 2014, available at http://uv-vis.aeronomie.be/software/QDOAS/QDOAS_manual.pdf, last access: 04 November 2014
- Lefebvre, W., Van Poppel, M., Maiheu, B., Janssen, S. and Dons, E.: Evaluation of the RIO-IFDM-street canyon model chain, Atmospheric Environment 77, 325-337, 2013
- Schaeppman, M. E., et al.: Advanced radiometry measurements and Earth science applications with the Airborne Prism Experiment, Remote Sensing of Environment, 158, 207-219, 2015
- Spurr, R., LIDORT and VLIDORT: Linearized pseudo-spherical scalar and vector discrete ordinate radiative transfer models for use in remote sensing retrieval problems, Light Scattering Reviews, Volume 3, ed. A. Kokhanovsky, Springer, 2008
- The authors want to express their gratitude to the Belgian Federal Science Policy Office for funding the BUMBA project through the STEREO III research programme for earth observation.
- We also wish to thank the other partners of the BUMBA project, i.e. the Belgian Interregional Environment Agency (IRCEL- CELINE) and the air quality modelling group and remote sensing group at the Flemish Institute for Technological Research (VITO)

4 Preliminary results

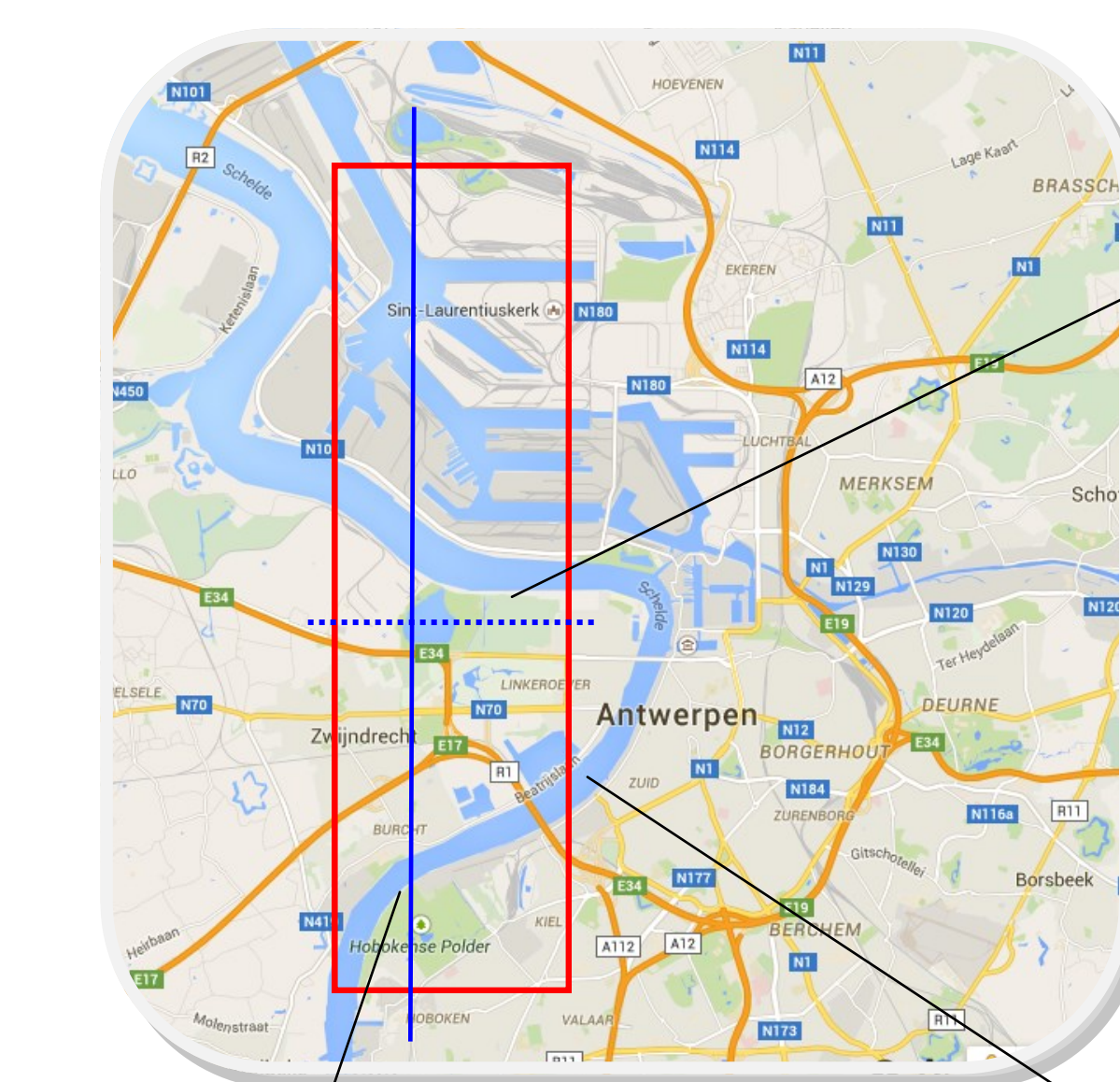


4.1 Future data sets

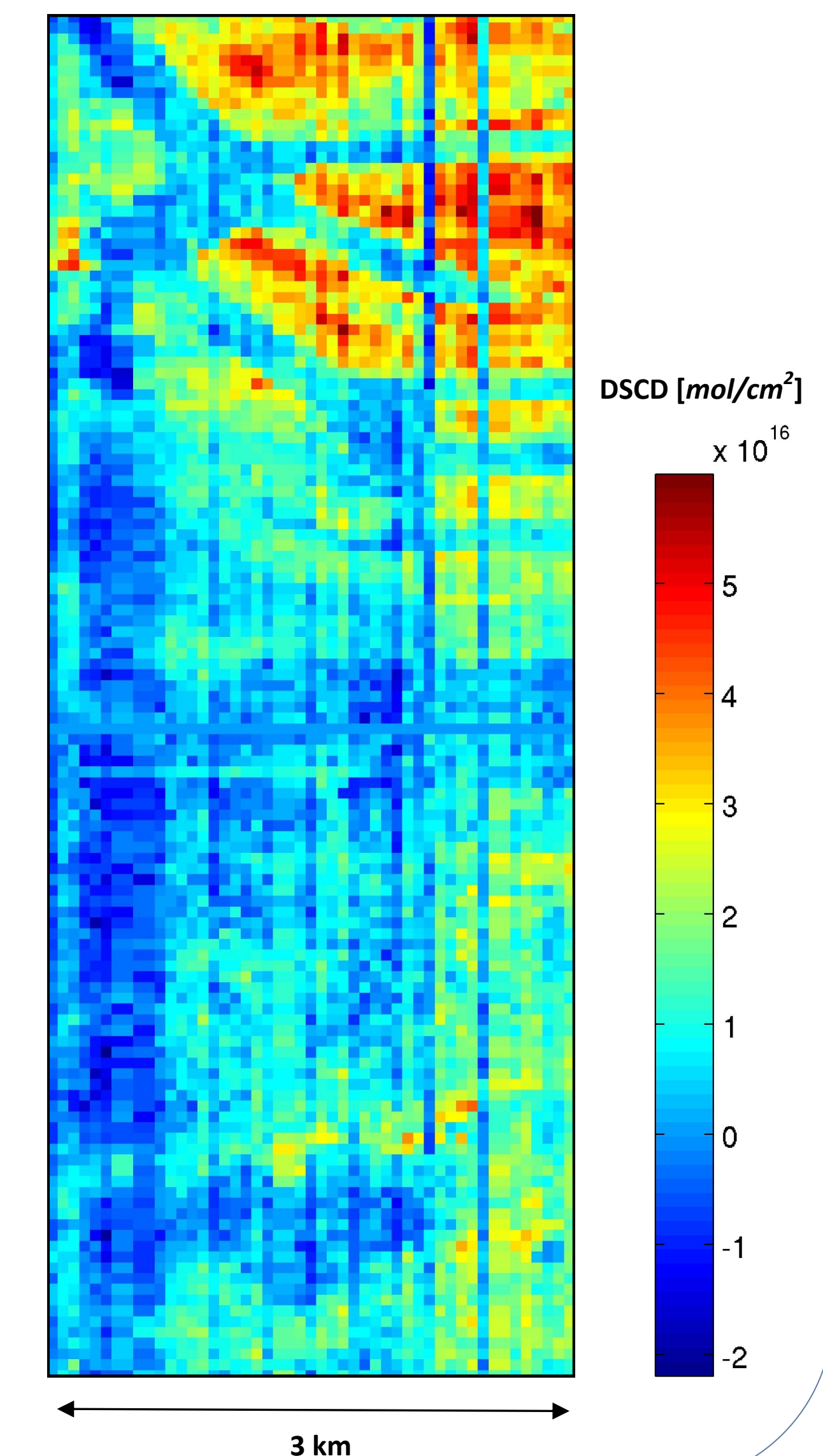
- Campaign flights are planned in spring - summer 2015 above the three largest and most heavily polluted Belgian cities: **Brussels, Antwerp and Liège**
- Validation** of NO₂ retrievals will be done based on correlative datasets from **car mobile-DOAS systems and mini MAXDOAS**

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 NO₂ retrieval! Furthermore no clean reference area was acquired or simultaneous ground based measurements were performed



Reference spectra



Analysed flightline

Analysed binned column

- Left three plots show output for the DOAS analysis, applied on a binned column → RMS of the noise and retrieved NO₂ 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

- Preliminary map (50 binned columns, 127 binned rows) of the **NO₂ distribution**, West of Antwerp city center
- Clear **patterns of enhanced NO₂** can be identified

5 Perspectives

- Retrieval of clear NO₂ signals and spatial patterns of enhanced NO₂, based on APEX observations, is demonstrated here
- Short term planning
 - Optimisation 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 NO₂ 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 NO₂ columns
 - Conversion of retrieved NO₂ columns to high resolution surface concentrations for spatial validation of the RIO-IFDM air quality model