Local scale CFD modeling of aerosol transport over complex urban areas using code_saturne

Atmospheric Physics Seminar

Warsaw, 25 October 2024

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GRASP Earth

Content

- What is Urban scale simulations of aerosol
- Automatic Mesh Generation
- Simulation of wind velocity dynamics
- Simulation of aerosol dynamics
- Satellite and ground stations to retrieve road emissions

Urban scale models of aerosol transport

Complex multi physical problem:
turbulence, advection, diffusion, radiative transfer and heat exchange, chemical reactions
Multiscale: from mm to km

complexity

- Gaussian plume models (AERMOD, ADMS)
- Street-in-greed models (MUNICH)
- CFD models (OpenFoam, PALM, code_saturne)

Urban scale CFD simulations

- Resolve **velocity** and **temperature** fields in the calculation domain with high resolution (up to **1 meter**).
- Take into account the all **complexity of buildings'** geometry.
- Take into account complex processes like **turbulence**.
- Account for **different types of surfaces** (e.g., water, roads, vegetation).
- Optionally include the effects of **trees and bushes**.

- **Fragmental knowledge** about the geometry of the urban areas;
- **High requirements** to the quality of the geometry for mesh generation;
- Computational **cost**;
- Importance of the **proper** initial and boundary **conditions**;

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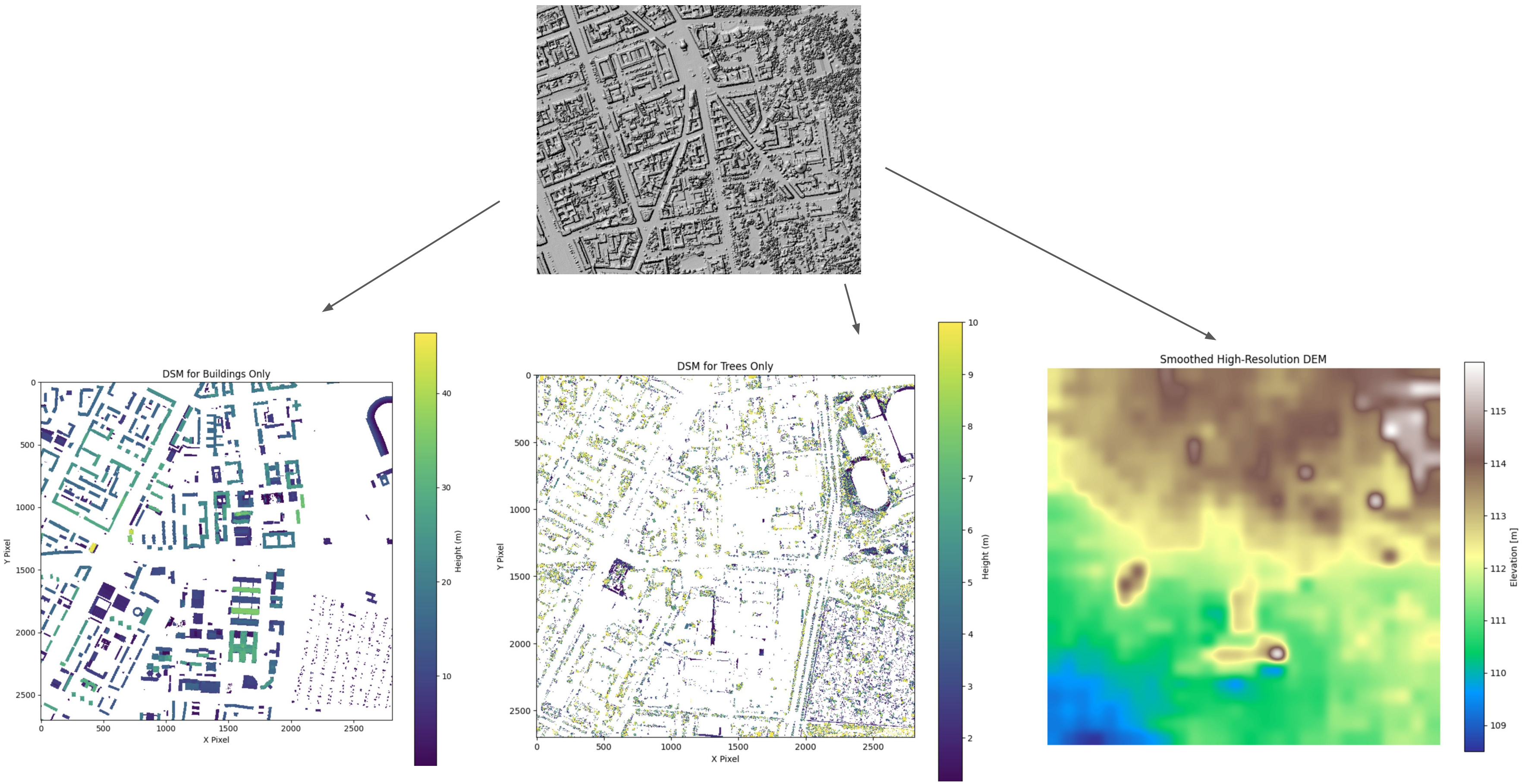
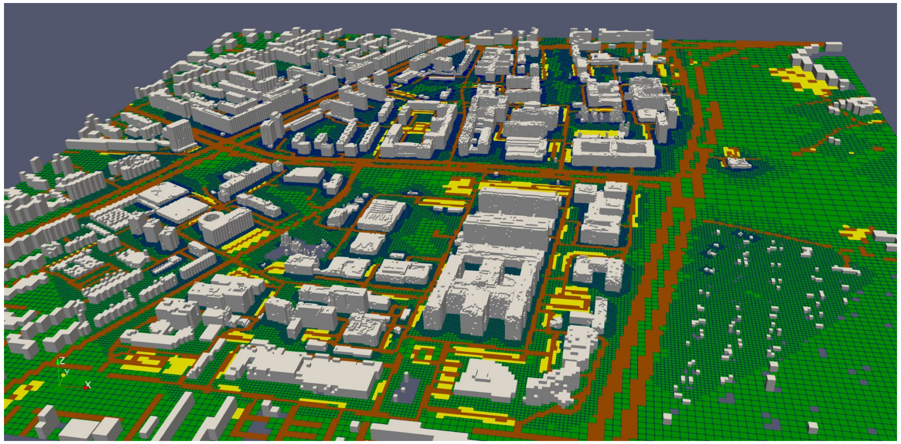
Prepare geo data about domain

- By QGIS prepare data of **LIDAR measurements of heights** and OpenStreetMaps with high resolution **50 cm**;
- Apply **Unsupervised Classification** to separate trees, buildings, roads, water, and open areas;



Automatic Mesh Generation

- Prepare cartesian grid of the **terrain** with resolution **32 meters**.
- **Refine only important zones** buildings, monitoring stations etc.
- **Remove cells** corresponding to buildings
- Add **boundary zones** (water, roads, buildings)



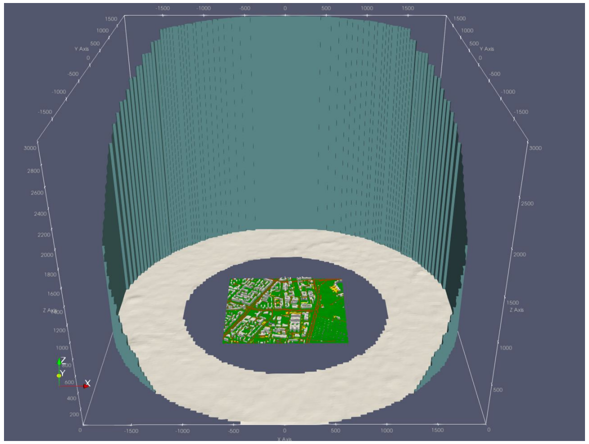


Fig.: Example of mesh generated for area 1x1km in Warsaw

Automatic Mesh Generation

Fig.: Example of mesh generated for area 2x2km in the center of Paris

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Boundary and Initial Conditions

$$u(z) = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) - \psi_m\left(\frac{z-d}{L}\right)\right],$$
$$T(z) = T_0 + \frac{\theta_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) - \psi_h\left(\frac{z-d}{L}\right)\right];$$

1. u^* Friction velocity;
2. T_0 Ground temperature;
3. L Monin-Obukhov length;
4. α wind direction;
5. ψ_m, ψ_h stability functions;
6. TKE and ϵ defined from theoretical assumptions.

And parameters defined from the topography:

1. $d = 11.6$ m, Displacement height;
2. $z_0 = 0.6$ m, roughness length;

Wind velocity dynamics

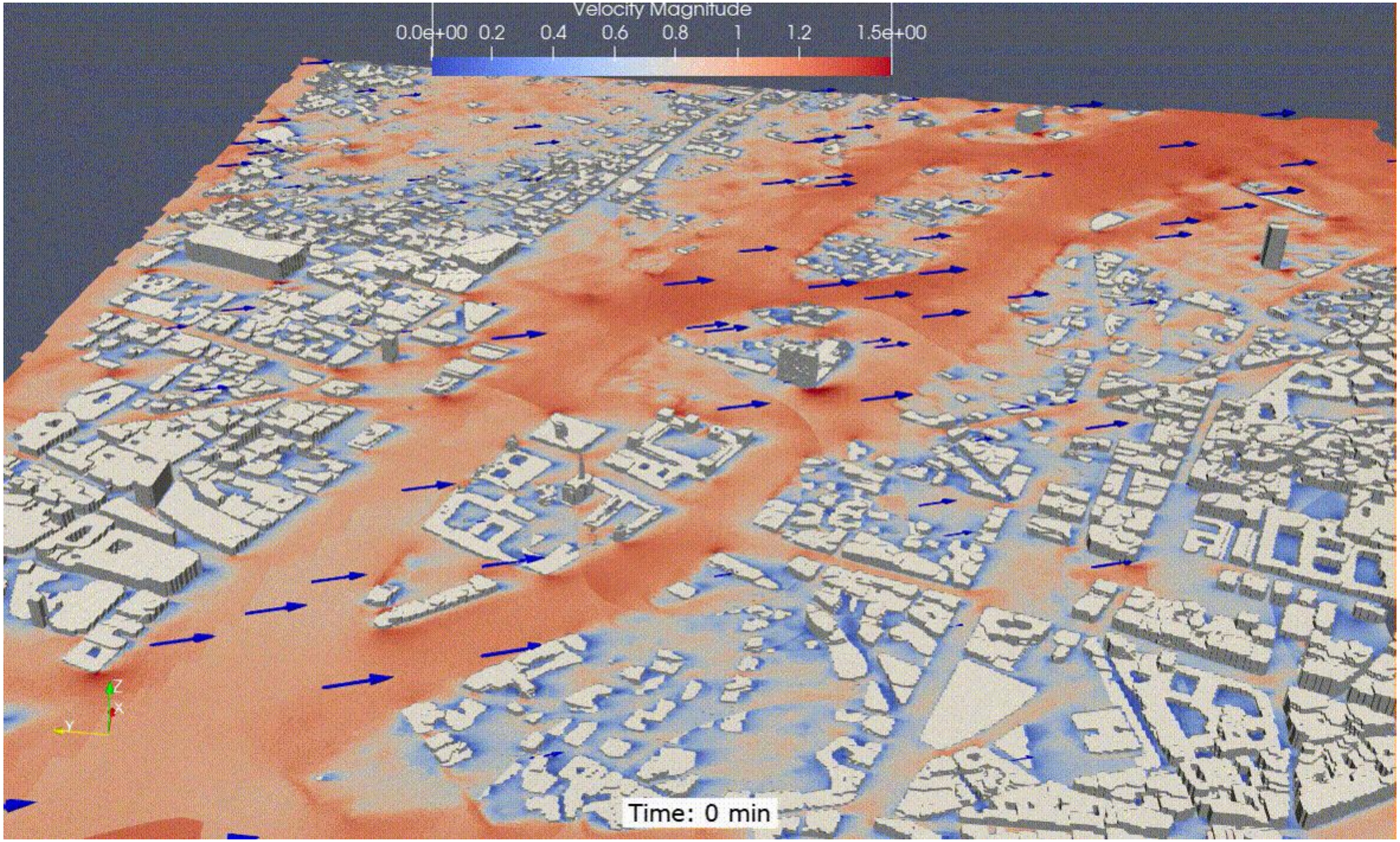
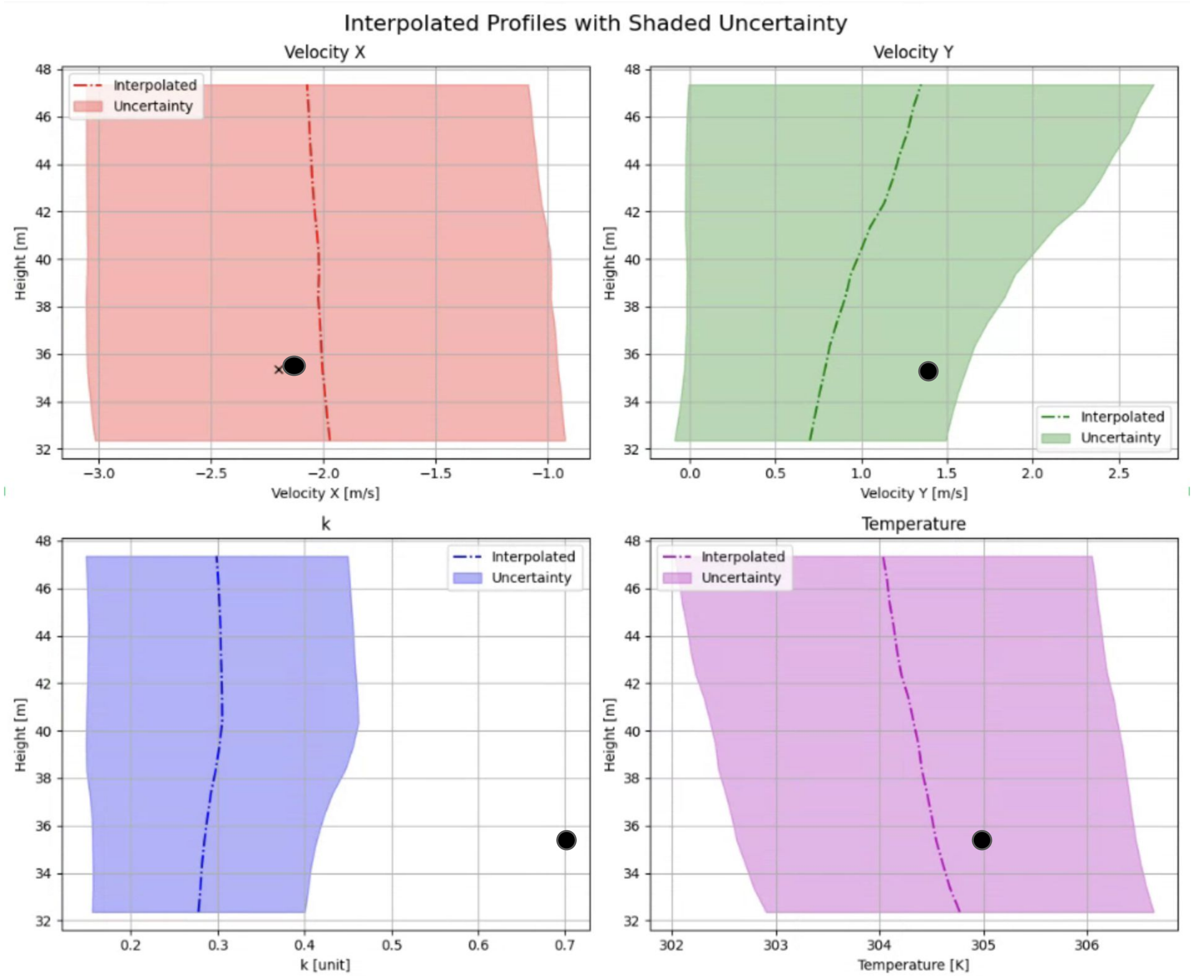


Fig.: Velocity magnitude in the center of Paris during time with dynamic boundary conditions

Wind velocity dynamics



Intercomparison of models and measurements in Paris in collaboration with Karine Sartlet (ENPC), Chao Lin (Uni of Tokyo), Jani Stromberg (Uni of Helsinki)

Content

Aerosol transport model [Zaichik, 2001]

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x_i}\left\{\left[U_i + \tau_p g_i - \tau_p\left(\frac{\partial U_i}{\partial t} + U_k\frac{\partial U_i}{\partial x_k}\right) - \right.\right.$$
$$\left.\left. - \frac{\partial}{\partial x_k}\left(D_b\delta_{ik} + \frac{\Omega}{1+\Omega}D^T_{ik}\right)\right] C\right\} = \frac{\partial}{\partial x_i}\left(\left(D_b\delta_{ik} + D^T_{p,ik}\right)\frac{\partial C}{\partial x_k}\right) - F_d,$$

where:

- C is the concentration of the aerosol;
- U_i is the velocity of the fluid;
- Gravitational settlement velocity;
- Inertial term or centrifugal term;
- Thermophoresis and Turbophoresis term;
- F_d deposition term
- $\tau_p = \frac{\rho_p d_p^2}{18\mu_f}$ is the relaxation time of the aerosol

COMPLEX BUT LINEAR

Example of the pollution field

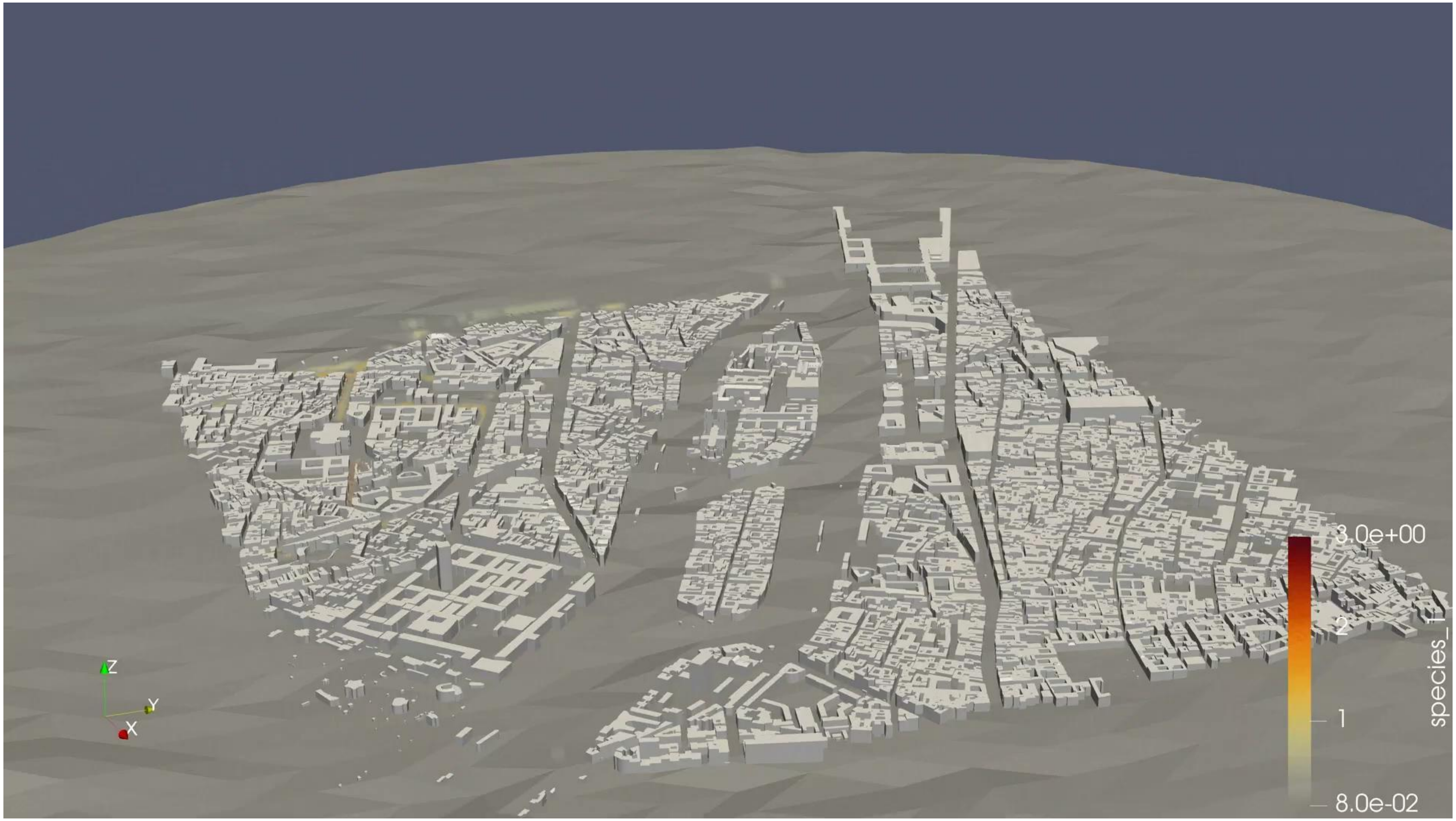
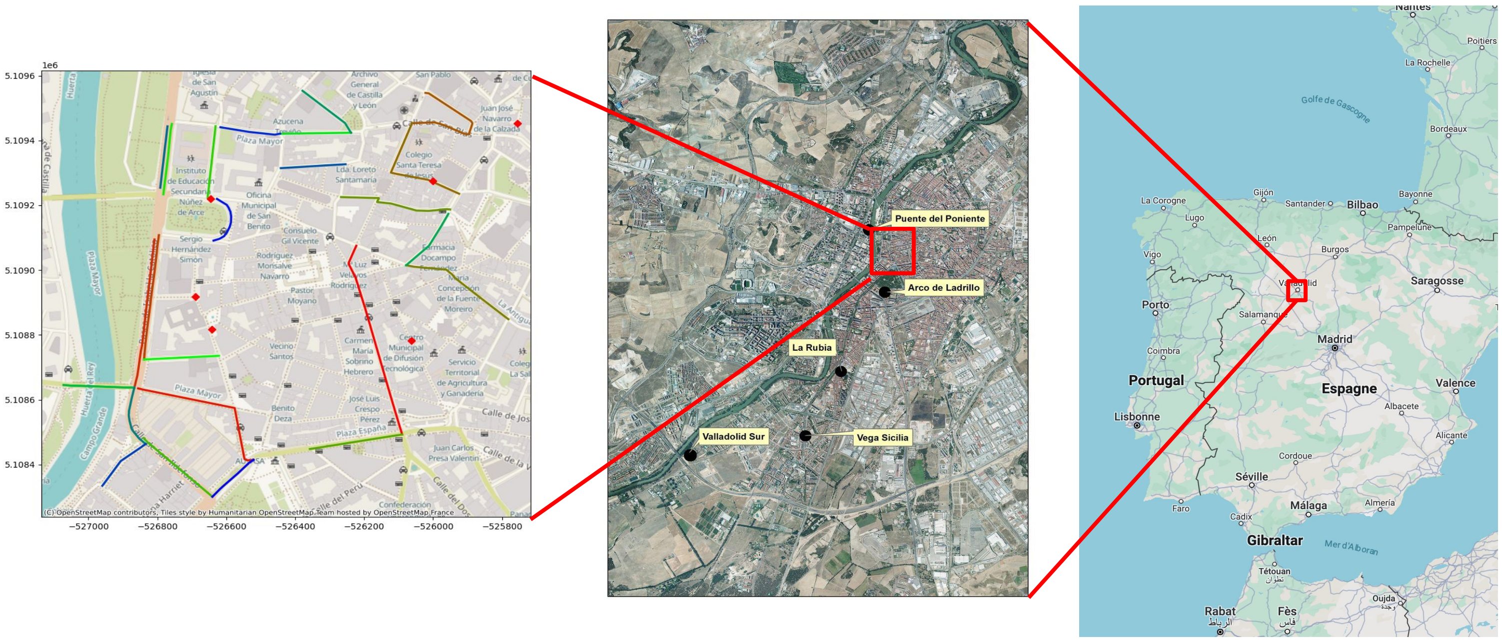


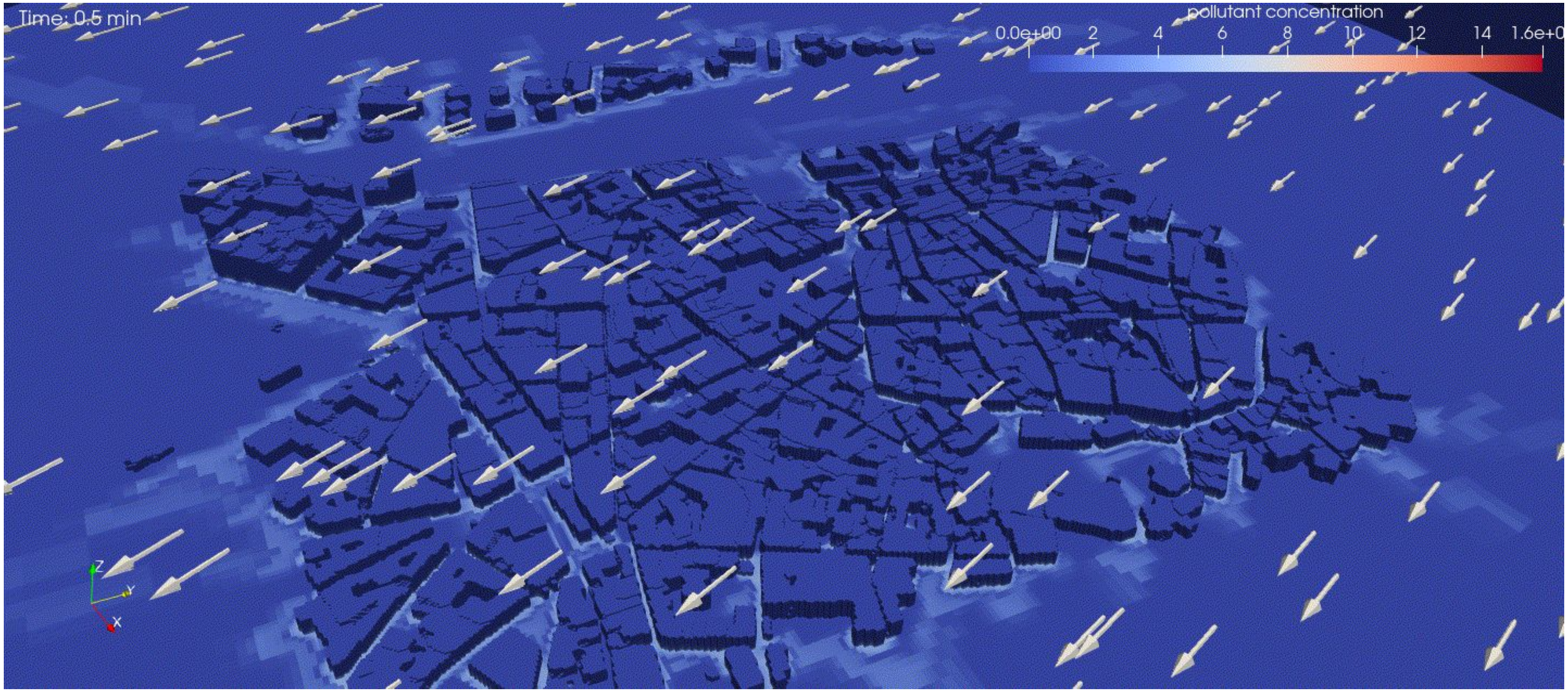
Fig.: PM0.3 dispersal field from roads in Paris

Center of Valladolid, Spain



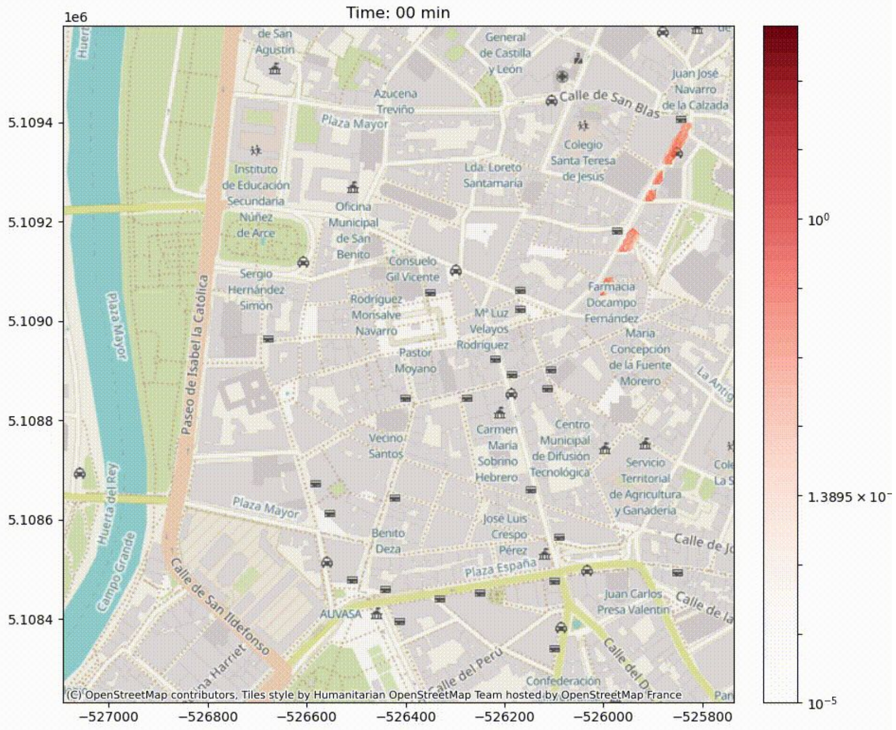
Study domain is 1km x 1km with 800m height

CFD modeling of velocity fields



- Dynamic in time boundary conditions;
- Advanced second-order turbulence model;
- 1 hour of physical time

Pollution field from one road



Dynamics of the pollution field from street ***C. de la Angustias*** the at the pedestrian level (2m height) during 1 hour;

Assumptions for PM0,3 field modelling

1. All pollutants in the domain are defined by **25 roads segments** and the **boundary** and considering **isolated**
2. Focusing on PM of one diameter
3. **Constant emission** along the road segment were using
4. **Steady state** meteo condition for **20 min** period.
5. **Nucleation and chemistry** processes are **neglectable** on the period of 20 min

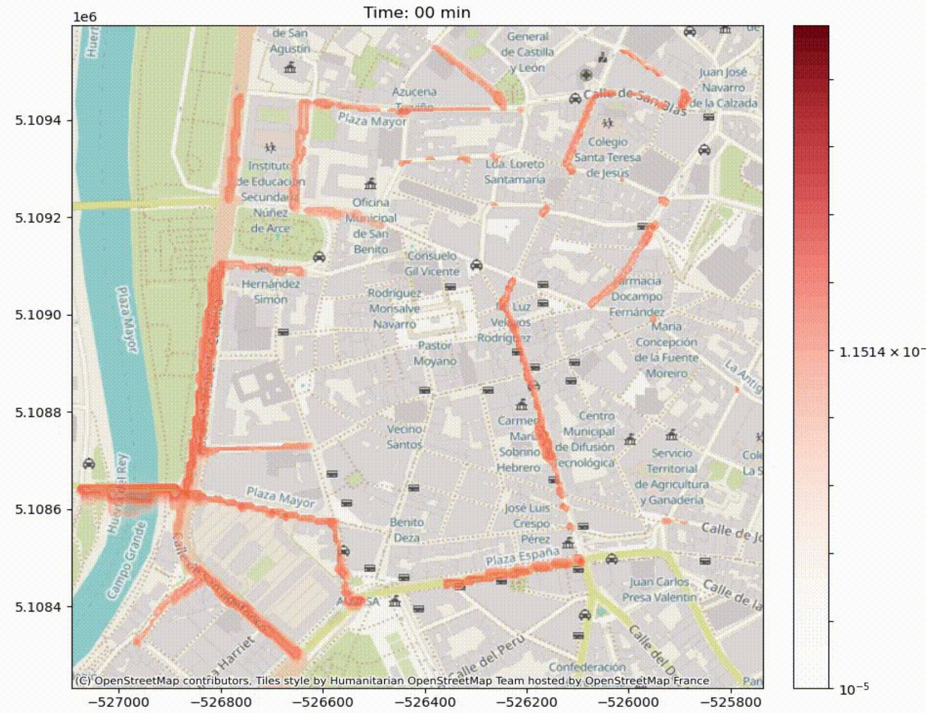


*Fig.: PM0.3 field generated by linear composition of 25 streets with **predefined emission** values*

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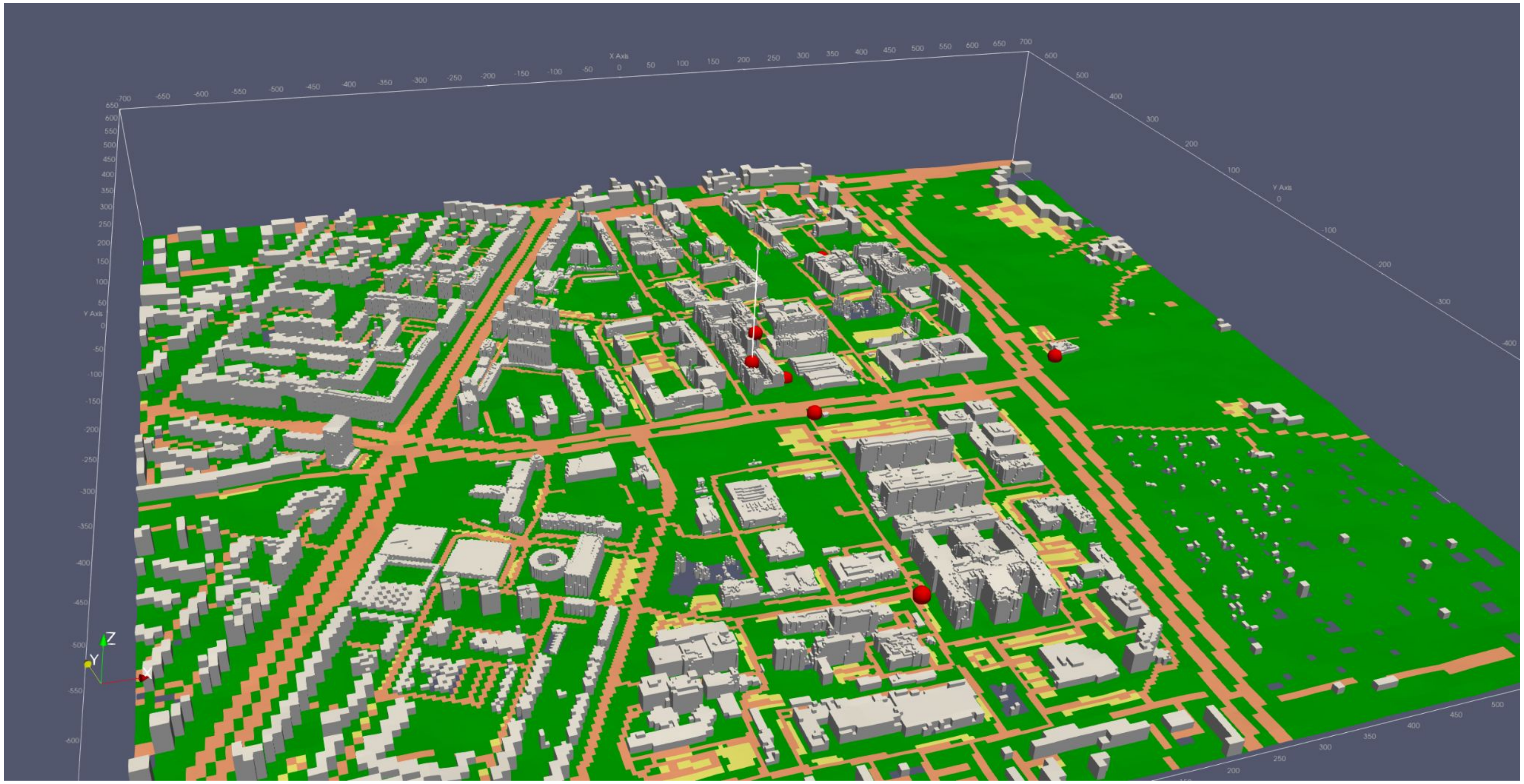
Project TNA AQUA 2024 in UW

K.Kuznetsov[1], Abhinna Behera[1],Iwona Stachlewska[3], Karine Sartlet[2], Dominika Szczepanik[3], Rayonil Carneiro[3], Anna Abramovich[4], Mariola Jablonska[4], Miroslaw Szczyrba[4]

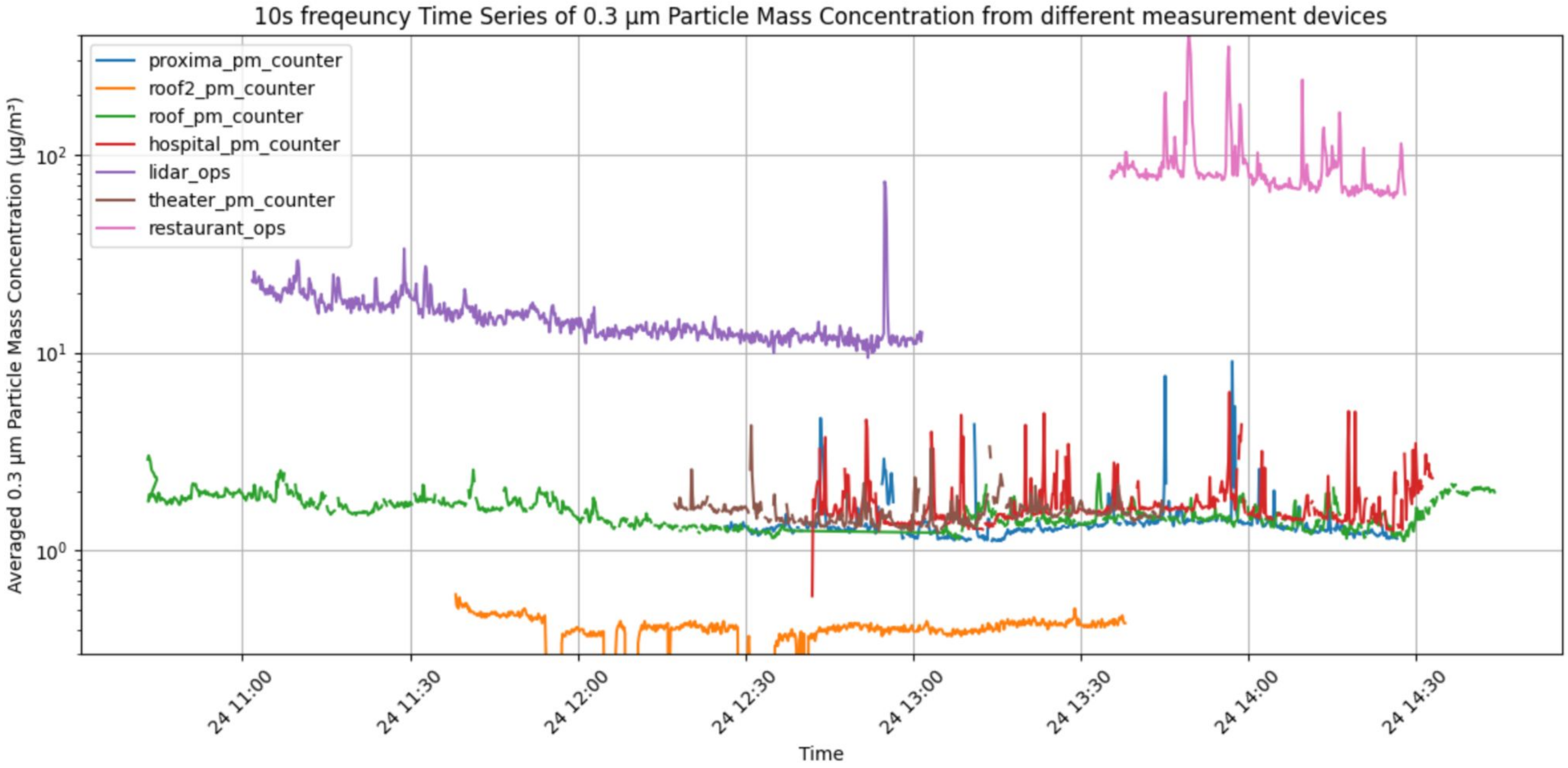
1. ***GRASP Earth***
2. ***Ecole des Ponts et Chausse Insitut Polytechnique***
3. ***University of Warsaw***
4. ***University of Silesia***

Ground based measurements



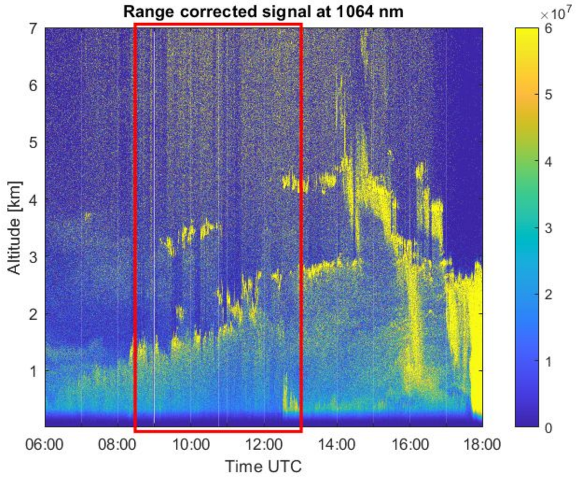
7 ground based PM counters in the area of 1 x 1 km, Lidar and AERONET station

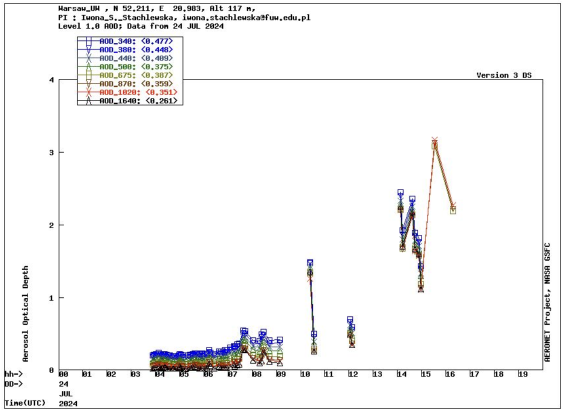
Ground based measurements

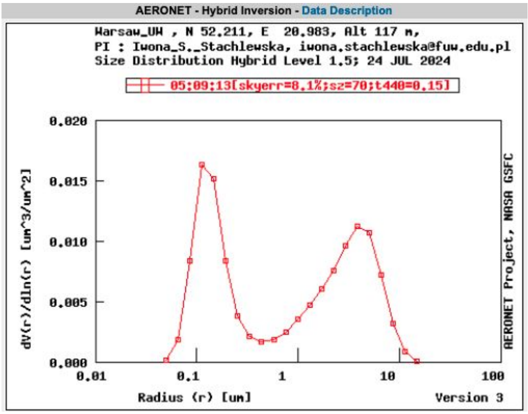


Preliminary example of data from PM counters from measurements campaign of 24 July 2024

Lidar and AERONET measurements

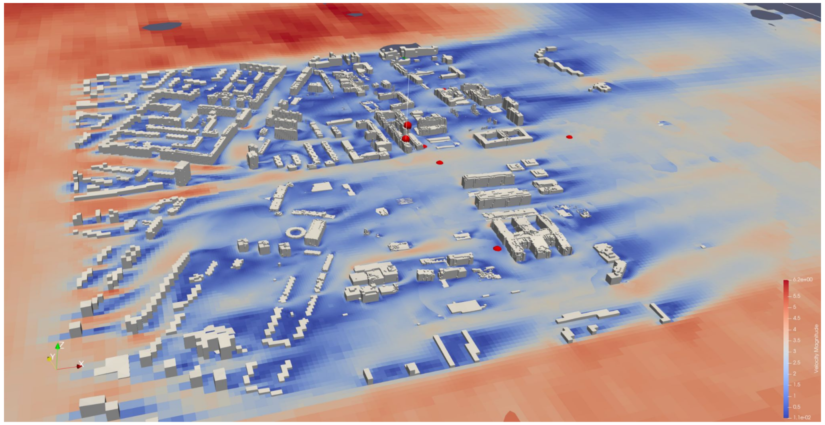


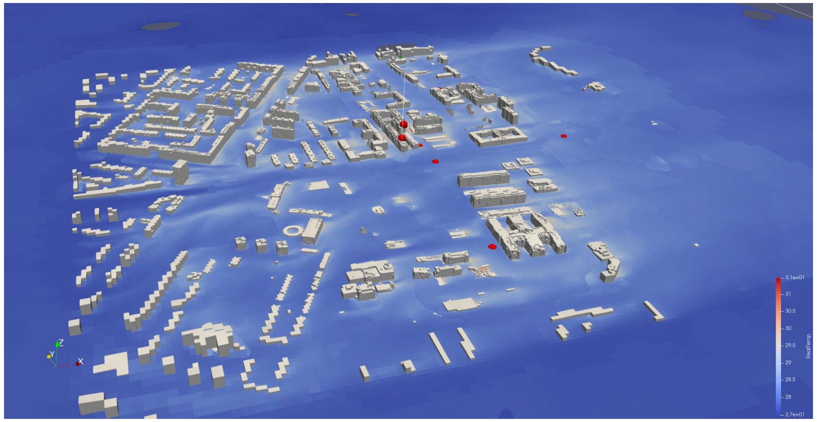




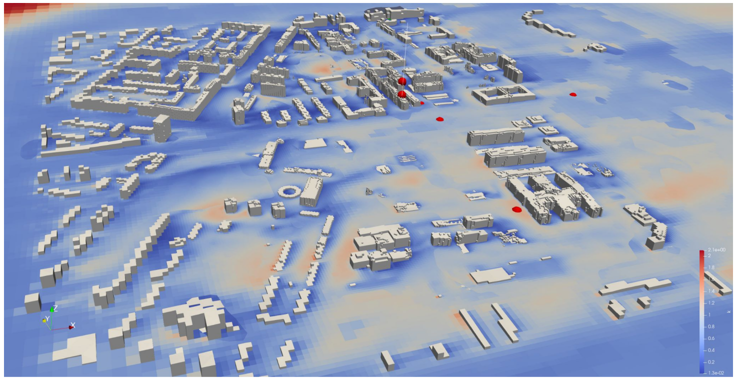
Lidar and AERONET data 24 July 2024

Velocity and temperature fields





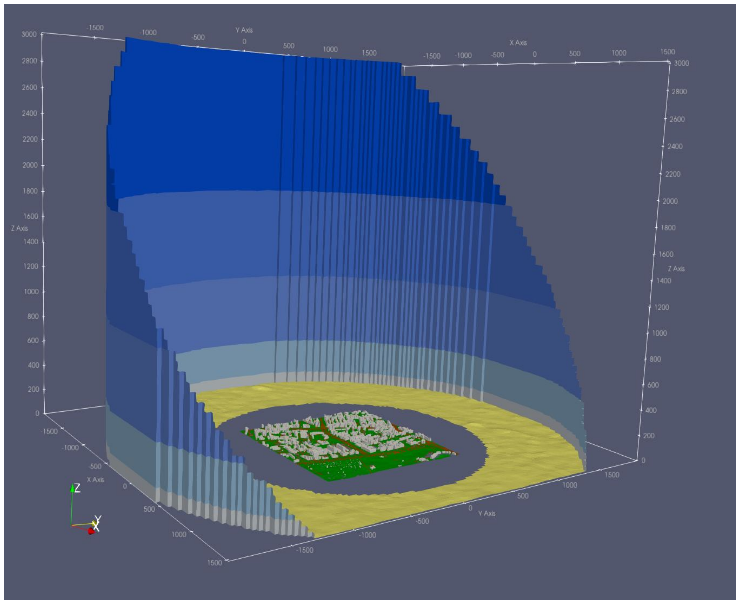
Magnitude of velocity

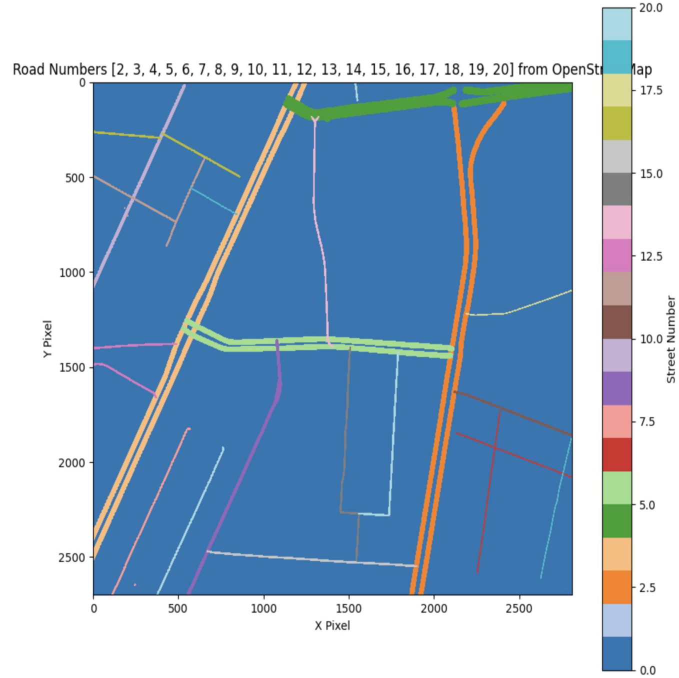


Temperature

Turbulence kinetic energy

Warsaw emission zones





5 vertical levels + 1 periphery + 20 road segments.
Initial conditions could be avoided during retrieval (domain is completely updated after 10 min of wind propagation)

Example of PM03 field in Warsaw

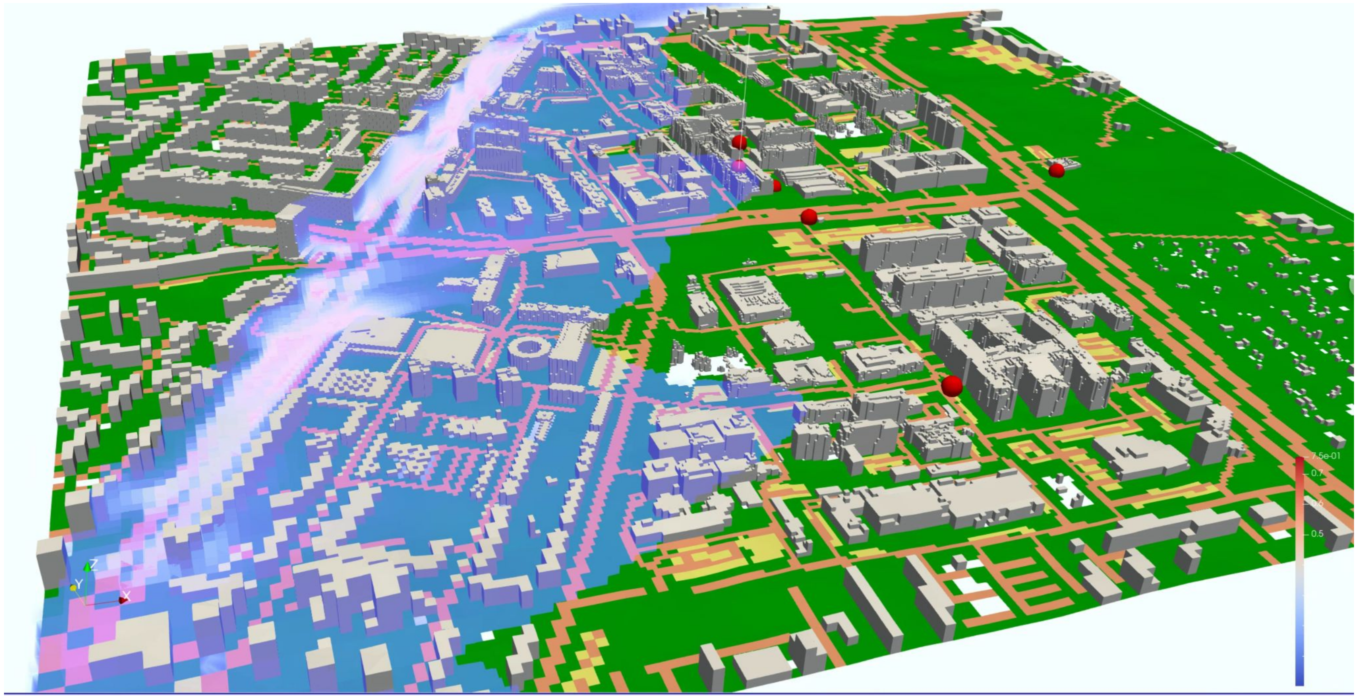
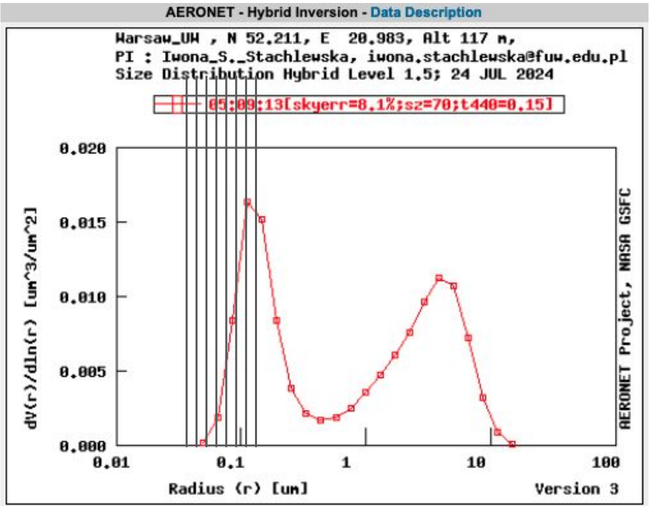
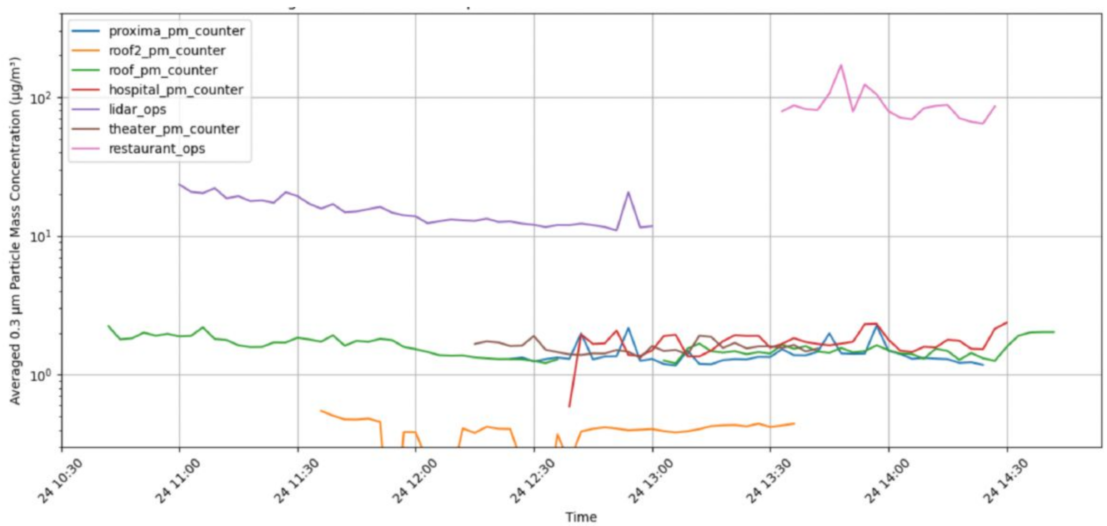


Fig: Example of the pollution field from one road in Warsaw

Assimilation of measurement into model

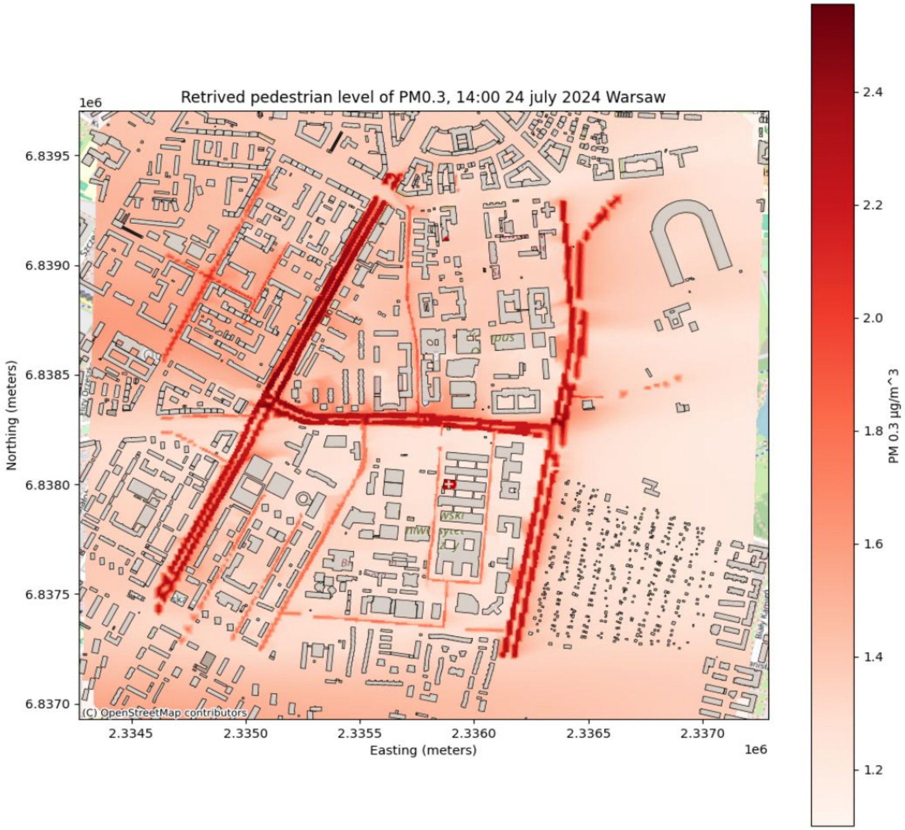
1. We use 1 integrated value of PM0.3 from AERONET for 14:30 24 july 2024
2. We use 5 values from 10 min averaged PM0.3 measurements





Reconstruction of PM03 field from ground measurements

1. Convex optimization with constraints on the emissions
2. 10 min averaged PM0.3 field
3. 2 meters resolution
4. 1 km x 1 km



Conclusions

- Framework to automatically generate mesh for any city
- Project TNA AQUA allows to create a base for the future collaboration
- It is possible to retrieve **roads emissions from** integral observations (**aeronet, satellite**)
- **Integral observations** (if we have enough measurements) can provide **more accurate** retrieval than ground based sensors

Thank you University of Warsaw for the warm welcome!

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