Greenhouse Gas Emission Estimate Using a Fully-automated Permanent Sensor Network in Munich

Florian Dietrich, **Jia Chen**, Benno Voggenreiter, Xinxu Zhao, Magdalena Altmann

Technical University of Munich, Environmental Sensing and Modeling, Munich, Germany

Correspondence: *Florian Dietrich (flo.dietrich@tum.de) and Jia Chen (jia.chen@tum.de)*

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Objectives

- Creating an GHG emission map based on concentration measurements
- Improving the emission inventories
- Finding and quantifying unknown emission sources
- Evaluating existing and planned GHG mitigation policies

- **Approach**:
  - Differential column measurements (*Chen et al. 2016*)
  - $E \propto C_{downwind} - C_{upwind}$

- **Fully-automated sensor network necessary**

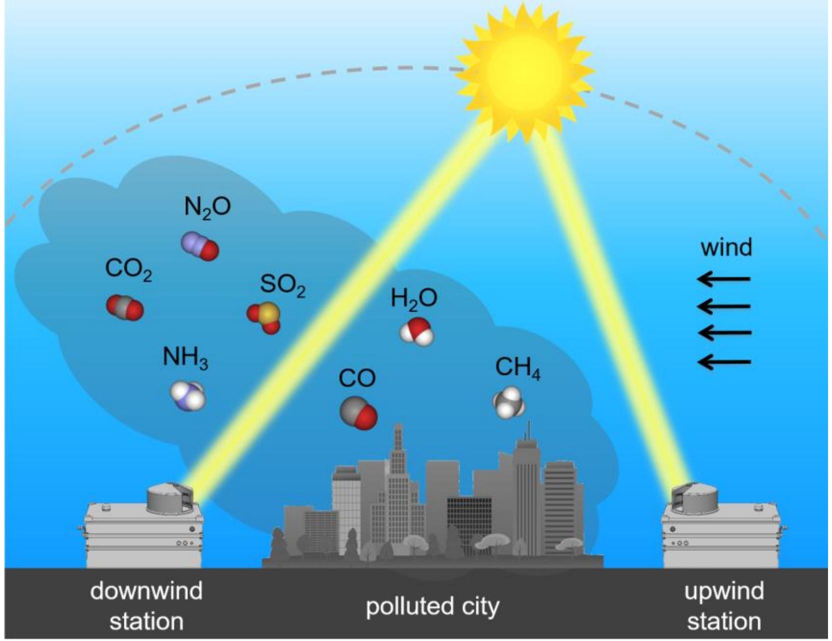
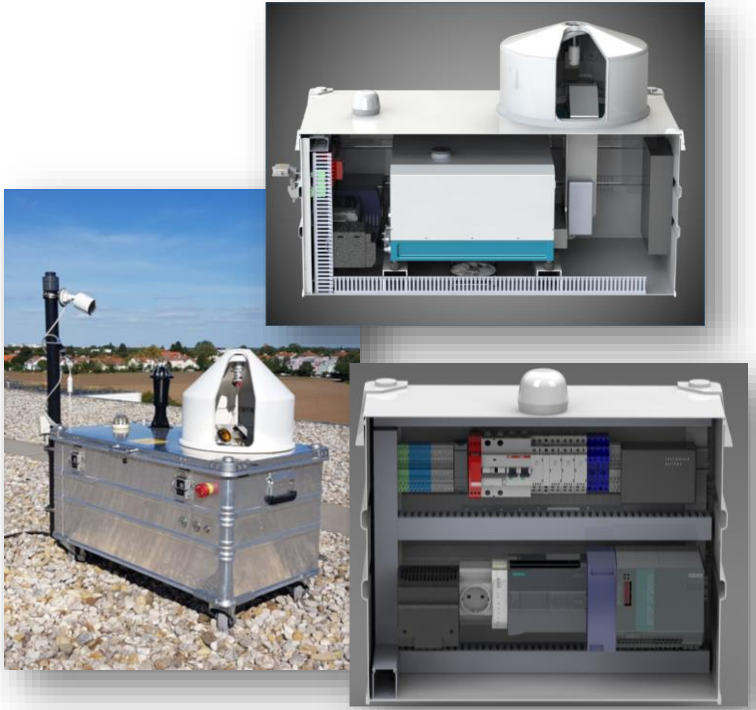


Fig. 1: Principle of the differential column measurements

Enclosure System

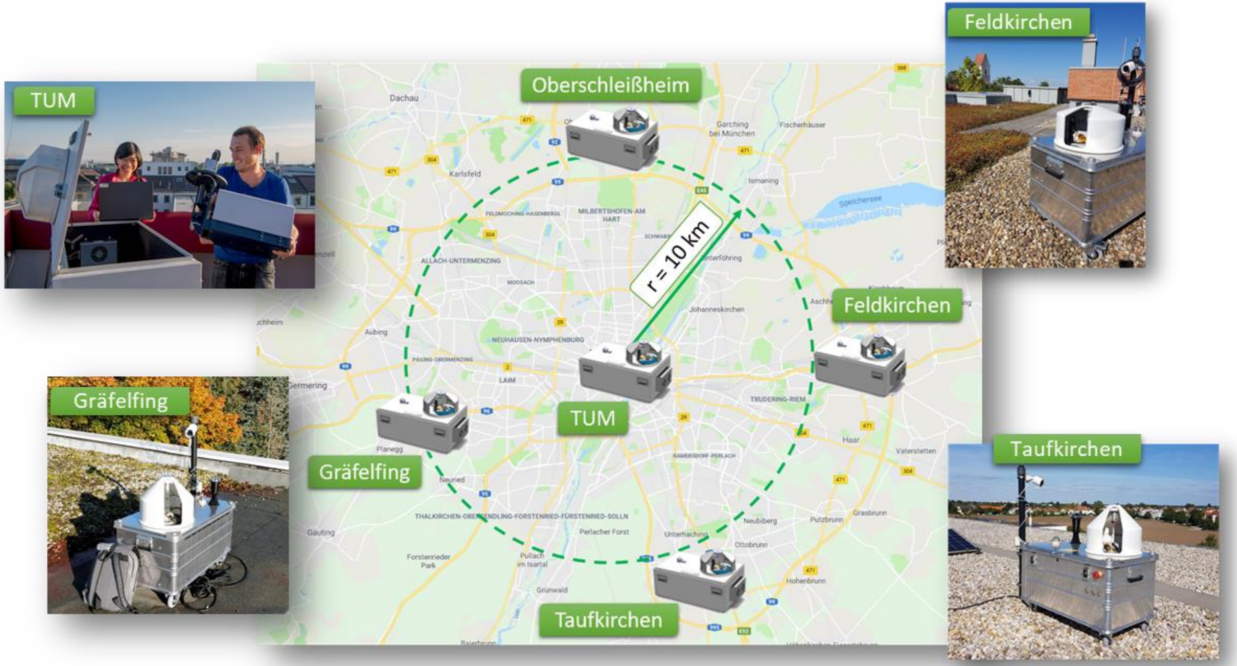
(Heinle and Chen, 2018; Dietrich et al. 2019)

- Fully-automated system
  - Rain/sun detection
  - Automatic start/stop of measurements
  - Remote control
  - Fail-safe → reliable protection of the instrument
  - Easy to transport
- Deployed in Munich (5 stations), Finland and Uganda



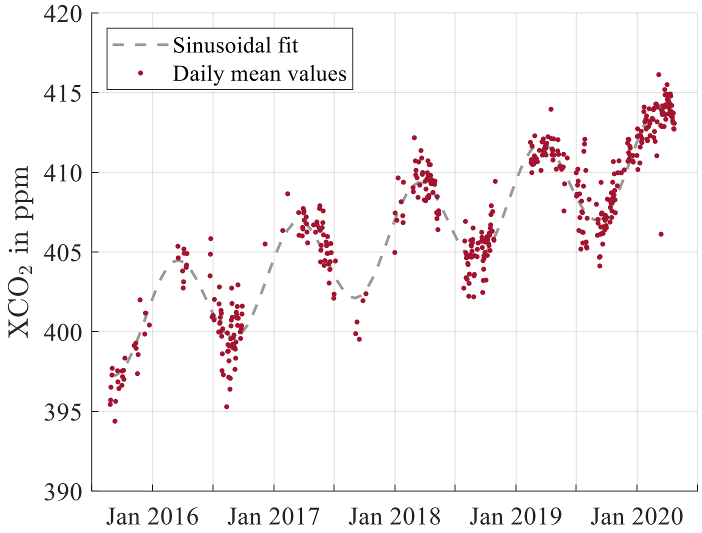
→ Our system reduces the personnel costs to a minimum and increases the amount of measurement data to a maximum

Sensor Network Setup



- 5 FTIR spectrometer in our fully-automated enclosures
- Distributed in and around Munich
  - Always at least one upwind/downwind station for arbitrary wind conditions
  - Center station is the downwind of half the city
- Running permanently since September 2019 with 5 stations

Measurement Results – Seasonal Cycle

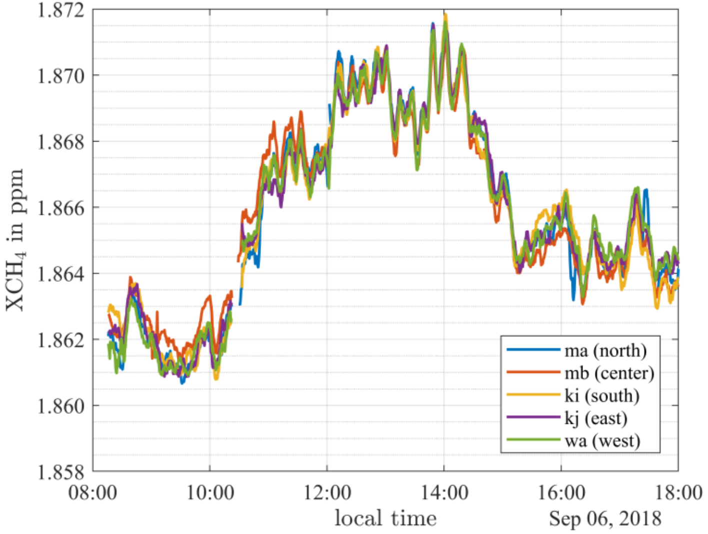


- Center station is operating since summer 2015
- Capturing the seasonal cycle and increasing trend of CO_2 (≈2.4 ppm per year)
- No measurement gap in winter 2019/2020 thanks to the full automation.

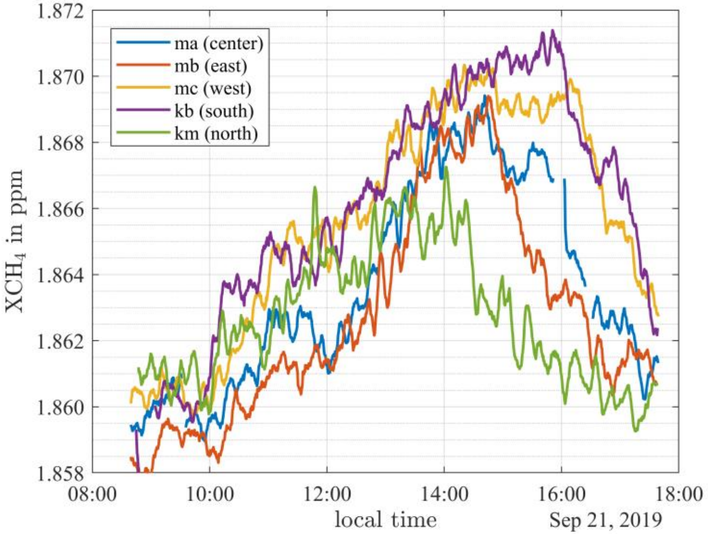
→ Inner-city station captures the seasonal cycle of CO_2 for the last 4.5 years very well

Measurement Results – Concentration Gradients

Side-by-side measurements



City gradient measurements

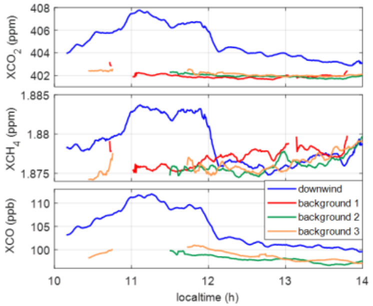


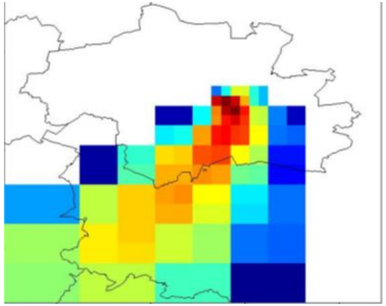
→ Sensor network can sense the GHG concentration gradients to quantify the emissions

Framework for Estimating Emission (Bayesian Inversion)

(Jones, Chen et al. 2020)

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





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

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

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TUM Department of Electrical and Computer Engineering
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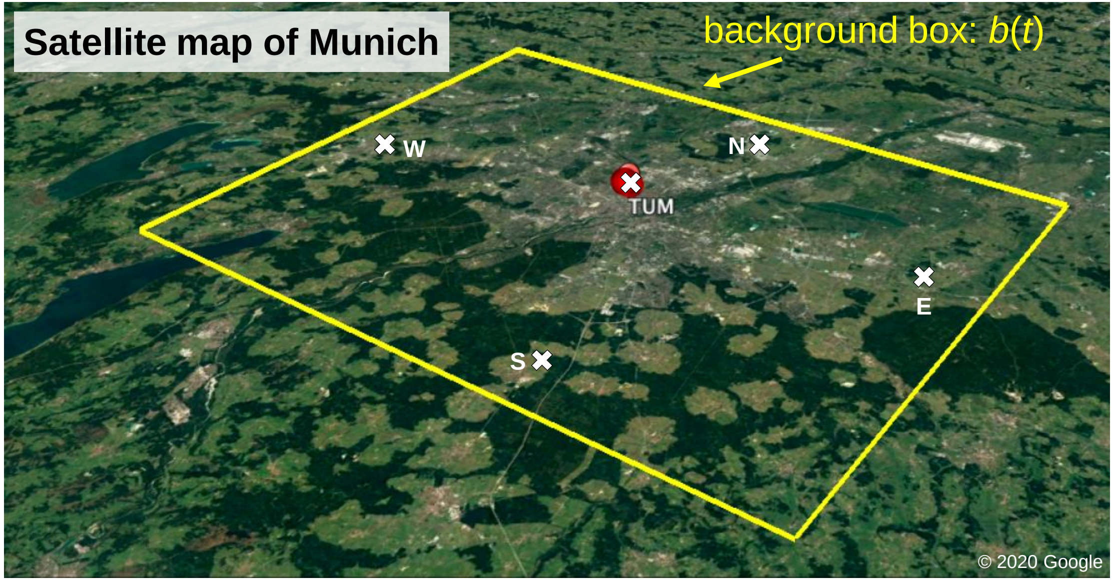
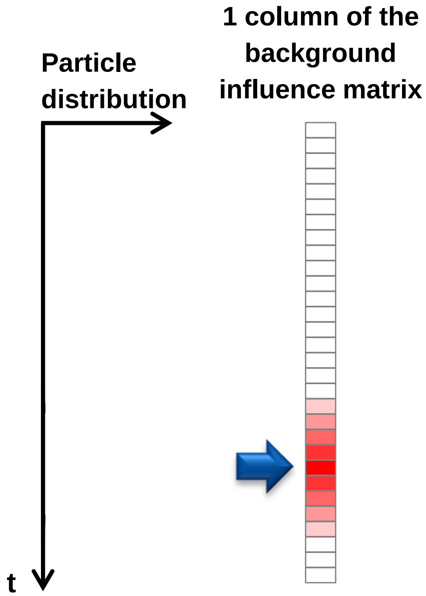
Particle Simulation - Footprints

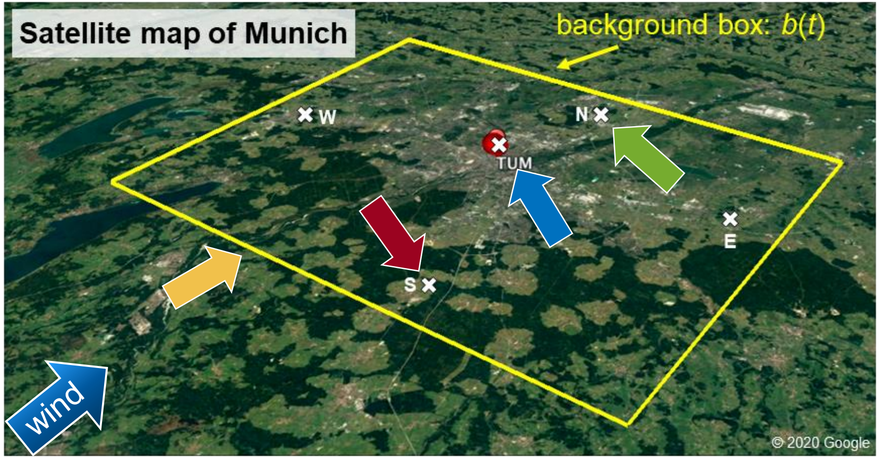


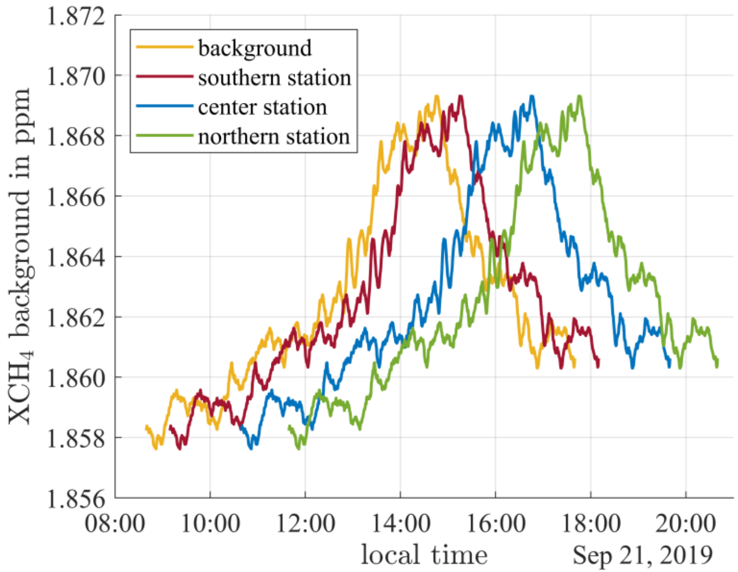


→ Particle backwards trajectory simulation (STILT) produces the footprints for the inversion

Background determination for the single stations

For this example we assume constant wind conditions (speed and direction) throughout the day





→ The background for each station is calculated separately to account for the time the particles take to travel

Inverse Modeling Results

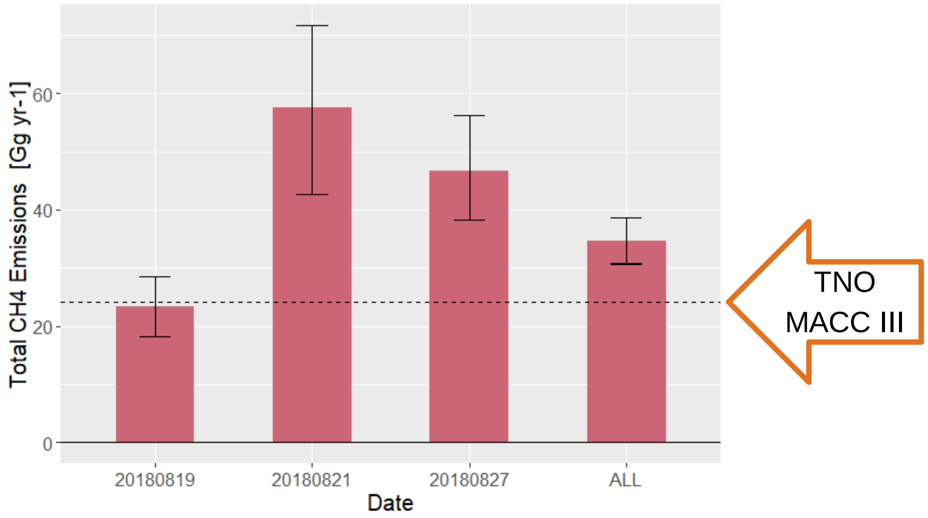


Fig. 2: Methane emission results of the inversion framework

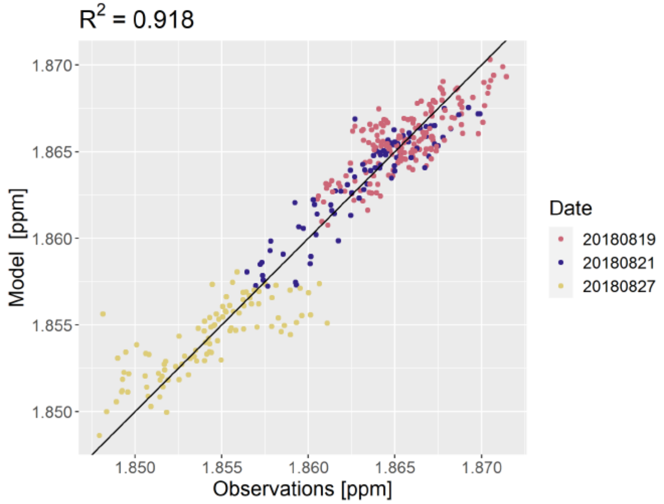


Fig. 3: Correlations between measurements and the model

→ Emission number 1.5 times higher than the emission inventory
→ Good correlation between measured and modelled concentrations

Results so far

- Initial results show that the **emissions are about 1.5 times higher** than the state-of-the-art emissions inventories (such as TNO-MACC III) suggest

- The measurements of our network indicated that the **Munich Oktoberfest is an unknown emitter of CH_4**:

Chen, J., Dietrich, F., Maazallahi, H., Forstmaier, A., Winkler, D., Hofmann, M. E. G., Denier van der Gon, H., and Röckmann, T.: *Methane emissions from the Munich Oktoberfest*, Atmos. Chem. Phys., 20, 3683–3696, https://doi.org/10.5194/acp-20-3683-2020, 2020.

- We figured out that the largest Munich **power plant (natural gas based) is not a significant CH_4 producer** as stated by the inventories

Conclusion

- We established the world's first permanent urban GHG sensor network based on the principle of differential column measurement

- Our network allows us to:
  - Monitor urban GHG emissions
  - Identify unknown emission sources
  - Assess how effective the current mitigation strategies are

Fig. 4: Our 5 sensor systems on the roof of the university building during the calibration measurements 2018

Authors & References

Florian Dietrich

PhD student at the Professorship of Environmental Sensing and Modeling

Technical University of Munich

Jia Chen

Professor of Environmental Sensing and Modeling

Technical University of Munich

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