Estimating the source strength of nitrogen oxide emissions of Berlin based on airborne imaging DOAS measurements

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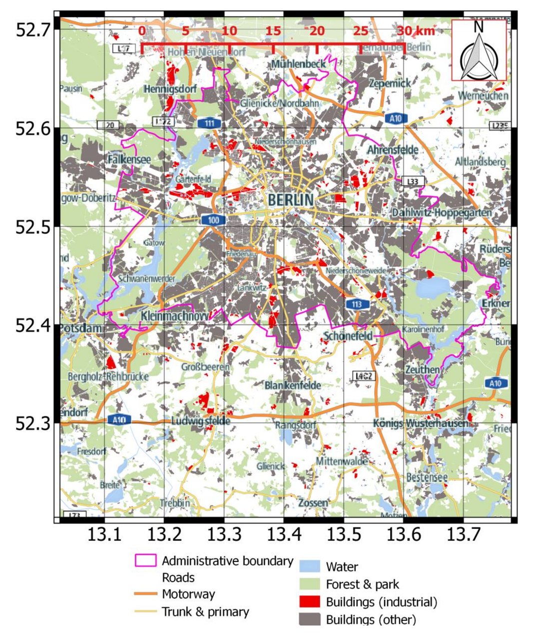
1. Introduction

- Nitrogen oxides (NO_x = NO + NO_2) are:
  - harmful to health and environment and play a key role in atmospheric chemistry
  - a major pollutant in urban areas, despite reduction in the last decades
- Chemical modeling requires knowledge on emissions, which is sparse at high spatial resolution
- Top-down estimates can be used to validate bottom-up inventories

2. Campaigns & target site

- Airborne imaging DOAS measurements performed with the AirMAP instrument, developed at IUP-Bremen on board of the FU Berlin Cessna
- Flights carried out in the framework of the campaigns AROMAT-1 (2014), AROMAT-2 (2015) and AROMAPEX (2016) funded by ESA / EUFAR
- Four mappings of NO_2, each covering almost the entire city of Berlin
- Berlin is capital and largest city of Germany with about 3.6 million inhabitants



3a. Method for emission estimates

- **Basis:** Gauss' divergence theorem, describing the flux (F) of a vector field though a closed surface
- Required input data:
  - Vertical Column Density (VCD) of trace gas
  - Wind vector ($\vec{w}$) (speed & direction)
  - For NO_x: Correction factor (c_f)
  - Eventually correction for chemical loss (neglected here)

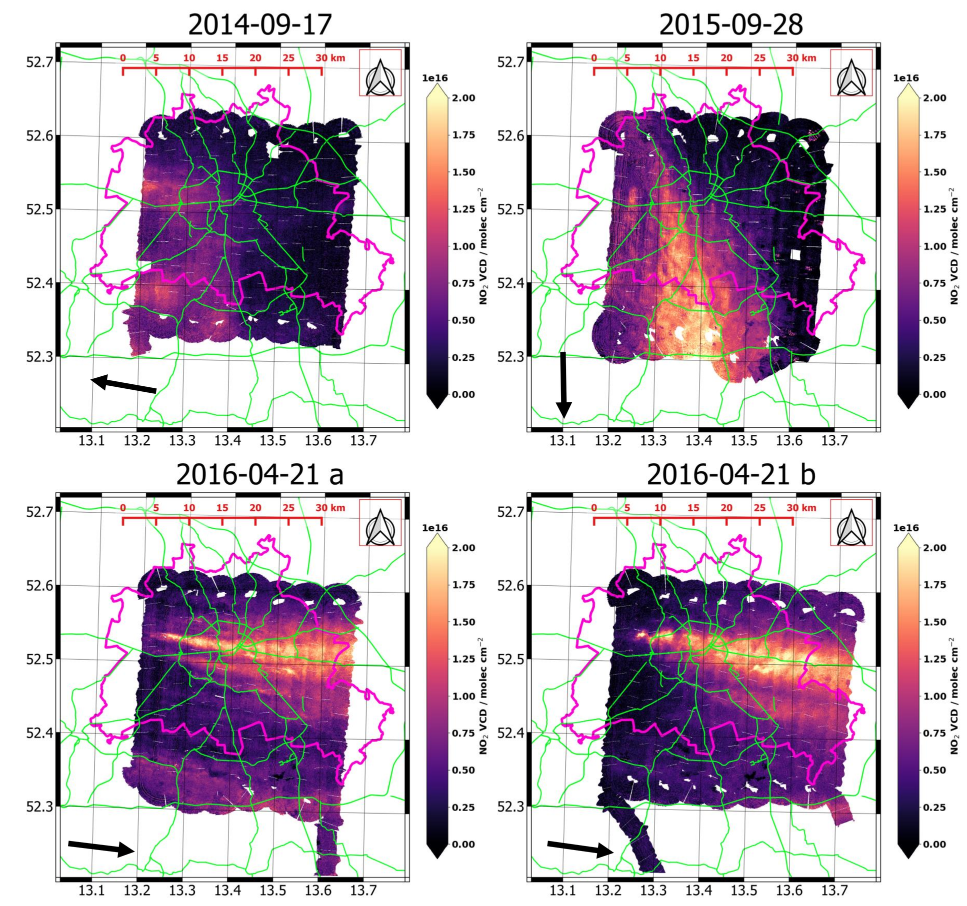
$$F = \oint_S VCD(s) \cdot \vec{n} \cdot \vec{w} \cdot ds \approx \sum_i VCD(s_i) \cdot |\vec{w_i}| \cdot cos(\beta_i) \cdot \Delta s_i$$

$c_f = 1 + \frac{[NO]}{[NO_2]}$; assumed constant 1.32

$$F_{NO_x} = F_{NO_2} \cdot c_f$$

3b. Implementation

1. Gridded NO_2 VCD maps as basis

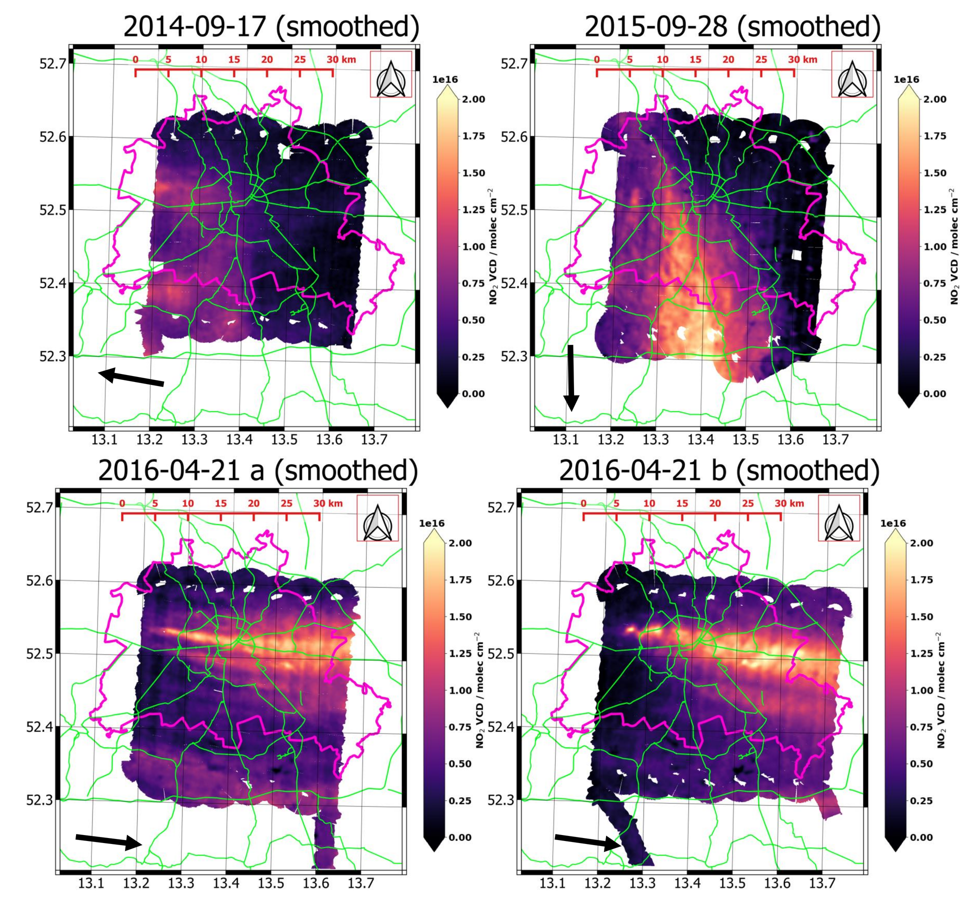


Left: Gridded maps of NO_2 VCD retrieved from four flights on three days above Berlin with the AirMAP instrument

- Different wind directions (easterly, northerly, westerly) lead to distinct spatial patterns

Flight	Wind direction / °	Wind speed / m s^{-1}
2014-09-17	100	7.8
2015-09-28	359	5.3
2016-04-21 a	277	4.9
2016-04-21 b	278	5.1

2. Smoothing of NO_2 maps to discriminate noise and artifacts

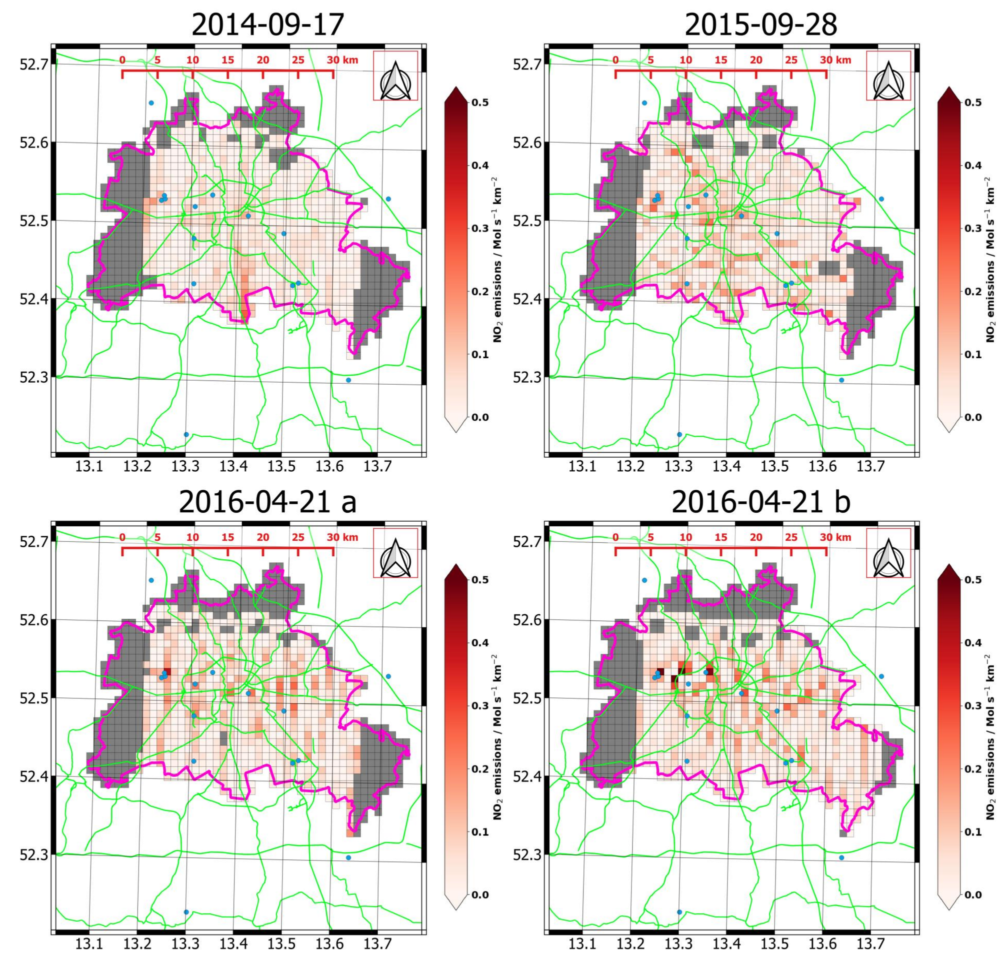


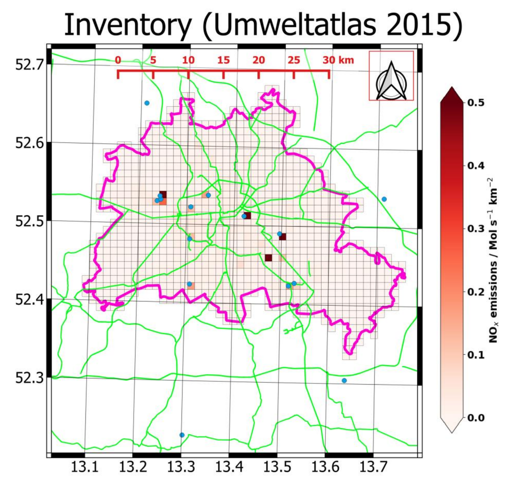
Left: Gridded maps of NO_2 VCD from above convolved with a Gaussian kernel to reduce impact of noise and artifacts from temporal variability

- Little impact of smoothing on general spatial pattern
- Large emitters are readily discernible in the maps

3. Sampling the NO_2 VCD map along the perimeter for each grid cell in a sampling grid
   - Here sampling grid is aligned with a high spatial resolution (1km x 1km) emission inventory
   - The perimeter of each cell is sampled in steps of 100 m
   - Integrating along the perimeter by method in 3a
   - Wind speed is interpolated from ERA-Interim reanalysis data, wind direction is determined from the NO_2 maps

4. Results



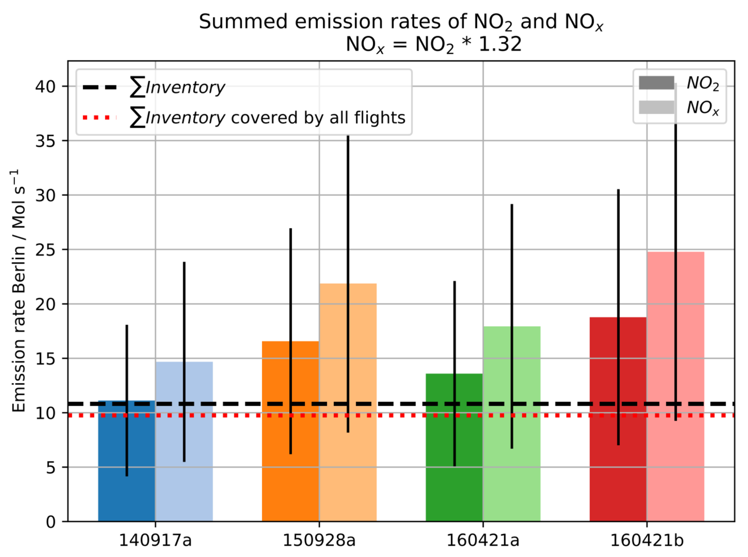


Top: Emission inventory for 2015 of total NO_x as published by the senate of Berlin. Blue markers correspond to large emitters listed in the E-PRTR.

Left: Emissions of NO_2 retrieved from AirMAP measurements.

Bottom: Sum of grid cells covered in every flight totaling to 632 km^2. Error bars estimated from uncertainties in VCD and wind.

- Largest emitter in the north west visible in all emission maps
- Spatial pattern variable between days, 2016 flights show best agreement with inventory
- Small shift between E-PRTR sources and elevated grid cells (NO -> NO_2 conversion?)
- Summing over all grid cells gives consistent results
- Retrieved emissions larger than annual average inventory



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5. Summary & Outlook

- Airborne imaging DOAS data from the AirMAP instrument was used to derive emission rates of NO_2 on small spatial scales
- Novel approach based on established concepts
- Retrieved emissions larger than inventory. Large uncertainty from wind data
- Comparison of single days to annual average
- Improving the method requires reliable high-resolution meteorological data, e.g. to calculate accurate trajectories
- The concept can be applied to satellite data

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