Mesoscale Column Network for Assessing GHG and NO$_x$ Emissions in Munich

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Develop a Concept for Long-term GHG Monitoring in Cities

Measurement Concept

Modeling Framework

→ Necessity to develop a permanent and fully automated measurement network with a suited modeling framework
Measurement Concept

Differential Column Measurements for Emission Monitoring

\[
\text{Emission} \propto \text{Concentration}_{\text{downwind}} - \text{Concentration}_{\text{upwind}}
\]

→ Insensitive to boundary layer height dynamics and upstream influences, direct measure for mass loading of the pollutants in the city
Automated Sensor System Deployed in Center Munich

(More information in the poster session today evening)

Challenges/Properties:

- Protection against rain, snow, hail and power failure
- Enable sun measurement in all seasons and locations
- Lightweight, mobile deployable
- Thermal and humidity controlled
Munich Campaign – Sensor Stations

→ Pilot network configuration for a permanent monitoring network.
   For the first time: Test of full automation and multiple CO column measurements
Oktoberfest 2017 (Sept. 16th – Oct. 3rd)

- Largest folk festival in the world
- Over 6 Million visitors
- Density: ~ 1 pers./m²
- Over 40 % of the used energy is provided by natural gas (80 % cooking, 20 % heating)
- Gas grills (in the tents and on the street) and temporal constructed pipelines

https://www.kontor-ffo.de/
Concentration comparison

Higher concentration levels and enhancements during the Oktoberfest compared to the time before and after
Munich Campaign - Measurements

1 day during Oktoberfest

- \( \text{XCO}_2 \) (ppm): 6 ppm
- \( \text{XCH}_4 \) (ppm): 8 ppb
- \( \text{XCO} \) (ppb): 12 ppb

Jia Chen, Florian Dietrich et al. | April 9th, 2018 | EGU
Munich Campaign - Measurements

1 day during Oktoberfest

- log(footprint/\frac{ppm}{\mu mol/m^2 \cdot s})

- TUM (downwind)
- Sauerlach (background)
- Markt Schwaben (background)
- Vaterstetten (background)

6 ppm
8 ppb
12 ppb
Munich Campaign - Measurements

1 day during Oktoberfest

log \left( \frac{\text{footprint}}{\frac{\text{ppm}}{\mu\text{mol}}} \right) \text{ m}^2 \cdot \text{s}^{-1}

\begin{align*}
\text{XCO} \_2 \text{ (ppm)} & \quad 6 \text{ ppm} \\
\text{XCH} \_4 \text{ (ppm)} & \quad 8 \text{ ppb} \\
\text{XCO} \text{ (ppb)} & \quad 12 \text{ ppb}
\end{align*}

TUM (downwind) \quad \text{Sauerlach (background)}
\quad \text{Markt Schwaben (background)} \quad \text{Vaterstetten (background)}
Munich Campaign - Measurements

1 day during Oktoberfest

![Graph showing XCO₂, XCH₄, CO concentrations over local time with marked peaks at 6 ppm, 8 ppb, and 12 ppb.]

![Map with color gradient representing log(footprint/μmol·m⁻²·s⁻¹) with TUM indicated.]
Munich Campaign - Measurements

1 day during Oktoberfest

- $6 \text{ ppm}$
- $8 \text{ ppb}$
- $12 \text{ ppb}$

$\log \left( \frac{\text{footprint}}{\frac{\text{ppm} \text{ mol}}{m^2 \cdot s}} \right)$

TUM (downwind)  Sauerlach (background)
Markt Schwaben (background)  Vaterstetten (background)
Framework for Estimating Emission*

\[ \min_{x, b} \| y - (Hx + Bb) \|_2 \]

- \( y \): observations
- \( H \): footprint matrix
- \( x \): emissions
- \( B \): background influence matrix
- \( b \): background concentration

*: developed by Taylor Jones, Harvard

Approach: Minimizing a cost function to determine emissions and background influence
CO: Example of Transient Signal Crossing the City

Date: 20170908, 5 min average

Important to know the time the air mass needed for traveling from upwind to downwind
Particle Simulation Movie

→ Particle distribution provides distribution of the time shifts and the background influence matrix B
Background Influence Matrix

\[
\min_{x, b} \| y - (Hx + Bb) \|_2
\]
Inversion Results

Model agrees relatively well with the observations
Preliminary emission estimate - Inversion

<table>
<thead>
<tr>
<th></th>
<th>Oktoberfest</th>
<th>Diffuse source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inversion</td>
<td>27 $\frac{\mu g}{m^2\cdot s}$</td>
<td>0.3 $\frac{\mu g}{m^2\cdot s}$</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td>Boston: 0.6 ± 0.1 $\frac{\mu g}{m^2\cdot s}$ [1]</td>
</tr>
</tbody>
</table>

Human CH$_4$ emissions per area:

$E_{\text{human}} < 2 \frac{\mu g}{m^2 \cdot s}$

Emission by gas grill:

$E_{\text{Gasgrill}} = 0.5 \text{ to } 5 \frac{\mu g}{m^2 \cdot s}$ [2]

→ Oktoberfest could emit significant amount of CH$_4$ which is not contributed by humans


Conclusion

- Oktoberfest is a potential significant methane source, likely contributed by natural gas leakage and incomplete combustions.
- We developed a method (differential column measurement + modeling) to find unknown local and city emissions.
- First step to an automated permanent city sensor network.

Thank you for your attention!