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Accounting for surface reflectance in the derivation of vertical column densities of NO_2 from airborne imaging DOAS

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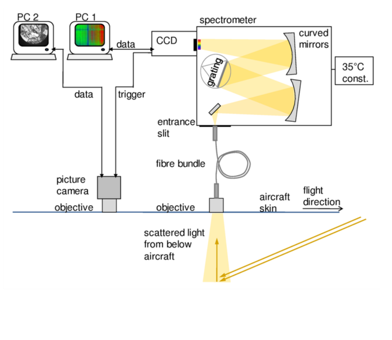
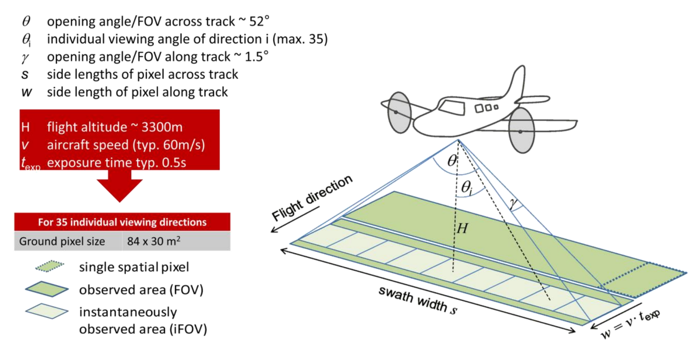
1. AROMAT campaign

- The AROMAT (**A**irborne **RO**manian **M**easurements of **A**erosols and **T**race Gases) campaign was held in September 2014
- Dedicated to comparison of multiple remote sensing and in-situ instruments for satellite data validation
- Many European research institutions involved
- Two target sites
  - City of Bucharest (Urban emissions from traffic and industry)
  - Jiu Valley (Two large power plants with high emissions and localized plumes)
- **Shown here:** are solely measurements in the Bucharest area

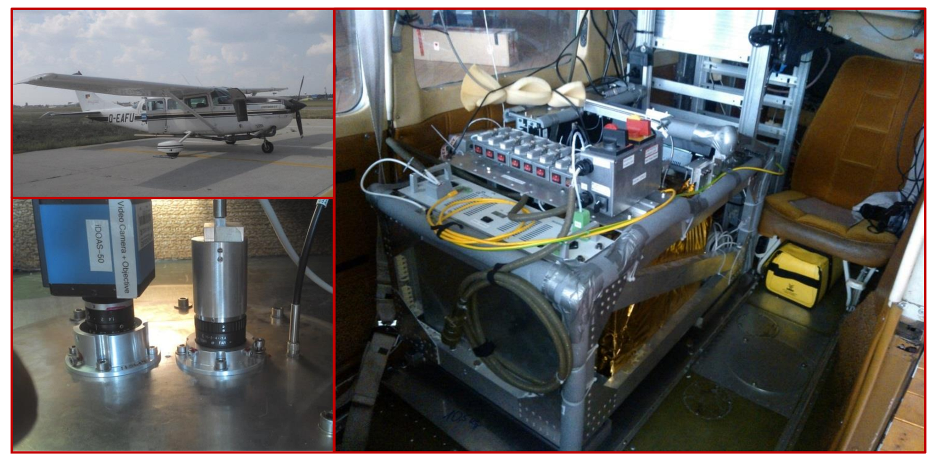
2. Instrumental setup and method





Instrumental setup
Scattered sunlight from below the aircraft is collected and fed into an imaging spectrometer via a sorted fiber bundle (35 individual fibers), retaining the spatial information.

The AirMAP viewing geometry
The swath of the push-broom imager depends on flight altitude, groundspeed of the aircraft and exposure time. For typical values during AROMAT this results in a spatial resolution of 30 x 84 m^2.



Photographs of AirMAP & Aircraft :
- **Top left**: Aircraft AirMAP was installed on (Cessna 207 Turbo); operated by FU Berlin.
- **Bottom left:** Nadir ports of entrance optics and video camera
- **Right**: Instrument rack carrying spectrometer, PCs, UPS etc.

- For the retrieval of trace gas distributions the recorded spectra are georeferenced and the DOAS method (**D**ifferential **O**ptical **A**bsorption **S**pectroscopy) is applied.
- The settings used are shown in the table to the right

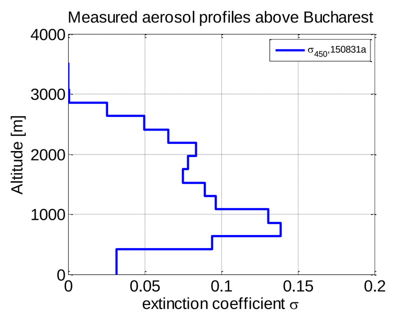
Parameter	Value
Spectral calibration	Using Fraunhofer lines
Fitting window	425 – 450 nm
Trace gases	NO_2 (298K), O_3 (223K), O_4 (293K), H_2O (HITRAN2012)
Atmospheric Effects	Ring effect (SCIATRAN calculation), constant intensity offset
Polynomial	Quadratic
Reference spectrum I_0	Rural scene with low NO_2
Slit function	Individual per viewing direction
AMF	SCIATRAN (see following sections)

3. Air Mass Factors

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

- The air mass factor (AMF) converts the measured differential slant column densities (DSCD) into vertical column densities (VCD)

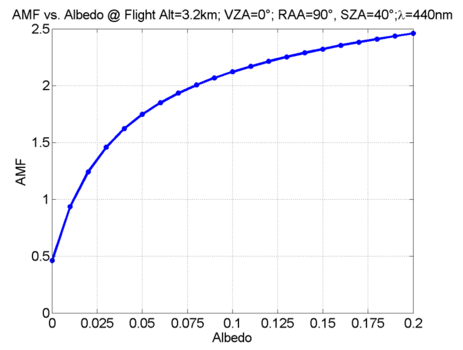
- AMFs computed with SCIATRAN and compiled into a look-up-table with the following dependencies:
  - NO_2 box profile 500m
  - Surface reflectance
  - Solar zenith angle
  - Relative azimuth angle
  - Viewing zenith angle
  - Flight altitude



- Aerosol profile derived from AOT measurements from FUBISS-ASA2 instrument on a flight one year later on the same day of the week (Monday)
- (No measured profile available for the flight shown)

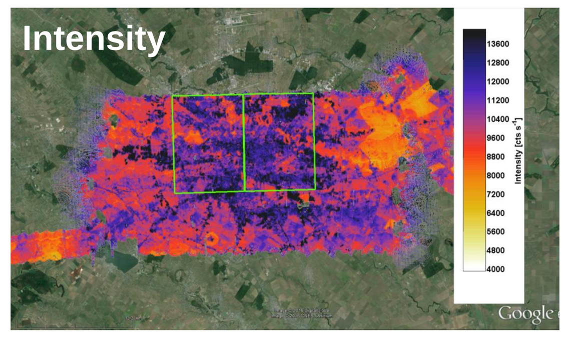
4. Surface reflectance

Importance of surface reflectance for the Air Mass Factor

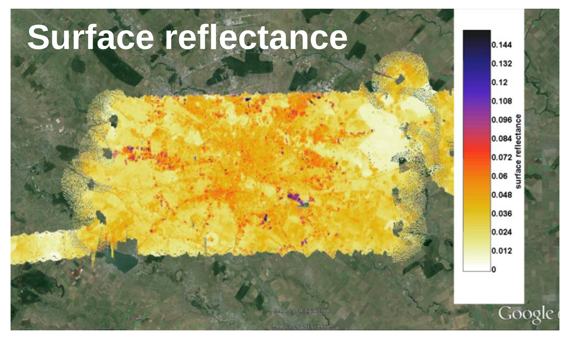


- Strong dependency of the AMF on surface reflectance
- Bright surfaces increase the contribution of light coming from the surface
- Thereby increasing the fraction of light that has passed the trace gas layer (close to the ground)

Derivation of surface reflectance from measured intensities

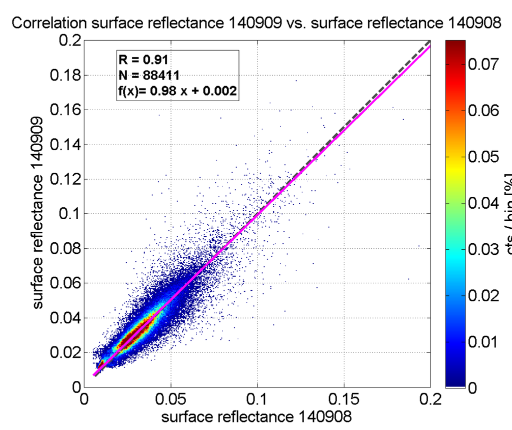


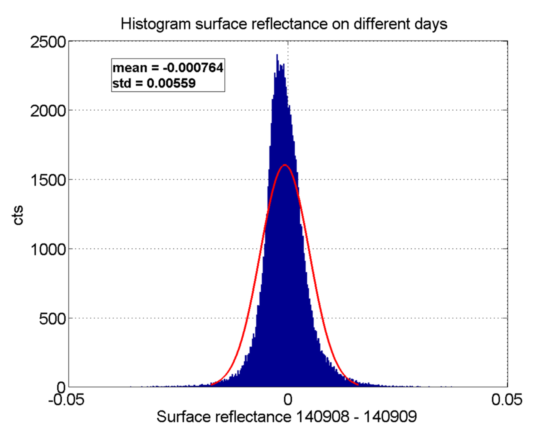
- Measured intensities are normalized to a reference region with known surface reflectance (green boxes)
- surface reflectance data of reference region from ADAM database (based on MODIS)
- Application of atmospheric correction by a look-up table of modeled intensities computed with SCIATRAN



- Figure left shows the derived surface reflectances
- Advantage of method: retrieved surface reflectance corresponds to the measured spectra. No pointing / interpolation issues

Consistency of the method

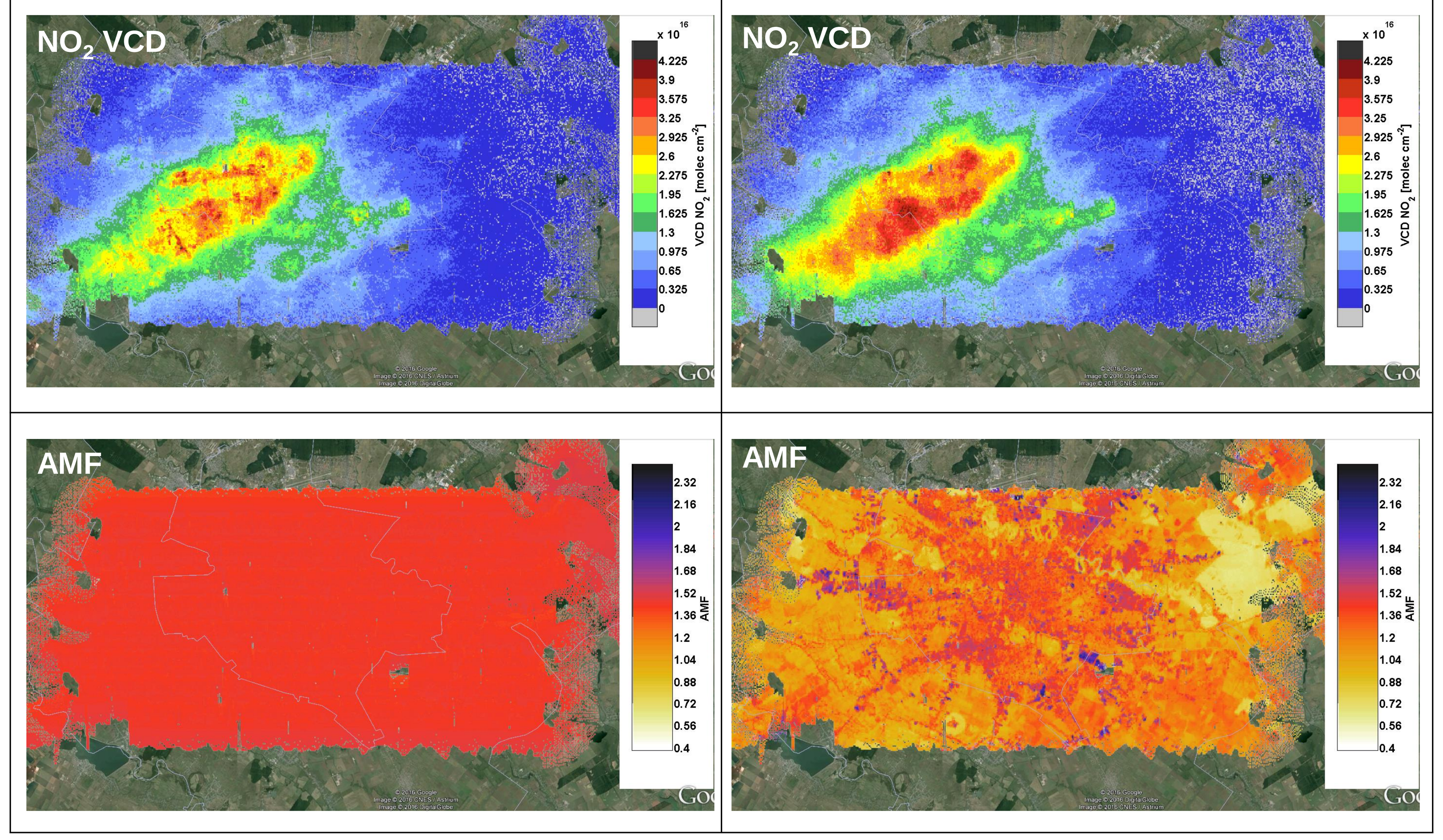




- Figures above show the correlation and corresponding histogram of the intensity derived surface reflectances during 2 flights on different days (2014-09-08 & 2014-09-09).
- The applied method yields consistent results for different flights

5. Application of surface reflectance on VCD retrieval

Surface reflectance constant (0.05)	Surface reflectance derived from measured intensities



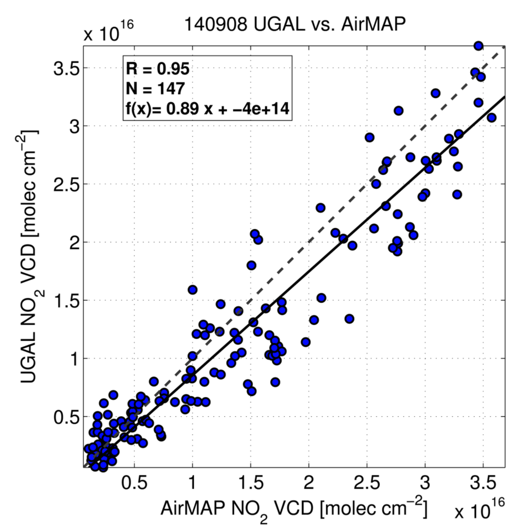
- Compare box 3. for the assumed aerosol profile

- Assuming a constant surface reflectance the VCD show clear structures co-located to bright surfaces.
- Applying the derived surface reflectance in the AMF yields a much smoother NO_2 field

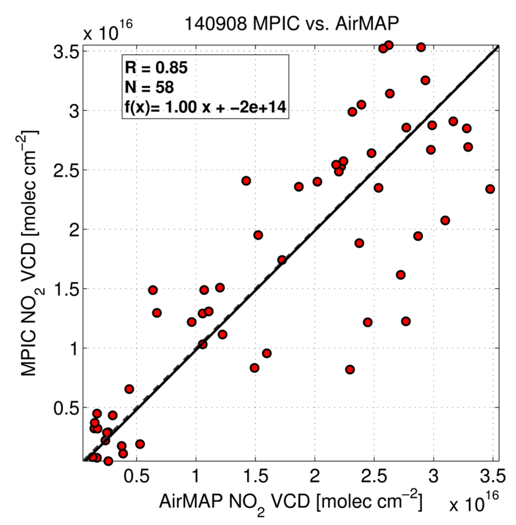
- The AMF without inclusion of a variable surface reflectance shows only relatively small dependencies on viewing zenith angle, solar zenith angle and relative azimuth angle

6. Comparison to mobile car-DOAS measurements

University of Galati
Elevation angle: zenith



Max-Plank-Institute for Chemistry Mainz
Elevation angle: 22°



- Generally good agreement between the mobile car-DOAS measurements and AirMAP
- The slope of the linear orthogonal fit is mainly determined by assumptions on the aerosol and NO_2 profile
  - Depending on the viewing geometry (airborne / ground-based) aerosols above the NO_2 layer can shield the sunlight from passing though the layer (airborne) while they might enhance the NO_2 signal for the ground based system by multiple scattering processes.
  - Up to now the data was evaluated independently by the different research groups, without common assumptions in the AMF computation

Selected references

- Schönhardt et al.: "A Wide Field-of-View Imaging DOAS Instrument for Two-Dimensional Trace Gas Mapping from Aircraft." *Atmos. Meas. Tech.* 8 (12): 5113–31. doi:10.5194/amt-8-5113-2015, 2015
- Heue et. al.: "Direct observation of two dimensional trace gas distributions with an airborne Imaging DOAS instrument". Atmos. Chem. Phys 8: 6707–17, 2008
- A surface reflectance DAtabase for ESA's earth observation Missions (ADAM), ESA final report, (http://adam.noveltis.com/pdfs/NOV-3895-NT-12403_FR-v2.1.pdf)

7. Summary & Outlook

- We have developed a method to account for highly variable surface reflectance in an urban environment
- Applying the derived surface reflectances in AMF computation successfully eliminates spatial patterns in the retrieved NO_2 VCD originating from varying surface reflectances
- Comparison to two independent co-located mobile car-DOAS measurements yields good agreement
- Comparison between car and airborne measurements can be further improved by homogenized assumptions on the aerosol and NO_2 profile
- Further analysis of the dataset to better understand the influence of aerosols on the radiative transfer

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