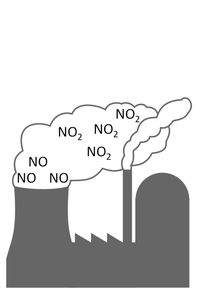
Lifetimes and emission fluxes of nitrogen oxides from cities and power plants estimated by Sentinel-5P observations

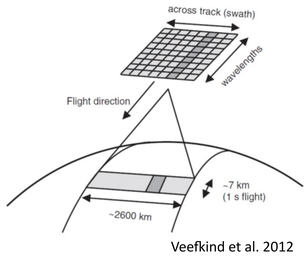
Kezia Lange (klange@iup.physik.uni-bremen.de), Andreas Richter and John P. Burrows
Institut für Umweltphysik (IUP), Universität Bremen

Poster as PDF

1. Nitrogen oxide emissions

- Nitrogen oxides (NO_x = NO + NO_2) are important trace gases in the atmosphere
- Impact on human health, ozone formation and climate
- Emitted by combustion of fossil fuels
- Lifetime of NO_x in the troposphere between a few hours within pollution and about a day
- NO_x emissions mainly in form of NO with a fast conversion to NO_2
- NO_2 is near the sources and can be used as a tracer of air pollution
- Measurable with differential optical absorption spectroscopy (DOAS) from ground, air craft or satellite





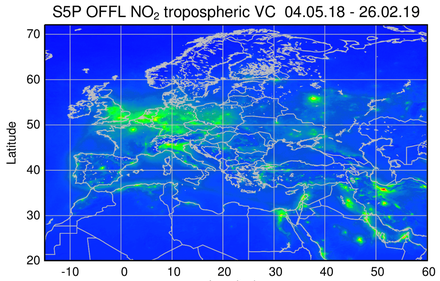
Veefkind et al. 2012

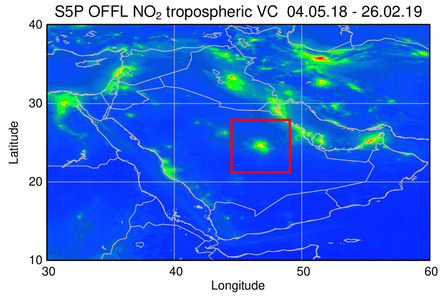
2. TROPOMI on Sentinel-5P

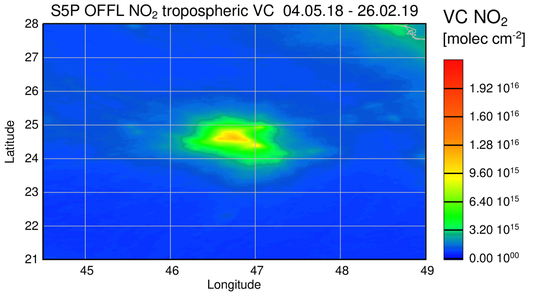
- Measurements with TROPOMI on the satellite Sentinel-5 Precursor
- Started in October 2017 in a sun-synchronous orbit in 824 km altitude
- Daily global coverage with the ascending node at 13:30 LT
- TROPOMI measures within one second an area of 2600 km x 7 km with a high spatial resolution of 3.5 km x 7 km in nadir
- Measurements in UV (270 - 320 nm), VIS (310 - 500 nm) and IR (675 - 775 nm, 2305 - 2385 nm)
- Information about atmospheric composition of for example ozone, sulfur dioxide, formaldehyde and nitrogen dioxide

3. Used Data

- One year 01. March 2018 - 28. February 2019 operational Sentinel-5P NO_2 data (Level 2)
- Pixels with cloud fractions of more than 50% are filtered and not used
- ECMWF ground wind data (0.75°) → Each TROPOMI pixel is linked to wind data
- Region of interest: Riyadh, capital of Saudi Arabia with a population of ~ 8 Million
  - High tropospheric columns of NO_2
  - Isolated → high contrast between city and background
  - Meteorology: only rarely covered by clouds and rather homogenous wind patterns







4. Wind sector analysis

- Each TROPOMI measurement is classified after the method of Beirle et al. (2011) in one of eight wind sectors corresponding to ECMWF wind direction
- Mean over each wind sector → avoidance of neutralization of outflow patterns lear outflow patterns corresponding to wind direction of sector
- Due to the high spatial resolution of TROPOMI in comparison to previous studies, like Beirle et al. (2011), in which OMI data from 2005 - 2009 are used, much more details are visible
- Additionally to increased NO_2 columns over the city center of Riyadh, single strong sources of NO_x are identifiable

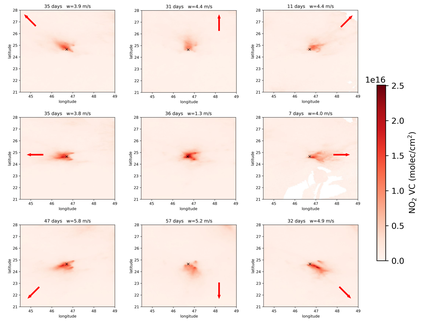


Fig.: Mean tropospheric column NO_2 for Riyadh (black cross). Centered for low wind speed of w < 2 m/s and surrounded with eight main wind directions with wind speed of w > 2 m/s. The arrows indicate the wind direction for the respective sector.

5. Calculation of lifetimes and emission fluxes

- Reduction from 2D maps to 1D line densities by integration across wind direction
- Maximum shifted in wind direction and curve less steep downwind than upwind
- Fit of observed line densities as function of distance x with an exponential function, which describes transport and chemical decay:
  $e(x) = \exp\left(-\frac{x - X}{x_0}\right)$ with $x > X$ (downwind), else 0
  with X: location of apparent source and x_0: distance when concentration is decreased to 1/e
  A Gaussian function for the broadening of the source by spatial smoothing:
  $G(x) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{x^2}{2\sigma^2}\right)$ with standard deviation σ
  Scaling with an emission factor E' and a constant background concentration B:
  $M(x) = E' \cdot (e \otimes G)(x) + B$
- Thereby lifetimes $\tau = \frac{x_0}{w}$ of ~2.5 h and NO_2 fluxes $E = E' \cdot w$ of ~130 mol/s are calculated

6. Separation of single sources

- Due to the high spatial resolution of TROPOMI it is possible to separate single sources within a city
- Used to determine line densities and calculate lifetimes and emissions for single plumes
- After applying a filter for wind direction to avoid mixing of different plumes, the data of the five detected sources are rotated on a suited uniform wind direction
- In an area of +/- 10 km around the source line densities are determined and lifetimes and emissions are calculated identically as for the wind sectors
- Calculated lifetimes between 3 h and 6 h. Increased values by mixing with extrinsic emissions
- The sum over the NO_2 fluxes of the five sources and conversion in NO_x emissions with a ratio of [NO]/[NO2] of 0.32 (Beirle et al. 2011) gives 125.44 mol/s, which can be compared to emissions from EDGAR database for the latest data from 2012 of 154.65 mol/s

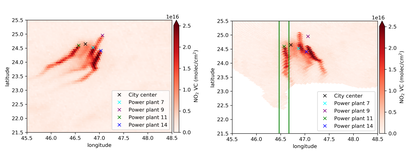


Fig.: Tropospheric column NO_2 for 01. July 2018 (left). Rotation of pixel according to respective wind direction around the green power plant to north wind. The green lines mark the area of +\- 10 km around the source for which the line densities are determined (right).

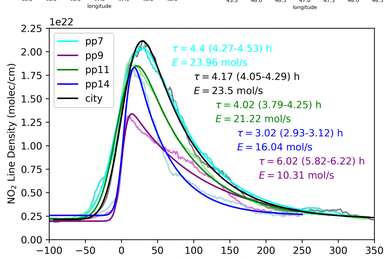
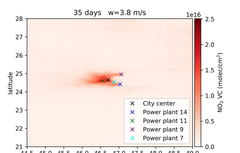


Fig.: Line densities for the single plumes within the area of +\- 10 km around the source as function of distance to the respective source for the city center (black) and the four power plants (colored). Lifetimes in the range of 3 h to 6 h and NO_2 emission fluxes between 10 mol/s and 25 mol/s are calculated.



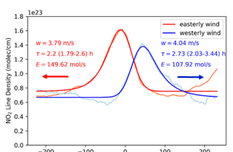


Fig. (left): Mean tropospheric column NO_2 for Riyadh (black cross) for easterly wind. The colored crosses correspond to power plants.

Fig. (right): Line densities as function of distance to the city center (black cross, $x = 0$ km) for easterly wind (red) and westerly wind (blue).

7. Summary

- TROPOMI makes it possible to calculate lifetimes and emissions out of a one year dataset
- It is possible to identify single sources and separate them for separate investigations
- The sum of emissions over the single sources is comparable to the emission database EDGAR
- Extension to further cities, to investigate diurnal variations of emissions, like the rush hour

Acknowledgements:
Copernicus Sentinel-5P level 2 NO_2 data for the year 2018 and 2019 were used in this study (http://www.tropomi.eu/data-products/nitrogen-dioxide).
Data from July 2018 onwards are freely available over ESA Copernicus Open Access Hub.
This study was done in the context of the MAXGRAD project, which is funded by the German Aerospace Center (DLR) Bonn.

Selected references:
BEIRLE, Steffen, et al. Megacity emissions and lifetimes of nitrogen oxides probed from space. *Science*, 2011, 333. Jg., Nr. 6050, S. 1737-1739
VEEFKIND, J. P., et al. TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. *Remote Sensing of Environment*, 2012, 120. Jg., S. 70-83.