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Microscale Modelling of Air Pollution in Prague-Dejvice in 2018

Document provides insight into the pollution patterns in urbanized areas where traffic is the main pollution source, summarizes validation of concentration modelled by the LES model PALM and describes briefly modelling system used.

Project: SS02030031: Air quality Research, Assessment and Monitoring Integrated System

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Date: 3rd March 2022

Hlavním uživatelem výstupů tohoto projektu je Ministerstvo životního prostředí

Ministerstvo životního prostředí

Obsah

1. Introduction

A majority of the world's population live in large cities and the urban microclimate has a large impact on the well-being of its citizens. Problems of pollution and heat stress in urban areas are of direct concern to municipal authorities. Concerned citizens are very interested in details of any pollution they and their families are exposed to and are not afraid to ask questions of the authorities.

Microscale modelling of the urban environment, on a scale of a few meters, has the potential to evaluate the details of urban pollution in a form which can be easily understandable, though they require detailed emission inputs at local scale to be reliable.

A recently published study on the Dejvice quarter of Prague using the PALM microscale model system (Resler et al., 2021) has evaluated modelling results against a measurement campaign done in 2018 and shows the potential of this approach to air quality as well as urban climate evaluation. This report highlights outcomes of the study relevant for air quality, and shows the capability of the modelling approach to visualise detailed pollutant distribution.

Section 2 visualises results of the pollution modelling and how they compare to the observations. Section 3 gives more details of the observation campaign and the set-up of the PALM microscale model needed to produce these visualisations. Section 4 looks at the potential for future use of the PALM model in pollution monitoring. References and acknowledgments are provided in section 5.

2. Visualisation of the modelling results

The Resler et al. (2021) study focussed on the area of Prague, Dejvice shown in Fig. 1, and this is the area for which model results will be presented. This area is densely built-up and includes the Vítězné náměstí roundabout and the Evropská – Čs. armády and Jugoslávských partyzánů – Svatovítská boulevards. The area also has residential blocks with intra-block courtyards with gardens and trees. The location of monitoring vehicles whose data is used in this report are shown as green squares. The pollutants modelled were nitrous oxides (NO_X), particulate matter less than 10 micrometres in diameter (PM_{10}), and particulate matter less than 2.5 micrometres in diameter ($PM_{2.5}$). Modelling was done for two episodes in the summer of 2018, 14–16 July and 19–23 July, and three winter episodes: 24–26 November, 27–29 November, and 4–6 December.

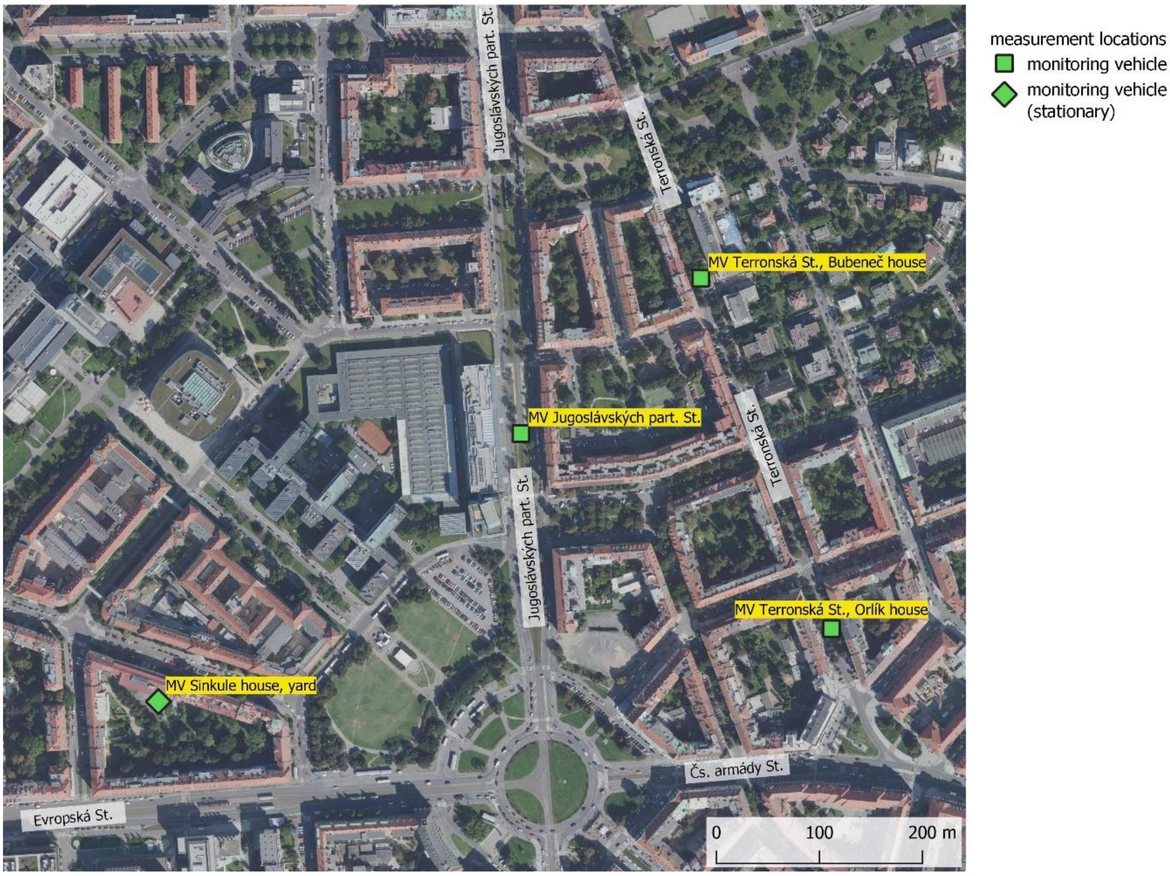

Fig. 1 Map of study area. The locations of measurement vehicles used in this report are marked by green squares. Orthophoto was provided by the Web Map Service (WMS) of the Czech Office for Surveying, Mapping and Cadastre (ČÚZK, 2022).

Fig. 2 visualises the surface modelled NO_X pollution for the area indicated in Fig. 1, as averages over both summer periods. Panel (A) shows a pollution map which clearly shows elevated pollution levels along the two major boulevards and the roundabout. Panel (C) shows a cross-section of surface pollution along an east-west line through the Orlík house monitoring location. Terronská Street has a strong east-west pollution gradient. The pollution peak at Jugoslávských partyzánů is obvious, and shows peaks on both sides of the boulevard. The low pollution levels for the intra-block courtyards are evident along with reduced pollution levels on minor streets. Panel (B) shows a north-south cross-section through the location of the monitoring vehicle in the Sinkule house courtyard. Again the most elevated pollution levels are seen at the major boulevard, here Evropská, and pollution on the northern side is significantly more than the south side. The low concentrations in the intra-block courtyards are again evident along with the slightly elevated levels in quieter streets. Range of concentrations between ca 10 and 60 (100) $\mu g \cdot m^{-3}$ suggests, that local traffic is dominant source of NO_X close to the main roads. It is necessary to stress that situation for NO_2, for which hourly limit value is set, may be very different.

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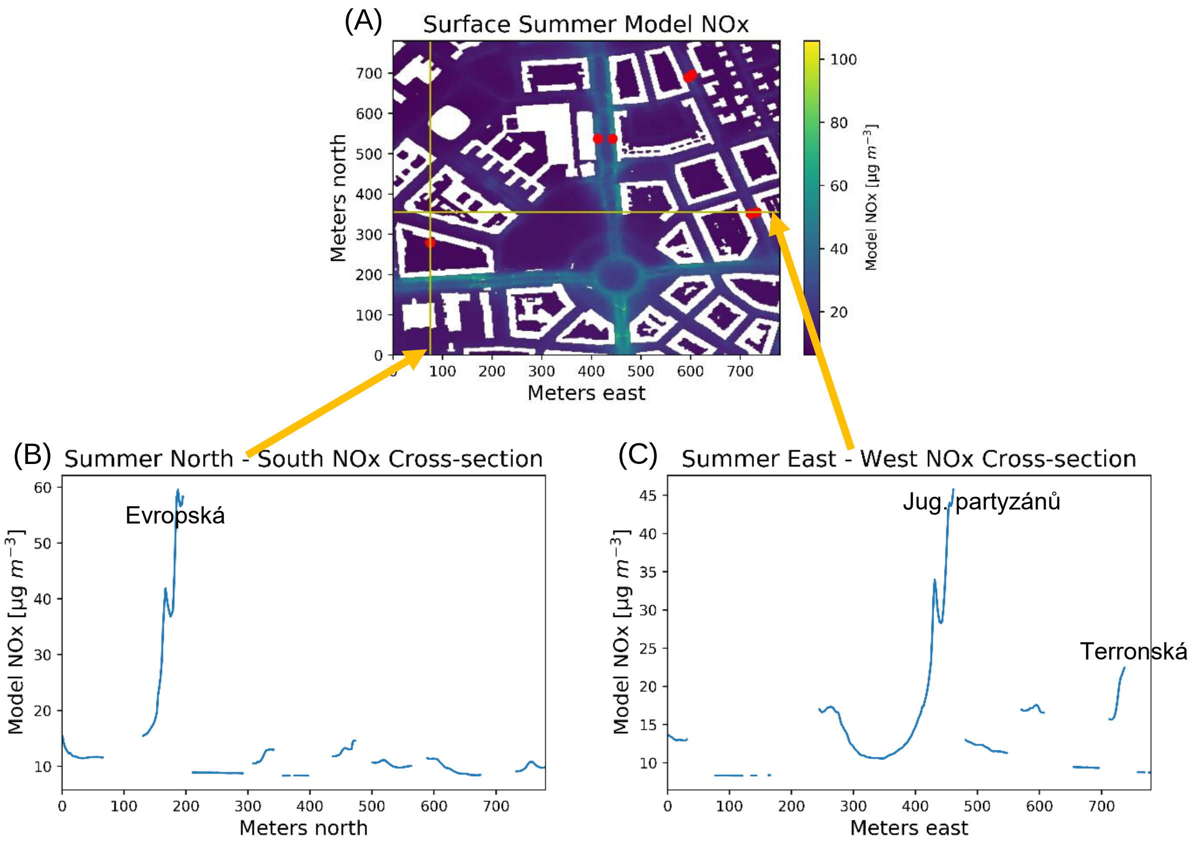

Fig. 2 Surface summer NO_X concentrations: (A) Area map; (B) North-South cross-section on the line in (A) indicated by the arrow; (C) East-West cross-section on the line in (A) indicated by the arrow. On cross-sections, major roads are labelled. Red circles show the locations where monitoring vehicles were stationed.

Fig. 3 is similar to Fig. 2, but for winter $PM_{2.5}$ averaged over the 3 modelled winter episodes. The main pollution patterns are similar to those seen in Fig. 2, with panel (A) showing the dominance of traffic as a pollution source. Again the busy boulevards and roundabout have significantly elevated levels. The east-west and north-south cross-sections in panels (B) and (C) do show some different details; in panel (B) the pollution on Jugoslávských partyzánů is less concentrated to the east and in panel (B), the pollution across Evropská is also more symmetrical, and in general pollution gradients across streets have different shapes. In panel (B), the intra-block courtyard just west of Terronská shows higher pollution than the courtyard near the western edge. Range of concentrations between ca 24 and 36 $\mu g \cdot m^{-3}$ suggests, that even in the vicinity of the main roads the local traffic is important, but not dominant source of $PM_{2.5}$.

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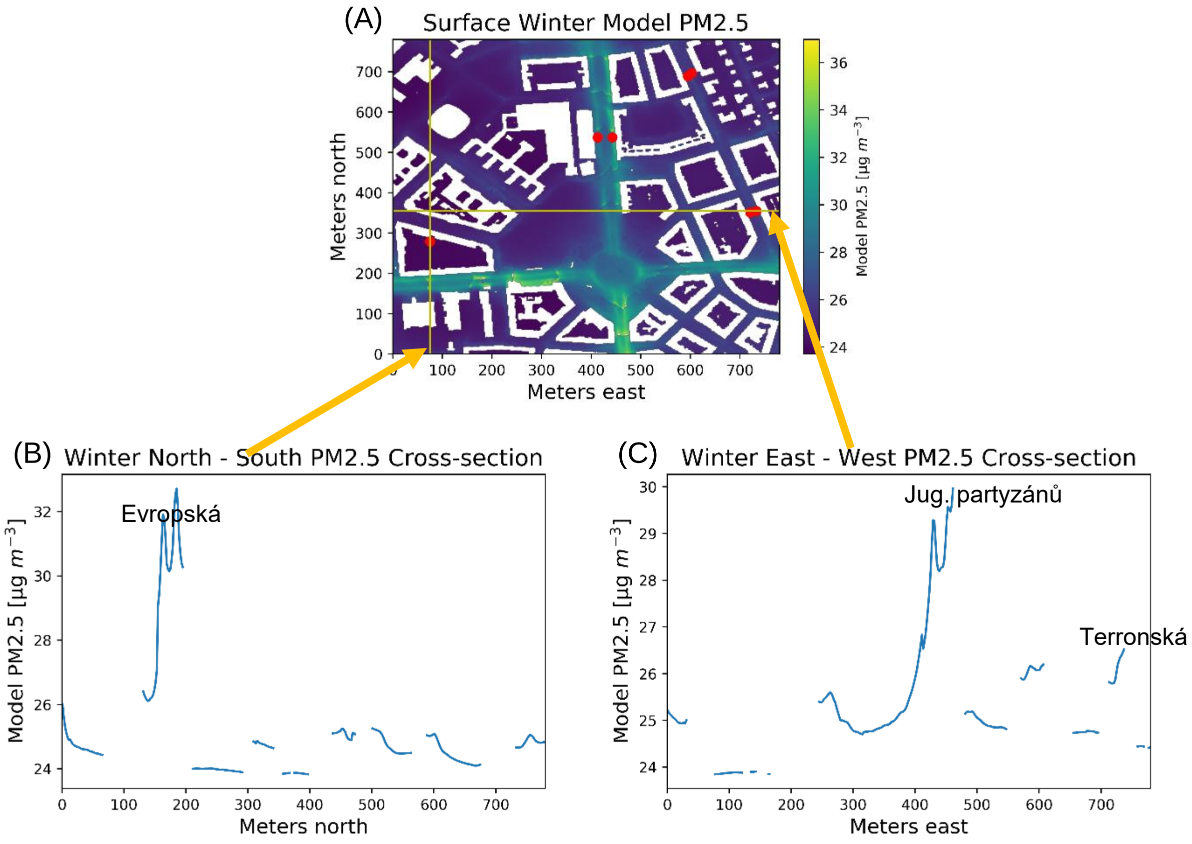

Fig. 3 Surface Winter $PM_{2.5}$ concentrations: (A) Area map; (B) North-South cross-section on the line in (A) indicated by the arrow; (C) East-West cross-section on the line in (A) indicated by the arrow. On cross-sections, major roads are labelled. Red circles show the locations where monitoring vehicles were stationed.

Fig. 4 illustrates average vertical pollution gradients of NO_X in the Jugoslávských partyzánů urban canyon for winter episode 3, The position is that of the monitoring vehicle shown in Fig. 1. The building outlines are shown in white. Part of the courtyard of the block on the eastern side is also shown. Though pollution in the urban canyon is strongest in the lowest 5 meters, elevated pollution going up the walls of the canyon can clearly be seen.

Fig. 5 is a comparison of modelled pollution against that measured by the monitoring vehicles using scatterplots. Overall, the modelled values fit reasonably well, but there are clear differences. Panel (A) shows a comparison for NO_X hourly averages on the east side of Jugoslávských partyzánů Street. Summer is shown as green open circles, and winter as blue crosses. The fit for summer is better than for winter, with the observations showing several elevated measurements not captured by the model. Panel (B) shows the comparison for hourly $PM_{2.5}$ at the east side of Terronská Street near Bubeneč house. Again summer values are green open circles and winter blue crosses. There is a clear increase in winter in both modelled and observed values. Panel (C) shows hourly NO_X values at the same location as panel (B), but split into periods of quiet traffic, defined as midnight to 5 am, and busy or "rush" traffic, defined as 6 am to 6 pm. Quiet values are black crosses, and rush values are yellow crosses. Rush values are generally elevated compared to quiet values in both the model and measurements. However, this distinction was not evident for Jugoslávských partyzánů Street (not shown).

The PALM model takes boundary pollution values from a larger-scale pollution chemical transport model CAMx, which had a resolution of 1km and couldn't represent small-scale street urban canyons. PALM's improvement over CAMx in street canyons is shown by comparison with the street canyon measurements. For NO_X, during the whole campaign the mean of all street canyon measurements was 42.3 $\mu g \cdot m^{-3}$; the mean PALM value for these locations was 36.0 $\mu g \cdot m^{-3}$, much closer to the measurements than the CAMx mean value of 10.4 $\mu g \cdot m^{-3}$. While not getting every detail right, overall compared to observations PALM provides a reasonable view of the microscale pollution.

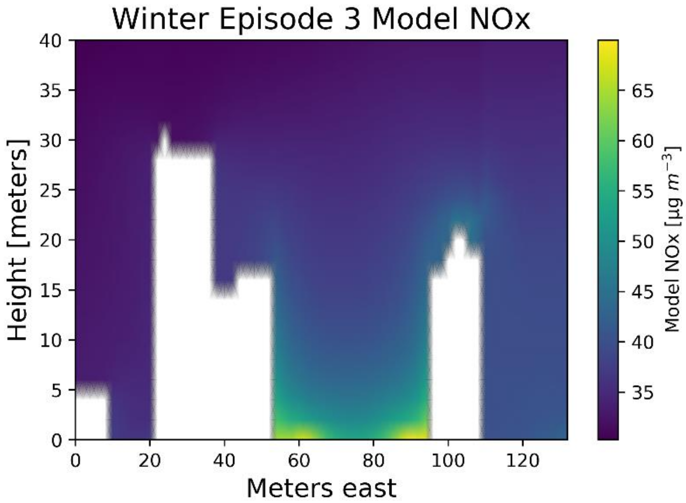

Fig. 4 Vertical Cross-Section of NO_X for Winter Episode 3 across the Jugoslávských partyzánů boulevard. The building outlines are in white. The position is that of the measurement vehicle marked by the green square in Fig. 1.

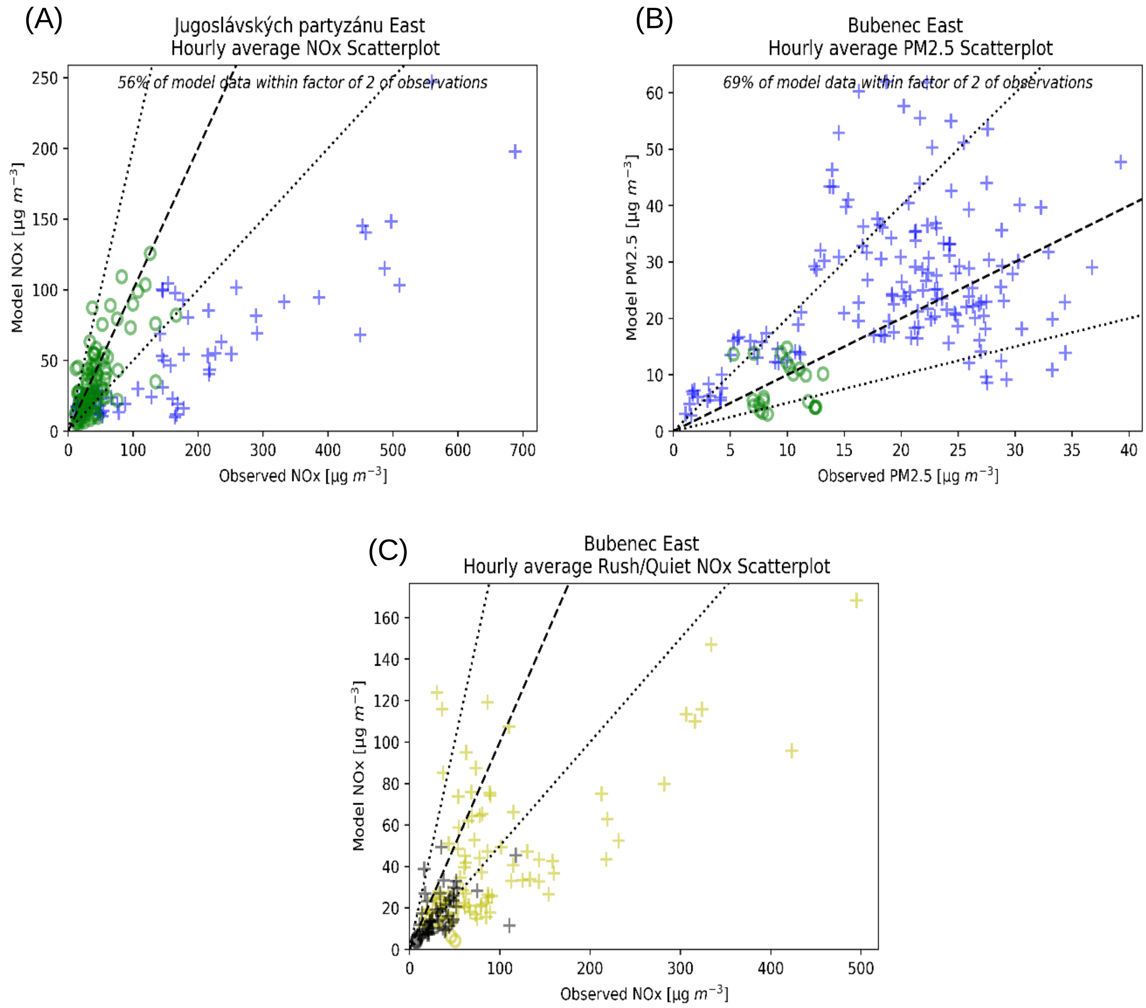

Fig. 5 Scatterplots comparing modelled pollution against measured pollution for all episodes. Measurement locations are marked by green squares in figure 1. The dashed lines indicate the 1 to 1 line. The dotted lines indicate the area where modelled concentrations are within a factor of 2 of measured observations: (A) Hourly averaged NO_X concentrations at the east side of Jugoslávských partyzánů; (B) Hourly averaged $PM_{2.5}$ concentrations at the east side of Terronská Street at Bubeneč house. In (A) and (B) green open circles indicate summer observations, blue crosses indicate winter observations; (C) Hourly averaged NOx concentrations at the east side of Terronská Street at Bubeneč house. Yellow crosses indicate "Rush-hour" or busy traffic between 6am and 6pm, black crosses indicate "Quiet" traffic hours between midnight and 5am.

3. Description of the measurement campaign and modelling system

These details are taken from Resler et al. (2021). The observation campaign which is part of that work covered part of the summer (10–23 July 2018) and winter (23 November–10 December 2018). The Dejvice area chosen for the study represents a typical Prague historical residential area, with a combination of old and new buildings and a variety of other urban components, such as gardens, parks, and parking places. The north-west quarter is home to the larger buildings belonging to ČVUT. Location-specific features include green intra-blocks with gardens and trees. The building heights bordering the streets range from approximately 20 to 30 m. Both boulevards are about 40 m wide. The majority of the trees are located in the intra-blocks.

From the summer campaign, two shorter episodes were selected for model simulations: 14–16 July (e1) and 19–23 July (e2). The weather was mainly influenced by high-pressure. Daily maximum temperature as measured at the Praha-Karlov station was below 30 °C except for 21 July when it reached 31.2 °C.

The three winter episodes selected for modelling were 24–26 November (e1), 27–29 November (e2), and 4–6 December (e3). Weather was a typical late-autumn type with westerly flow and low-pressure systems but with two high pressure events on 27–29 November and 5 December. Average daily temperatures ranged from −4 °C on 29 November to 9 °C on 3 December.

Air quality measurements in the street canyons were from two monitoring vehicles, which were shuttled periodically among the three locations marked using green squares in Fig. 1. One location was in Jugoslávských partyzánů Street. The other locations were in the 25 m wide Terronská Street, one next to Bubeneč house and the other next to Orlík house. Near Bubeneč house, there are full-grown broadleaf trees with crowns covering the whole street. Near Orlík house, trees are smaller and their crowns cover less of the street canyon. Buildings at all locations are approx. 25 m high. Each monitoring vehicle remained at a particular location for at least 2 whole days. There was also one stationary monitoring vehicle in the Sinkule house courtyard throughout the whole campaign to provide urban background meteorological values.

Among other quantities, the vehicles measured all nitrous oxides (NO_X), particulate matter less than 10 micrometers in diameter (PM_{10}) and particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$), and these were the quantities selected for the air quality modelling. Calibrations of all air quality analysers were done during transfer between locations to reduce loss of data. Both vehicles also had a video camera which were then used as part of the detailed time disaggregation of traffic emissions at the measurement location. The Sinkule house vehicle did not measure $PM_{2.5}$.

The microscale model used was the PALM model system version 6.0 with the land surface model and building surface model components. Processes involving trees and shrubs were managed by the embedded plant-canopy model. The model was used for modelling of passive transport/dispersion of NO_X and primary PM_{10} and $PM_{2.5}$. For the area covered in this report, the model grid spacing was 2 m both horizontally and vertically. Meteorological boundary conditions were taken from the WRF mesoscale model. The CAMx model (coupled to WRF) provided pollutant boundary conditions (PM boundary concentrations included secondary aerosols). Horizontal resolution of these two models was 1 km.

A detailed model such as PALM requires detailed pollution emissions to produce reliable pollution maps. In this case, air pollution sources are dominated by the local road traffic. Annual emissions totals were based on the traffic census 2016 conducted by the Technical Administration of Roads of the City of Prague – Department of Transportation Engineering (TSK-ÚDI). The emissions themselves were prepared by ATEM (Studio of ecological models; http://www.atem.cz) using the MEFA 13 road transport emission model. Jugoslávských partyzánů and Terronská streets, where air quality was measured during the campaigns, were both covered by this census. Emissions from streets not included in the census were available on a grid with a 500 m spatial resolution. These emissions were distributed between the streets not covered by the census. Particulate matter (PM) emissions included resuspension of dust from the road surface. Time disaggregation was calculated using a Prague transportation yearbook for 2018, public bus timetables, and our own census conducted over a short time period.

Other emissions came from stationary sources in the REZZO Czech national inventory. Residential heating was based on a 2017 inventory and rescaled to 2018 temperature conditions. Residential heating emissions were available on elemental dwelling units with average area 0.5 km^2 and were spatially distributed to building addresses, where local heating sources are registered, in proportion to the number of flats. Residential heating emissions were then allocated to days according to the standardized load profile of natural gas supply for the households.

4. Evaluation of potential and future development

The PALM pollution modelling can be used to visualise details of pollution that are very difficult to capture with measurements alone. The modelling for Prague-Dejvice demonstrates that the modelling is able to capture seasonal variations of pollution, as well as variation due to the changing traffic volumes throughout the day. Though not perfect, the general agreement with measurements at specific points gives confidence to the aspects of the detailed modelled pollution pattern away from the measurement sites. The Resler et al. (2021) study was retrospective, but gives confidence in using PALM to prospectively model the effects of any pollution mitigation measures. However it is important to recognize that such detailed modelling requires a correspondingly detailed emission database if local emissions are dominant, as was the case in this study. Microscale models such as PALM should not be seen as a stand-alone tool, but as a vital element, along with local emissions, background meteorology and pollution values and validating observations, in a system capable of visualising details of pollution in an urban environment.

Further development of microscale modelling tools and their application continues in the TURBAN project (TA ČR grant no. TO01000219, https://project-turban.eu/) and ARAMIS project (TA ČR grant no. SS02030031, http://www.projekt-aramis.cz)

5. References and acknowledgements

The source for this report is the paper “Validation of the PALM model system 6.0 in a real urban environment: a case study in Dejvice, Prague, the Czech Republic” by Resler, J., Eben, K., Geletič, J., Krč, P., Rosecký, M., Sühring, M., Belda, M., Fuka, V., Halenka, T., Huszár, P., Karlický, J., Benešová, N., Ďoubalová, J., Honzáková, K., Keder, J., Nápravníková, Š., and Vlček, O, published in the Journal Geoscientific Model Development, Volume 14, pages 4797–4842, https://doi.org/10.5194/gmd-14-4797-2021, along with the observation and modelling dataset assembled by the authors. This is the paper referred to in the report as Resler er al. (2021).

Financial support for the Resler et al. (2021) was provided by the

- URBI PRAGENSI project (financed by the Operational Program Prague – Growth Pole of the Czech Republic, grant no. CZ.07.1.02/0.0/0.0/16_040/0000383, http://www.urbipragensi.cz),
- the Federal German Ministry of Education and Research (grant no. 01LP1601A), and
- TURBAN project (financed by the EEA and Norway Grants, TA ČR grant no. TO01000219, https://project-turban.eu).

This summary was prepared within the ARAMIS project (financed by the TA ČR grant no. SS02030031, http://www.projekt-aramis.cz).