Milestone M12 (M3.1)

Validation of regional models' vertical profiles including diagnostics relevant to urban air

RI-URBANS

Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS (GA n. 101036245)

By

KNMI, TU-Delft, TNO, VU, INERIS, CNRS & FZJ

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Milestone M12 (M3.1): Validation of regional models' vertical profiles including diagnostics relevant to urban air

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Comments	This document summarizes of the main elements of the tools applied for Air Quality (AQ) models over urban aeras by showing a number of examples that were shown and discussed in various workshops and project meetings. It includes data of the pilot cities from RI-URBANS.

Table of Contents

1. About this document

This document summarizes of the main elements of the tools applied for Air Quality (AQ) models over urban areas by showing a number of examples that were shown and discussed in various workshops and project meetings. It includes data of the pilot cities from RI-URBANS.

This is a public document, available at the RI-URBANS website, https://riurbans.eu/work-package-3/#milestones-wp3 and distributed to all RI-URBANS partners for their use as well as submitted to European Commission as a RI-URBANS milestone M12 (M3.1).

2. Approach

In order to improve modelling and emission inventories for policy assessment, RI-URBANS strives to accomplish this using advanced observation-based methodologies.

Current models, such as the CAMS (Copernicus Atmospheric Monitoring Service) suite generally models on a global scale, and regional scales. Therefore, resolution may, or may not be sufficient to obtain realistic results in urban areas.

At the same time, high-resolution models are under development and under testing on urban scale and in urban areas.

The approach, relies on the connection of several elements of the RI-URBANS project.

- WP3 Improving modelling and emission inventories for policy assessment using advanced observation-based methodologies.
- WP1 Novel metrics and advanced source apportionment Service Tools for PM and nanoparticles, including vertical profiling observations.
- WP4 Pilot implementations for testing and demonstrating services.

Using these elements, model outputs of various suites of models will be tested against the observations from the pilot studies. In particular, the pilots T4.3. and T4.5 that have intensively perused vertical profiling information of atmospheric dynamics and pollution within the urban aeras.

Using these analyses, the validity of the CAMS model suite and the high-resolution models can be assessed.

3. Examples

3.1 A field experiment to measure the dispersion of methane (CH_4) in the urban environment

A field experiment to measure the dispersion of methane in the urban environment took place on June the 13th, 2023 at the Utrecht University Campus (see Figure 1). The release rate varied between 0.5 and 18 L min^{-1} per minute. One of the motivations to carry out this kind of controlled experiment, with a single emission source of a chemical species, is the fact that concentrations of commonly present species like NOx are generally due to multiple sources, like cars, trucks and buses, at random locations and with random emission rates.

Measurements were taken from a vehicle that drove a fixed route around the source of release (see Figure 2).

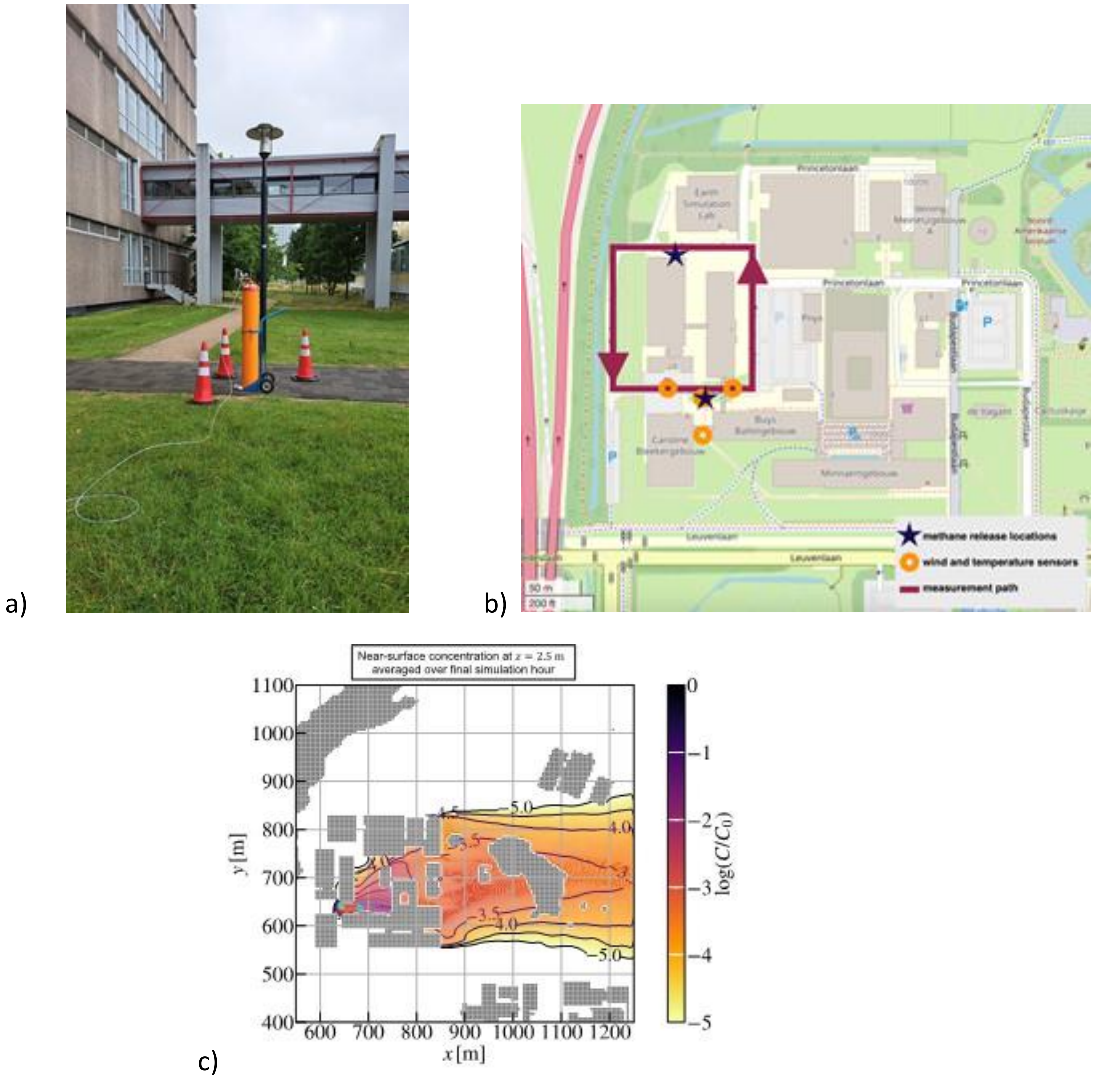

Figure 1. *a) Release source of methane (CH4). b) Map of the campus of the University of Utrecht. c) DALES simulation results.*

The Dutch Atmospheric Large-Eddy Simulation (DALES) model was applied by van der Linden and colleagues to perform numerical experiments on the dispersion of the methane plume. They used the Algemene Hoogte Kaart Nederland to incorporate buildings in the LES model domain. The large-scale forcing conditions were taken from ERA5. The LES results show a clear plume structure with a rapidly decaying concentration near the ground surface (at 2.5 m, see Figure 1c). Unfortunately, there were some issues with the measurements, such as a poor control over the methane flow rate, GPS position of the measurement car, we were not able to make a detailed comparison between the modelling experiments and simulation results (Zamuner, 2024, Simulating air pollutant dispersion in a Dutch neighbourhood using DALES, MSc thesis, TU Delft).

3.2 CO_2 Plume Dispersion Simulation at Hectometre Scale: DALES Formulation and Evaluation

This study was mainly performed by Doyennel of the Free University of Amsterdam as part of the Dutch national Ruisdael Observatory program, with contributions from Jansson of TUD. Doyennel et al. studied the CO_2 plume dispersion from simulations using DALES, with a focus on downscaling emission data, including both industrial emissions and area-based emissions from urban environments, to a hectometre-scale resolution. Exchange processes of CO_2 with the biosphere were also included. The results from DALES are compared with observational data and modelling results from the LOTOS-EUROS chemical transport model (CTM).

The study relies on emission data from the Annual National Emission Inventory, processed by RIVM (Netherlands Institute for Public Health and the Environment). The inventory data is categorized using the Standard Nomenclature for Air Pollution (SNAP) and made available at a kilometre-scale resolution. However, this resolution is too coarse for detailed simulations using DALES, necessitating a downscaling process to achieve the finer spatial resolution required for urban-scale simulations. To this end a downscaling workflow to prepare emission inventories suitable for high-resolution, urban-scale CO_2 simulations was developed. The CO_2 exchange with the biosphere is modelled in DALES using a land-surface model that includes the A-gs model (Ronda et al., 2001). This model simulates the net CO_2 flux from vegetation, incorporating soil respiration and photosynthesis processes in grass and forests, although the current model lacks full three-dimensional vegetation representation. See Figure 2.

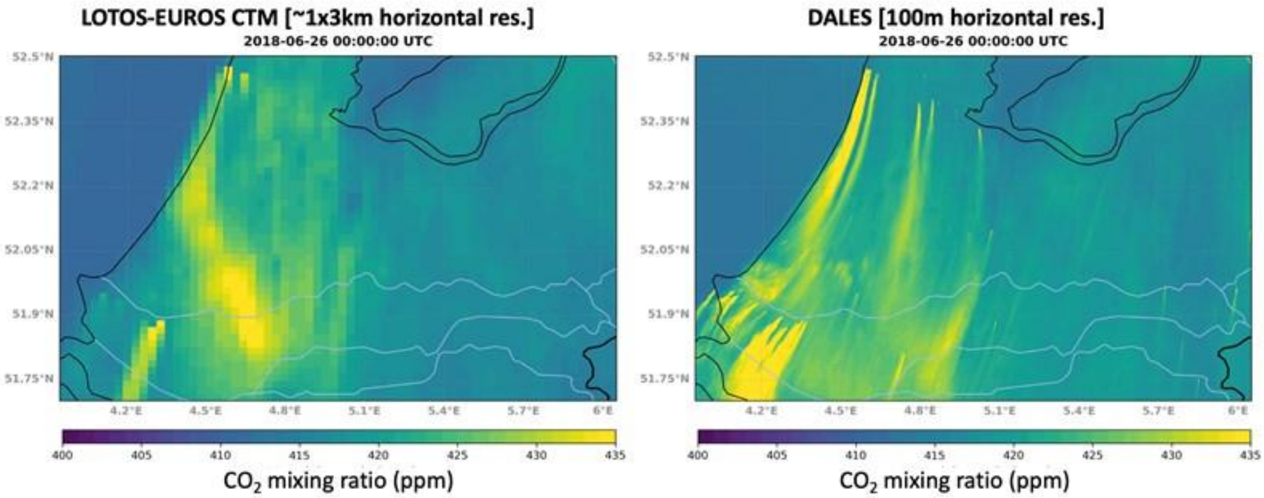

Figure 2. *This figure shows the CO_2 plumes from LOTOS-EUROS (left) and DALES (right).*

The model was evaluated using data from three measurement sites: ICOS Cabauw tower and the TNO measurements at Westmaas ((51.79°N, 4.45°E), an urban area) and Slufter (51.9461°N, 4.048°E), a coastal area on the North Sea shore). See Figure 3. The validation process compared the simulation results with in-situ observations and outputs from the LOTOS-EUROS CTM, which uses prescribed turbulence.

Key Outcomes

The study successfully developed a platform integrating the downscaling workflow and DALES model extensions. This platform can now calculate spatiotemporal CO_2 concentration variability at a fine resolution of 100 meters.

The major innovation lies in the calculation of upward CO_2 fluxes, with explicit representation of turbulent mixing and transport using LES.

Validation against observational data demonstrated significant improvements in the model's ability to capture CO_2 dispersion at fine scales. However, some limitations remain in fully incorporating turbulence into high-resolution CO_2 modelling, in particular during night-time conditions.

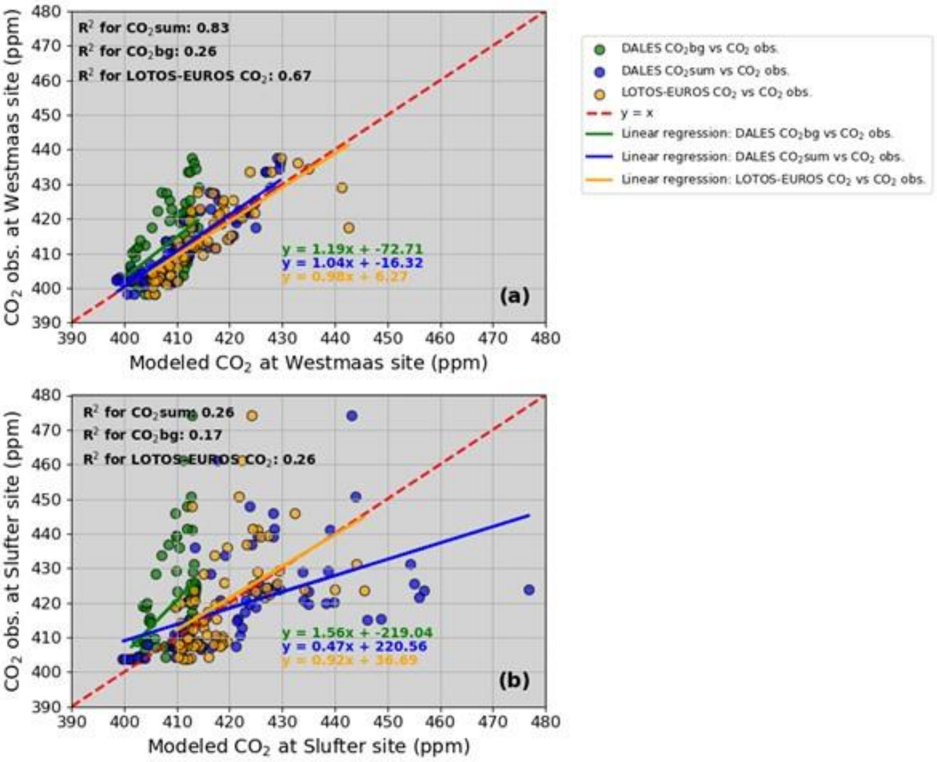

Figure 3. *This figure shows a comparison of the modelling results with observations for the locations Westmaas (upper pane) and Slufter (lower pane).*

This work represents an important advancement in the simulation of CO_2 emissions at urban and regional scales. The development of a high-resolution (100m) simulation platform provides valuable insights into CO_2 concentration variability, with the potential for improving emission inventory downscaling techniques and enhancing atmospheric modelling capabilities. Further refinement of the model, particularly in turbulence representation, will help to address the remaining limitations and improve its utility for urban air quality management and climate studies.

3.3 Vertical profile comparisons between models and observations

3.3.1 Aerosol extinction profiles

Advanced lidar observations from the ACTRIS aerosol remote sensing pillar, as well as the EUMETNET ceilometer network E-Profile/ALC (Automated Lidar Ceilometer) are routinely used to evaluate the performance of the CAMS suite of models for aerosol distribution and forecasting. The advanced lidars from ACTRIS provide aerosol extinction profiles enabling a quantitative comparison. The ceilometers can be used for the vertical distribution (profile shape). An example is shown in Figure 4.

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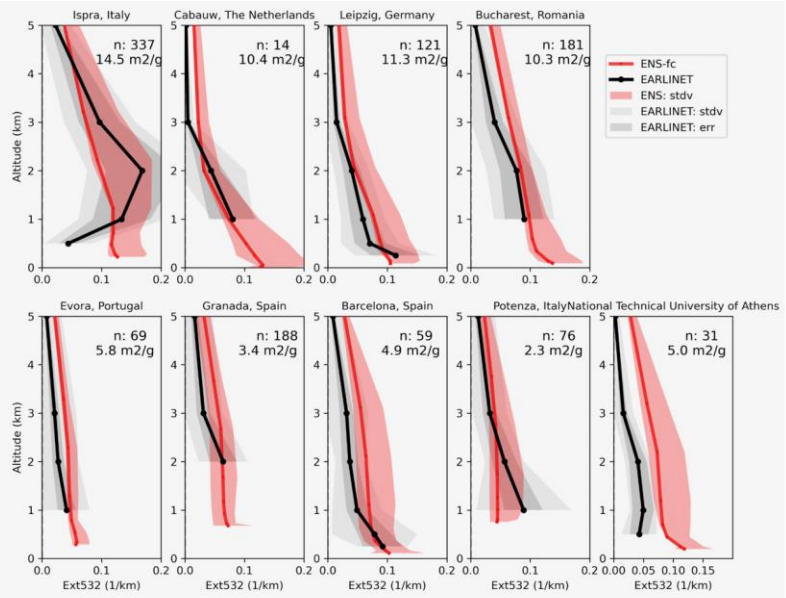

Figure 4. *Extinction profiles June - August 2021 derived from the ENSEMBLE forecast mass concentration profiles (red envelope) and from EARLINET (climatology) backscatter profiles (grey envelope: lidar ratio uncertainty, light grey: including sampling error). "n: XX means number of individual EARLINET profiles assembled (June-August 2006-2018). The EMC used for the calculation of the extinction from the concentration profiles is indicated for each station below the number of EARLINET profiles "n" used for the calculation of the climatology (Douros et al., 2021*

3.3.2 Trace gas profiles

Advanced observations from the IAGOS are used to evaluate the performance of the CAMS suite of models for trace gas distribution. An example is shown in Figure 5.

There is ongoing work in IAGOS to provide NO_2 profiles that will add to the suite of comparisons.

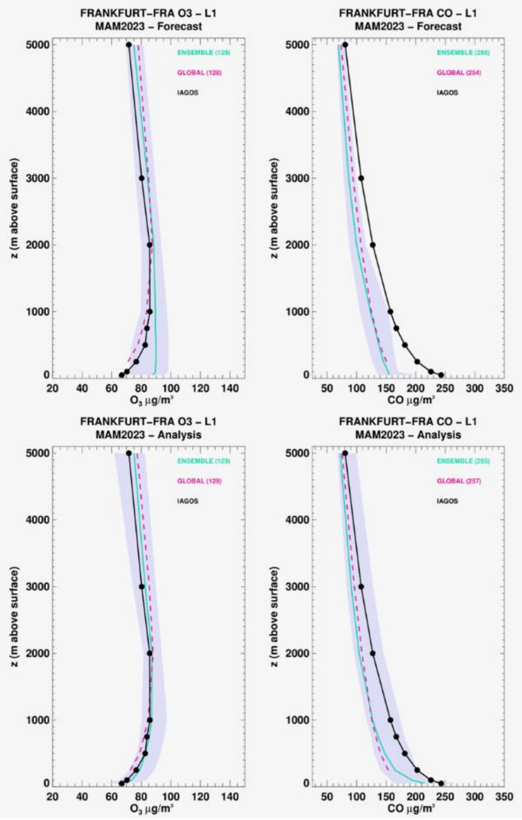

Figure 5. *Comparison between forecasts (top) and analyses (bottom) and measured atmospheric ozone (left) and CO (right) concentrations at Frankfurt, averaged for the MAM2023 period. The models are the ENSEMBLE and CAMS-global, while 'IAGOS' (black line) are measurements made by aircraft. The shaded area visualizes the spread among the CAMS regional models (min to max). The numbers in parentheses in the legends indicate the number of take offs/landings averaged to produce the profile.*

4. Conclusions

There is ongoing work to use advanced observations to improve models on a regional scale. Several examples are shown to indicate the current status for the stage of improvement of the models.

5. References

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