Professorship of Environmental Sensing and Modeling
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Technical University of Munich

# Mesoscale Column Network for Assessing GHG and $NO_X$ Emissions in Munich

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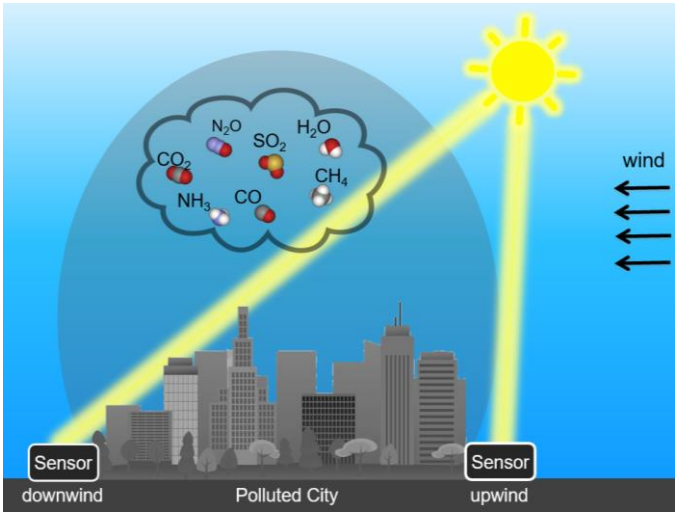
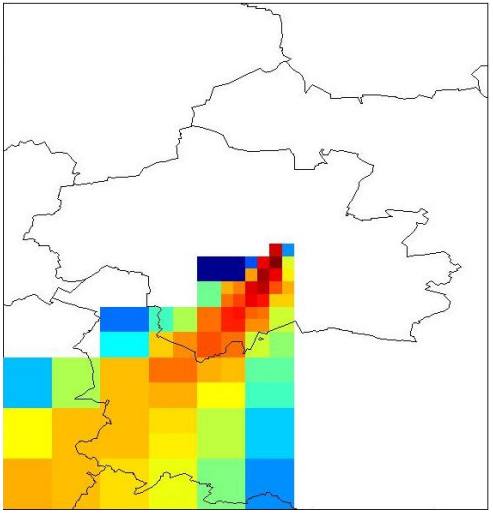
# Develop a Concept for Long-term GHG Monitoring in Cities

## Measurement Concept



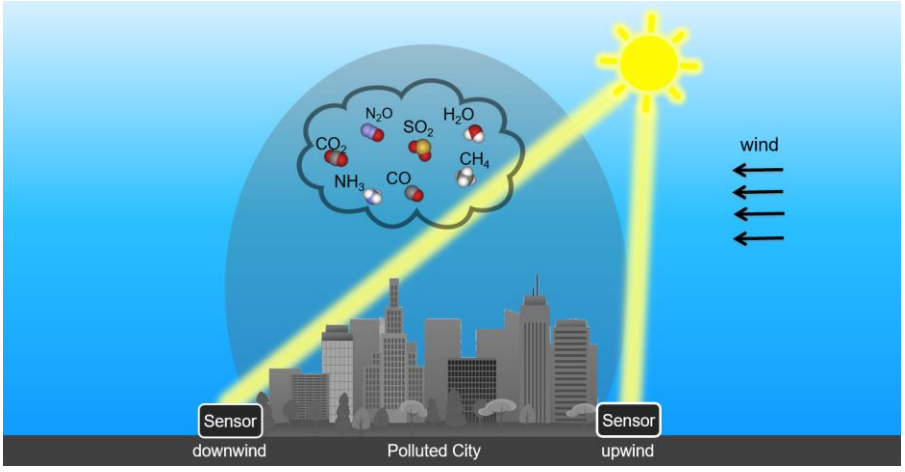

## Modeling Framework



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

# Measurement Concept

## Differential Column Measurements for Emission Monitoring




$$Emission \propto Concentration_{downwind} - Concentration_{upwind}$$

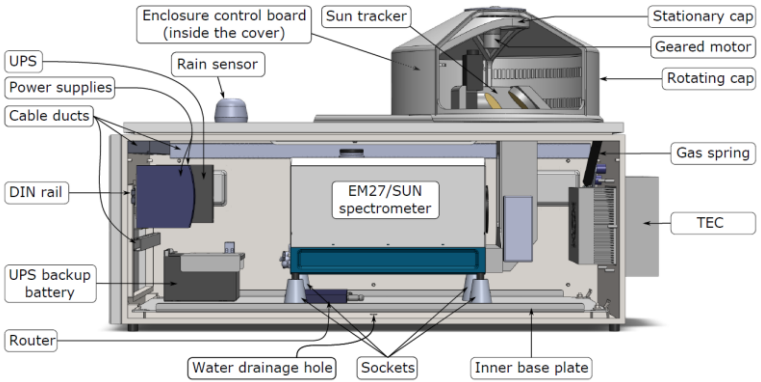
→ Insensitive to boundary layer height dynamics and upstream influences, direct measure for mass loading of the pollutants in the city

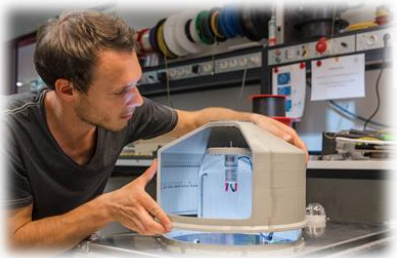


Chen, J. et al. Differential column measurements using compact solar-tracking spectrometers, Atmos. Chem. Phys., 16, 8479-8498, doi:10.5194/acp-16-8479-2016, 2016

# Automated Sensor System Deployed in Center Munich

(More information in the poster session today evening)



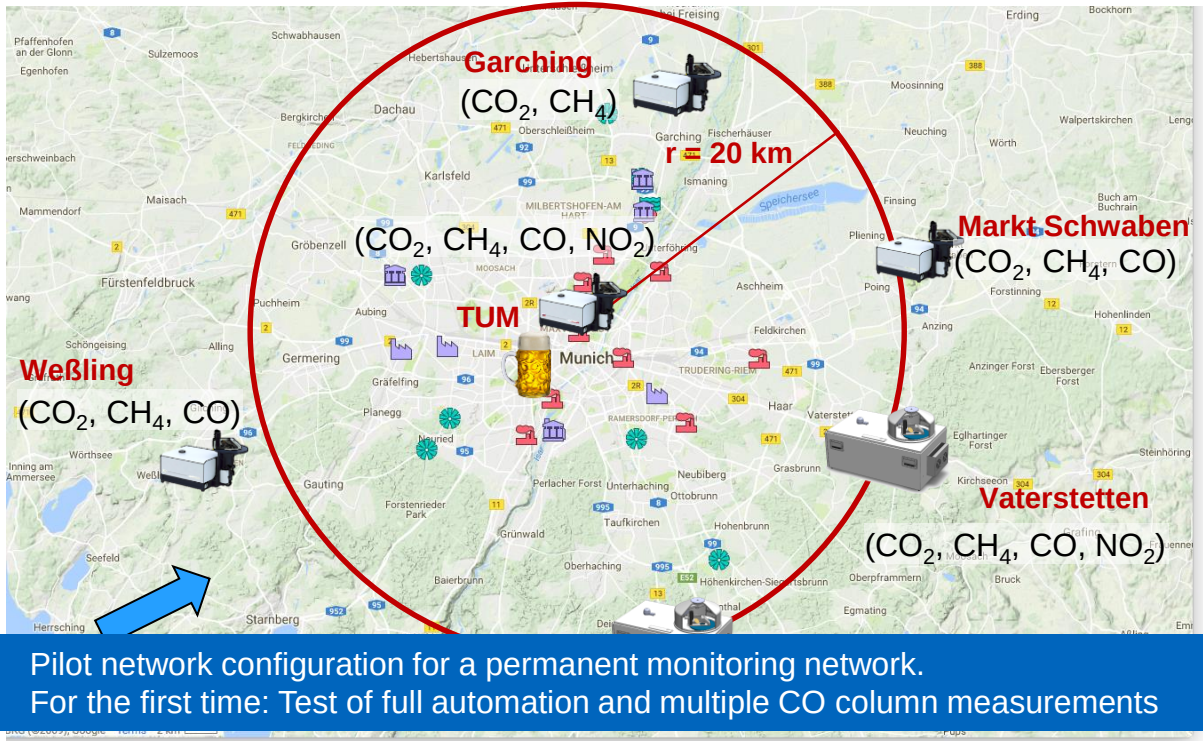
**Challenges/Properties:**

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



Heinle, L. and Chen, J.: Automated Enclosure and Protection System for Compact Solar-Tracking Spectrometers, Atmos. Meas. Tech. Discuss., doi.org/10.5194/amt-2017-292, 2017.

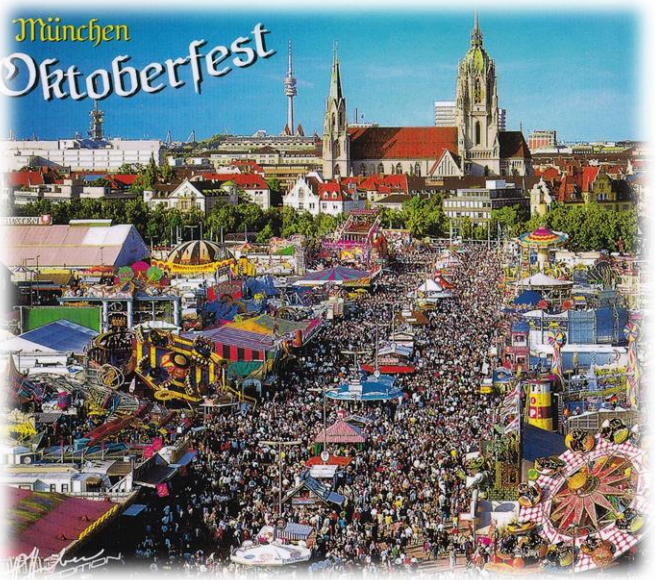
# Munich Campaign – Sensor Stations




→ Pilot network configuration for a permanent monitoring network.
For the first time: Test of full automation and multiple CO column measurements

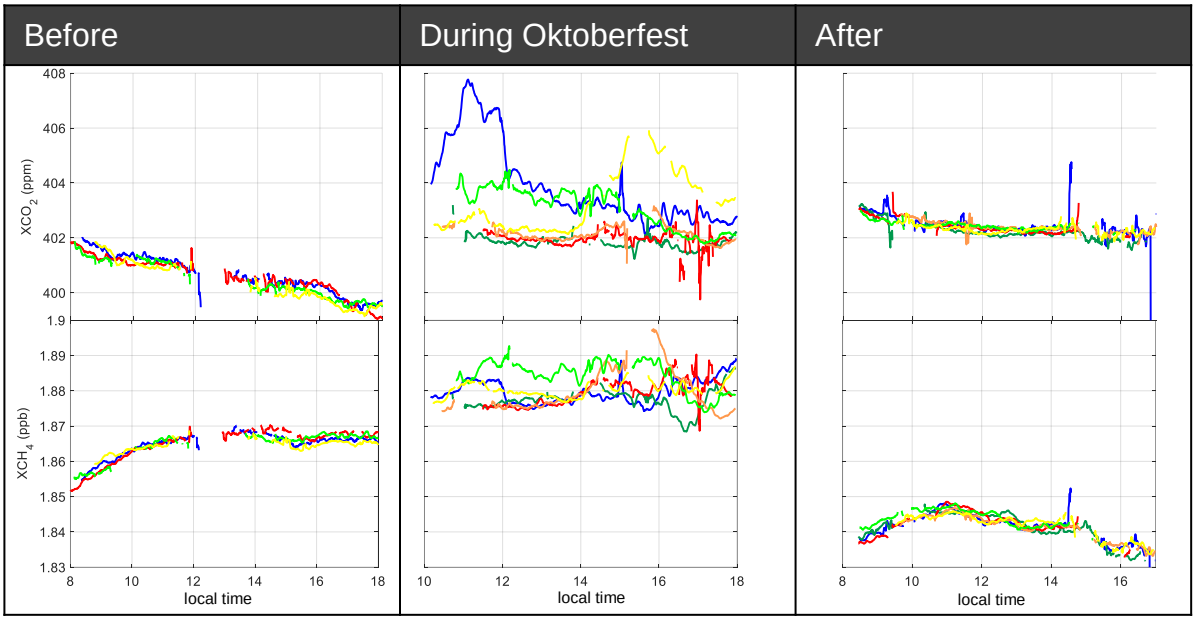
# Oktoberfest 2017 (Sept. 16th – Oct. 3rd)

- 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/

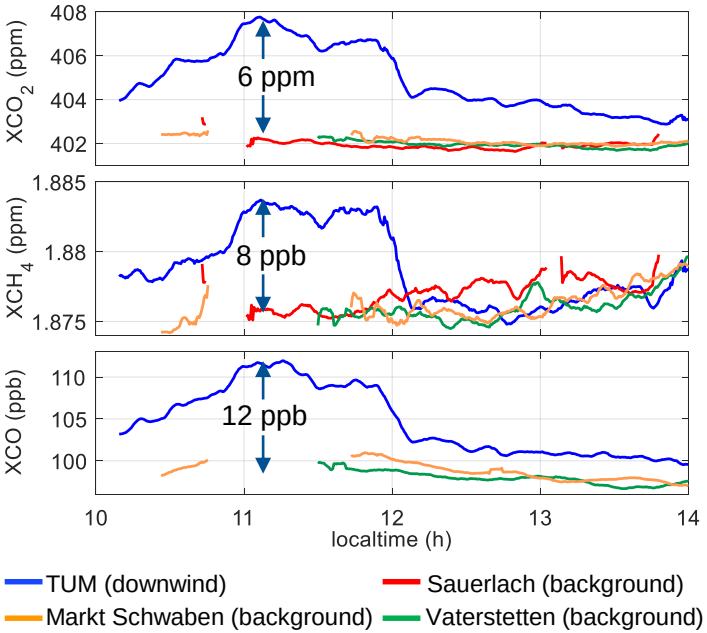
# Concentration comparison




→ Higher concentration levels and enhancements during the Oktoberfest compared to the time before and after

# Munich Campaign - Measurements

## 1 day during Oktoberfest



# Munich Campaign - Measurements

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

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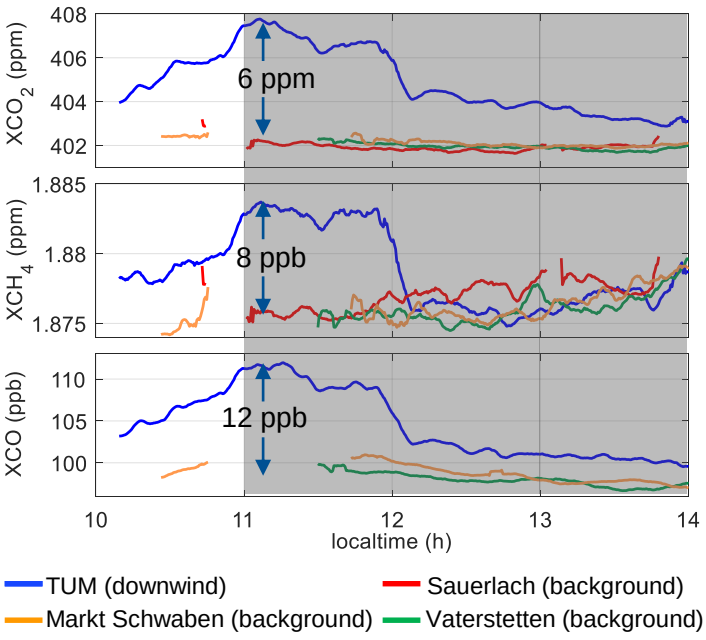


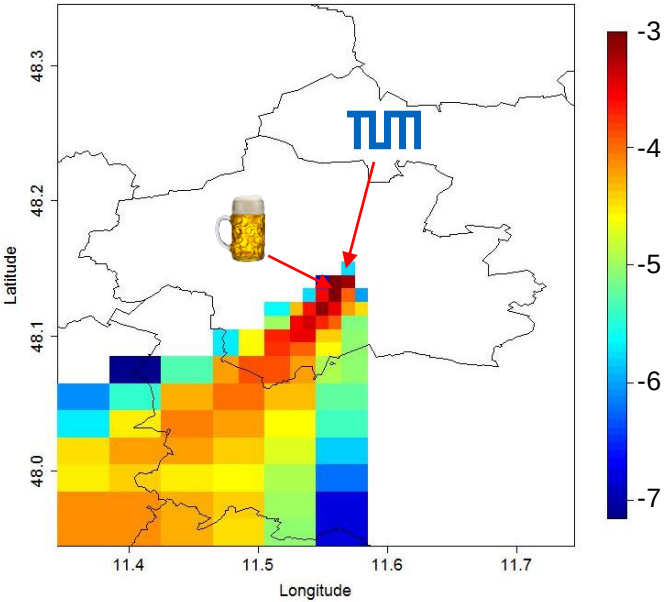

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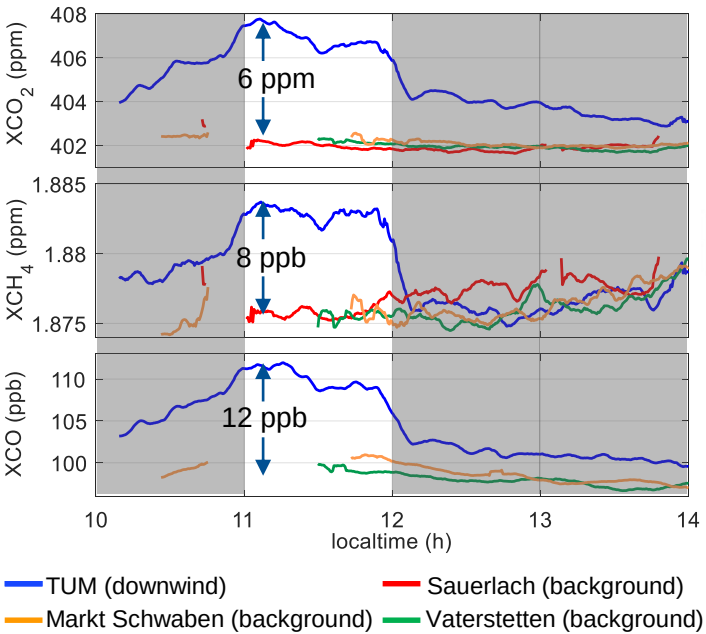


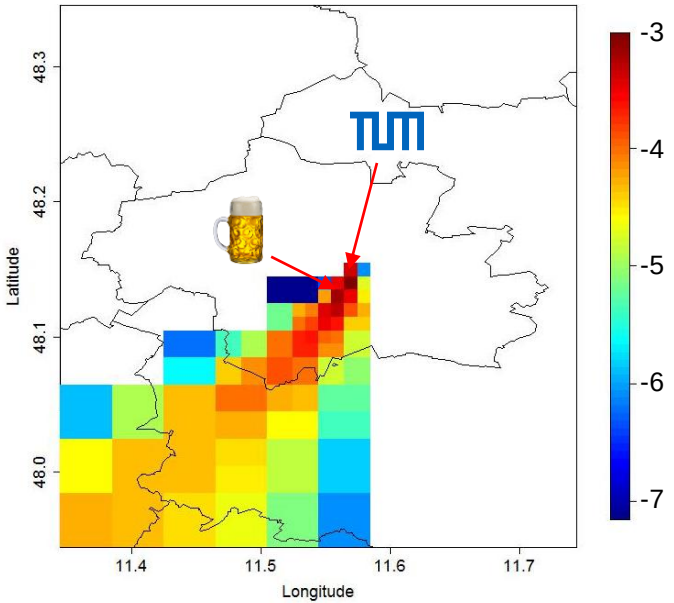

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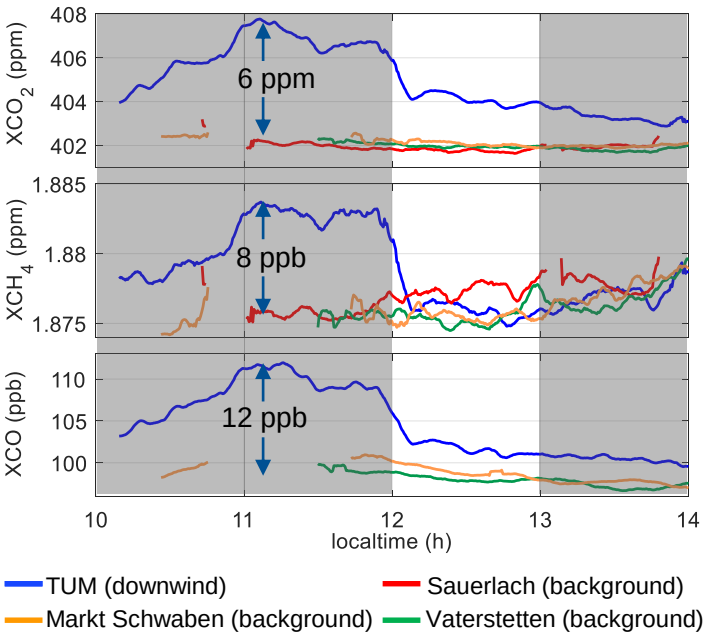


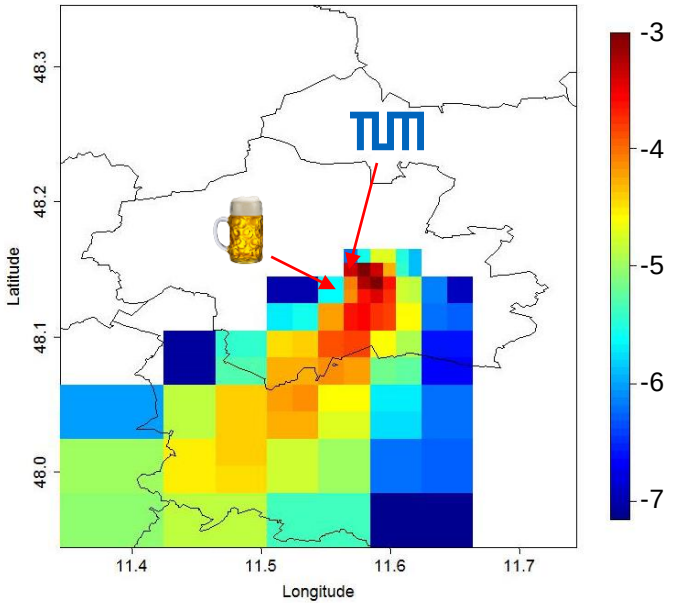

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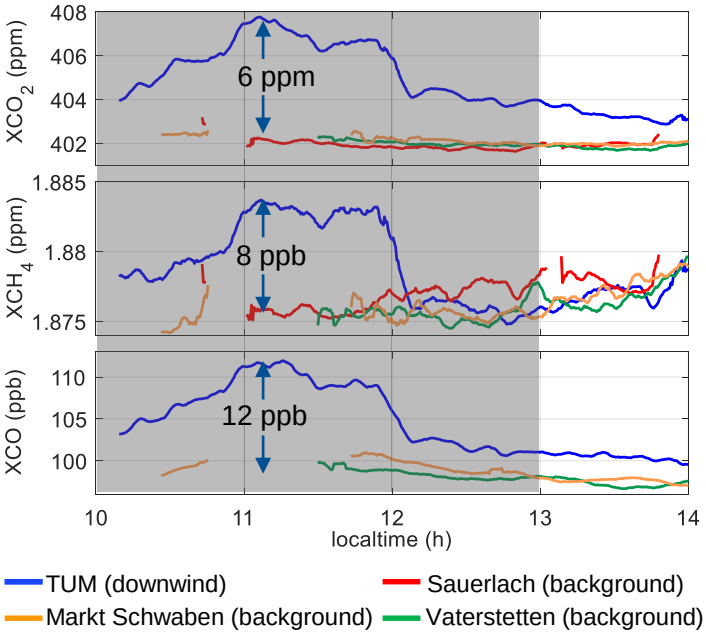
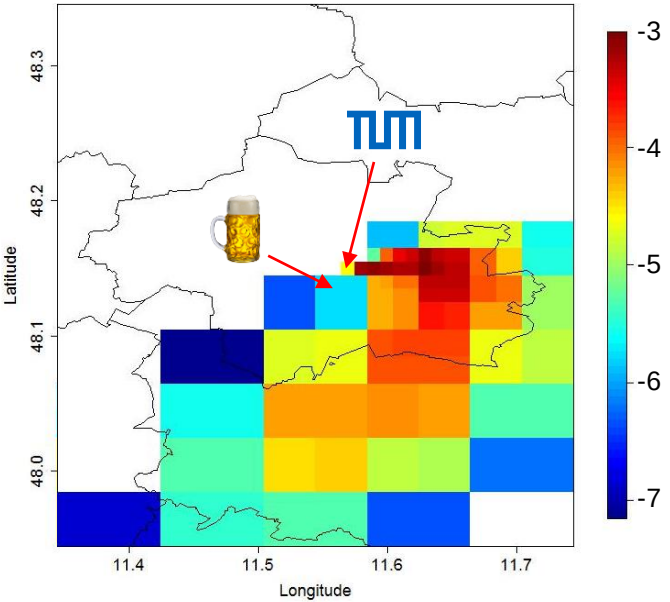
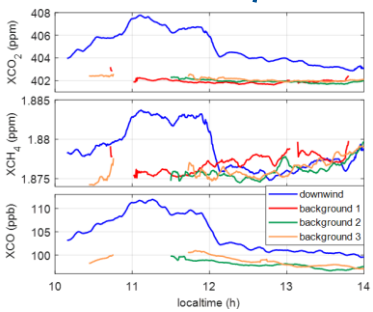


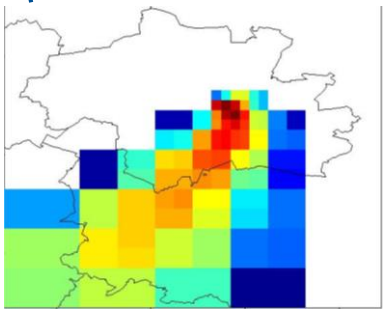



# Framework for Estimating Emission*

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

$y$: $observations$
$H$: $footprint\ matrix$
$x$: $emissions$
$B$: $background\ influence\ matrix$
$b$: $background\ concentration$

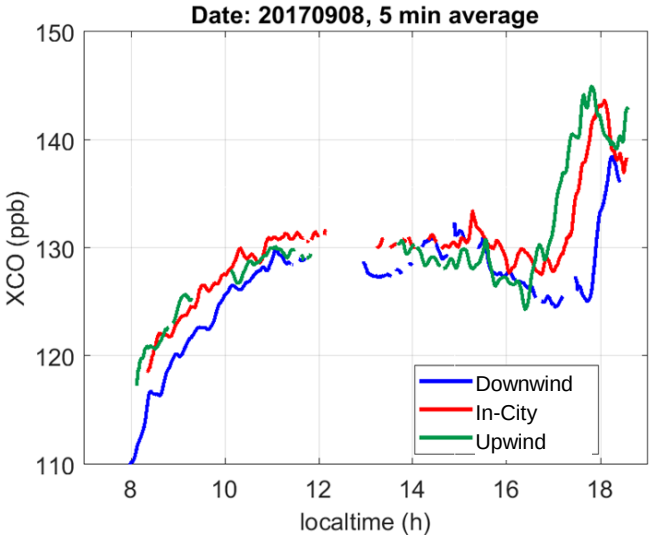


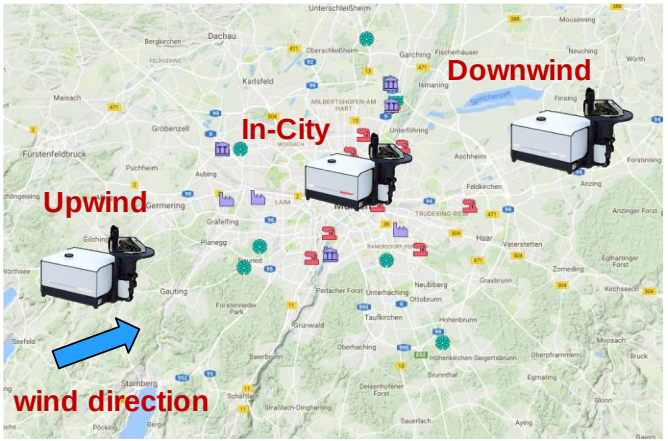



*: developed by Taylor Jones, Harvard

→ Approach: Minimizing a cost function to determine emissions and background influence

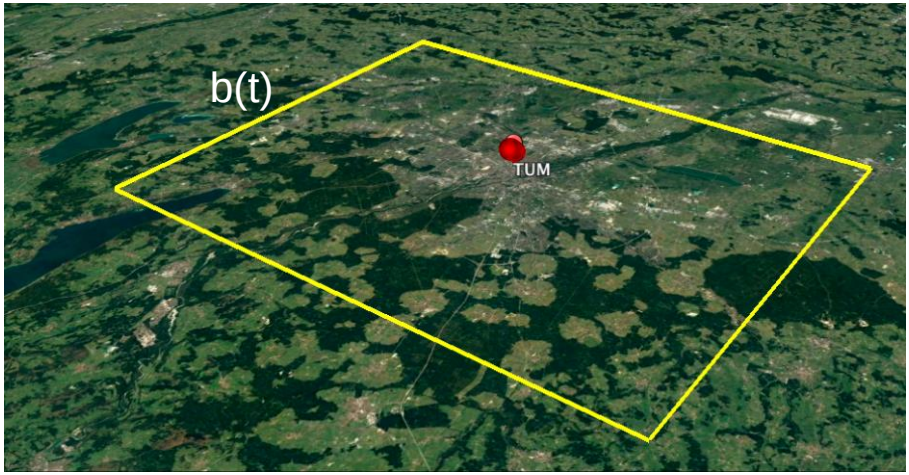
# CO: Example of Transient Signal Crossing the City

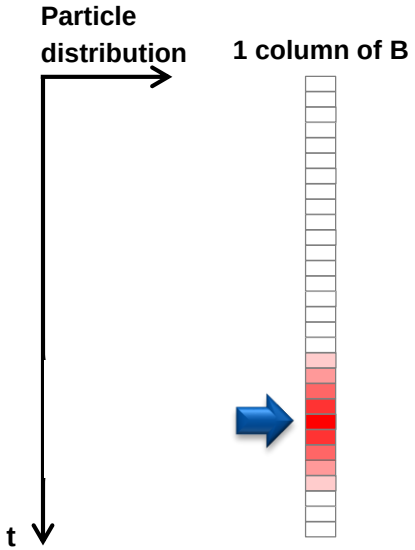



→ Important to know the time the air mass needed for traveling from upwind to downwind

# Particle Simulation Movie

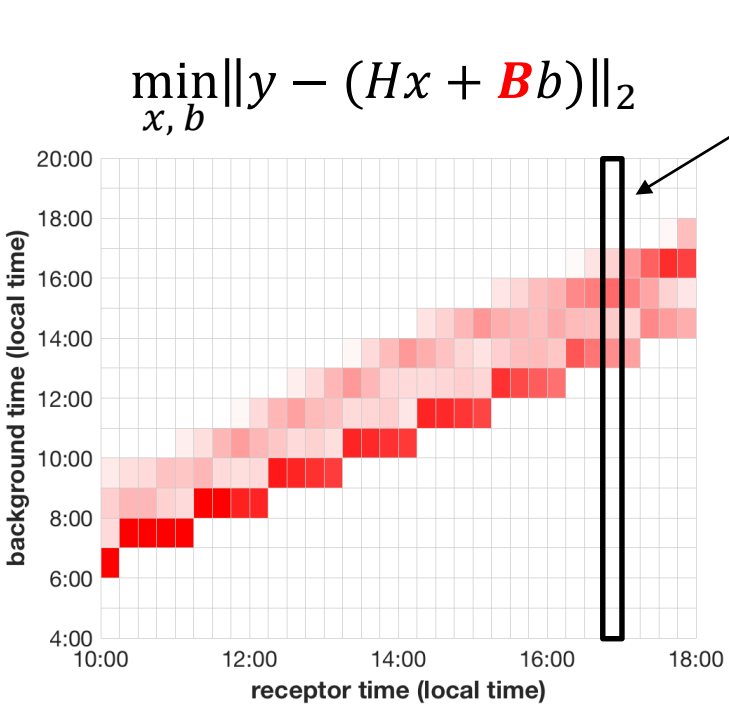


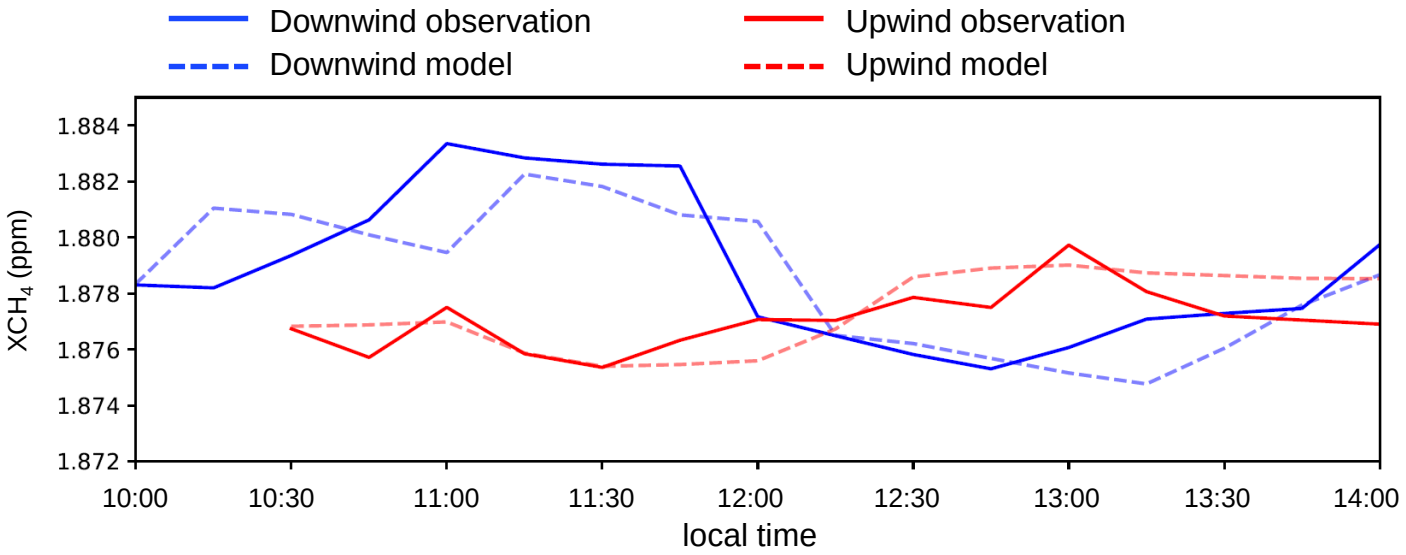

→ Particle distribution provides distribution of the time shifts and the background influence matrix B

# Background Influence Matrix

$$\min_{x,\,b} \|y - (Hx + \boldsymbol{B}b)\|_2$$



# Inversion Results




→ Model agrees relatively well with the observations

# Preliminary emission estimate - Inversion

| | Oktoberfest | Diffuse source |
|---|---|---|
| **Inversion** | $27\ \frac{\mu g}{m^2 \cdot s}$ | $0.3\ \frac{\mu g}{m^2 \cdot s}$ |
| **Comparison** | | Boston: $0.6 \pm 0.1\ \frac{\mu g}{m^2 \cdot s}$ [1] |

Human $CH_4$ emissions per area: $E_{\text{human}} < \mathbf{2}\ \frac{\boldsymbol{\mu g}}{\boldsymbol{m^2 \cdot s}}$

Emission by gas grill: $E_{\text{Gasgrill}} = \mathbf{0.5\ to\ 5}\ \frac{\boldsymbol{\mu g}}{\boldsymbol{m^2 \cdot s}}$ [2]

→ Oktoberfest could emit significant amount of $CH_4$ which is not contributed by humans

[1] McKain, K et al. Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts, PNAS, 2015, 112, 1941-1946

[2] Francisco Paul, EDF Presentation: Methane Emissions from Residential Appliances, 2018

# 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!