Assessing the constraint of the CO2 monitoring mission on fossil fuel emissions from power plants and a city in a regional carbon cycle fossil fuel data assimilation system

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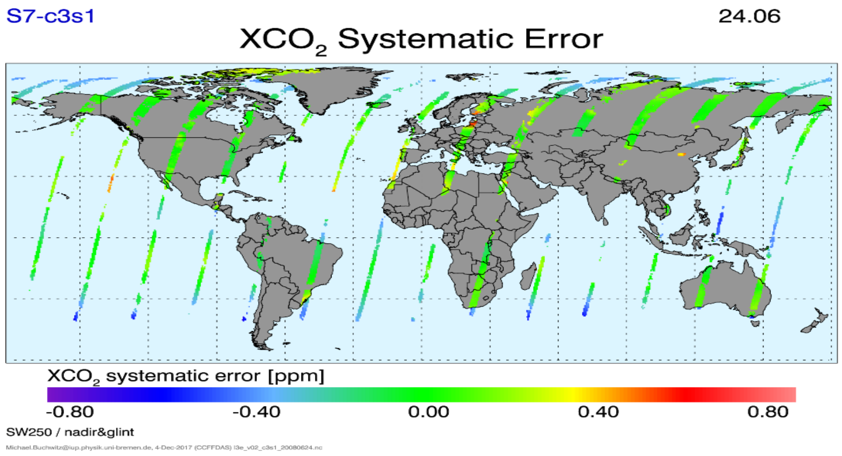
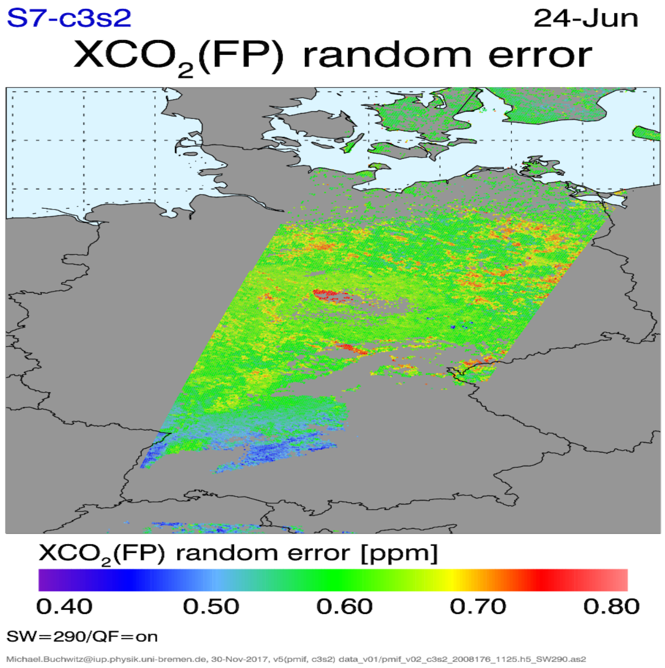
The CO_2 Monitoring Mission (CO2M)

- Planned by Copernicus Programme for a 2025 launch
- Multi-Satellite Constellation
- Imaging Capability at 2 km x 2 km grid with wide swath
- XCO2, NO_2, Multi-Angular Polarimeter (Aerosols)





Capabilities of the Copernicus CO2MVS capacity

Assessments require high-resolution modelling of CO2M Images

1.5.1 Stepwise approach for a CO_2 emissions MVS capacity

The need and capabilities for a Monitoring and Verification Support capacity have been illustrated in previous sections using projections of emissions based on current inventories and two plausible scenarios. These analyses have highlighted the necessity for this system to properly address the following set of capabilities:

C1. Detection of hot spot. A hot spot is defined as a small area surrounded by a strong CO_2 concentration gradient, because the area contains a large emitting CO_2 source. This can be a large power plant, a megacity or any other activity characterized by strong CO_2 emissions with different time evolution;

C2. Monitoring the emissions of the hot spot. Consecutive measurements are needed to link the measured emission level to previous measurements and to monitor local emission reductions of the activities within the hot spot. The accuracy of the measurements must ensure the capability to attribute CO_2 emissions anomalies relative to the CO_2 concentration background level;

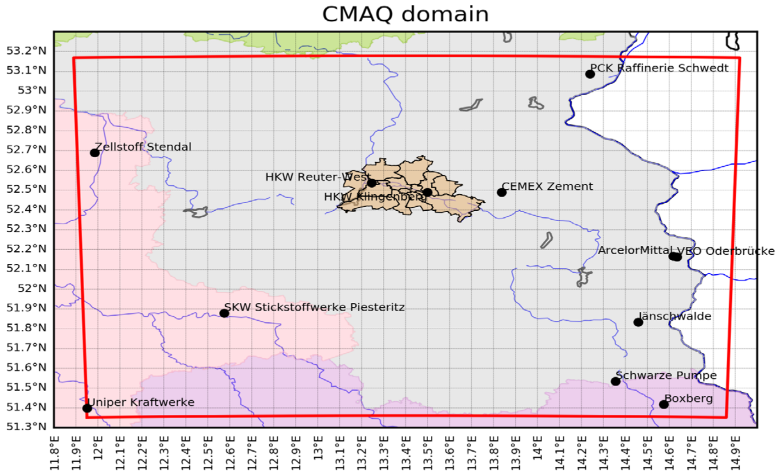
C3. Assessing emission changes against local reduction targets. This concerns the monitoring of the implemented emission reduction strategies on the hot spots, which all add up to achieve NDC targets. In the EU this requires the monitoring, at the most appropriate time scale, of not only the point source facilities (which are under the Emissions Trading System) but also the megacities with peak emissions of transport and buildings;

C4. Assessing the national emissions and changes with 5 year time steps. This requires the entire screening of the full area covered by the country, in order to account for changes in emission patterns with new or occasional hotspots.

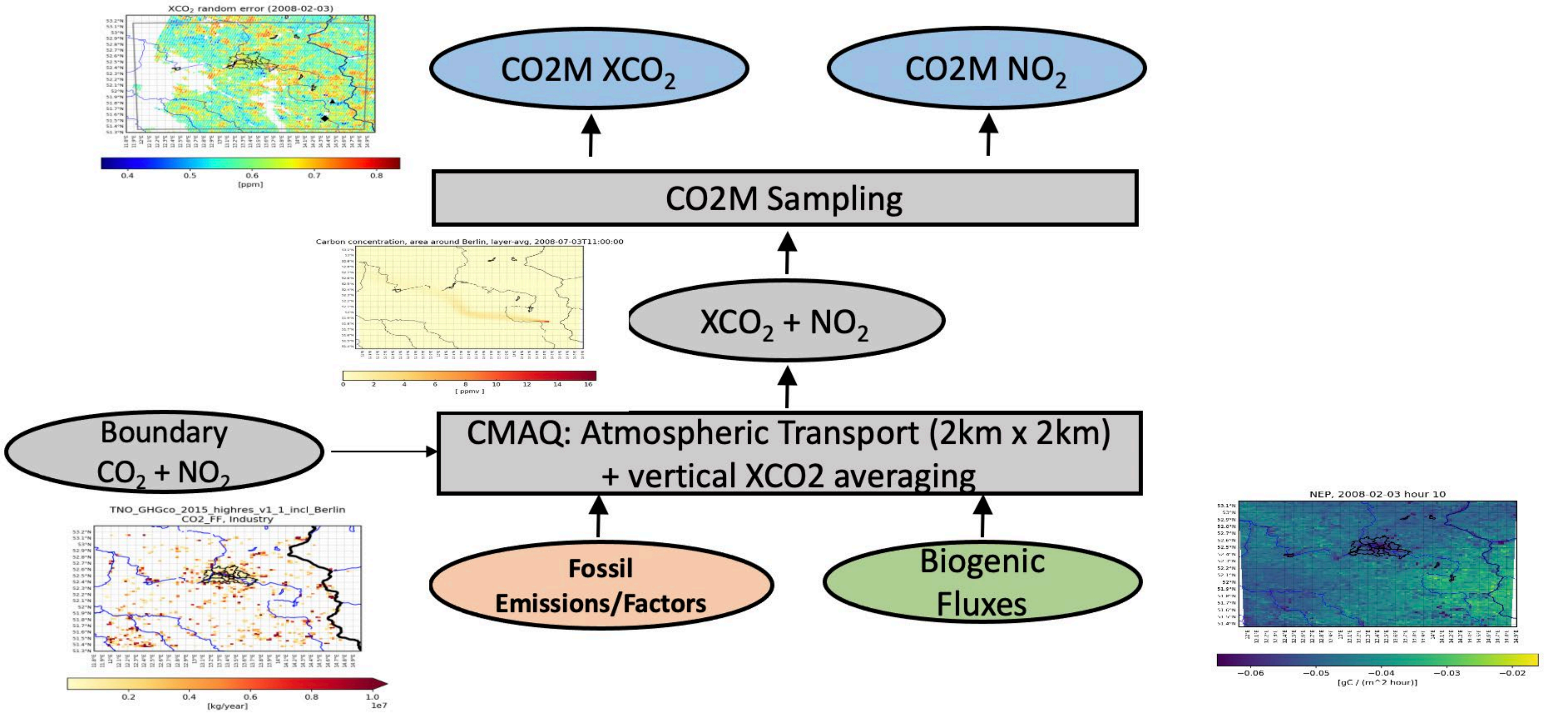
High resolution set-up over Berlin

Modelling System:

- CMAQ in 2 km x 2 km resolution
- 200 km area around Berlin
- Use simulated CO2M images
- Assess accuracy requirement for XCO2 alone
- And in conjunction with NO_2
- Assess added value of a multi-angular polarimeter (MAP)
- Simulating 24 hour period before overpass



Modelling chain



Quantitative Network Design

Uncertainty

$$\mathbf{C}(d)^2 = \mathbf{C}(d_{\mathrm{obs}})^2 + \mathbf{C}(d_{\mathrm{mod}})^2.$$

What we do know already

$$\mathbf{C}(x)^{-1} = \mathbf{M}'^{\mathrm{T}}\mathbf{C}(d)^{-1}\mathbf{M}' + \mathbf{C}(x_0)^{-1}.$$

Coverage

$$\sigma(y)^2 = \mathbf{N}'\mathbf{C}(x)\mathbf{N}'^{\mathrm{T}} + \sigma(y_{\mathrm{mod}})^2.$$

$$\sigma(y_0)^2 = \mathbf{N}'\mathbf{C}(x_0)\mathbf{N}'^{\mathrm{T}} + \sigma(y_{\mathrm{mod}})^2.$$

Performance Metric “uncertainty reduction”

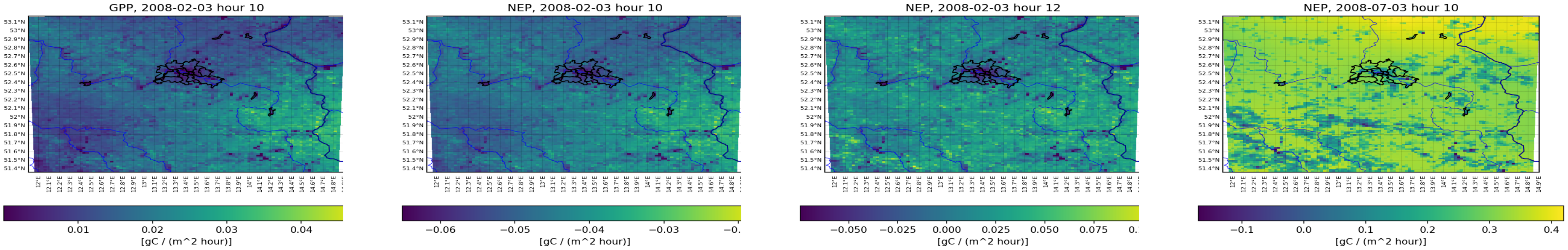
$$\frac{\sigma(y_0) - \sigma(y)}{\sigma(y_0)} = 1 - \frac{\sigma(y)}{\sigma(y_0)}.$$

Notation:

y:	vector of target quantities
d:	vector of observations
x:	vector of unknowns/control variables
d=M(x):	model linking unknowns to observations
y=N(x):	model linking unknowns to target quant
C:	covariance of uncertainty

Model for terrestrial fluxes

- Newly developed version of SDBM (Knorr and Heimann, 1995)
- Runs on transport model grid (2 km by 2 km)
- Simulates Net and Gross (GPP, eocsystem respiration) fluxes at hourly time step
- Driven by JRC-TIP FAPAR and climate (Incoming solar/thermal radiation, precipitation, 2m-temperature) from ERA5
- Calibrated 5 parameters against complete ensemble of Tier-1 166 Fluxnet 2005 sites
- Prior parameter uncertainty 20%



Fossil fuel emissions

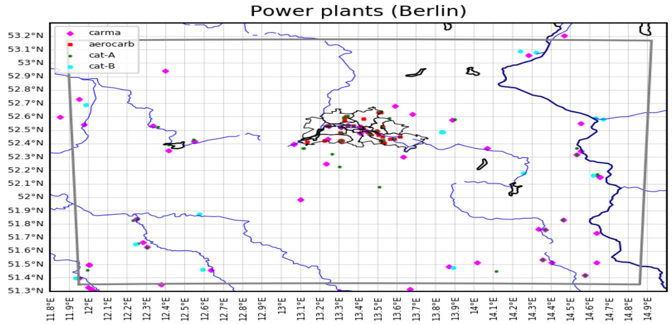
Based on Super et al, ACP, 2020:

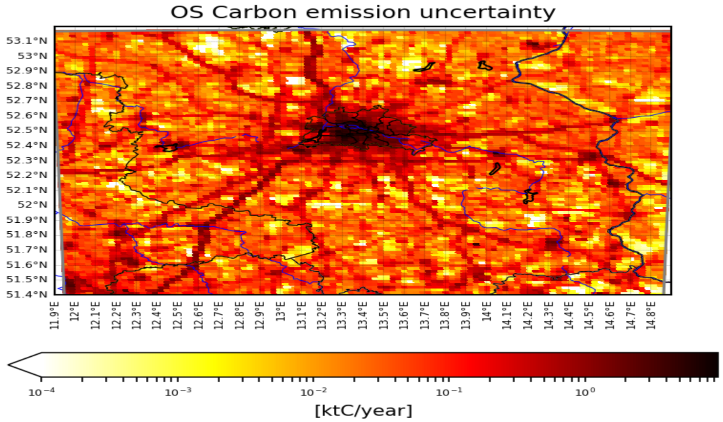
Energy Generation

- Detailed plume simulation (VDI guidelines implemented by G. Kuhlmann) for largest power plants and some Vattenfall plants within Berlin: 11 plants in total; Stack information from A. Kerschbaumer (Berlin Kataster) and G. Kuhlmann.
- Standard Vertical Profile (Bieser et al., 2011) for the remainder
- Fixed temporal profile
- Prior Uncertainty: 20%

Other Sector

- “High resolution (1/60° x 1/120° ; ~1x1km) regional gridded emission inventory for a zoom domain in Europe”
- Fixed temporal profile
- Prior Uncertainty: 20%



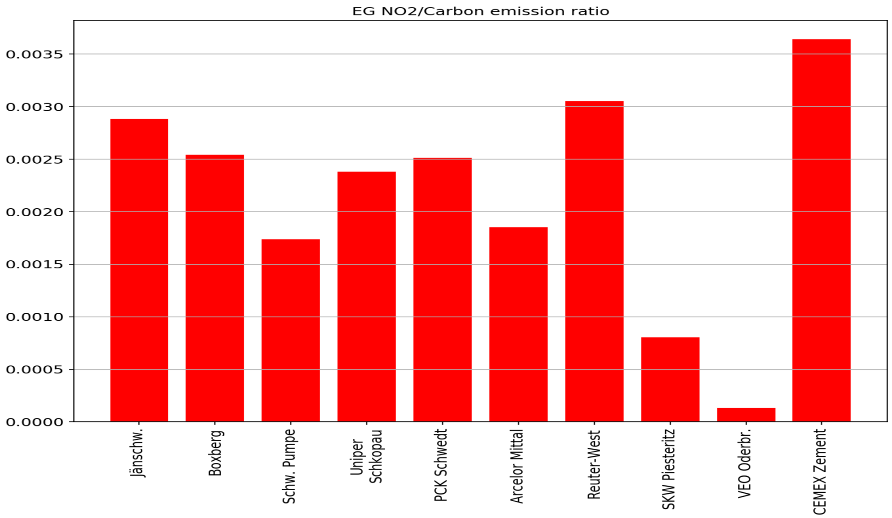


Emission factors: linking CO_2 and NO_2

$e_{NO2} = r\ e_{CO2}$

$NO_2 = T_{NO2}\ r\ e_{CO2}$

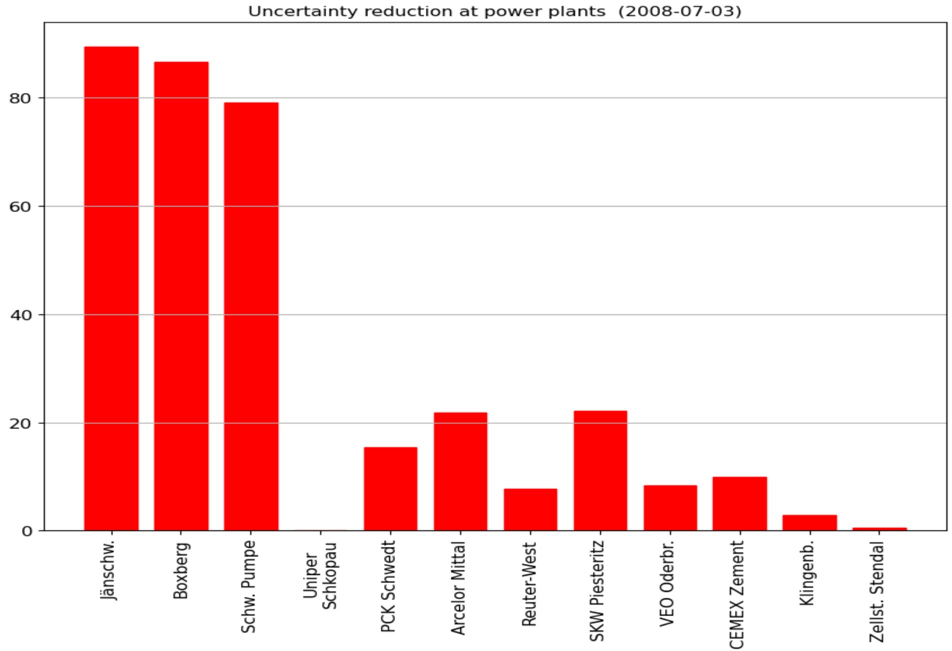
- **r**: emission ratio, provides link to CO_2
- Combined use of XCO2 and NO_2 observations provides constraint on **r**
- Need prior and uncertainty in **r** -> from TNO data base (Super et al., 2020)

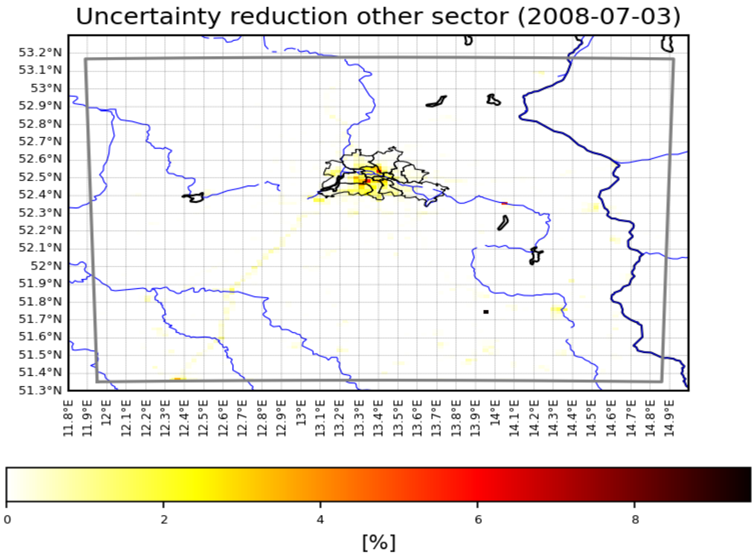


Setup default experiment

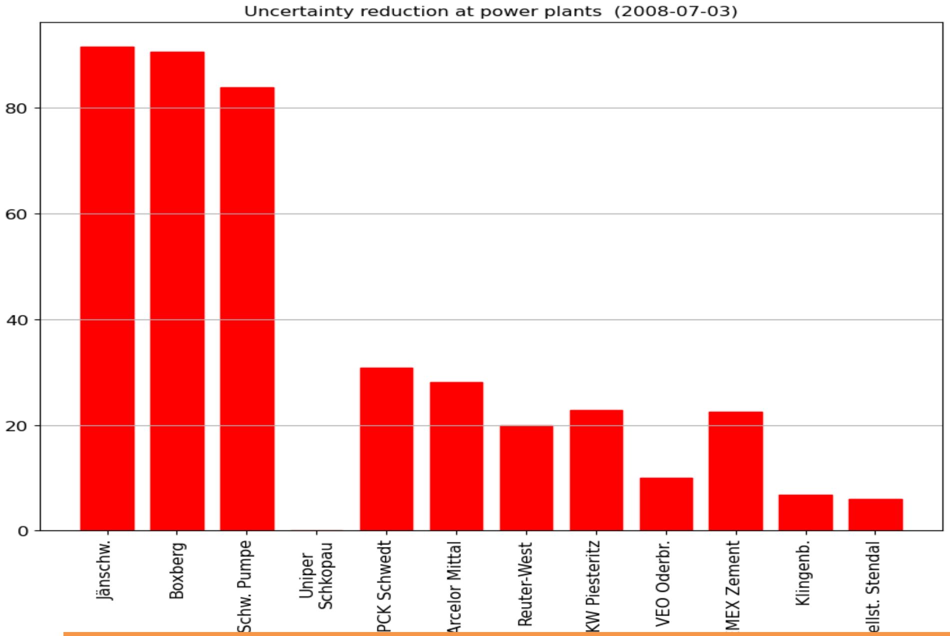
- XCO2 retrieval uses MAP
- no NO_2
- 20% prior uncertainty for each power plant
- 20% prior uncertainty for each natural flux parameter
- 20% prior uncertainty of other sector for Berlin (city-scale, 52.8% at pixel level)
- 1 ppm uncertainty of lateral inflow, fully correlated at 10 km horizontally, otherwise uncorrelated

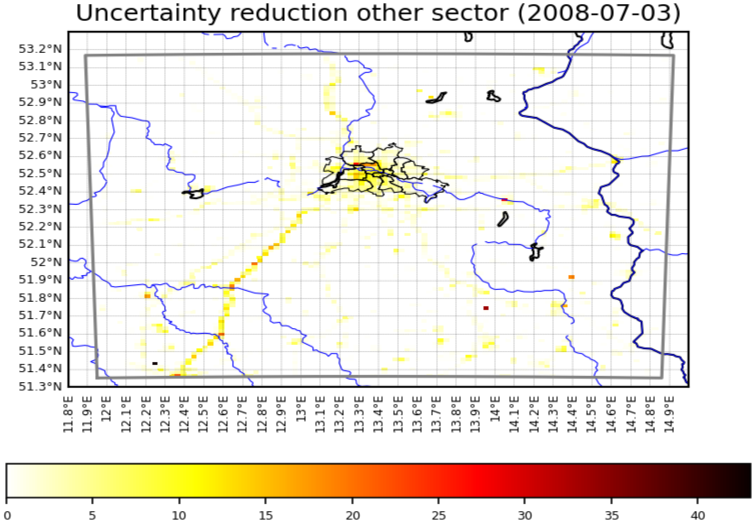
Default experiment, summer case

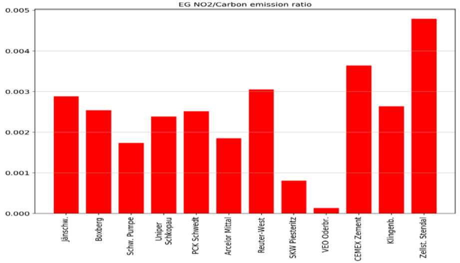




Default experiment + NO_2, summer case



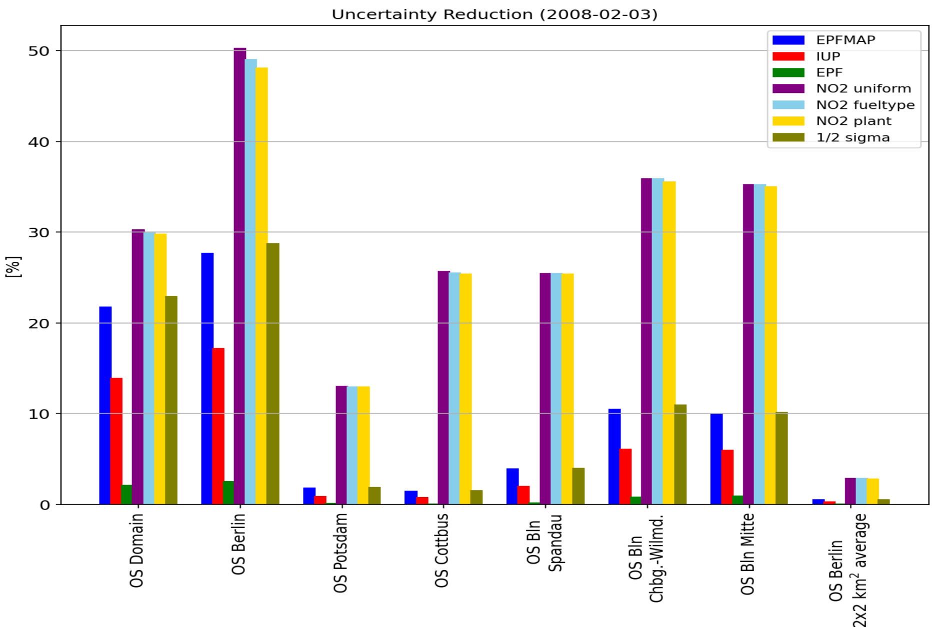


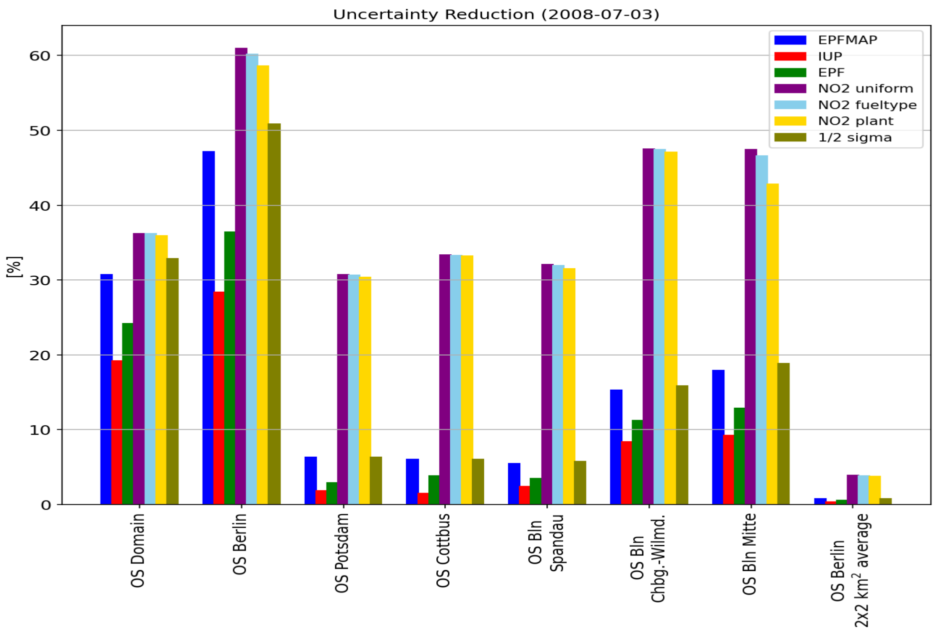


Adding NO_2:

- Added value for power plants larger in winter,
  where XCO2 leaves more scope for improvement and where lifetime is longer
- But combined performance for XCO2 and NO_2 better in summer

Overview Other sector





Performance for the other sector:

- Performance of default scenario better than that of IUP XCO2 error files on all scales
- The MAP has a strong impact, the added value is higher in winter, where the performance w/o MAP is low
- The smaller the scale the larger the effect of adding NO2
- The differentiation of uncertainty in the emission factor has a small impact over Berlin and some of its districts
- Reducing the prior uncertainty on plant emissions yields small improvement for the other sector

Summary and Outlook

- Developed modelling chain from parameters to XCO2 and NO_2 observations
- Full Jacobian allows
  - decomposition of XCO2 column in terms of spatial emission impact
  - rigorous uncertainty propagation (Quantitative Network Design approach) to assess CO2M observation impact
- High XCO2 constraint on emissions from larger power plants
- XCO2 constraint on emissions from Other sector increasing with spatial scale from 2km (uncertainty reduction: <1% average; ~8% maximum) to scale of Berlin district (~2-18 %) to the scale of Berlin (28-48%).
- Higher XCO2 constraint in summer on both, power plants and other sector
- The MAP has a strong impact in winter, where the performance w/o MAP is lower, its impact in summer is moderate
- NO2 powerful additional constraint for power plants and other sector