Multi-Year Urban Total Column Network Observations – Challenges and Insights of Using MUCCnet for Emission Estimates

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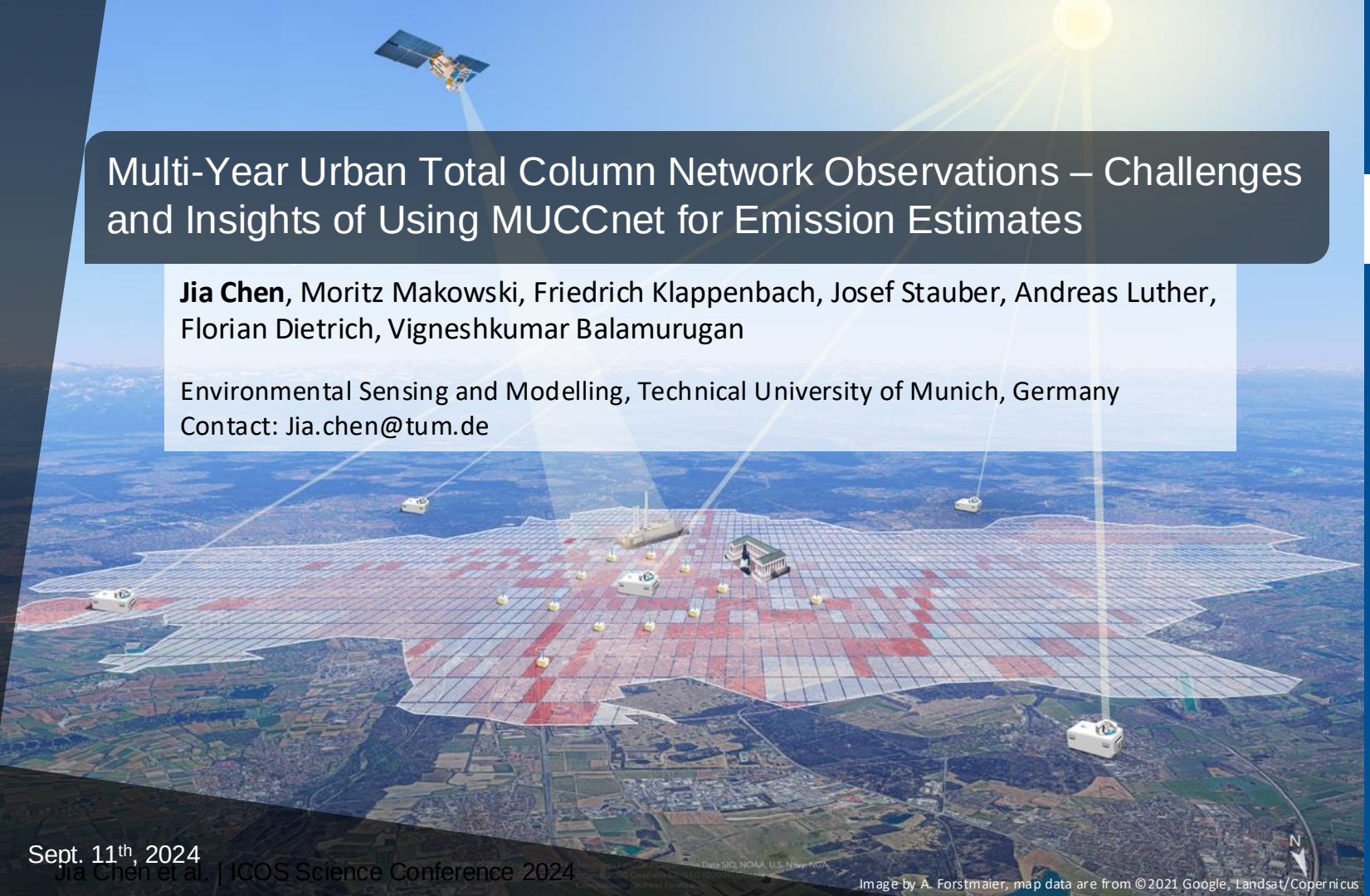


Image by A. Forstmaier, map data are from ©2021 Google, Landsat/Copernicus

People who contributed a lot

Josef Stauber

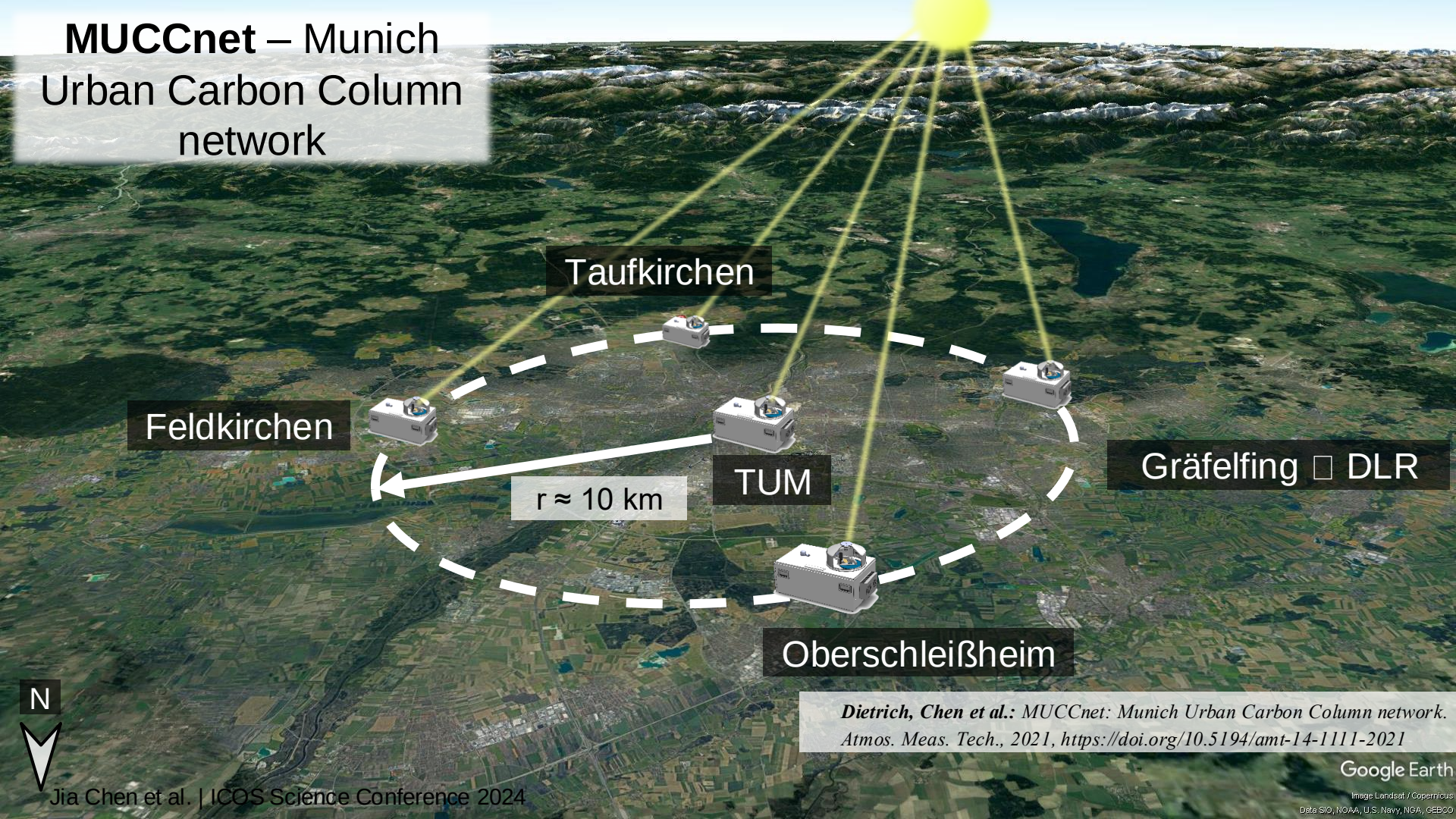
Moritz Makowski

Friedrich Klappenbach

Andreas Luther

Florian Dietrich

MUCCnet – Munich Urban Carbon Column network



Dietrich, Chen et al.: *MUCCnet: Munich Urban Carbon Column network. Atmos. Meas. Tech., 2021, https://doi.org/10.5194/amt-14-1111-2021*

Differential Column Measurements

(Chen et al., 2016, Dietrich et al. 2021)

- **Approach**: $Emission \propto C_{downwind} - C_{upwind}$
- **Species**: CO_2, CH_4 and CO
- **Advantages**:
  - Insensitive to boundary layer height dynamics
  - Representative for regional emissions
- **Precision**: 0.01% @10 min integration time [1]
- Included the **WMO IG3IS** Guideline for Urban GHG Emission Monitoring
- **Application**:
  - Monitoring emissions over long-time
  - Validate satellite measurements

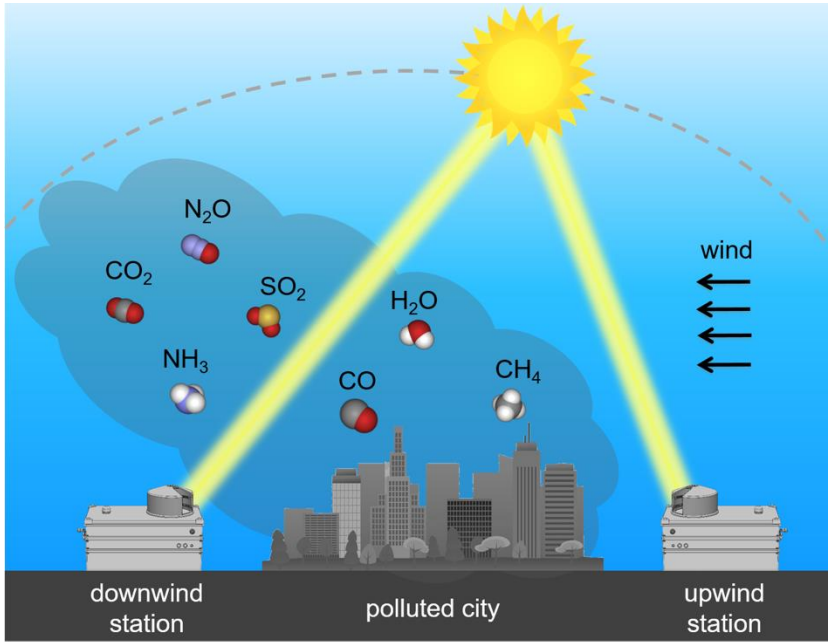


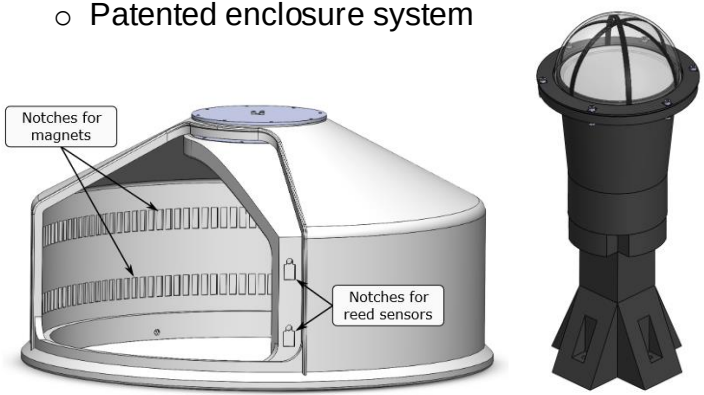
Fig. 1: Principle of the differential column measurements

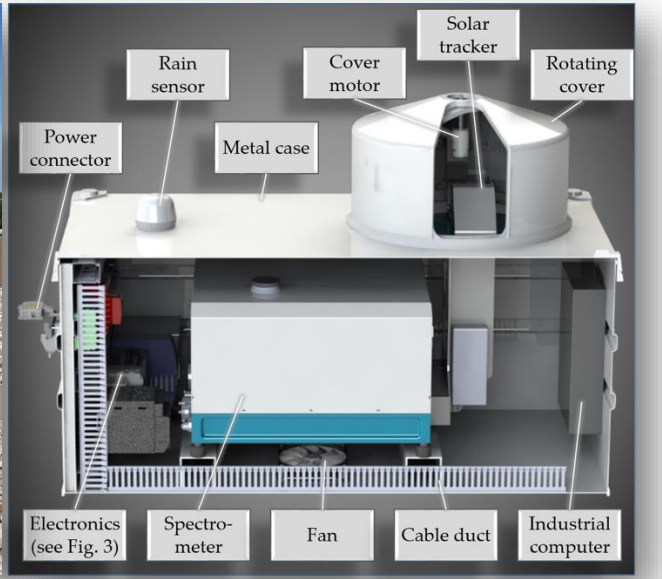
[1] Chen et al.: Differential column measurements using compact solar-tracking spectrometers. Atmospheric Chemistry and Physics, https://doi.org/10.5194/acp-16-8479-2016, 2016

MUCCnet Sensor System

(Heinle and Chen, 2018; Dietrich, et al. 2021)

- Fully-automated sensor systems:
  - Solar-tracking Fourier transform spectrometer (Bruker EM27/SUN)
  - Patented enclosure system





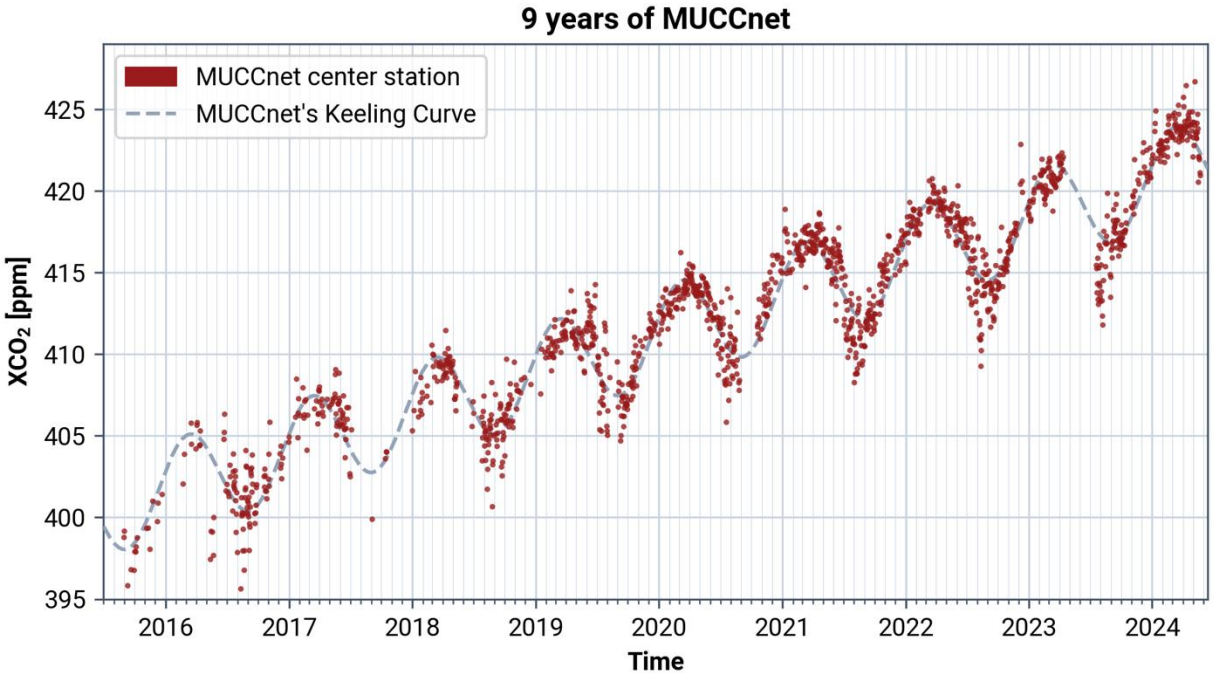
Our system reduces the personnel costs to a minimum and increases the amount of measurement data to a maximum

Heinle and Chen: *Automated Enclosure and Protection System for Compact Solar-Tracking Spectrometers. Atmos. Meas. Tech., 2018, https://doi.org/10.5194/amt-11-2173-2018*
Dietrich, Chen et al.: *MUCCnet: Munich Urban Carbon Column network. Atmos. Meas. Tech., 2021, https://doi.org/10.5194/amt-14-1111-2021*

COCCON Travel Stand – Evaluate TCCON Stations Globally

Herkommer et. al.: *Using a portable FTIR spectrometer to evaluate the consistency of TCCON measurements on a global scale: The COCCON Travel Standard, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-3089, 2024.*

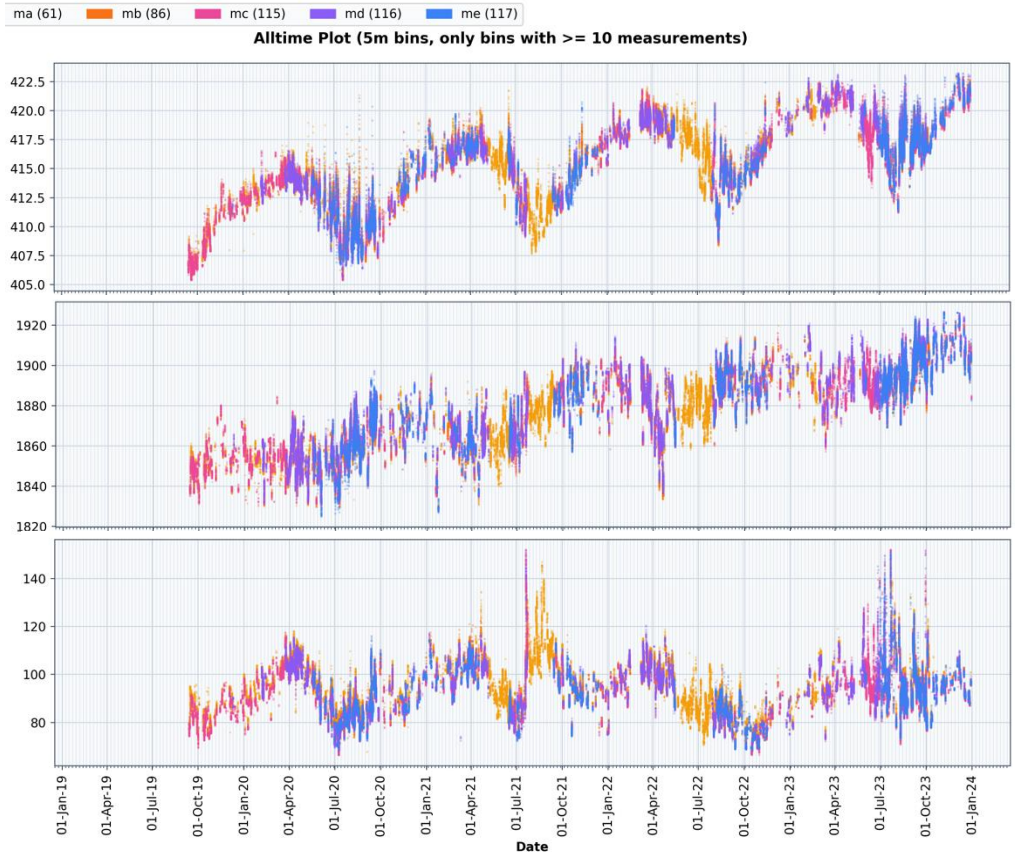
Measurements (2015 – now)



XCO_2 [ppm]

XCH_4 [ppb]

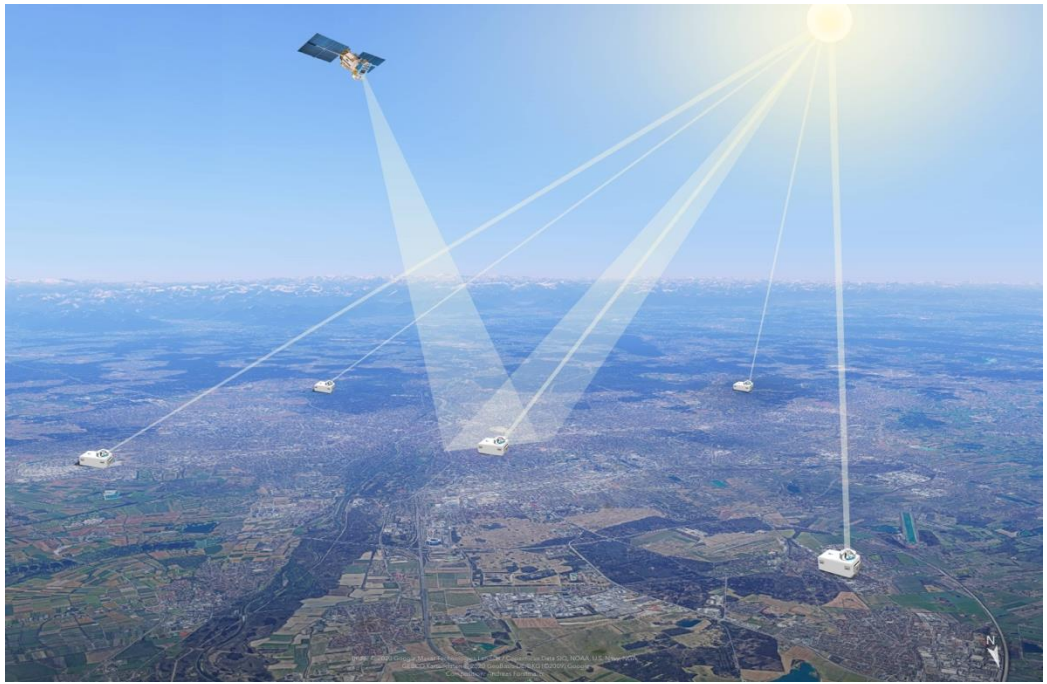
XCO [ppb]



~ 2.5% increase

~ 3% increase

Munich Greenhouse Gas and Air Quality Landscape 2020

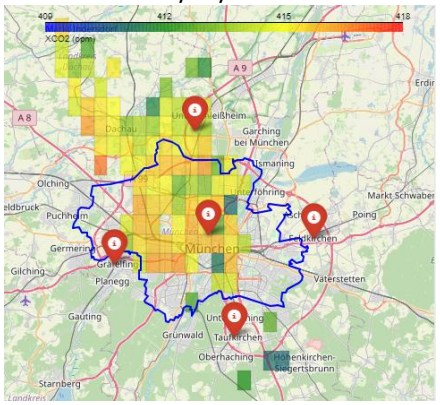


- 5 MUCCnet stations
- OCO target mode

OCO-2 (target mode)

Plots by Ayah Abu Hani

04/04/2020



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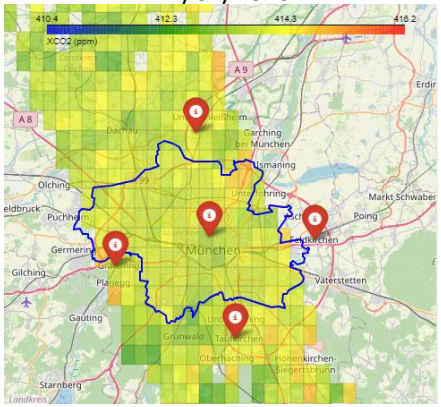

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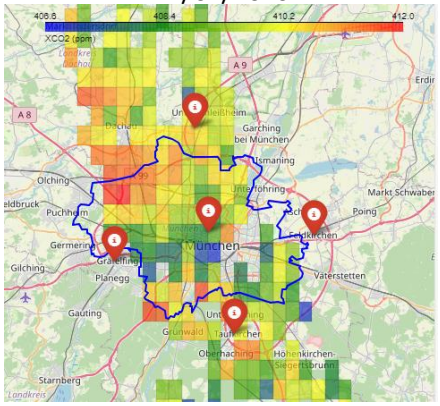

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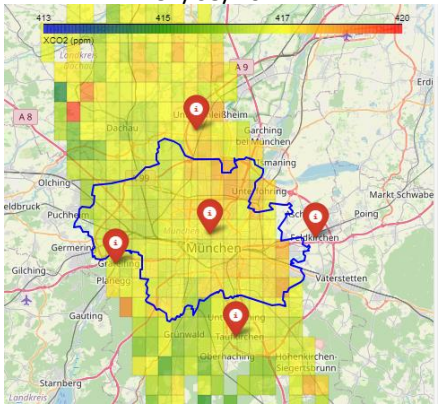
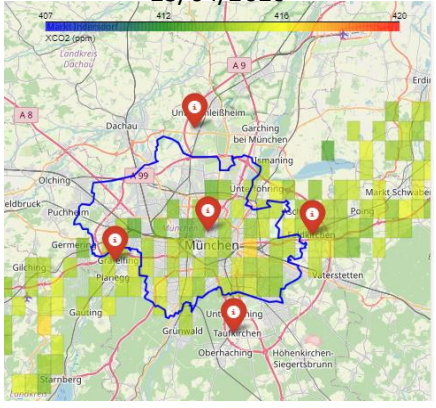
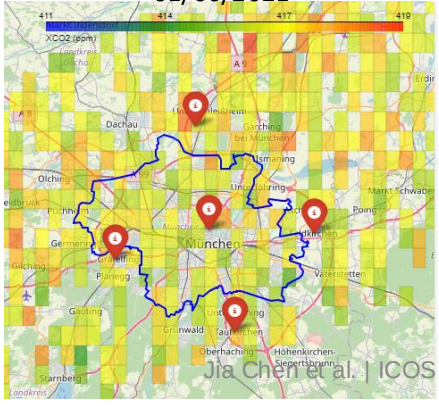


OCO-3 (Snapshot Area Mapping mode)

23/04/2020



01/06/2021



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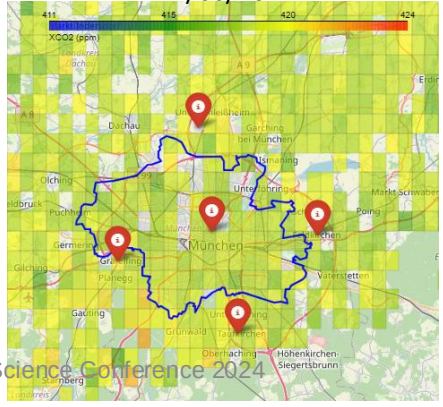
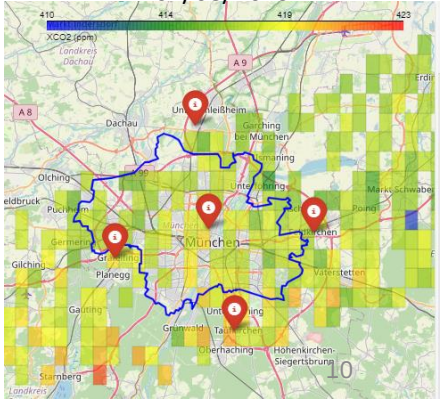
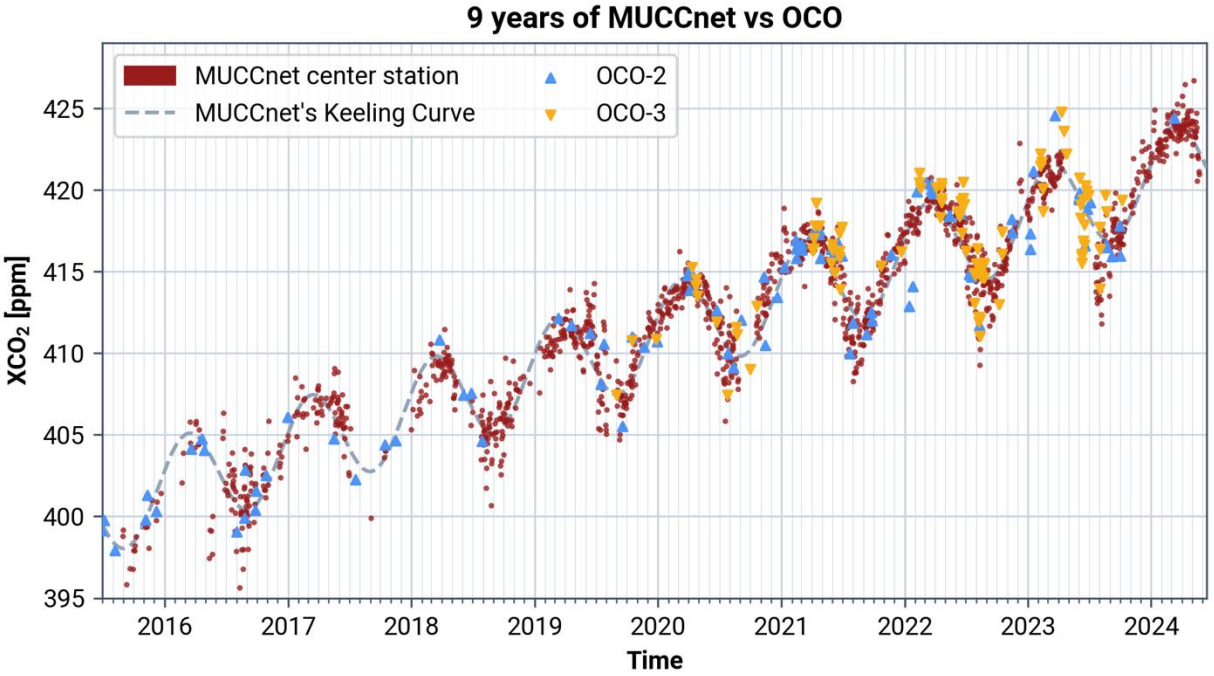


02/08/2023

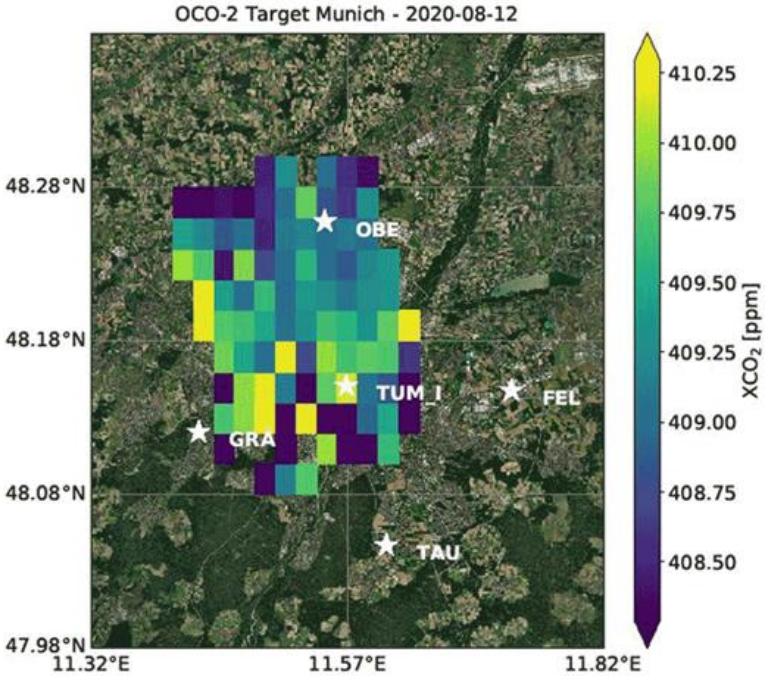


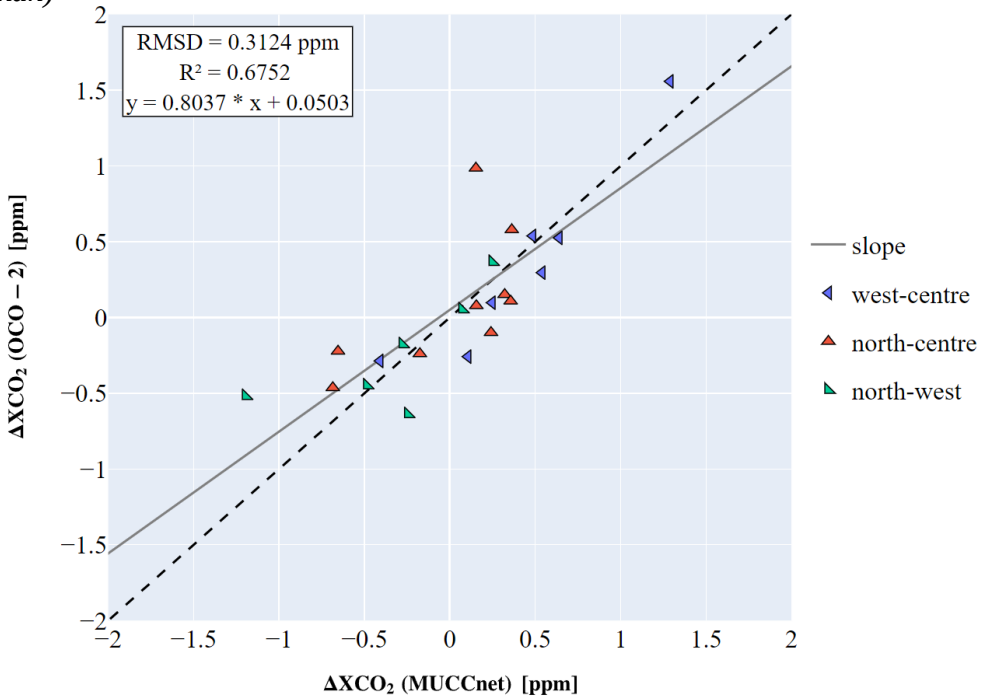
MUCCnet + OCO Seasonal Cycle



Satellite **Gradient** Validation using MUCCnet

(Rißmann et al. 2022 - in collaboration with M. Kiel and G. Osterman)

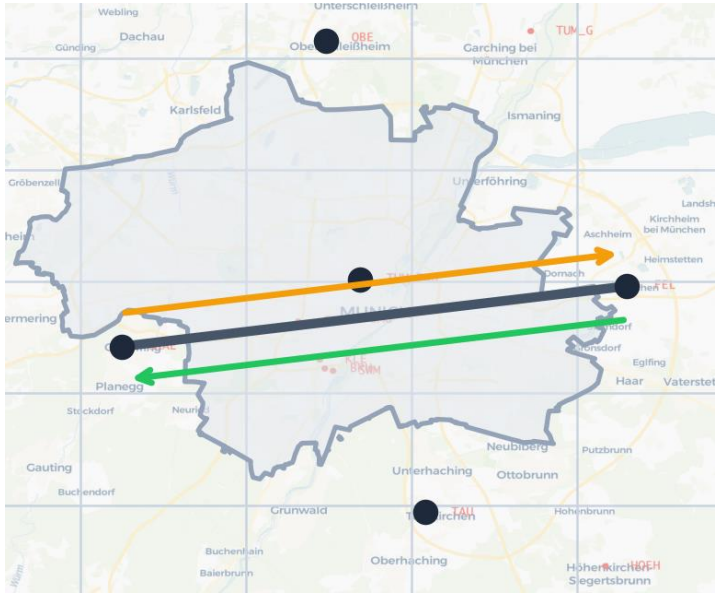


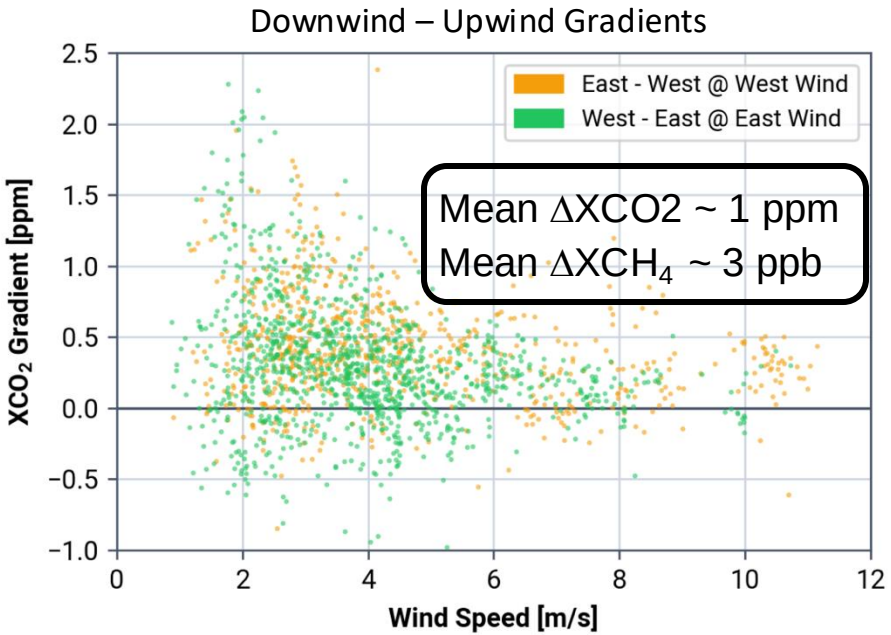


- Strong correlation between gradient measured by MUCCnet and by satellite

***Rißmann, Chen et al**: Comparison of OCO-2 target observations to MUCCnet - Is it possible to capture urban XCO2 gradients from space?, AMT, 2022, https://doi.org/10.5194/amt-15-6605-2022*

CO_2 City Gradients: As Expected





Challenges

Technical Challenges

Very small concentration gradients

Mean ΔXCO_2 ~ 1 ppm, Mean ΔXCH_4 ~ 3 ppb

Drift of pressure sensor

XCO_2: 0.15 ppm/hpa [1], XCH_4: 0.8 ppb/hpa [1]

Variation of the Instrument Line Function

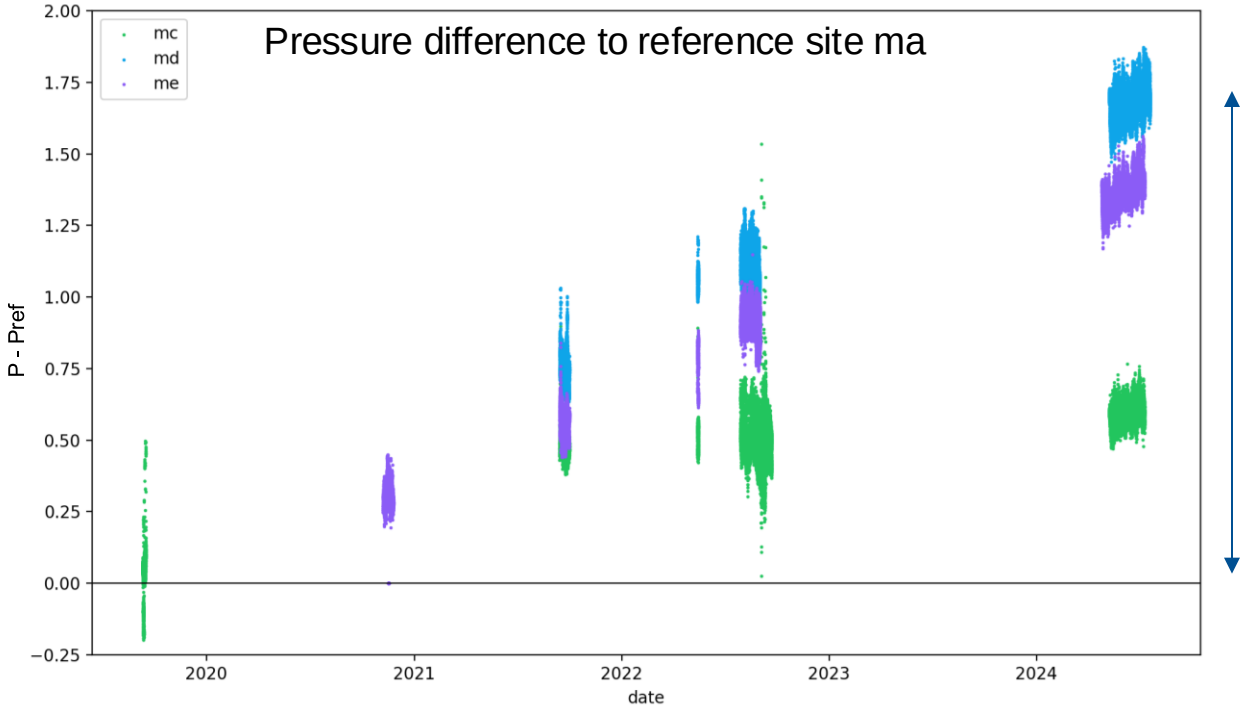
Modeling Challenges

Simple model does not work

Background assessments

[1]: Qiansi Tu, PhD thesis, https://publikationen.bibliothek.kit.edu/1000095901

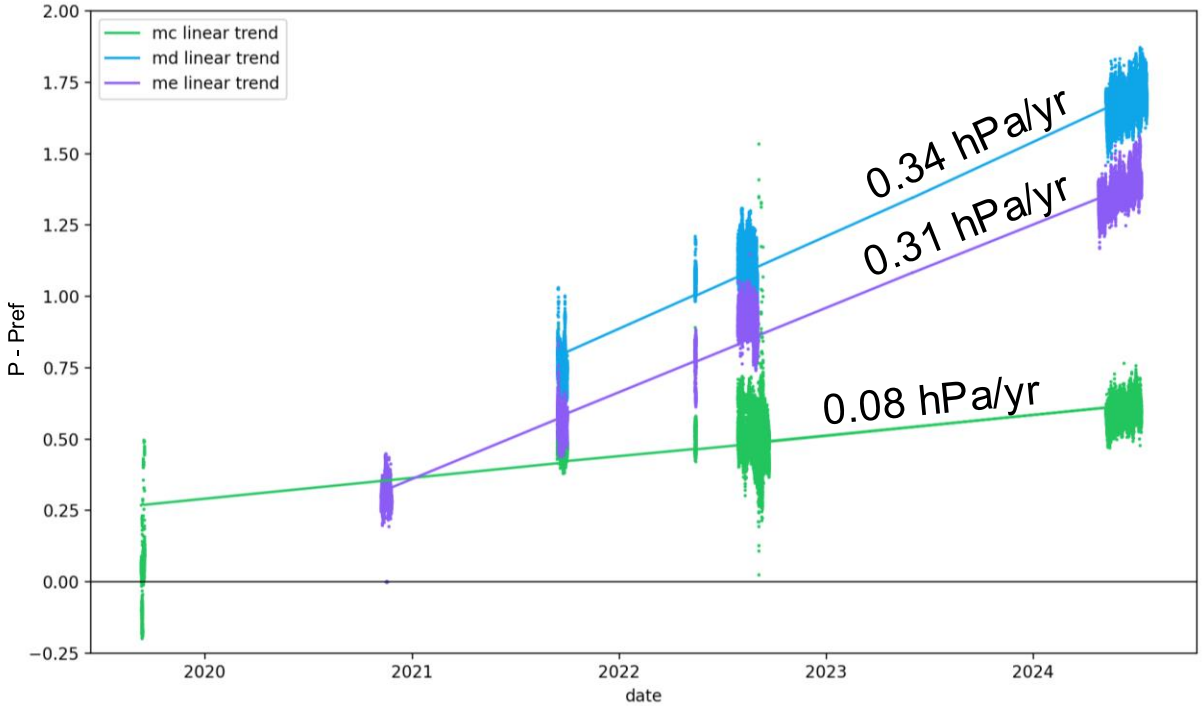
Pressure Calibration



Mean ΔXCO2 ~ 1 ppm
Mean ΔXCH_4 ~ 3 ppb

~0.3 ppm XCO_2
~1.4 ppb XCH_4
systematic error

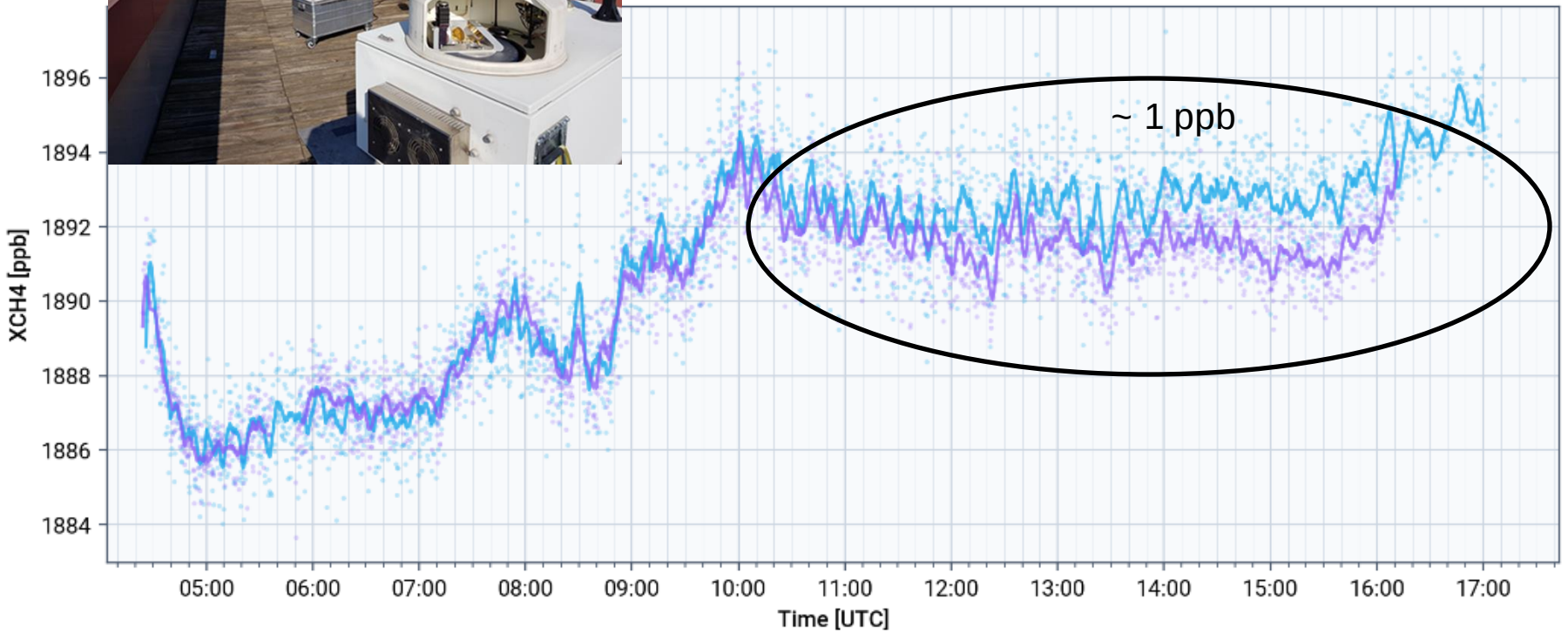
Pressure Calibration



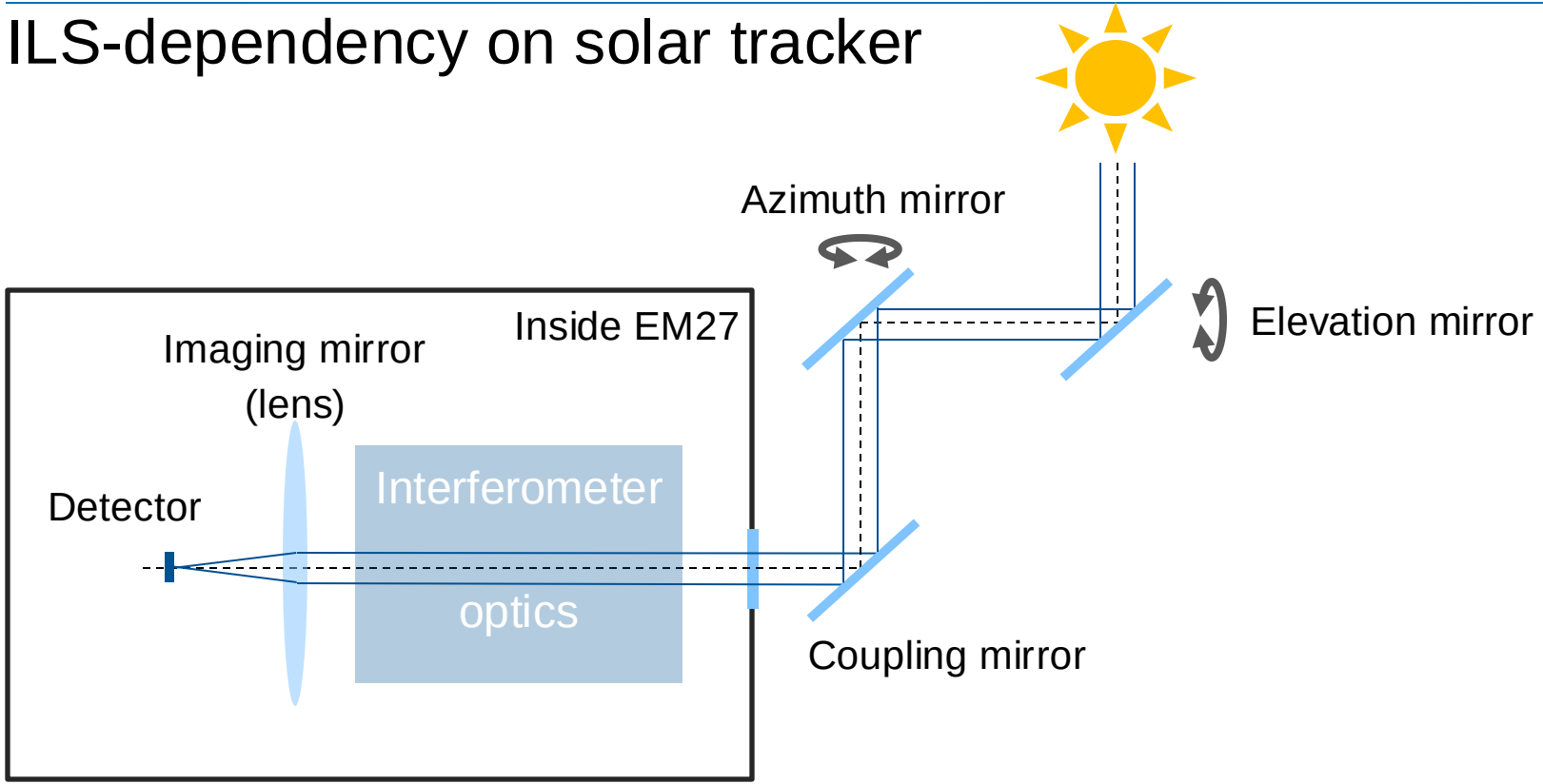
~0.3 ppm XCO_2
~1.4 ppb XCH_4
systematic error

Effect:
< **0.02 ppm** for XCO_2 @ 15 min
< **0.1 ppb** for XCH_4 @ 15 min

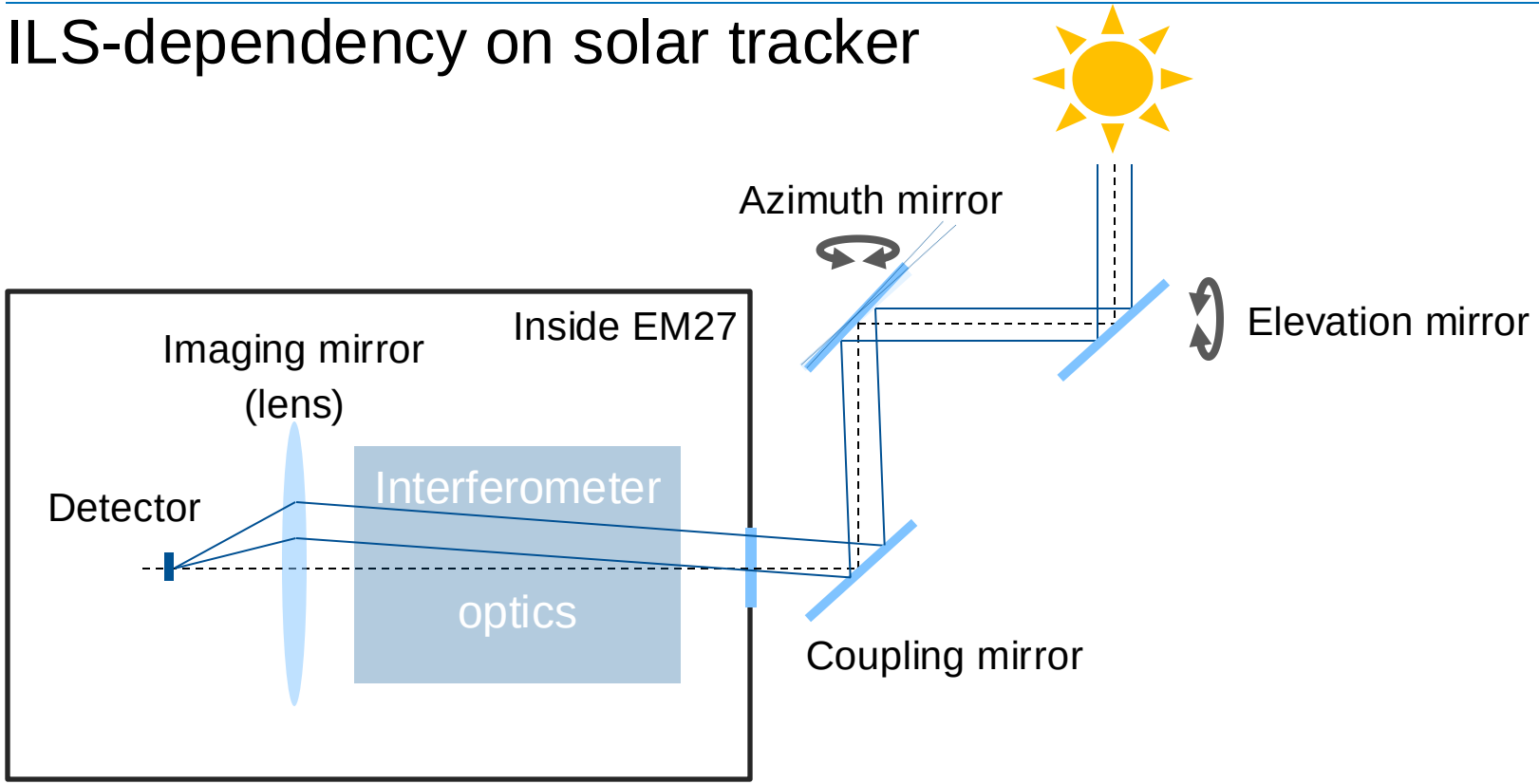
[1] ***Qiansi Tu***: *Observation of atmospheric greenhouse gas abundances on regional scales in boreal areas using portable FTIR Spectrometers, KIT, 2019, https://doi.org/10.5445/IR/1000095901*


~ 1 ppb
XCH4 [ppb]
1896
1894
1892
1890
1888
1886
1884
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
Time [UTC]

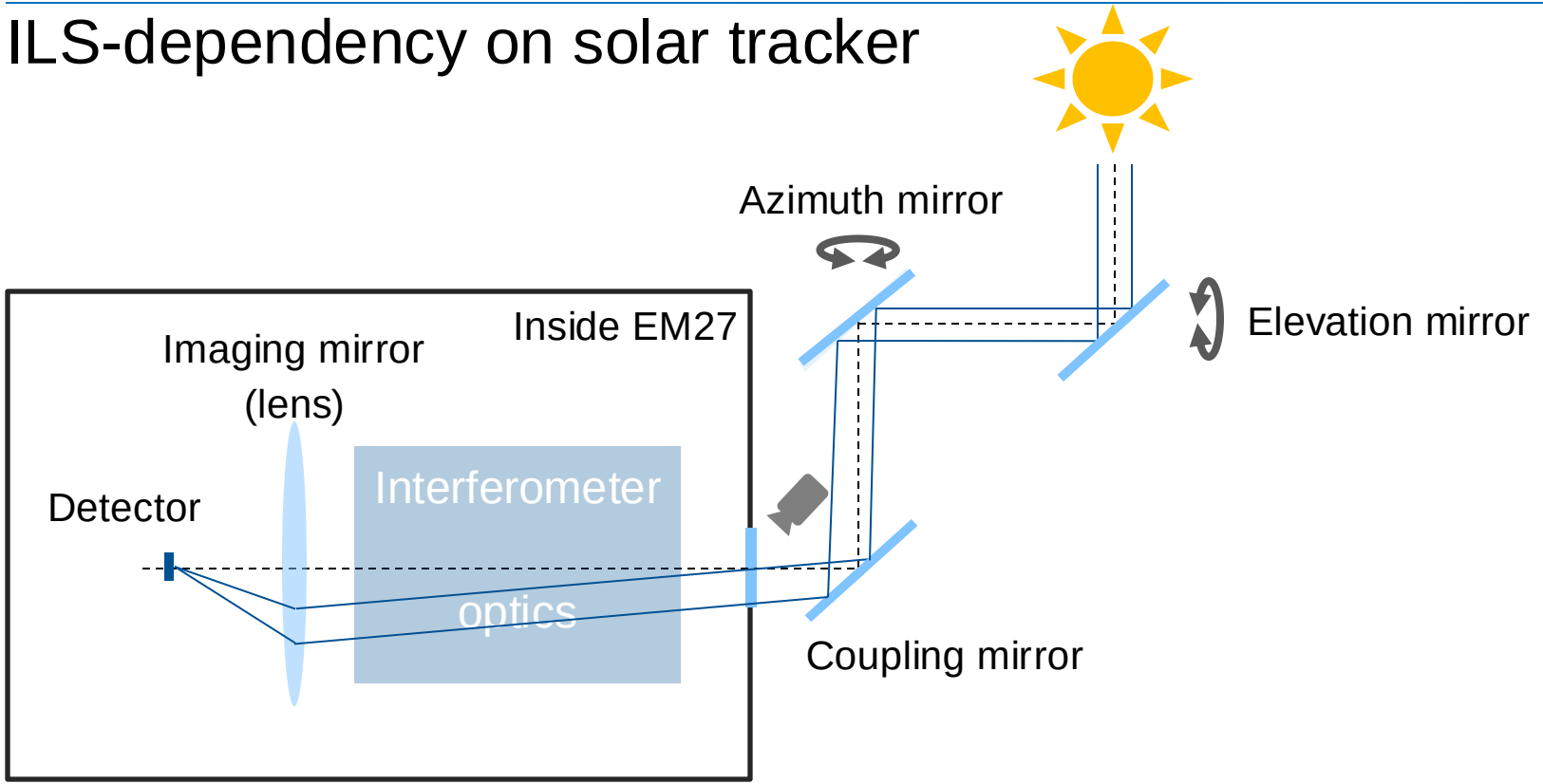
ILS-dependency on solar tracker



ILS-dependency on solar tracker



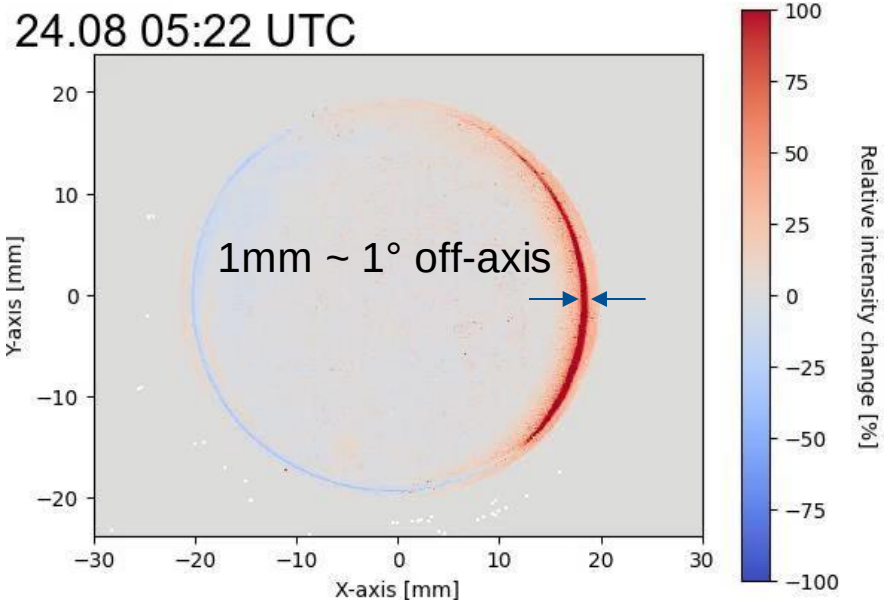
ILS-dependency on solar tracker



Video of the Camera Looking at Entrance Window

Reference Image at Noon

Relative Difference to Reference



Challenges

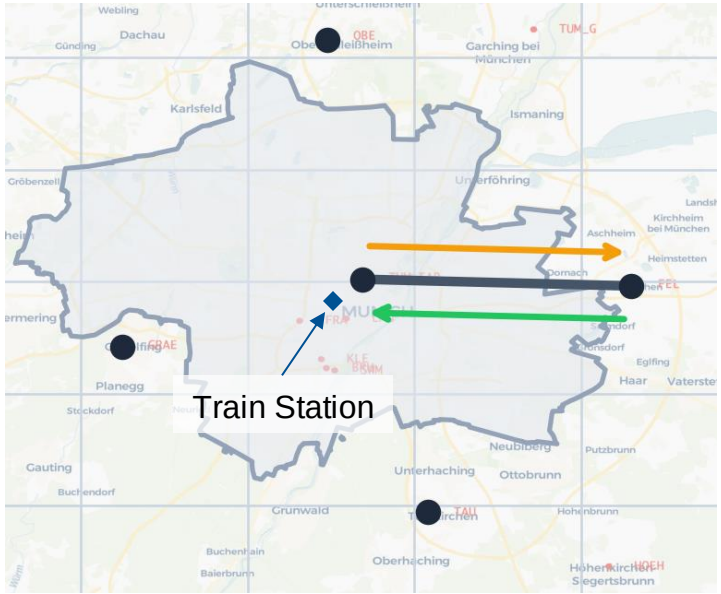
Technical Challenges

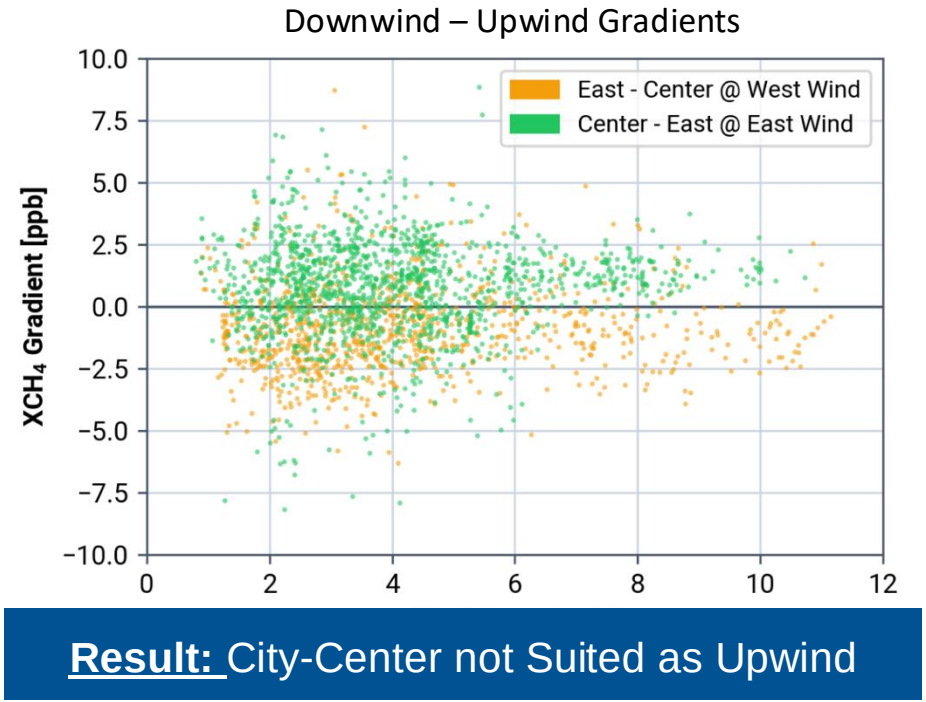
- Very small concentration gradients
- Drift of pressure sensor
- Variation of the Instrument Line Function

Modeling Challenges

- Simple model does not work
- Background assessments

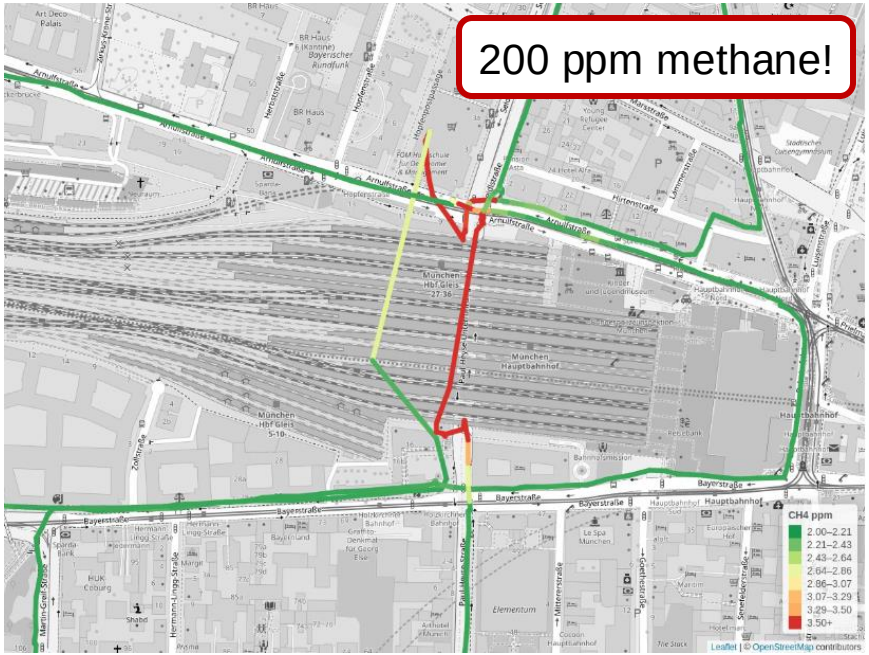
Half-City Gradients:





Result: City-Center not Suited as Upwind

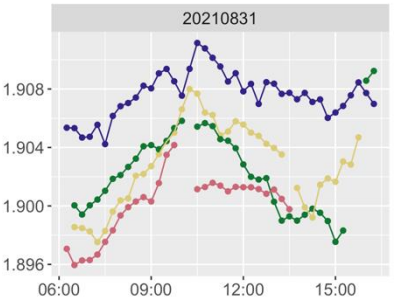
Additional Mobile Unit to Detect Unknown Sources



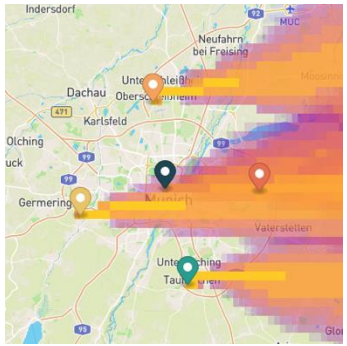
Bayesian Inversion

(Jones et al. 2021 – in collaboration with Harvard)

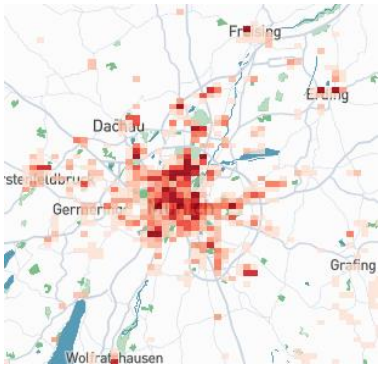
$$\min_{x,\,b}[(Hx+b-y)^T S_\epsilon^{-1}(Hx+b-y)+(x_a-x)^T S_a^{-1}(x_a-x)]$$



MUCCnet measurements



Footprints

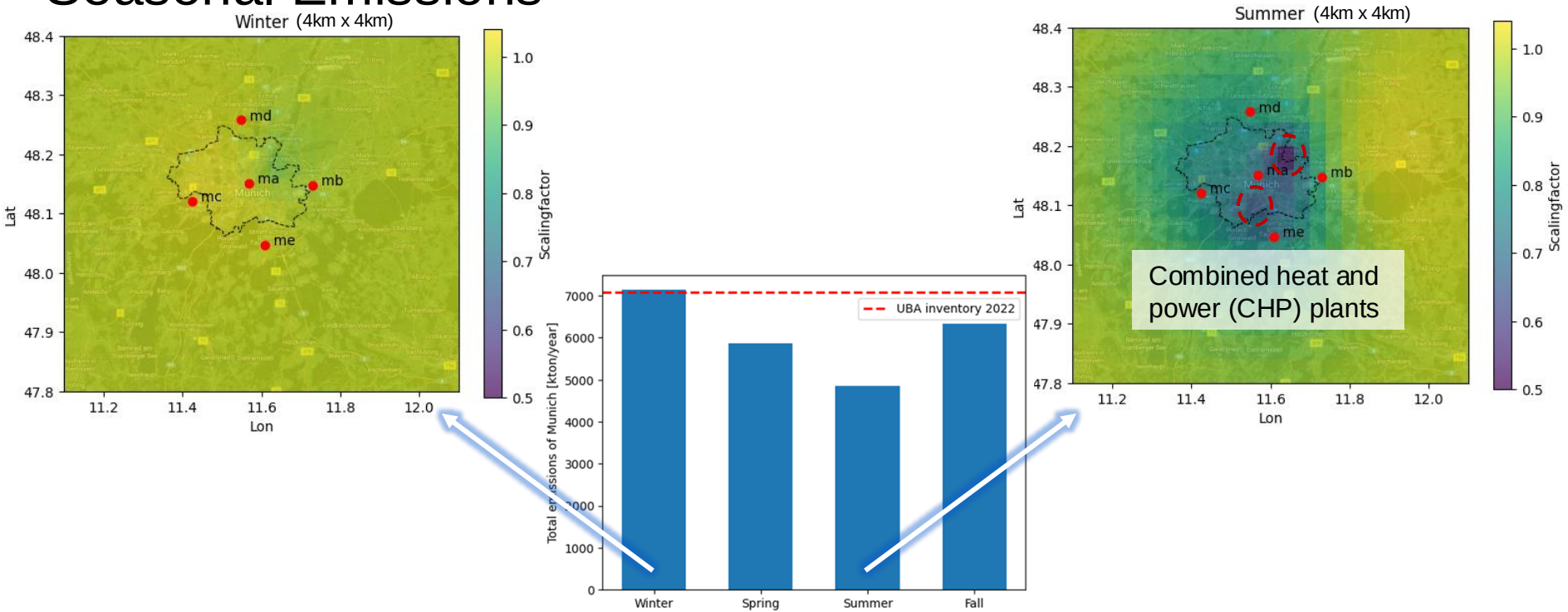


Emission Inventory

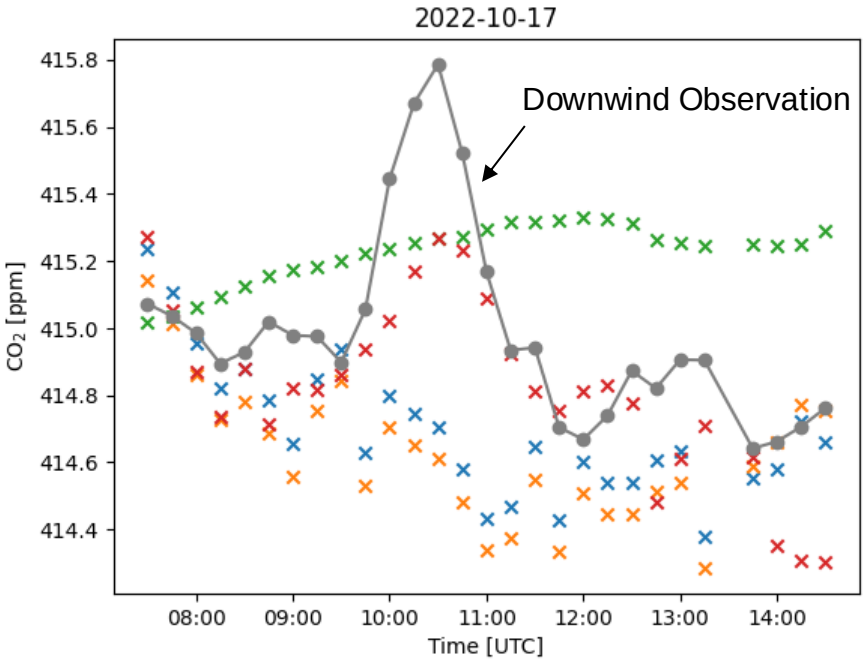
y: *observations*
H: *footprint matrix*
x: *emissions*
x_a: *prior emissions*
b: *background concentration*
S: *error covariance matrix*

Jones et al.: *Assessing Urban Methane Emissions using Column Observing Portable FTIR Spectrometers and a Novel Bayesian Inversion Framework, Atmos. Chem. Phys., 2021, https://doi.org/10.5194/acp-21-13131-2021*

Seasonal Emissions

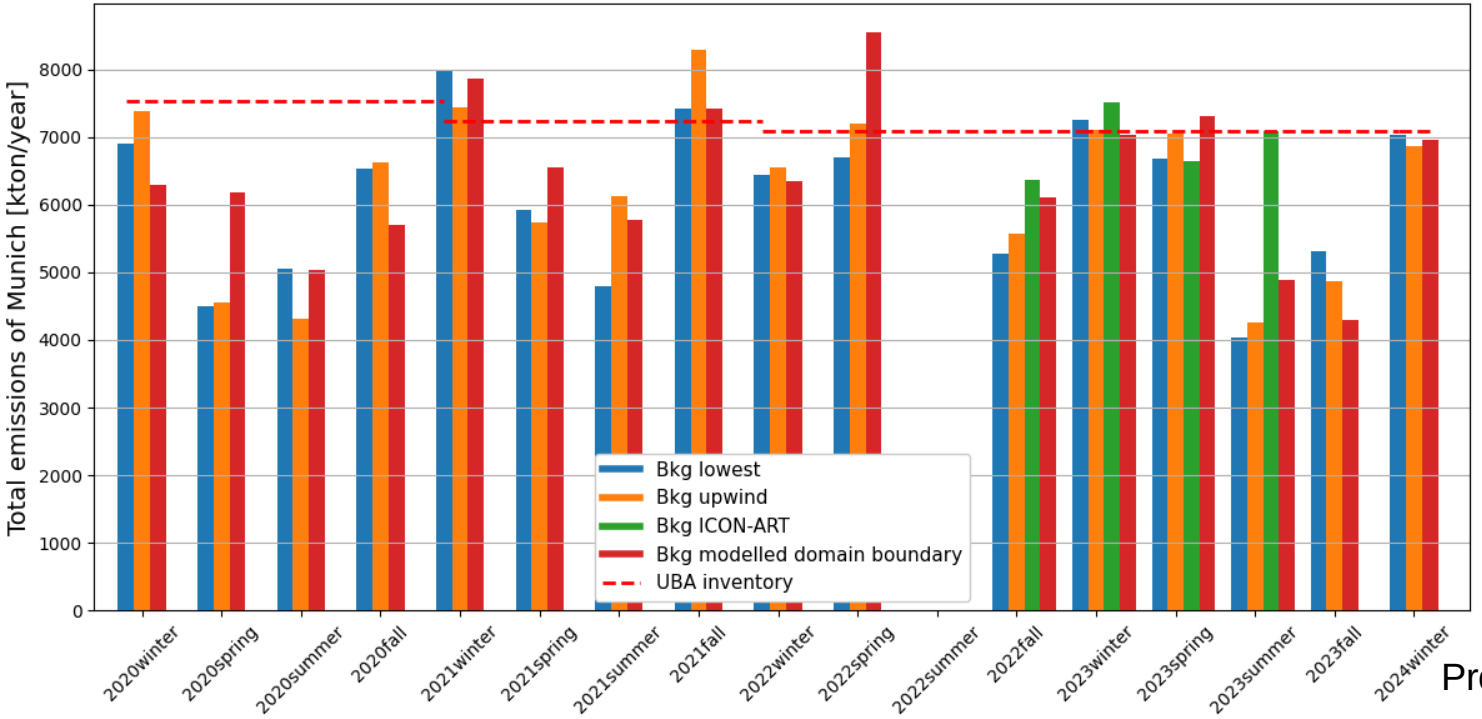


Exemplary Day with Different Background Approaches



	Background Method	Assumption
X	Based on site with lowest observation	Spatial homogeneity
X	Based on upwind site	Spatial homogeneity
X	Based on ICON-ART	Spatial heterogeneity
X	Modelled domain boundary	Same concentration at the domain boundary, but sites see different background

CO_2 Emission 2020 - 2024 (Munich) + Background Approaches



Preliminary results

Conclusion/Outlook

MUCCnet is capable of monitoring city emissions and validate satellite gradients!

- Develop a new approach to characterize ILS throughout the day (in collaboration with Frank Hase)
- Optimize the background approach using simulation experiment
- Weekly emission assessments in 1km^2 resolution
- Novel inversion approaches