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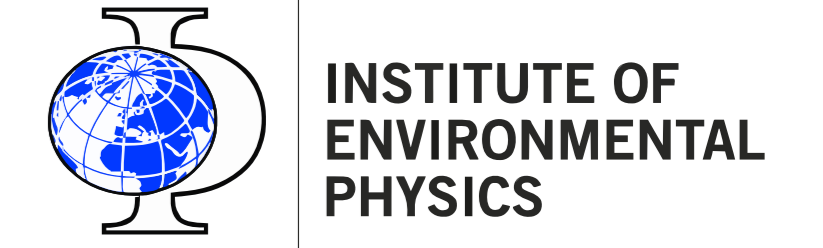
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Introduction

Cities are major sources of anthropogenic greenhouse gases, making accurate emission monitoring essential for effective climate action [1]. In this project, we measure carbon dioxide (CO₂) concentrations along kilometer-long light paths above the city of Heidelberg, Germany. The measured concentrations are representative of areas on the kilometer scale, and thus, of typical model grid scales. Our instrument uses dual-comb spectroscopy (DCS), enabling precise measurements of CO₂ with minute-level time resolution.



Take-home messages

Precise path-integrated CO₂ measurements demonstrated

Measurements are representative of kilometer-scale model grid cells

Turn-key dual-comb setup built from commercially available devices in continuous operation

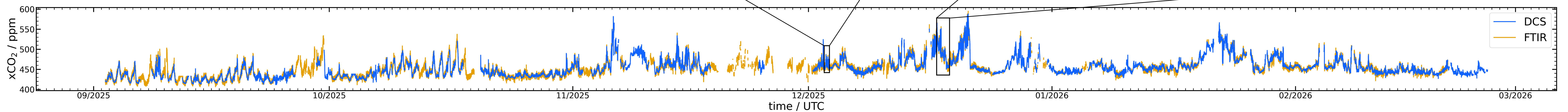
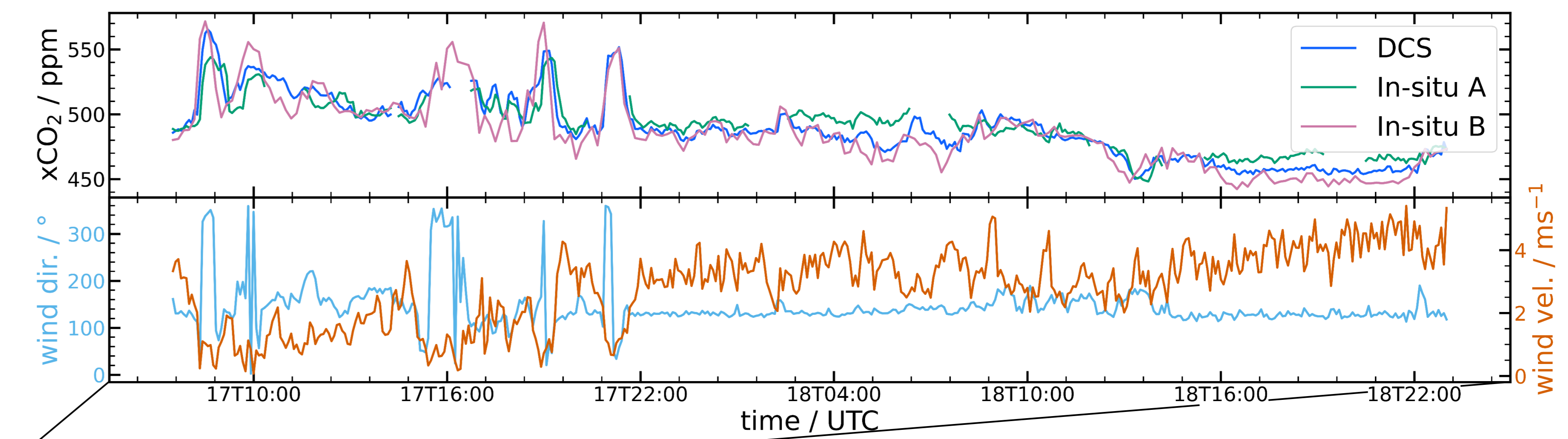
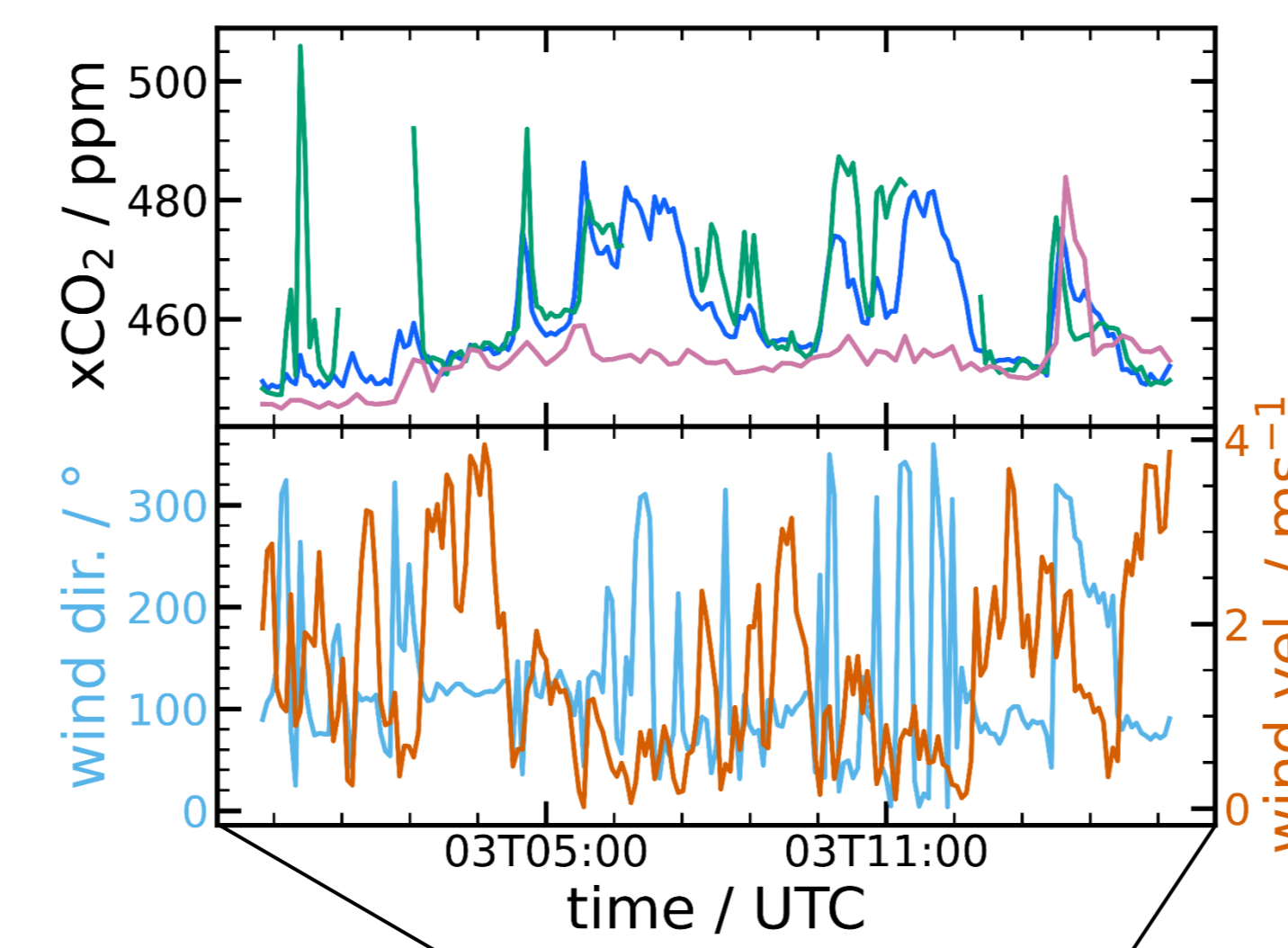
Towards a multi-path network for urban emission quantification

xCO₂ measurements above Heidelberg, Germany

- Continuous open-path dual-comb spectroscopy (DCS) measurements of xCO₂ since September 2025
- Comparison with co-located Fourier-transform spectroscopy (FTIR) measurements [2] shows **good agreement** and **higher precision** of DCS
- Zoomed-in view compares **path-integrated measurements** with **in-situ sensors** at both ends of the light path
- Path-integrated measurements capture the **mean trend** of in situ sensors and are **less influenced by local CO₂ fluctuations**

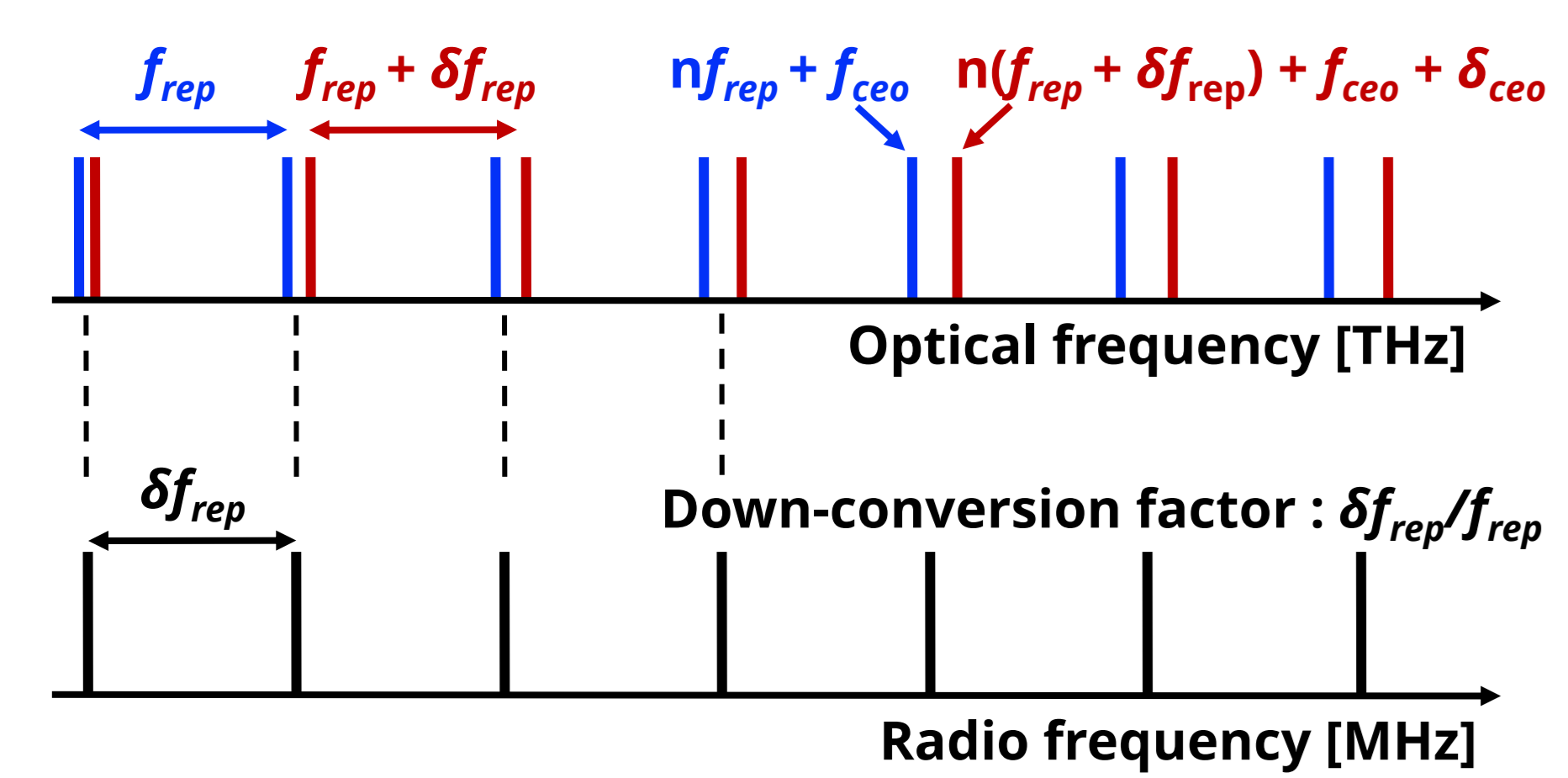
Involved instrumentation:

- DCS: MenloSystems SmartCombs
- FTIR: Bruker 125HR
- In-situ A: CRDS (Picarro) [3]
- In-situ B: Vaisala GMP343



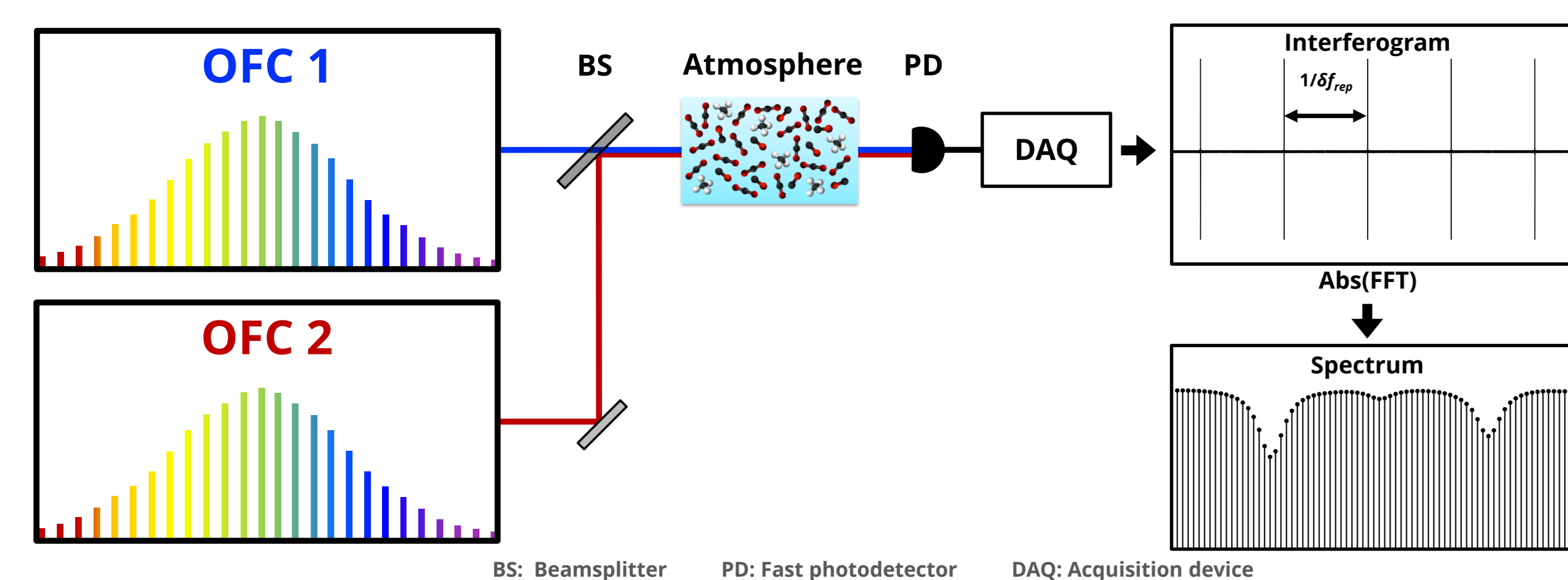
Dual-comb spectroscopy

Frequency domain representation of DCS

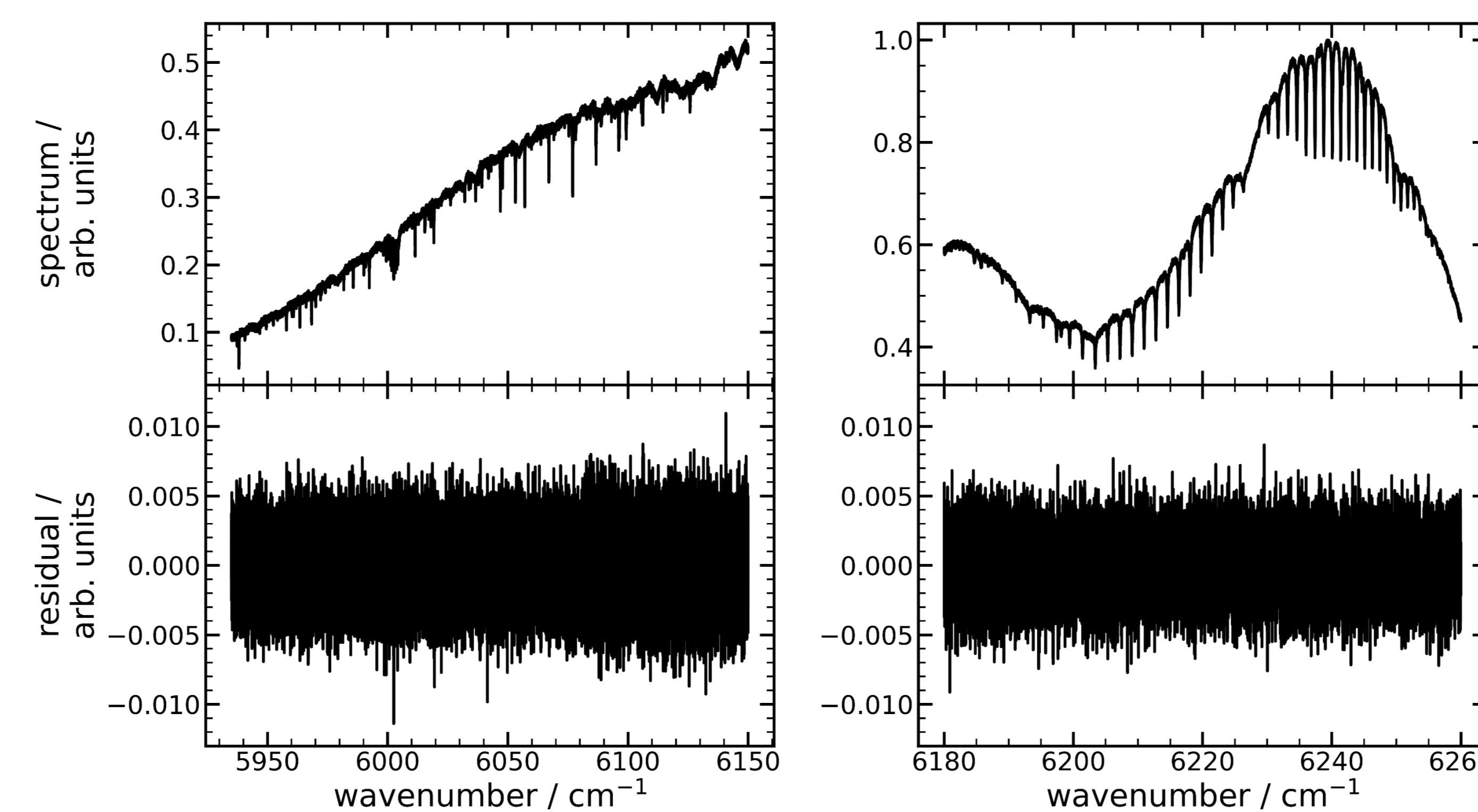


- Down conversion from optical to RF-domain
- One-to-one mapping: optical bandwidth
- $\Delta\nu < \frac{f_{rep}}{2\delta f_{rep}}$
- $1/\delta f_{rep}$ acquisition time for a single interferogram

DCS spectrometer

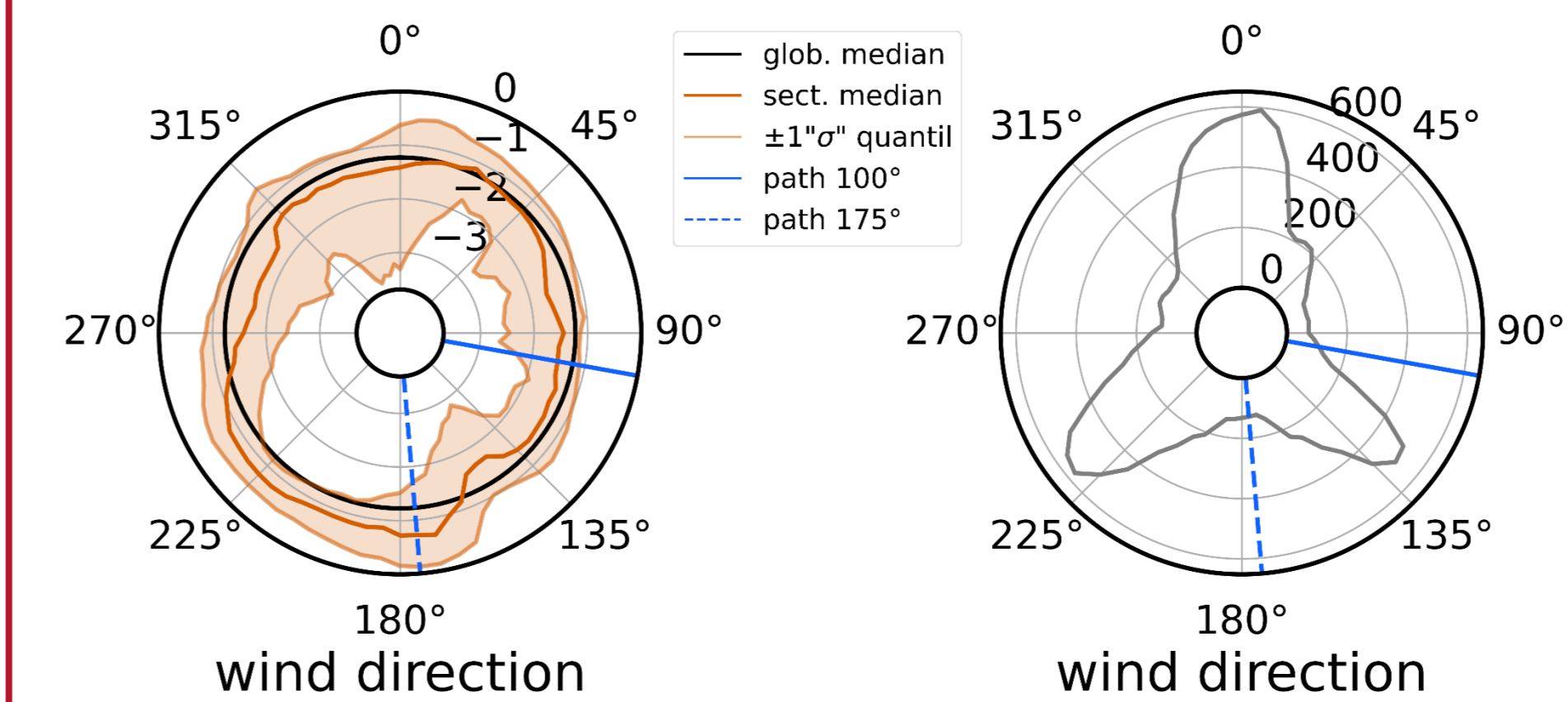


Gas concentration retrieval



- Spectrum recorded in **1 min** along the **3106 m** long atmospheric path covering **5935–6260 cm⁻¹** (1.60–1.68 μm)
- Left panel: **CH₄ absorption band**, enabling future retrievals of **xCH₄**
- Right panel: **CO₂ absorption band** used for **xCO₂ retrievals**
- Instrument precision: **0.62 ppm (1 min)** for **xCO₂**

Outlook



- MACRO-2018 dataset [4] used to characterize **spatial CO₂ gradients**
- Path-integrated modelling reveals **wind-dependent differences** between light paths
- Enables design of a **future multi-path measurement network**
- Aims to assess the **advantages of path-integrated GHG measurements** for future urban flux monitoring
- Supports validation of spectroscopic databases

References

- [1] Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, et al.]. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- [2] Schmitt, T. D., et al. (2023). An open-path observatory for greenhouse gases based on near-infrared Fourier transform spectroscopy. Atmos. Meas. Tech., 16(24), 6097–6110. <https://doi.org/10.5194/amt-16-6097-2023>
- [3] Schmidt, M., Feuerle, M., personal communication (2026)
- [4] Pilz, L., et al. (2025). MACRO-2018 - High-Resolution Simulation of CO and CO2 concentrations over German Metropolitan Areas for 2018 using WRF-Chem. World Data Center for Climate (WDCC) at DKRZ. <https://doi.org/10.26050/WDCC/MACRO-2018>



Digital poster



Abstract



Funding sources

