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Outstanding Student & PhD candidate Presentation contest

Evaluation of nine years of continuous $\delta^{13}CO_2$ measurements in Heidelberg, Germany

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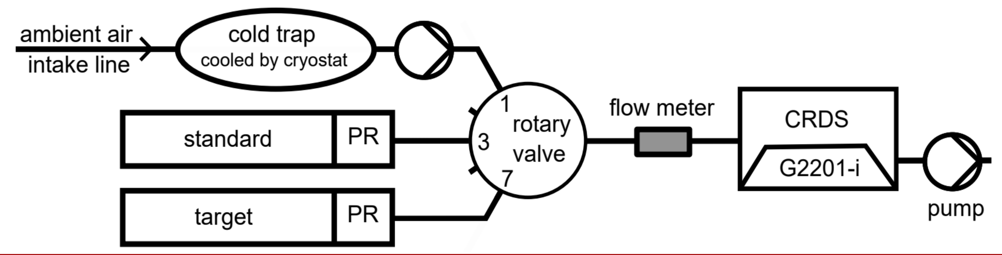
Motivation

- Urban areas produce ~ 70 % of anthropogenic CO_2 emissions [1]
- Provide a basis for tracking the effectiveness of emission reduction policies

Laboratory Setup: [2]

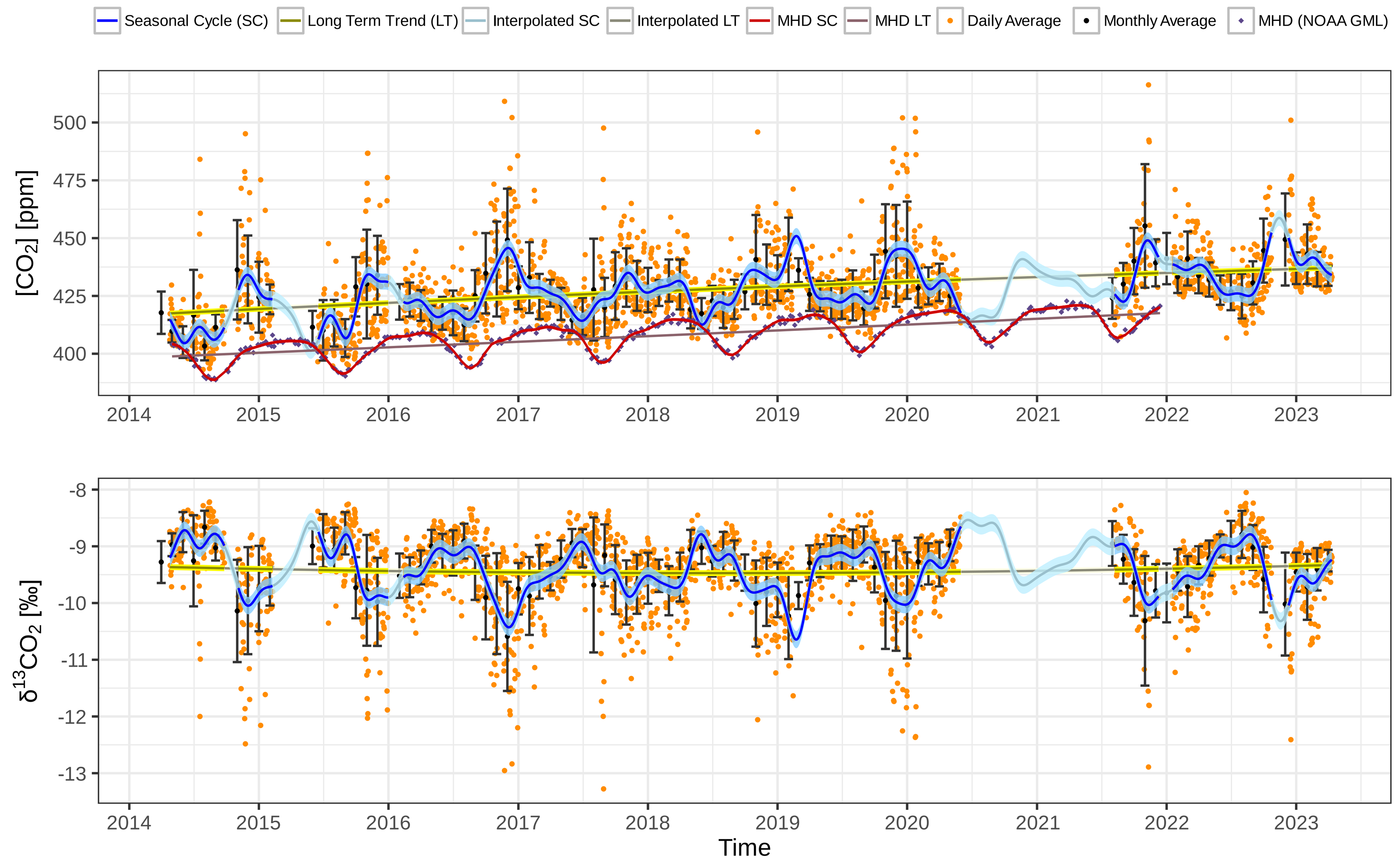


Ambient Air Measurements

- Continuous $[^{12}CO_2]$ and $[^{13}CO_2]$ measurements since 2014 from inlet 30 m above street level
- Cavity ring-down spectrometer (CRDS, Picarro model G2201-i) with drying system
- Single point calibration with interpolated values of known standards measured every 5 hours
- Calibration gases were analysed at MPI for Biogeochemistry in Jena for $\delta^{13}CO_2$ to link our measurements to the VPDB isotope scale
- Target mixtures measured to test long-term stability of measurements

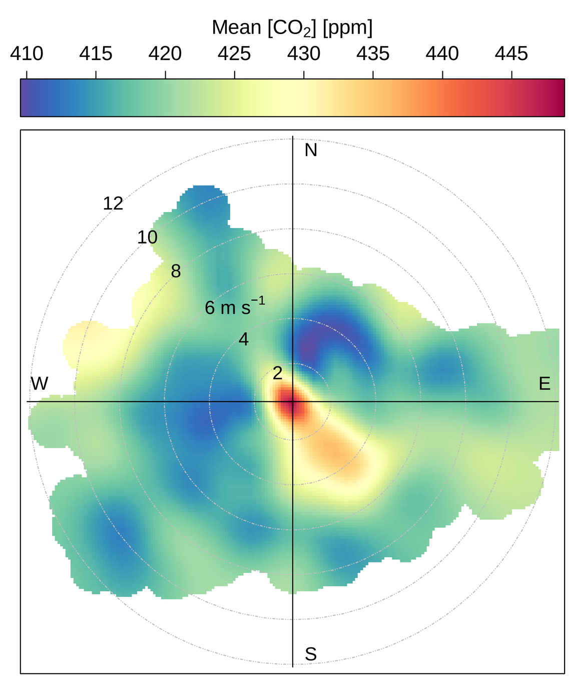
Years Target in Use	Mean $[CO_2]$ ± SD [ppm]	Mean $\delta^{13}CO_2$ ± SD [‰]
2014 - 2018	484.5 ± 0.1	-11.0 ± 0.1
2019 - 2020	381.7 ± 0.1	-8.8 ± 0.1
2021 - 2023	366.42 ± 0.08	-8.7 ± 0.2

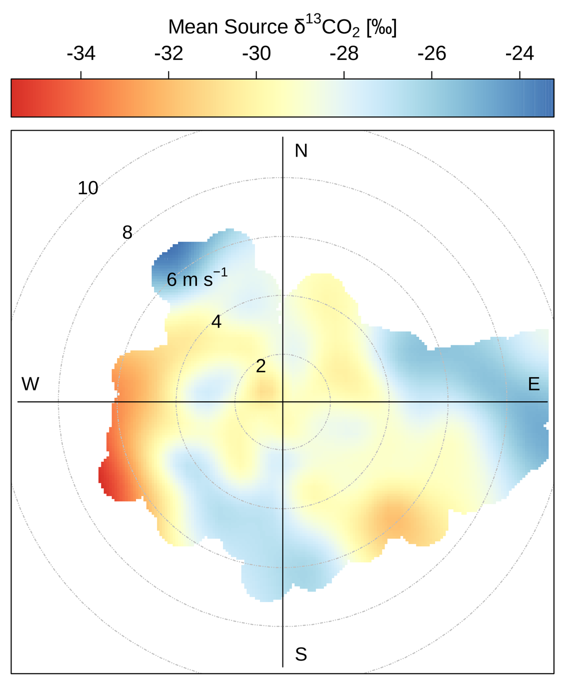
Nine Year Time Series

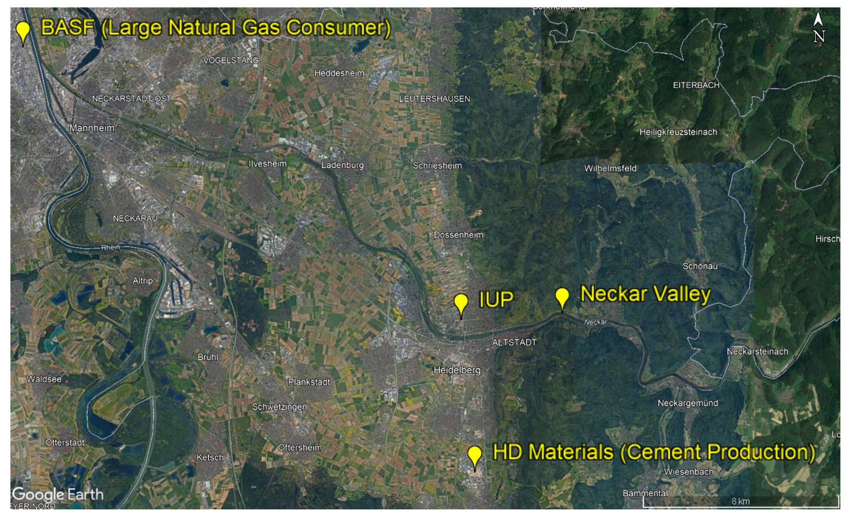


- Daily and monthly means of minutely values shown
- $[CO_2]$ background values from Mace Head (MHD) station, Ireland shown alongside for comparison [3]
- Seasonal $[CO_2]$ cycle similar to and slightly ahead of background cycle
- $\delta^{13}CO_2$ values relative to VPDB scale
- $\delta^{13}CO_2$ and $[CO_2]$ are quite strongly anticorrelated (Pearson's R^2 = 0.89)
- Significant increase of 2.32 ± 0.03 ppm yr^{-1} for $[CO_2]$
- No significant overall trend for $\delta^{13}CO_2$

Comparison with Wind Direction and Wind Speed







Google Earth 7.3.6, (2023) Heidelberg, Germany. 49°25'2.38"N, 8°40'28.12"E. Image Landsat / Copernicus

- CRDS located at Institute for Environmental Physics (IUP)
- Strong easterlies from Neckar Valley
- Enriched Isotope values likely from HD Materials
- Depleted values likely from natural gas combustion

Moving Keeling/Miller-Tans Plot Method

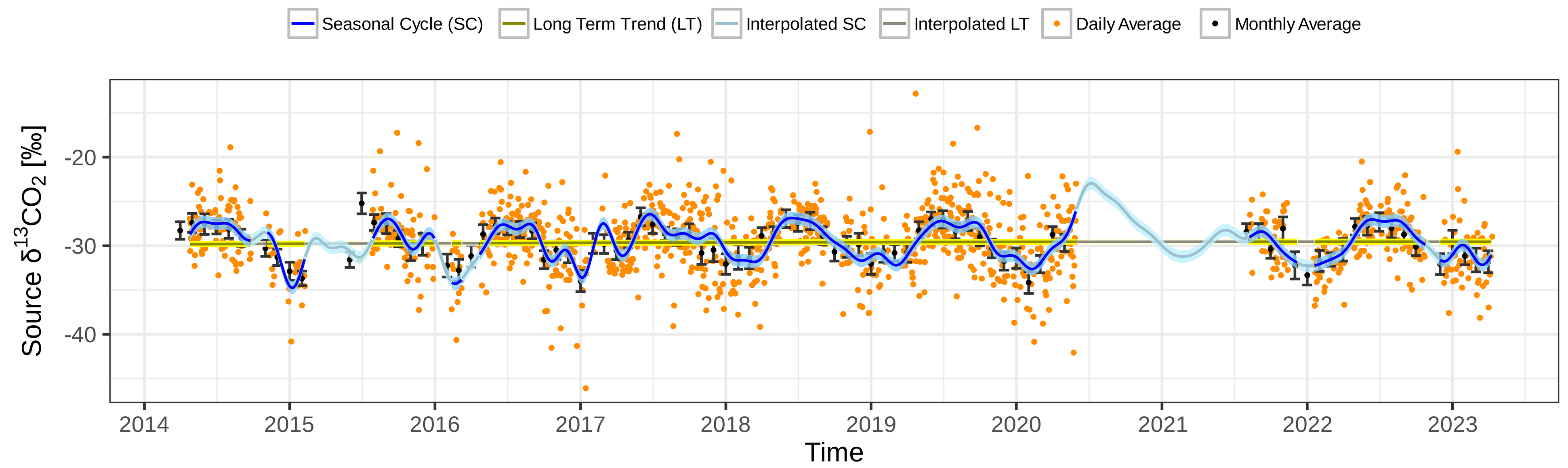
$$R^{13} = \frac{[^{13}CO_2]}{[^{12}CO_2]}, \delta c = \left(\frac{R_{sample}}{R_{VPDB}} - 1\right) \cdot 1000 \text{ ‰}$$

$$c_{obs} = c_{bg} + c_s \quad , \quad c = [CO_2]$$

$$\delta c_{obs} \cdot c_{obs} = \delta c_{bg} \cdot c_{bg} + \delta c_s \cdot c_s$$

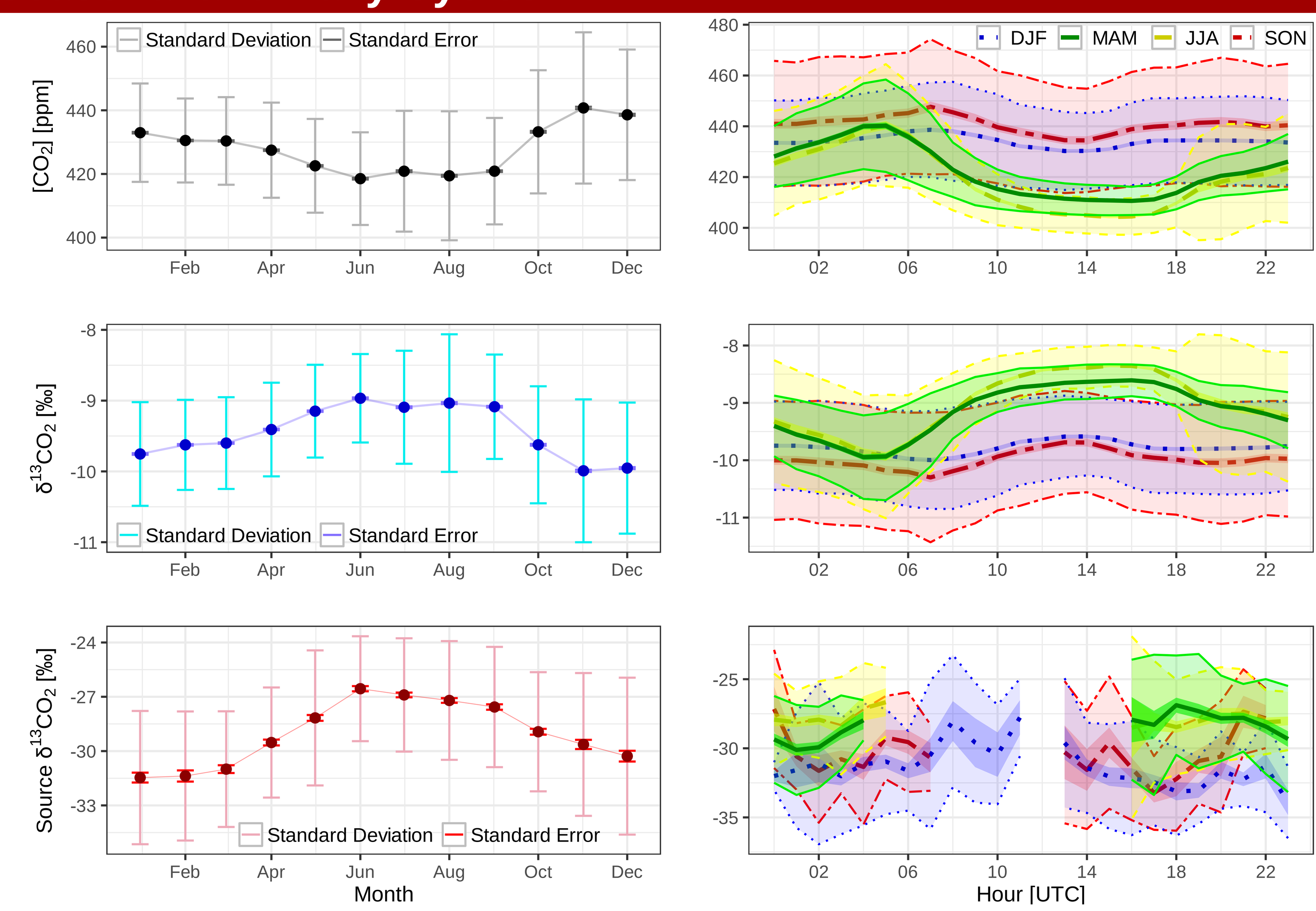
$$\delta c_{obs} \cdot c_{obs} = \delta c_s \cdot c_{obs} + c_{bg}(\delta c_{bg} - \delta c_s)$$

- 5 hour moving windows, using hour-averaged values
- Filter Conditions [4]:
  - ⇒ ≥ 5 ppm $[CO_2]$ total increase
  - ⇒ Monotonous $[CO_2]$ increase
  - ⇒ < 2 ‰ uncertainty in Miller-Tans Slope
  - ⇒ Reduced χ^2 < 10; R^2 > 0.75



Seasonal and Daily Cycles

- Long term trend subtracted and mean values added to calculate the annual and diurnal cycles
- Significant annual cycles for $[CO_2]$, $\delta^{13}CO_2$, and the source $\delta^{13}CO_2$
- Significant diurnal cycles for $[CO_2]$ and $\delta^{13}CO_2$ for all seasons
- Amplitude of $[CO_2]$ and $\delta^{13}CO_2$ diurnal cycles greatest in summer
- Limited daytime source $\delta^{13}CO_2$ values due to daytime CO_2 sink
- More source $\delta^{13}CO_2$ values obtained in summer and spring due to stronger $[CO_2]$ diurnal cycle



Outlook and Next Steps

- Collaborate with CO_2 modellers to better identify contributions from local sources
- Compare with local and regional emission estimates to test their accuracy
- Use as a baseline to check the effectiveness of emission reduction policies

References and Acknowledgements

[1] IEA (2021), Empowering Cities for a Net Zero Future, IEA, Paris https://www.iea.org/reports/empowering-cities-for-a-net-zero-future, License: CC BY 4.0

[2] Hoheisel A. (2021), Evaluation of greenhouse gas time series to characterise local and regional emissions, PhD Dissertation, Institute Environmental Physics, Heidelberg University

[3] Lan, X., E.J. Dlugokencky, et al. (2022), Atmospheric Carbon Dioxide Dry Air Mole Fractions from the NOAA GML Carbon Cycle Cooperative Global Air Sampling Network, 1968-2021, Version: 2022-11-21, https://doi.org/10.15138/wkgj-f215

[4] Vardag, S. N., et al. (2016) Evaluation of 4 years of continuous $\delta^{13}C(CO_2)$ data using a moving Keeling plot method, Biogeosciences, 13, 4237–4251, https://doi.org/10.5194/bg-13-4237-2016

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