Applying a high-resolution atmospheric inversion framework to CO_2 observations using GRAMM/GRAL

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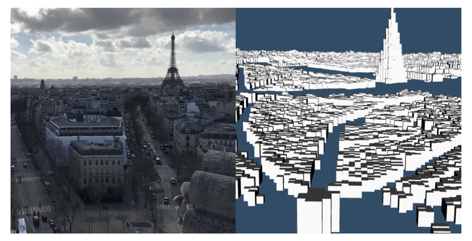
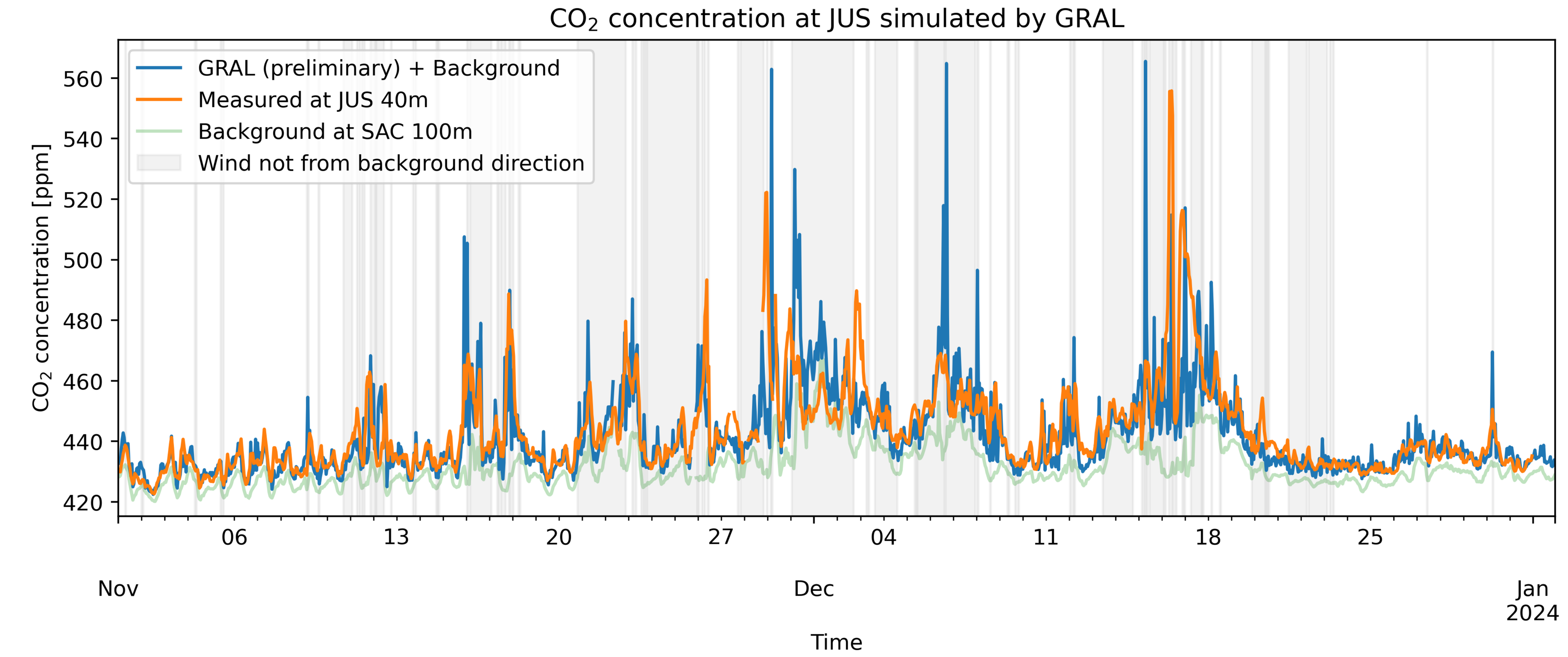
Why simulate urban CO_2 emissions with GRAMM/GRAL?

- Urban areas: Important role in climate change mitigation
- But: difficult to quantify emissions by sector

We use the model GRAMM/GRAL to simulate atmospheric transport of CO_2 to estimate emissions from atmospheric measurements. GRAMM/GRAL produces steady-state hourly meteorological wind fields which are used for a Lagrangian particle model in GRAL to create concentration fields. The hourly situations are stored in a catalogue. This catalogue can be used to create time series by selecting the appropriate entry for a given meteorological situation. With this approach, a horizontal resolution of 10m x 10m is possible even for yearly time series.



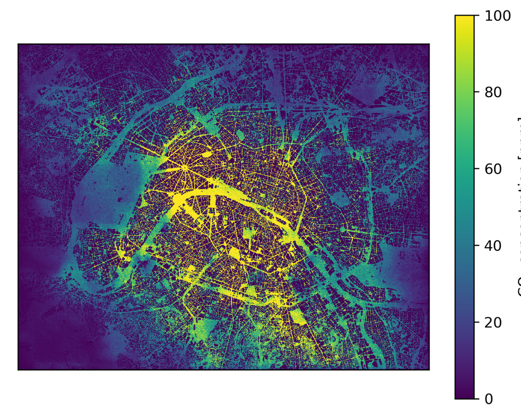
View of the Eiffel Tower in reality and model representation.



Simulated concentrations

- Catalogue of concentration maps per hourly meteorological situation
- Time evolution of emissions by grouping in sectors and applying sector specific scaling factors

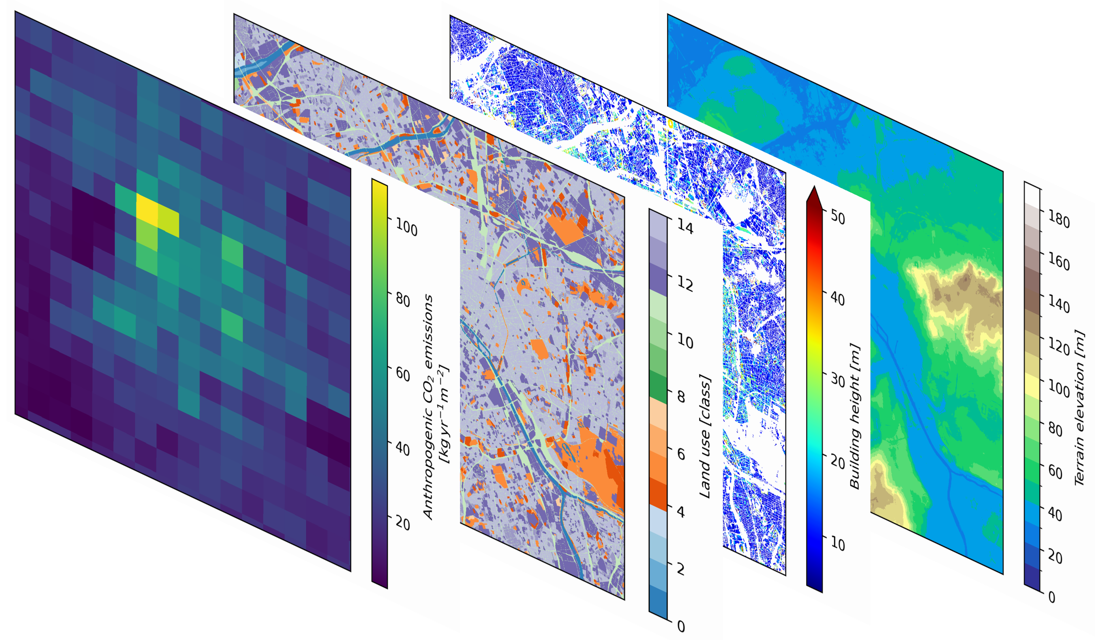
The catalogue can be used for atmospheric inversions because the hourly steady-state assumption allows to link concentrations with emissions at the same hour. Next to the high-resolution, the advantage of GRAMM/GRAL is the low computational cost once the catalogue has been computed.



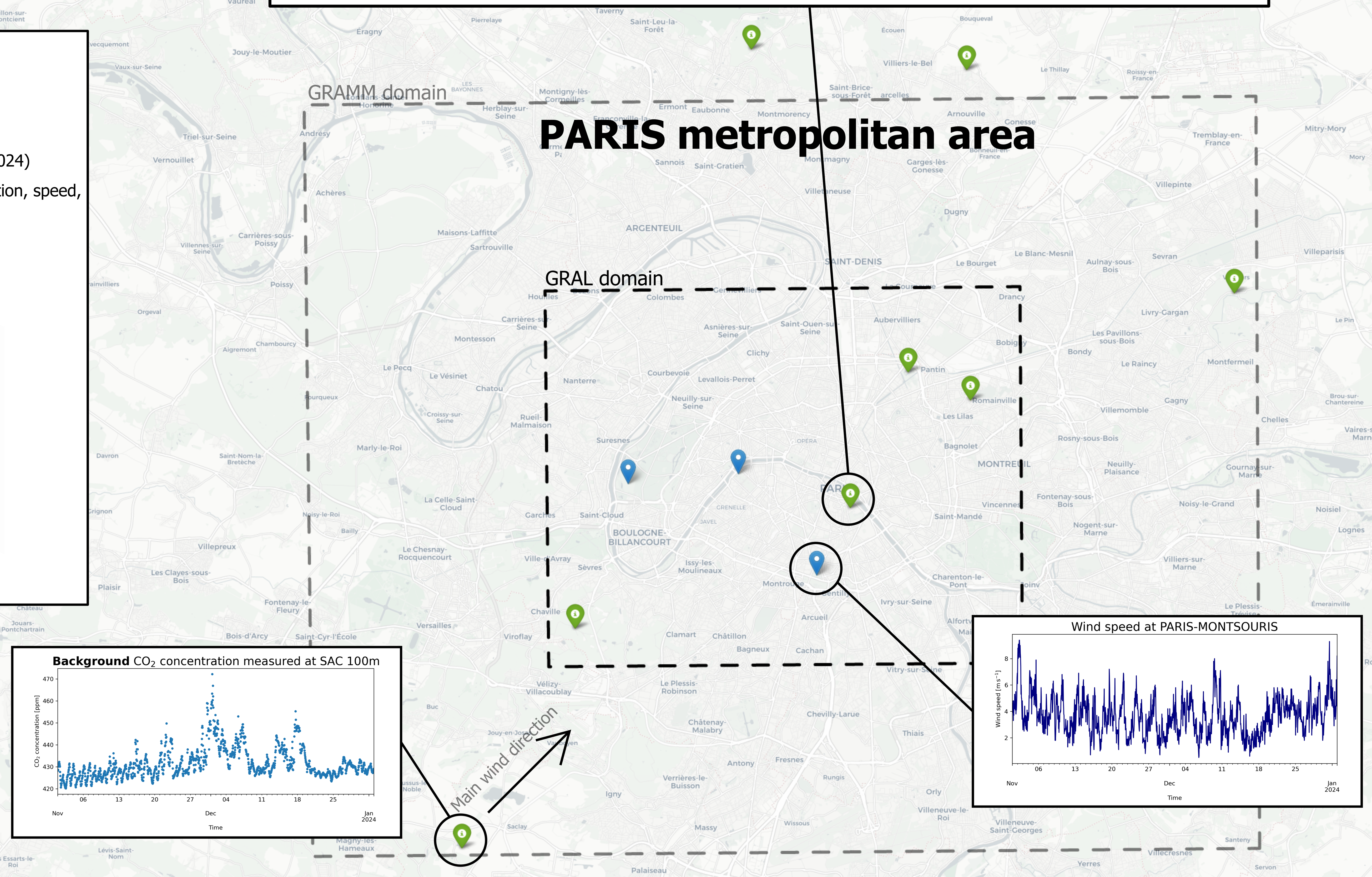
CO_2 concentration from GRAL 5m above ground for one hour.

Model input

- Maps: CO2 emissions (anthropogenic) from TNO (Super et al., 2020), land cover, buildings, and terrain
- Meteorological measurements for a match-to-observations algorithm (May et al., 2024)
- Catalogue of 1008 possible hourly meteorological conditions defined by wind direction, speed, and stability class



Emissions, land cover, buildings, and terrain elevation input for GRAL.

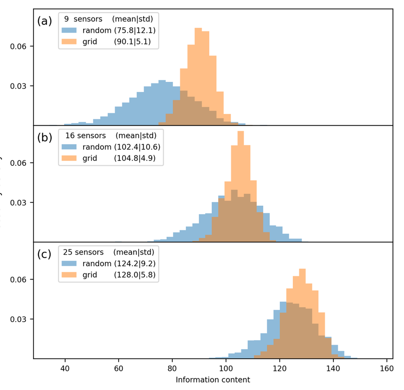


Outlook: Inversion framework

- Goal: Constrain CO2 emissions in Paris metropolitan area on high-resolution
- Inversion framework: Tested for Heidelberg (Vardag and Maiwald, 2024) as Observing System Simulation Experiment (OSSE) and will be transferred to Paris

Additional refinements:

- Include biogenic emissions
- Use more meteorological stations
- Increase the resolution of emissions to harness the high-resolution of GRAMM/GRAL
- Look at high- and mid-cost sensors
- Explore additional background options



Optimal network configurations from the framework applied in Heidelberg (Vardag and Maiwald, 2024)

References

May, Maximilian, Simone Wald, Ivo Suter, Dominik Brunner, and Sanam N. Vardag. 'Evaluation of the GRAMM/GRAL Model for High-Resolution Wind Fields in Heidelberg, Germany'. Atmospheric Research 300 (15 April 2024): 107207. https://doi.org/10.1016/j.atmosres.2023.107207.

Super, Ingrid, Stijn N.C. Dellaert, Antoon J.H. Visschedijk, and Hugo A.C.Denier Van Der Gon. 'Uncertainty Analysis of a European High-Resolution Emission Inventory of CO2 and CO to Support Inverse Modelling and Network Design'. Atmospheric Chemistry and Physics 20, no. 3 (2020): 1795–1816. https://doi.org/10.5194/

Vardag, S. N. and Maiwald, R.: Optimising urban measurement networks for CO2 flux estimation: a high-resolution observing system simulation experiment using GRAMM/GRAL, Geosci. Model Dev., 17, 1885–1902, https://doi.org/10.5194/gmd-17-1885-2024, 2024.

Laurent, O., Chariot, M., Lian, J., Utard, H., and Ramonet, M.: Paris Mid-cost CO2 sensor network., EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-19886, https://doi.org/10.5194/egusphere-egu24-19886, 2024.

Data sources

Emissions: TNO CO_2 fossil and biogenic fuel area emissions
Landuse: Urban Atlas Land Cover/Land Use 2018 (vector)
Buildings: Urban Atlas Building Height 2012 (raster 10 m)
Terrain: RGE ALTI® 1M, Institut national de l'information géographique et forestière
Meteorological data: Meteo France
CO_2 mole fractions: ICOS and ICOS Cities kindly provide measurements for this study.

This publication has been prepared using European Union's Copernicus Land Monitoring Service information; https://doi.org/10.2909/fb4dffa1-6ceb-4cc0-8372-1ed354c285e6, https://doi.org/10.2909/42690e05-edf4-43fc-8020-33e130f62023.

Acknowledgements

This work is funded by the Federal Ministry of Economic Affairs and Climate Action and ESA under contract S5L2PP.

This work used resources of the Deutsches Klimarechenzentrum (DKRZ) granted by its Scientific Steering Committee (WLA) under project ID 1170.

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

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