Project report

Project: **1170**

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

Principal investigator: **André Butz**

Report period: **2024-07-01 to 2025-06-30**

WP1: FLEXPART-ERA5 Simulation: Apportioning and understanding total column CO_2 observations

We used FLEXPART-ERA5 to calculate the footprints for a ship campaign in Japan using a total column spectrometer. We were able to determine the source regions influencing the signal. However, the coarse resolution limited the quantitative assessment. We also estimated the carbon emissions from North America. We calculated footprints of GOSAT XCO2 data over North America to optimize biogenic emissions in a Bayesian inversion. We chose this set-up to be able to compare to a reference set-up by TM5-4DVAR. First results (year 2010) show that this set-up can constrain sub-continental CO2 emissions enabling us to estimate top-down emissions in-house using Flexpart-ERA5. We plan to conduct an evaluation of the set-up and of the optimized carbon fluxes over longer time periods in the next allocation period.

WP2: WRF-Chem simulations: Refining simulations of CO_2 and fossil fuel tracer concentration fields in urban hotspots 2

We were able to re-run the WRF-Chem simulations over urban metropolitan regions in Germany and improve some shortcomings which have been identified earlier. These shortcomings include 1.) the use of anthropogenic and biogenic emissions over a larger European area, 2.) the implementation of improved biogenic CO2 emissions based on VPRM (following Glauch et al., 2025), 3.) the inclusion of background CO2 from CAMS, 4.) the use of two different planetary boundary layer height schemes (MYJ and YSU).

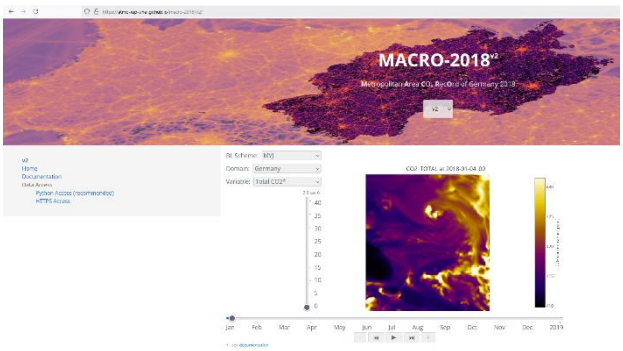

Fig.1: Screenshot of the website https://atmo-iup-uhei.github.io/macro-2018/v2/python.html *displaying the WRF simulation outputs on swift browser to enable easy data access for users.*

We have analysed the influence of these implementations. For example, we compared the CO_2 concentrations using the old and new biogenic emissions. Especially for urban areas the differences are large: The relative contribution of biogenic to fossil fuel emissions changes by about 20%, with large seasonal differences (between 0% and 100%). Therefore, these changes can have implications for urban monitoring, which we will now be able to account for within the ITMS project (see WP3). All data has been put on Swift browser to enable easy data usage within and beyond ITMS. DKRZ granted us a larger storage space on swift browser of 14 TB for this purpose. Further information the data set are given here: https://atmo-iup-uhei.github.io/macro-2018/v2/python.html (Fig.1).

WP3: FLEXPART-WRF Simulations: Inversion of fossil fuel CO2 in urban hotspots

We run FLEXPART-WRF to simulate footprints over urban areas to be used in the Bayesian inversion. In this project period, we were able to extend the inversion set-up in multiple ways by conducting the inversion

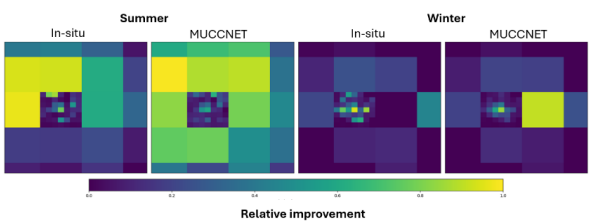

Fig.2: Relative improvement (also Verbesserung der Emissionschätzung durch Benutzung der Messungen) über München bei zwei verschiedenen Messkonfigurationen (in-situ vs. MUCCNET, also Gesamtsäulenmessung) für Sommer und Winter.

for longer time periods, multiple network configurations, different cities (Berlin and Munich, Fig. 2). These inversion results were also submitted as Deliverable ITMS-M.12.3 within the ITMS project. Also we have been able to reduce the computational time of the inversion significantly by xxx (following Yadav et Michalak, 2013). The new set-up enabled us to draw robust conclusion spanning a range of investigated monitoring strategies outlined in the first report on monitoring strategies submitted within ITMS (Deliverable ITMS-M.12.4).

WP4: Deciphering sub-urban emission patterns using GRAMM/GRAL

We have extended the GRAMM/GRAL setup to two additional regions, namely San Francisco and Paris, where actual measurement data within the city centers is available. First results show that GRAMM/GRAL is able to capture the urban transport dynamics although some meteorological periods (e.g. winter time inversions) show larger discrepancies between simulated and measured CO_2. The effect of using high-resolution emission inventories has been analysed. Within the ICOS Cities project, we have also compared the results with WRF simulations (Fig. 3) and are currently identifying limitations and advantages of both models.

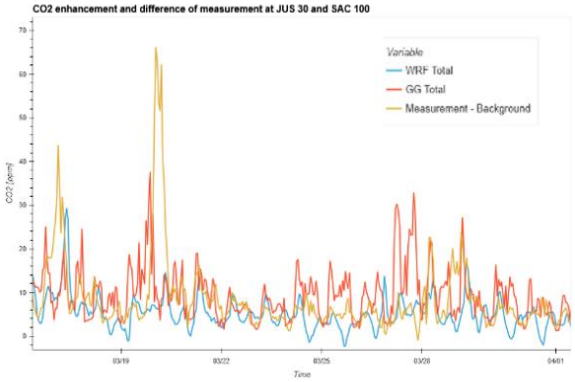

Fig.3: Example period in March 2023 of simulated (WRF in blue, GRAMM/GRAL in red) and measured CO_2 enhancement (orange) in Paris, France.

Additional remarks:

1. Note that within our project 4 Master students (Pernilla Kühn, Simon Cello, Sonja Gabriel, Vincent Enders) and 5 PhD students (Christopher Lüken-Winkels, Lukas Pilz, Robert Maiwald, Anna Sommani, Eva-Marie Metz) worked on Levante to conduct their work.

2. We have additionally used resources within this project for data analysis of satellite data over Southern Africa, which led to a publication of Metz et al., 2025 and South America, which led to a publication of Vardag et al., 2025 (accepted for publication in GRL) (both with acknowledgment of DKRZ ressources).

References:

Glauch, T., Marshall, J., Gerbig, C., Botía, S., Gałkowski, M., Vardag, S. N., and Butz, A.: pyVPRM: A next-generation Vegetation Photosynthesis and Respiration Model for the post-MODIS era, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3692, 2025.

Metz, E.-M., Vardag, S. N., Basu, S., Jung, M., and Butz, A.: Seasonal and interannual variability in CO_2 fluxes in southern Africa seen by GOSAT, Biogeosciences, 22, 555–584, https://doi.org/10.5194/bg-22-555-2025, 2025.

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Yadav, V., & Michalak, A. M. (2013). Improving computational efficiency in large linear inverse problems: an example from carbon dioxide flux estimation. Geoscientific Model Development, 6(3), 583-590.