NO_2 Remote Sensing Over Built-Up Areas: The Effects Of 3D Radiative Transfer

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23/11/2021

Introduction – Nitrogen dioxide maps from imaging spectrometers

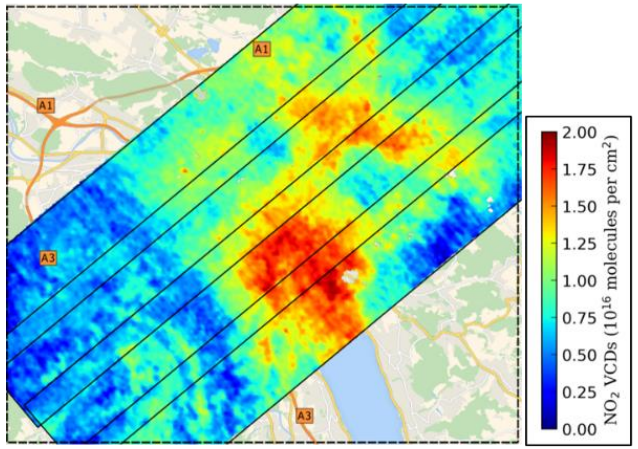
Motivation

- Nitrogen dioxide (NO_2) is an important air pollutant with high spatial and temporal variability.
- High resolution maps (<100m) are required for unbiased estimates of population exposure to NO_2.
- NO_2 maps with the required resolution can be obtained from airborne imaging spectrometers (e.g. APEX), but maps appear smoother than, for example, NO_2 fields from dispersion models.

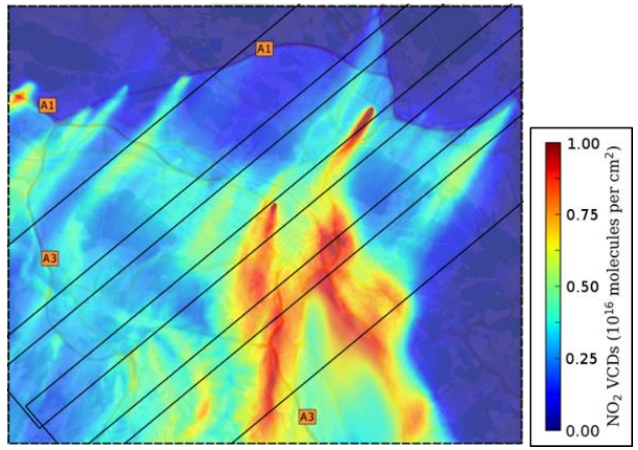
Research questions:

- What is the impact of 3D radiative transfer on NO_2 retrieval algorithms from airborne imaging spectrometers?
- What is the effect of buildings?

APEX NO_2 columns



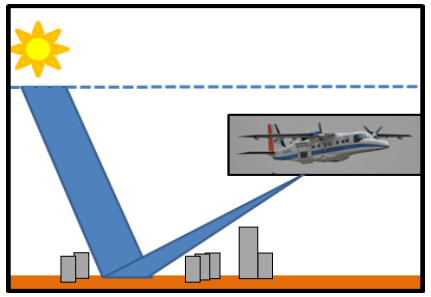
GRAL NO_2 columns



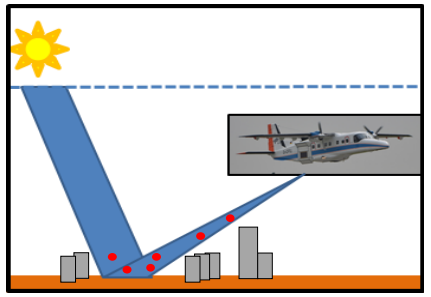
Zurich

Methods – Airborne spectroscopy

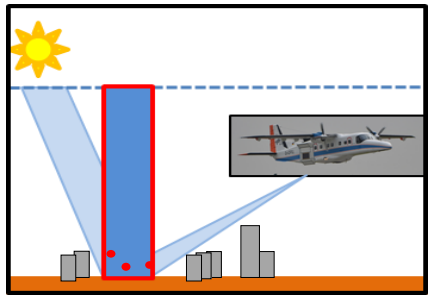
Sensing



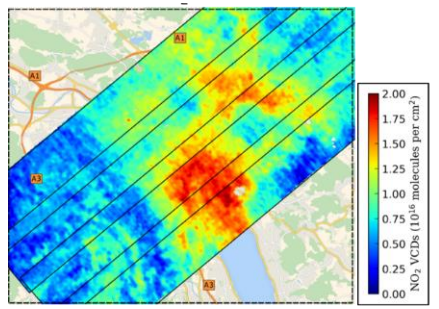
Measured SCD



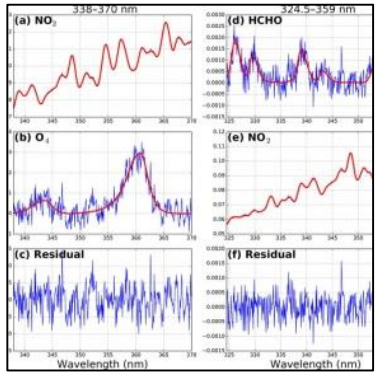
Meaningful VCD



VCD map



DOAS



AMFs

$$AMF = \frac{SCD}{VCD}$$

VCD: vertical column densities
SCD: slant column densities
AMF: total AMF

Traditional
1D-layer AMFs
(horizontal homogeneity)

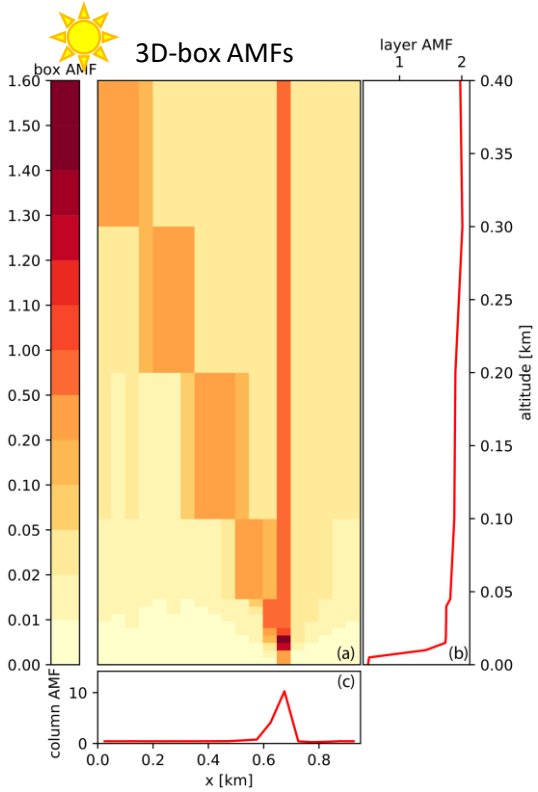
New 3D-box AMFs and urban canopy (Schwaerzel et al. 2020, 2021 in AMT)

For each pixel

Results – 3D-box air mass factors (AMFs) for a single pixel (50 m × 50 m)

Side view: AMFs for an airborne spectrometer pixel:

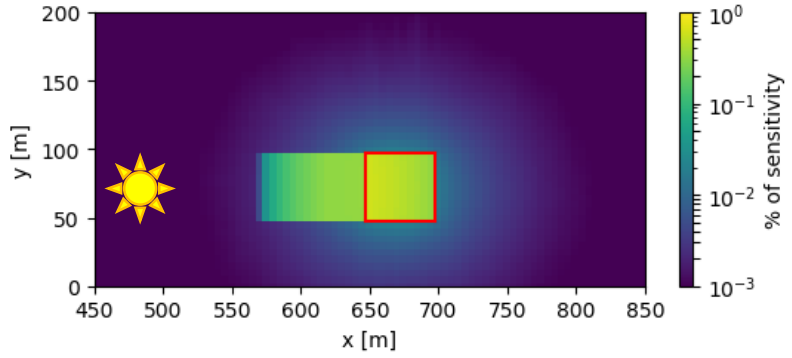
- 3D-box AMFs integrated in the y-direction (a)
- Sensitivity of the instrument
- Sun located in the West



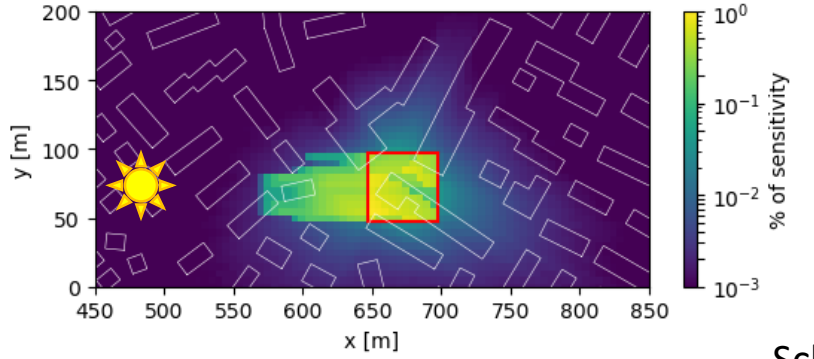
Top view: Airborne spectrometer footprint:

- 3D-box AMFs integrated vertically from 0 – 45m
- Sensitivity of the instrument
- Sun located in the West

Airborne spectrometer footprint



Footprint with buildings



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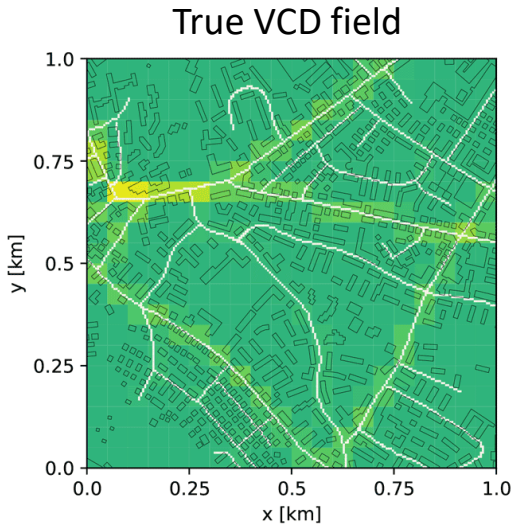
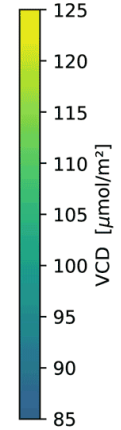
Results – VCD from true SCD and 1D / 3D AMFs





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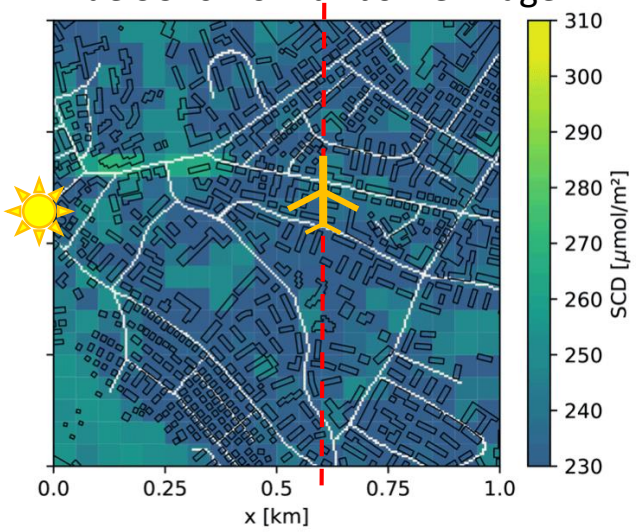
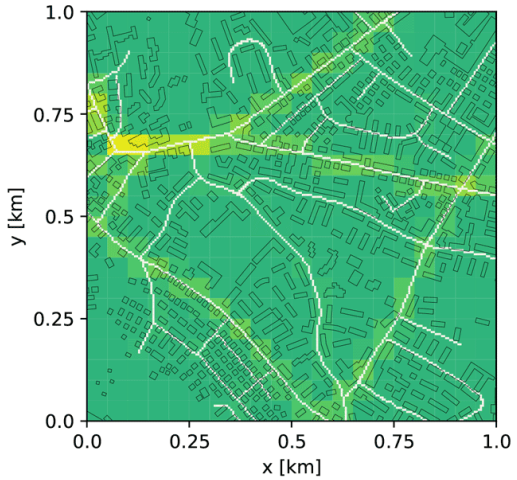
Results – VCD from true SCD and 1D / 3D AMFs

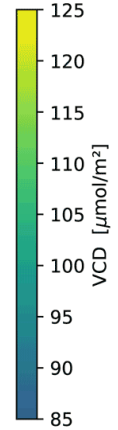
True SCDs from airborne imager



3D box-AMFs
+ urban canopy

True VCD field





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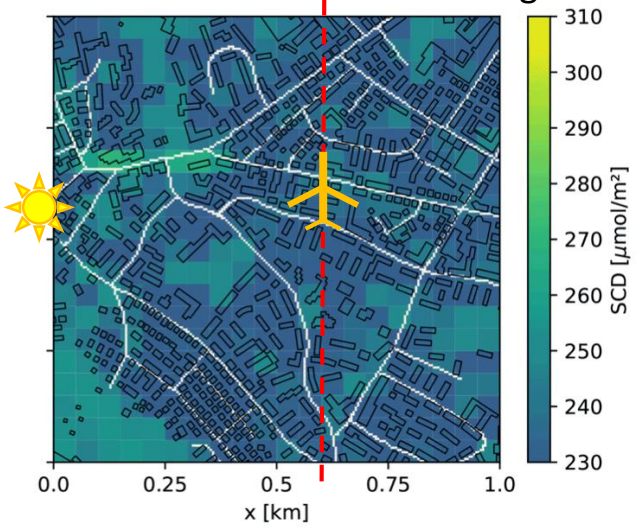

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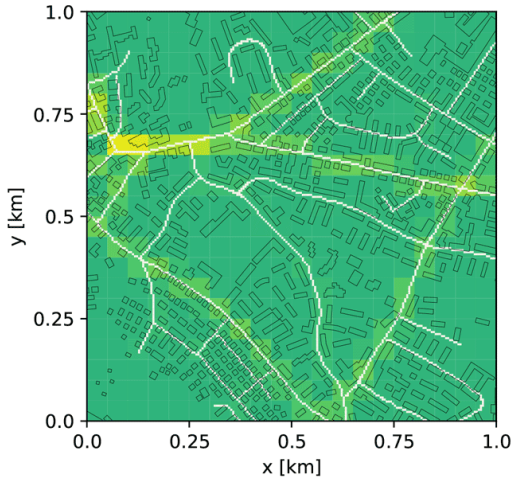
True VCD field



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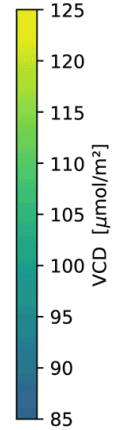

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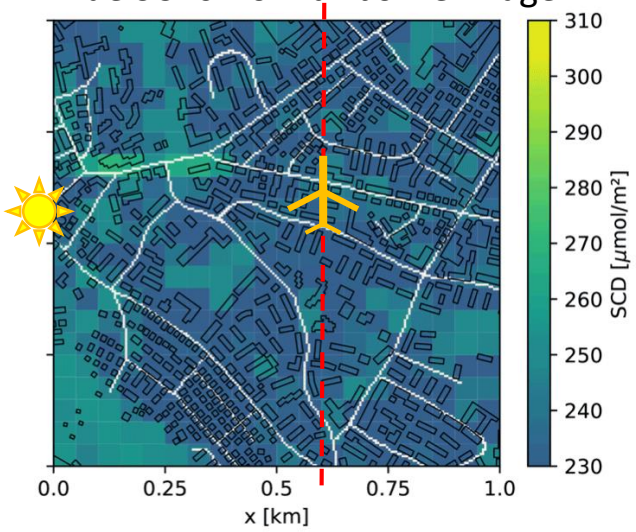
True SCDs from airborne imager

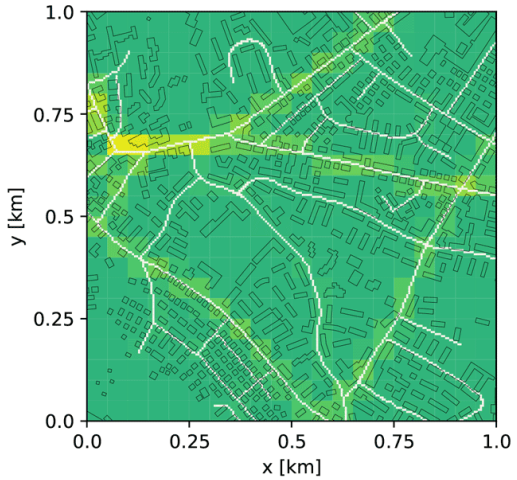


3D box-AMFs + urban canopy

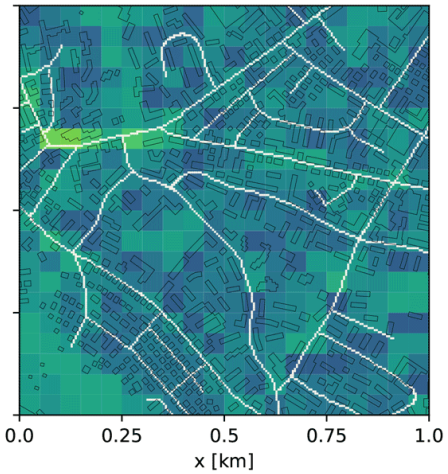
3D box-AMFs (ignoring buildings)

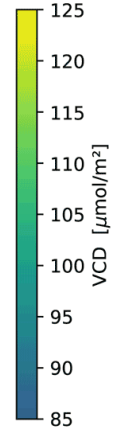
3D box-AMFs + urban canopy

True VCD field



Ignoring buildings





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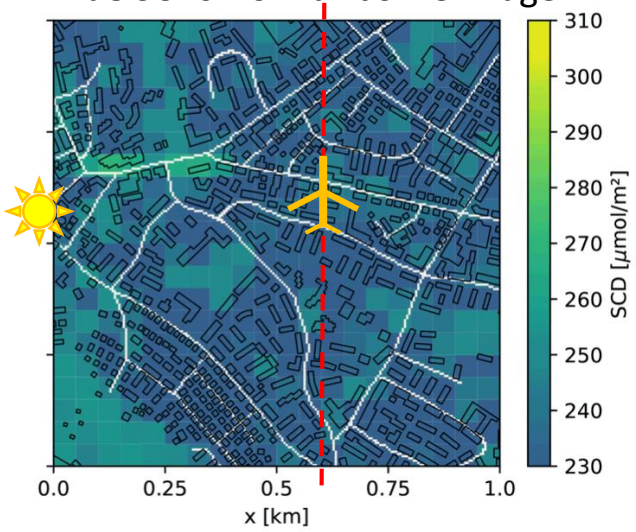
Results – VCD from true SCD and 1D / 3D AMFs

True SCDs from airborne imager



3D box-AMFs + urban canopy

3D box-AMFs (ignoring buildings)

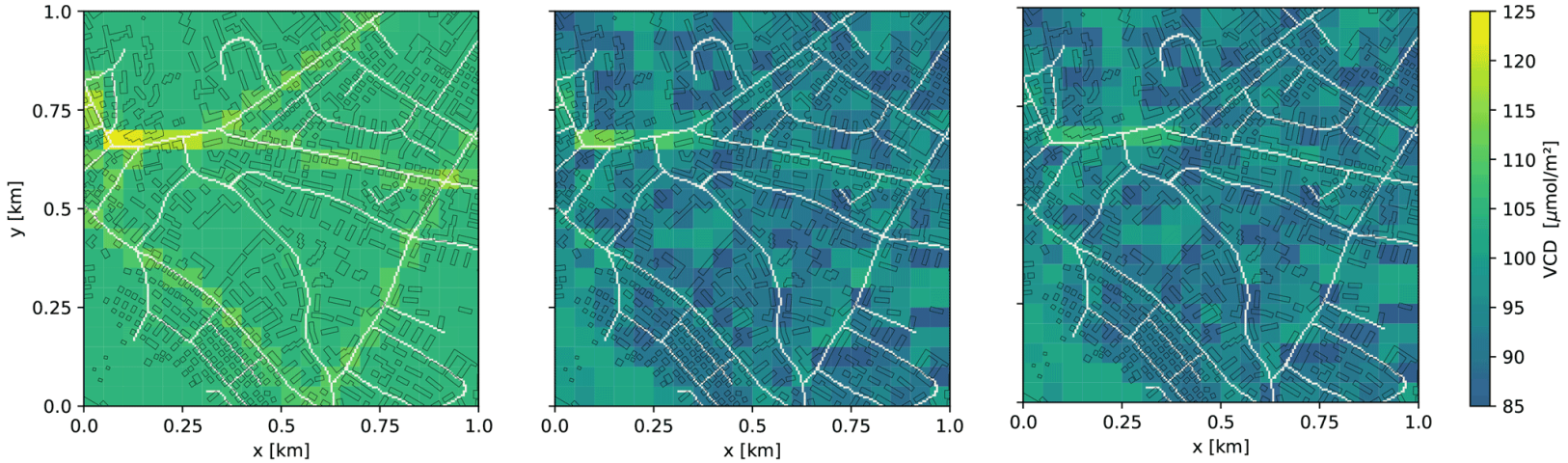
1D-layer AMFs

3D box-AMFs + urban canopy

True VCD field

Ignoring buildings

ignoring 3D effects



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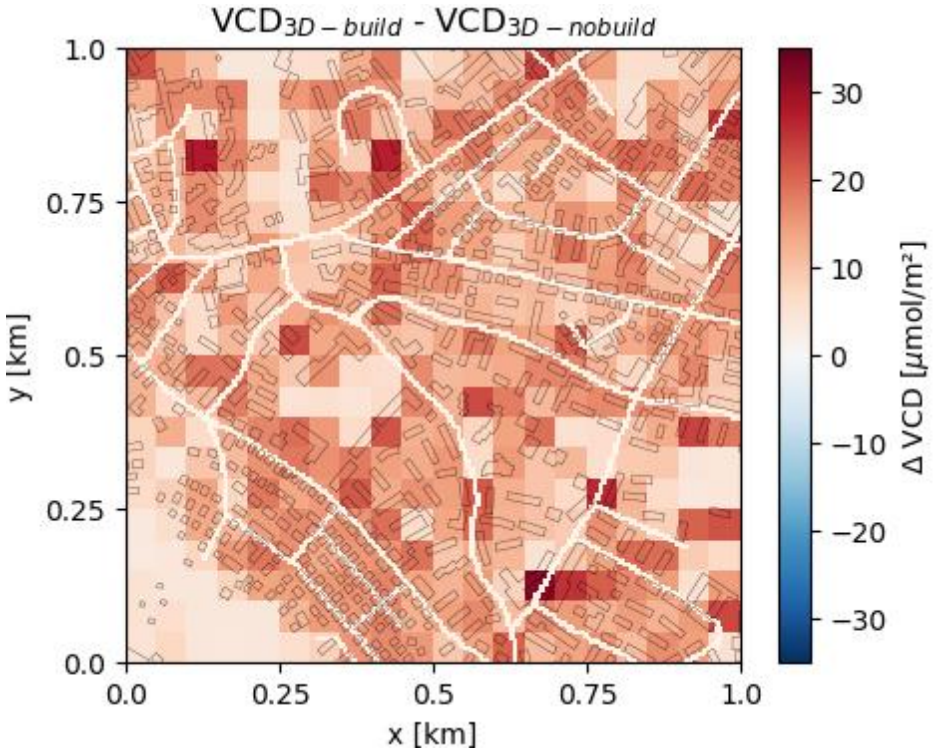
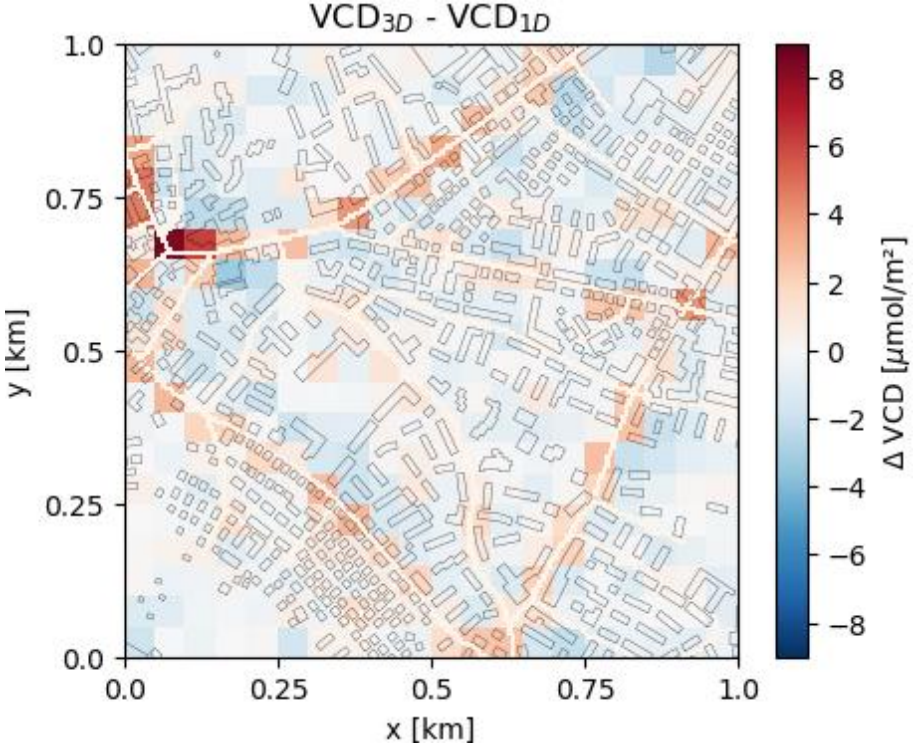
Results – difference VCDs

Buildings effects



STD: 4.94 µmol/m^2

3D effects



STD: 1.27 µmol/m^2

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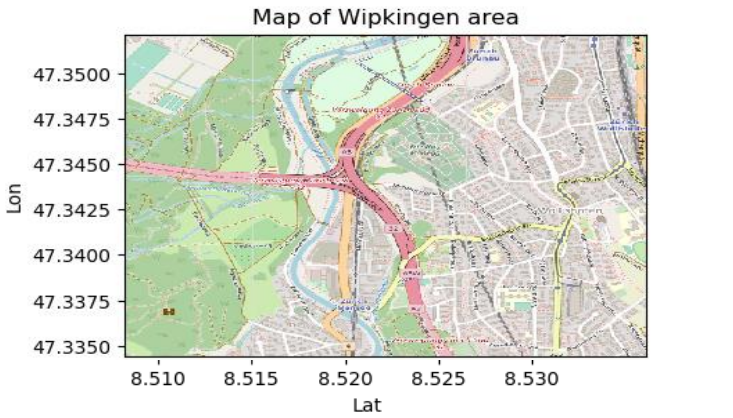
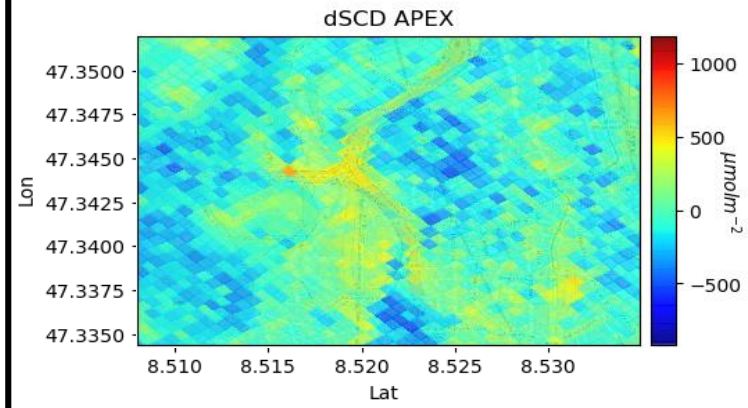
Results – APEX 2013 campaign over Zurich (preliminary)

Map and SCD from APEX





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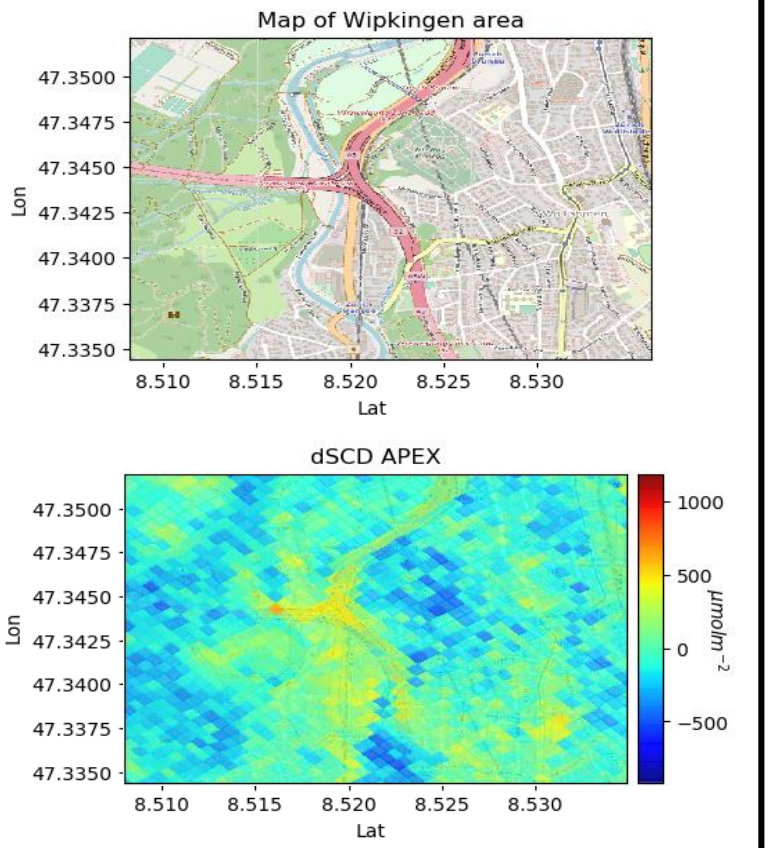
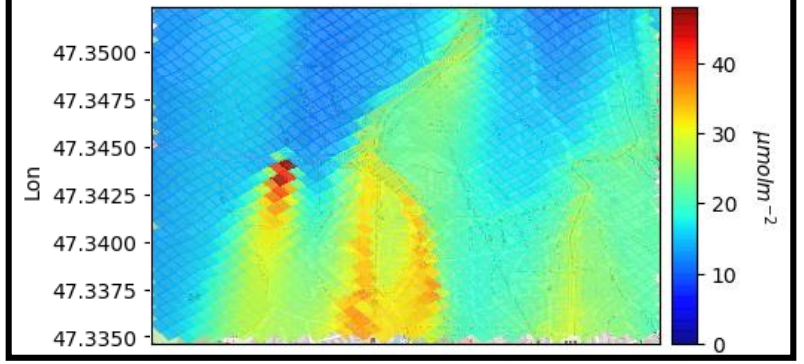


City scale NO_2 simulation with the GRAMM-GRAL (GG) model



Results – APEX 2013 campaign over Zurich (preliminary)

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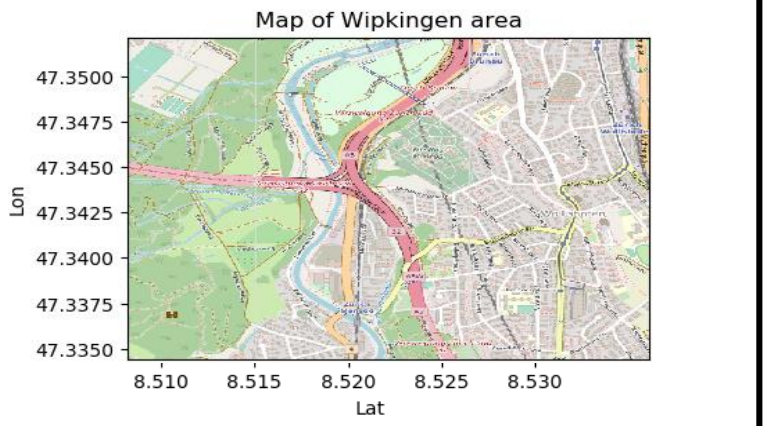
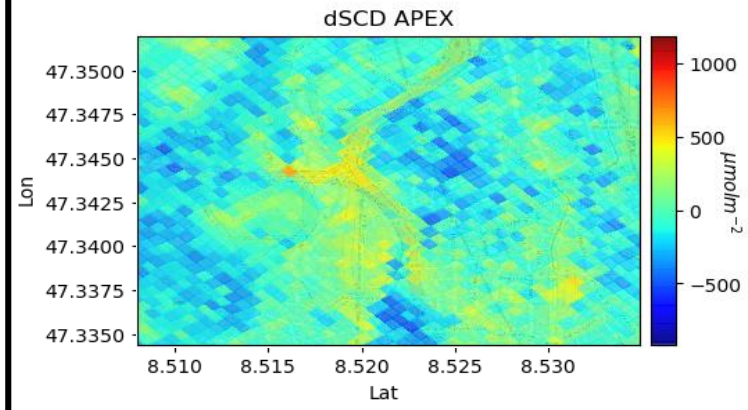
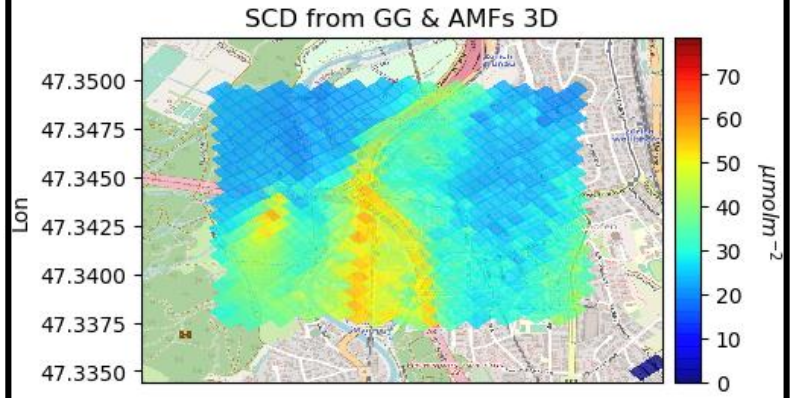
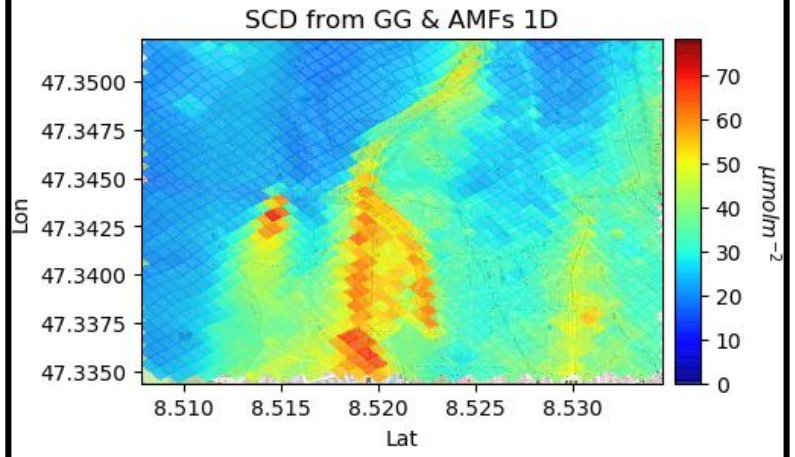


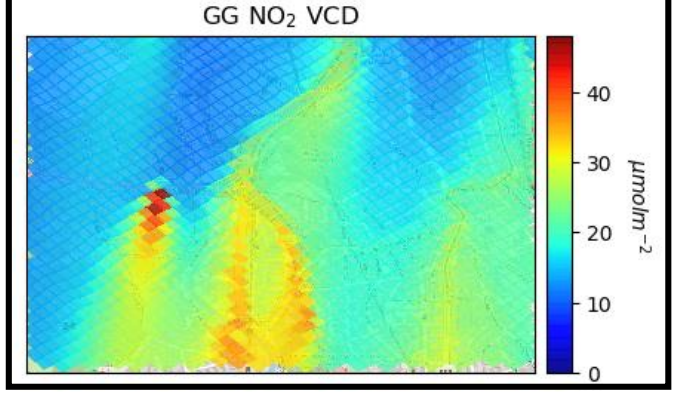


SCDs from GG NO_2 and AMFs





VCD from GG NO_2



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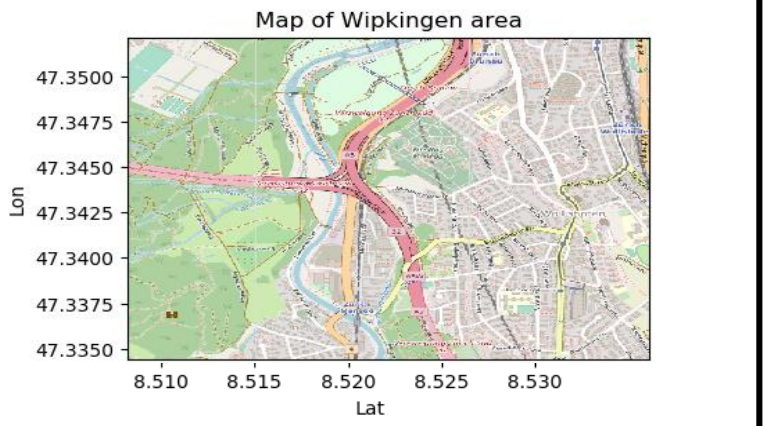
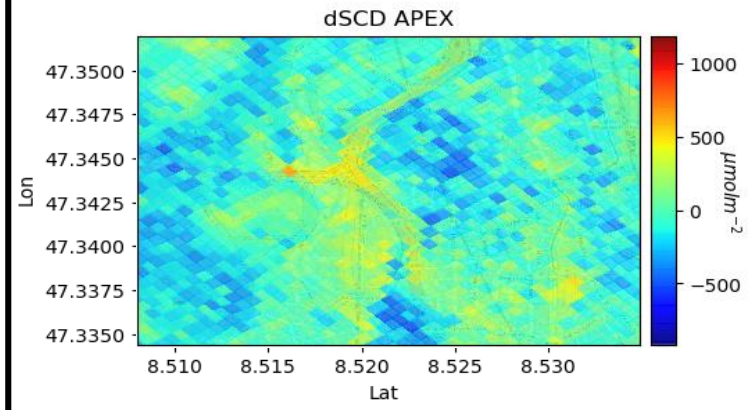
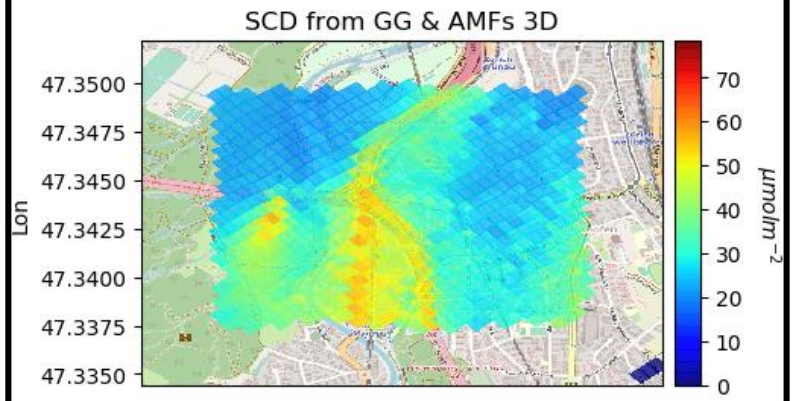
Results – APEX 2013 campaign over Zurich (preliminary)

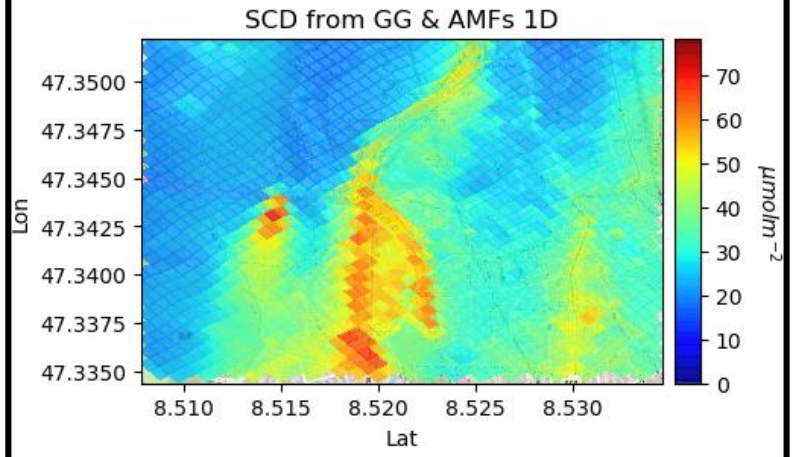
Map and SCD from APEX



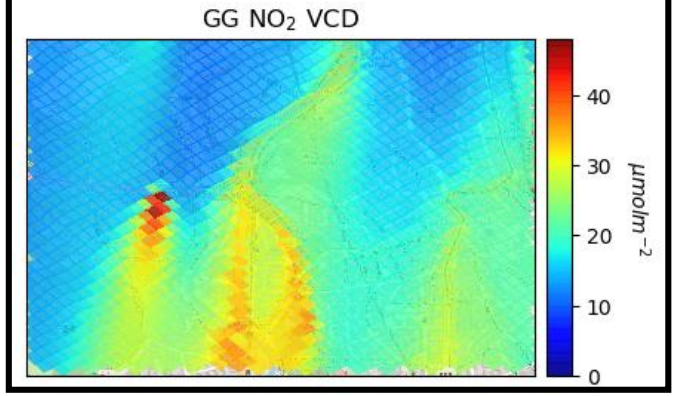


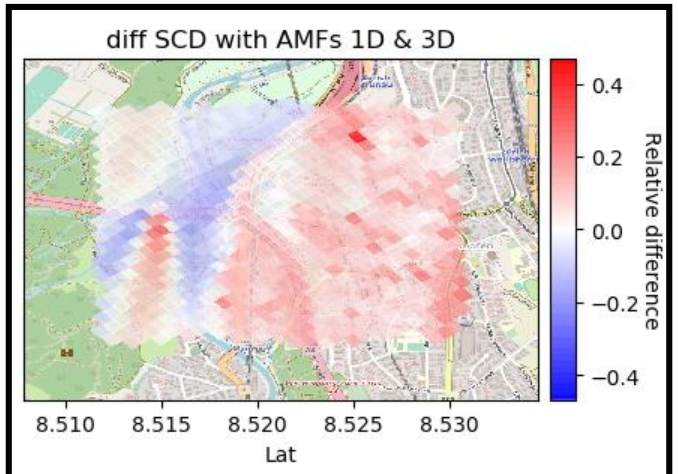
SCDs from GG NO_2 and AMFs





VCD from GG NO_2





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Conclusions

MYSTIC radiative transfer solver in libRadtran

- Implementation of 1D-layer and 3D-box AMFs.
- Implementation of urban canopy.

Case studies on imaging the NO_2 distribution in the city of Zurich using synthetic observations:

- 3D effects spatially smear the NO_2 field, which cannot be corrected using 1D-layer AMFs.
- Buildings shield NO_2 in their shadow resulting in underestimated and noisy NO_2 VCDs when not considered in the retrieval algorithm.
- Application on APEX campaign in Zurich (2013) using 3D-box AMFs and building-resolving dispersion model: first results show that 3D effect could explain some of the features seen in the APEX measurements.

Relevance:

- 3D radiative transfer effects are highly relevant at high spatial resolution impacting AMF computation.
- 3D effects also impact ground-based MAX-DOAS measurements and emission quantification from plume images (Schwaerzel et al. 2020).
- Potentially relevant impact on the next generation of satellite missions with higher spatial resolution (e.g., GHGsat, Sentinel-2, CO2M, Nitrosat).

Questions?

Thank you for your attention ☺

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