Project report

Project: **1170**

Project title: **Atmospheric greenhouse gases and the Carbon cycle (AtmoC)**

Principal investigator: **André Butz**

Report period: **2025-07-01 to 2026-06-30**

WP1: FLEXPART-ERA5: Analysis of Biogenic Fluxes over North America and Europe (2010-2019)

We have implemented substantial improvements to our set-up and tested it thoroughly. Within two Master thesis, we were able to implement a diurnal cycle of the biogenic fluxes (in two possible manners – additive and multiplicative), implement the averaging kernel of the satellite XCO_2 retrievals, adjust spatial and temporal correlations and finally, analyse the effect of boundary conditions in our set-up using two different global CO_2 products (TM5 and CAMS). We evaluated the sensitivity of our results to these refinements using data of the year 2009. We are currently extending the inversion for further 1.5 years. These results will be presented at the EGU General Assembly 2026 along with the sensitivity results (Grandke et al., 2026). Note that we still plan to extend the regional inversion to longer time periods and to conduct an optimization based on climate extreme indices, which is why we are requesting additional resources in our project proposal.
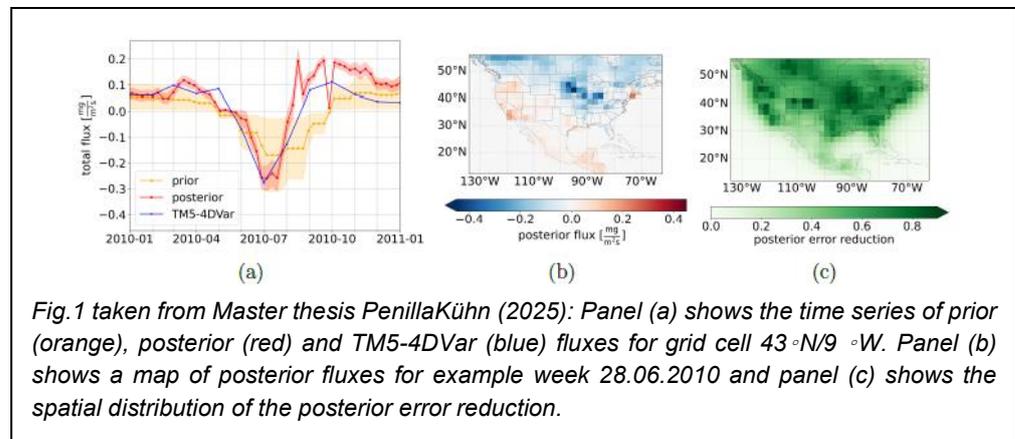

Fig.1 taken from Master thesis PenillaKühn (2025): Panel (a) shows the time series of prior (orange), posterior (red) and TM5-4DVar (blue) fluxes for grid cell 43 °N/9 °W. Panel (b) shows a map of posterior fluxes for example week 28.06.2010 and panel (c) shows the spatial distribution of the posterior error reduction.

Grandke, S., Kühn, P., Metz, E.-M., Lüken-Winkels, C., Basu, S., Butz, A., and Vardag, S. N.: GOSAT and in-situ based inversion of North American CO2 fluxes using FLEXPART , EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-10102, https://doi.org/10.5194/egusphere-egu26-10102, 2026.

WP2: FLEXPART-ERA5: Interpretation of FTS data

The interpretation of FTS data could not be conducted due to parental leave of the main project employee.

WP3: WRF-Chem Simulations: Recent High-Resolution CO_2 Simulation in Urban Hotspots

We have updated the WRF-Chem simulation for 2018 to include a new version of biogenic emissions using VPRM. The large domain size enabled us to investigate systematic differences over large areas covering Europe, which we are analysing together with the developer of pyVPRM (Theo Glauch). The results of the sensitivity analysis (DKRZ project 2022/23), as well as the simulations runs (DKRZ projects 23/24 and 24/25) have been published in Pilz et al. (2025), Pilz and Vardag (2026, dataset) and Pilz (2026, dissertation).

- Pilz, L., Lüken-Winkels, C, Gałkowski, M., Ho, D., Gerbig,C, Chen, F., Vardag,S.N.: Evaluation of high-resolution WRF simulation in urban areas — Effect of different physics schemes on simulation performance in the Rhine-Main-Neckar area, Atmospheric Research, https://doi.org/10.1016/j.atmosres.2025.108435, 2025

- Pilz, Lukas: Monitoring urban greenhouse gas emissions using high-resolution models, DISSERTATION at University Heidelberg, DOI: 10.11588/heidok.00037983

- Pilz, L., Vardag, S.N.: MACRO-2018 - High-Resolution Simulation of CO and CO_2 concentrations over German Metropolitan Areas for 2018 using WRF-Chem, doi:10.26050/WDCC/MACRO-2018

WP4: FLEXPART-WRF Simulations: Inversion of Fossil Fuel CO_2 in Urban Hotspots

FLEXPART-WRF was run and analysed for the two cities of Berlin and Munich. To obtain robust conclusions, we have extended the time periods to include growing and dormant seasons, and we have conducted additional analysis with respect to the influence of biogenic emissions, as well as by analysing the transport model effect effectively. We have found optimal sensor locations depending on the sensor quality (see Fig. 2) and determined the effect of transport errors for the inversion (Lüken-Winkels et al., 2026). This work is also submitted as deliverable D.-M.12.5 within the ITMS project.

Lüken-Winkels, C., Pilz, L., Vardag, S.N., Designing urban CO_2 sensor networks under realistic uncertainties and biases: Results from synthetic studies in Berlin and Munich, accepted in Elementa- Science of the Anthropocene, 2026
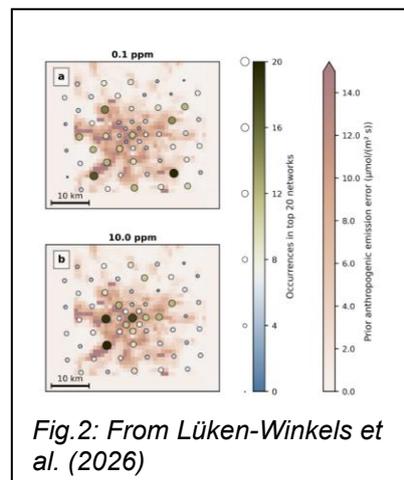

Fig.2: From Lüken-Winkels et al. (2026)

WP5: Deciphering Sub-Urban Emission Patterns Using GRAMM/GRAL

A large amount of the resources have been used to set-up the high-resolution GRAMM/GRAL model in Heidelberg/Mannheim (extended domain), as well as to run the model in Paris with refined emissions, and Toronto. For Paris, we have simulated two runs with biogenic emissions from VPRM and from two different anthropogenic emission inventories (TNO and origins.earth) and find a very good agreement between measurements and models (see Fig. 3). We are currently finalizing a paper, which will be submitted to JGR Atmosphere. The VPRM emission fields for Paris were shared with Betty Molinier and Natasha Kjun (Lund University), and the results have been submitted to ACS ES&T. In Heidelberg, the set-up still is very preliminary, as also the emission inventory still is work in progress and discrepancies between measurements and model still seem quite high. We are currently investigating where the discrepancies stem from. We expect to run additional simulations (see proposal) with new emission inventories, and adjusted parametrizations (vertical transport) to improve the estimates. We are currently preparing a Bayesian inversion of emissions over Paris (see proposal). We have decided to additionally set-up a model domain in Toronto, as there exist an extensive amount of local greenhouse gas measurements and we cooperate with Debra Wunsch and Dylan Walker (University of Toronto) to interpret this data. So far, inner-city gradients can be reproduced, but numerical instabilities still occur and need to be solved, which we are applying for in the upcoming proposal.
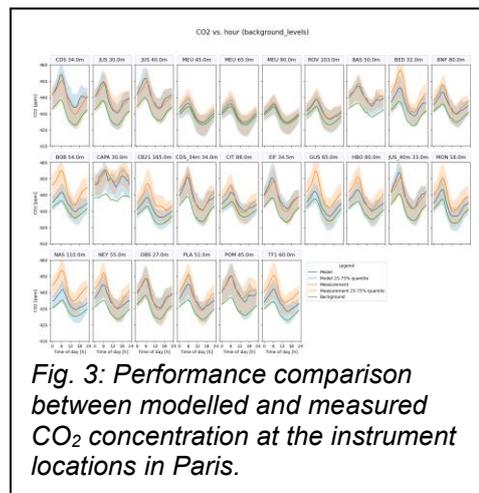

Fig. 3: Performance comparison between modelled and measured CO_2 concentration at the instrument locations in Paris.

Molinier, et al.," "Insights from the Convolution of Emission Inventories with Flux Footprints from Tall Eddy Covariance Towers at Three European Cities", submitted to ACS ES&T Air, 2025

Additional remarks:
1. The only partially used ressources in 1st and 2nd quarter are due to a parental leave time in WP2.
2. Within our project 5 Master students and 5 PhD students worked on Levante to conduct their work.
3. We have additionally analysed the sensitivity of Australias CO2 fluxes with respect to climatic drivers using computing resources provided by the DKRZ and leading to publication by Metz et al., (2025) acknowledging the DKRZ.

*Eva-Marie Metz, Sanam N. Vardag, Andrew F. Feldman, Benjamin Poulter, Thomas Colligan, Brenden J. Fischer-Femal, André Butz, Responses of Terrestrial Ecosystem Respiration to Soil Moisture Across Australia's Aridity Regimes, Environmental Research Letters, **DOI** 10.1088/1748-9326/ae0051,2025.*