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INTEGRATED URBAN AIR POLLUTION DISPERSION MODELLING FRAMEWORK AND APPLICATION IN AIR QUALITY PREDICTION OF THE CITY OF GYŐR

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Abstract: Model accuracy versus model running time - urban air pollution dispersion modellers have to balance between them when selecting models to be implemented. CFD based models seem to be the best candidates for an accurate model that can be validated at urban scale at highest level on the price of a longer running time. In this paper we shall introduce 3DAirQC software framework which addresses a portable and validated CFD model for air quality prediction and control.

Key words: *Urban scale modelling, air pollution, CFD, integrated monitoring and modelling*

INTRODUCTION

Urban citizens are exposed to air pollution at an increased level which causes many premature deaths, see (WHO, 2014). One of the main producer of pollutants in cities is the traffic, which is responsible for emitting more than 40% of relevant contaminants. In order to support policy makers in their job for reducing the risk of health issues computational models have been used for running scenarios for some decades. An overall vision of many stakeholders is the traffic control subject to air quality indicators. The aforementioned computational models can serve as main components in a system integrated with other more traditional tools based on historical and monitoring data and other modelling tools. Although the scientific community has invested significant efforts to develop proper computational models, accurate, fast and easy-to-use models seem to be lacking. The ultimate goal of the research groups of this paper is to fulfil these conditions with developing a portable, modular software framework for urban air quality control called 3DAirQC which is composed of state-of-the-art results and tools of mathematics, scientific computing (including HPC – High Performance Computing) and ICT (in particular cloud computing for providing 3DAirQC as service) as modules of this framework.

In this paper we present the actual state of the software framework, the 3DAirQC, with a demonstration of its application to the city of Győr, Hungary, which is a city of 130.000 inhabitants with strong cross traffic as main emission source. We show validation results as well.

THE 3DAIRQC FRAMEWORK AND ITS MODULES

For the modelling of the dispersion of urban traffic emitted pollutants in particular gases such as NOx or O3, the Simulation and Optimization Research Group and the Research Centre of Vehicle Industry of the Széchenyi István University, Győr, have developed a software framework, the 3DAirQC. The main goal of this framework is to model air quality indicators of cities capturing real 3D spatial geometry of the towns to be able to compute expositions accurately. Note that for a reliable air quality exposition computation we need high spatial resolution (cell sizes of some metres only) since there is a statistically significant difference of the measured AQ indicators between different points of the street, see e.g. Rácz and Horváth, 2014).

The framework is composed of modules, namely traffic, emission, meteorology, dispersion and the core module, which is either for evaluating assessments or performing optimization or control. An overview of the 3DAirQC workflow can be seen on Figure 1. Note that in this paper we shall confine ourselves to air quality prediction workflow, which is validated and leave the air quality control to a future work when it will be demonstrated and validated.

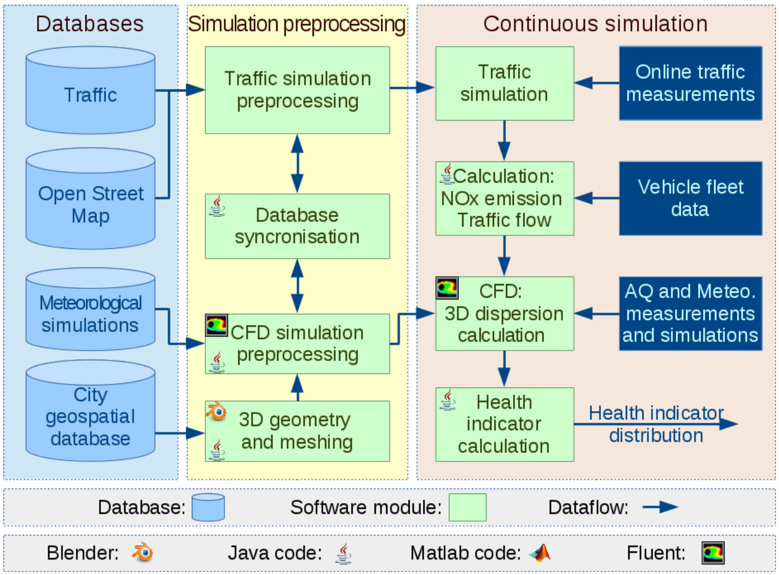

Figure 1. An overview of the 3DAirQC workflow for running scenarios for health indicators depending on traffic, fleet and meteorology data or traffic and meteorology measurements and simulations.

Preprocessing of the data

The preprocessing steps of the simulation modules are based on a toolkit of in-house Java scripts, Blender (see https://www.blender.org/) tools for 3D modelling, in-house 3D meshing tools and some commercial tools of ANSYS. All of these steps need normally special and time consuming work, which is done mainly automatically using our tools. For illustration of the tools with geometry preprocessing and meshing see Figure 2 and Figure 3, respectively.

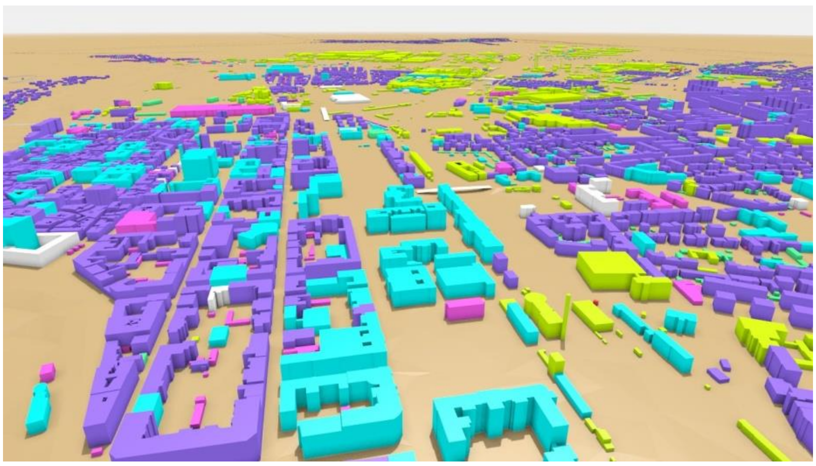

Figure 2. CAD geometry of the town resulted from city geoinformatic data base using Blender scripts

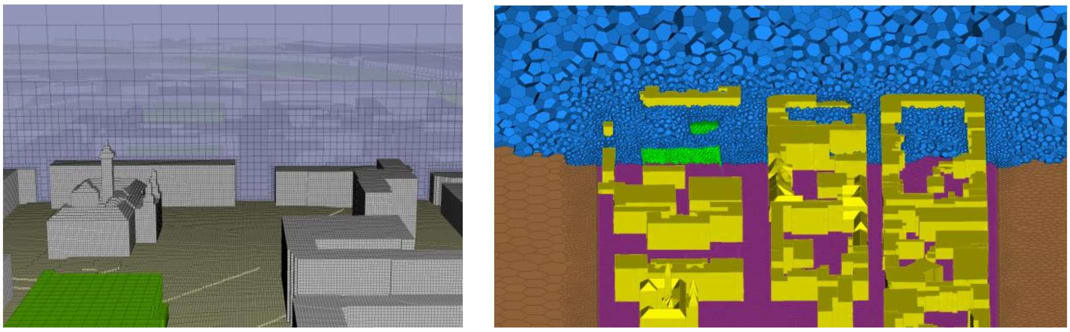

Figure 3. An overview of the meshes used in 3DAirQC: octree mesh generated by in-house multi thread Java code (left) and polyhedral mesh resulted from using ANSYS Fluent (right).

The traffic module

For modelling the urban traffic we have been using macroscopic and microscopic models. These are based on historical traffic count data of a big campaigne and monitoring data arising from operational data collected by city and national road authorities. The macroscopic model can be understood as the interpolated result of the operational measured loop data. Since loop data are not available for all road segments, the measurement values are used for calibrating historical data at these segments. In 3DAirQC we have an option to choose PTV VISSIM for microscopic simulation of the traffic as well.

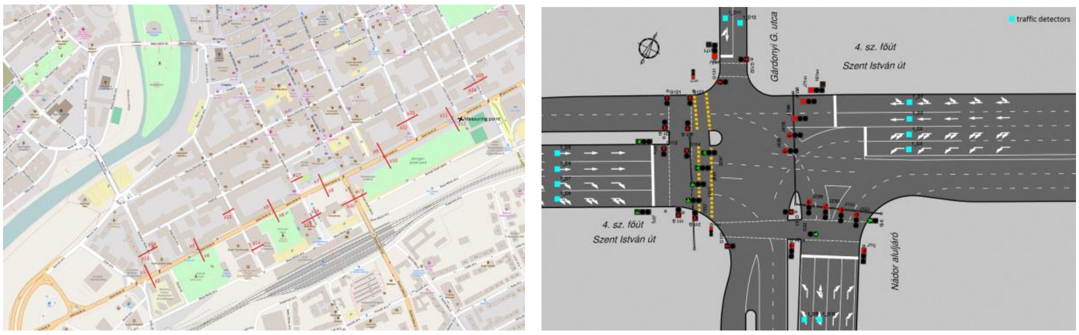

Figure 4. An overview of traffic sensor network of the city (on the courtesy of Hungarian National Roads Nonprofit Ltd. -Magyar Közút Nonprofit Zrt.

The emission module

For modelling the emission of the vehicles in the traffic we use one of the European standard emission model, the COPERT model. Fleet data are adjusted to regional vehicle data. Moreover, in rush hours when in the driving cycles the stop-and-go mode dominates, we used a factor of 1.8 according to the research results in (Fontaras et al., 2014). (Note that in the paper loc. cit. a smaller factor was proposed but that paper tested Euro 5 vehicles and in our case in the bus category Euro 1 and pre-Euro buses are significant.) In a free flow regime, i.e. before and after rush hours, we used the standard COPERT model.

The meteorology module

For boundary conditions of the dispersion module we used meteorology data from the national official operational data of the Hungarian Meteorology Service (HMS). HMS has been applying the AROME (Application of Research to Operations at Mesoscale) non-hydrostatic numerical weather prediction (NWP) model (Seity et al., 2011) since 2010, see (Szintai et al., 2015) and Figure 5. For the 3DAirQC we interpolated the AROME results at several height to the boundary of the AQ computational domain.

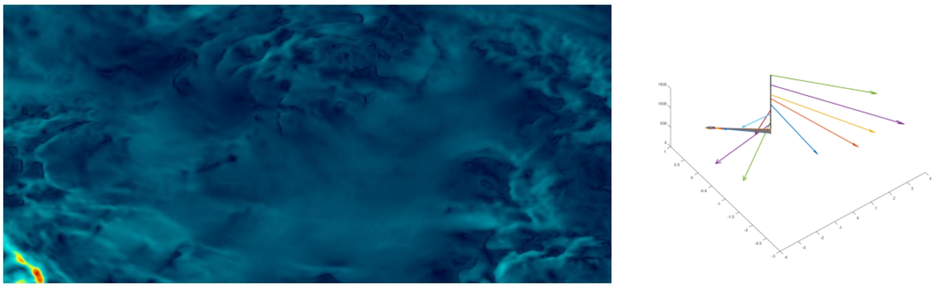

Figure 5. AROME simulation data for the Carpathian basin (left) and extracted velocities at several altitudes (right).

The dispersion module

Dispersion simulation has been done in 3DAirQC with either the commercial state-of-the-art CFD solver ANSYS Fluent or the open source OpenFOAM. There are two options of running these CFD solvers. The first one is the frozen flow field mode where the wind field is precomputed with RANS k-epsilon model and then dispersion of the pollutants with simple advection-diffusion (note that at present only NOx dispersion is computed without reactions). In the second option we compute the wind field and dispersion of the pollutants simultaneously.

The computational time of the full dispersion simulation on a modern laptop with 8 CPU cores takes 4 hours when predicting 4 hours in advance. On clusters, this time is reducible significantly. Note that with the frozen flow field option the advection-diffusion parts, which are repeated many times in optimal control mode of the 3DAirQC takes much shorter, namely just couple of minutes.

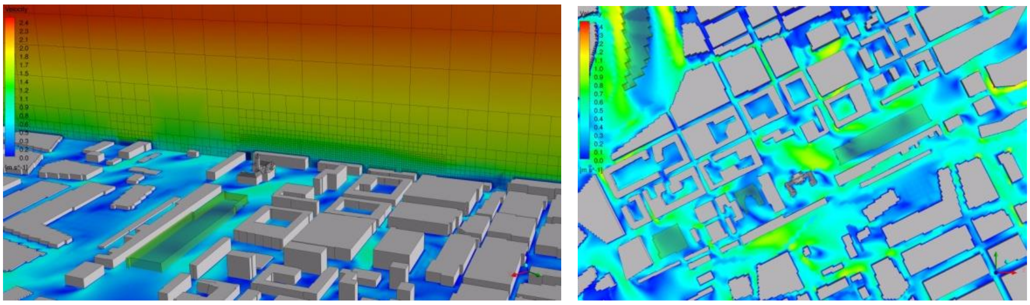

Figure 6. Simulation results: wind velocity magnitude.

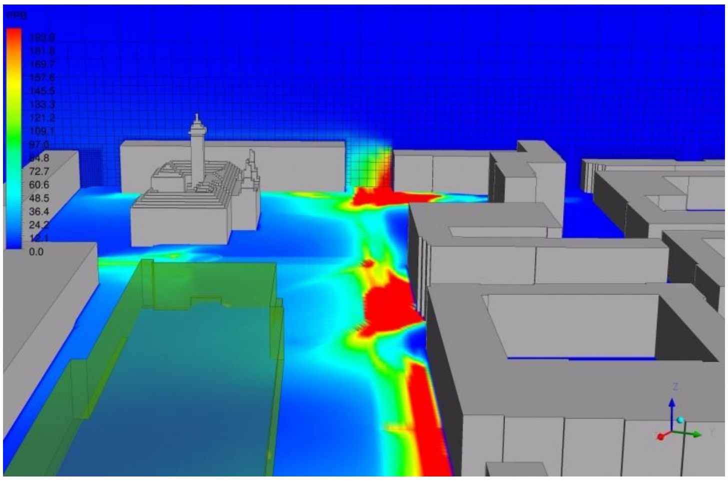

Figure 7. NOx concentrations at 1.5m height according to the simulation results.

VALIDATION OF 3DAIRQC FOR PREDICTION

We applied 3DAirQC to Győr for the time period covering the first rush hours of the day of March 9, 2016. The comparison of measured and simulated data can be seen on Figure 8. The validation of our model is based on high quality measurement data originated from the automata stations of the Hungarian Air Quality Network (HAQN), which is providing official air quality indicators towards the public and EEA. Namely, the validation point is the HAQN station near the junction on Figure 4 (right) and urban background data were taken from the measurement data of the official HAQN point for Győr at Sarród. Comparison of measured and computed data show that 3DAirQC is capable to provide very accurate results before the peak hours and captures pretty well the first maximum near 8am. Concerning the second peak, which seems to be the result of the direction changing of the weak wind (during the validation period the typical wind magnitude was below $1 ms^{-1}$ and changed direction exactly around 8:10 starting to blow temporary from the polluted region of the street, which could not be captured by CFD on the applied mesh).

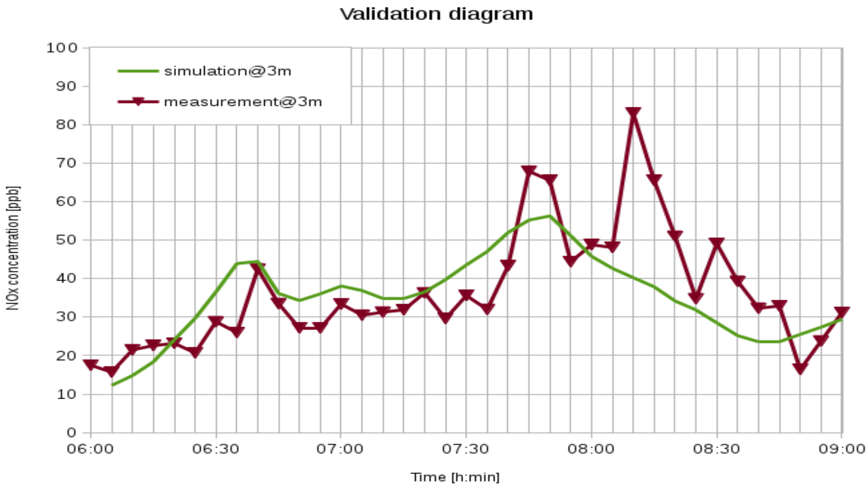

Figure 8. Computed and measured NOx data at “Győr1” official national air quality measurement container.

CONCLUSIONS

In this paper we presented the main components and a use case for validation of the 3DAirQC monitoring based model for urban air pollution prediction. More details and steps in the direction of a service, in particular significant improvements of the components are given in the lecture of the conference.

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