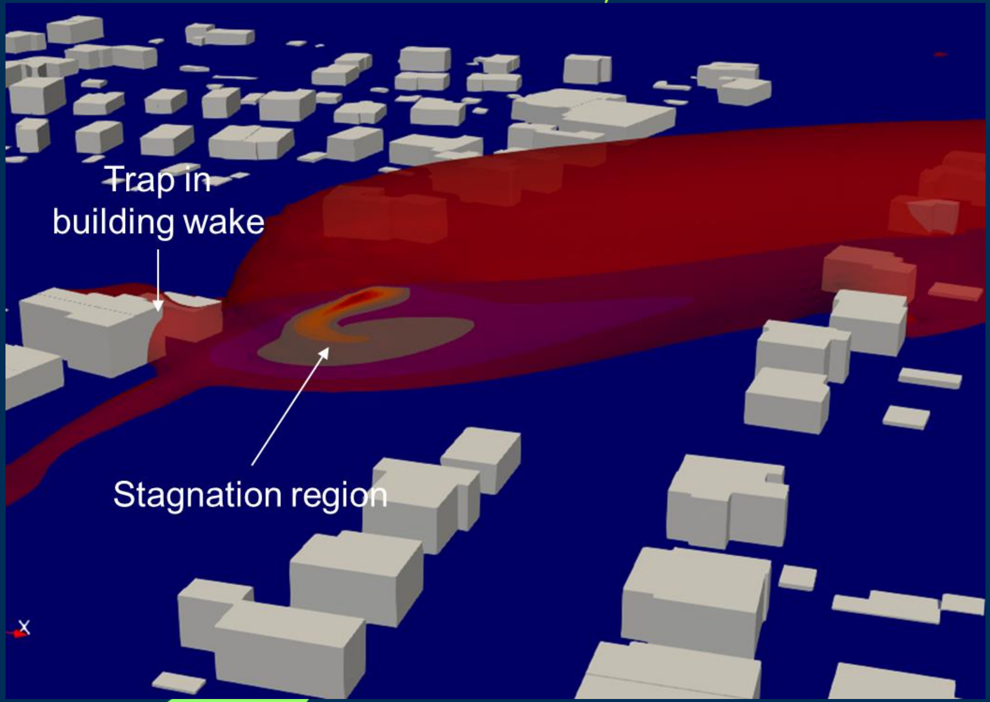
Computational Fluid Dynamics for Pollution dispersion

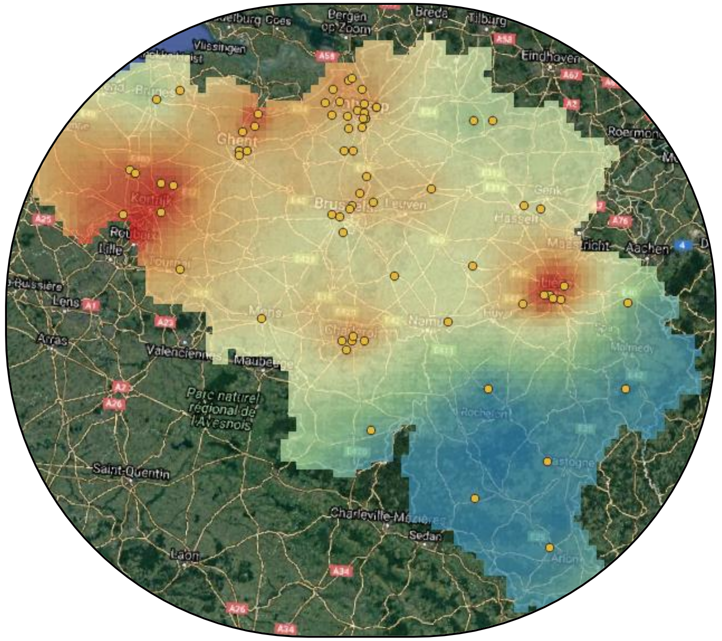
ATMOSYS workshop

Jorge Sousa*, Stijn Vranckx, Alessandro d’Aussilio



ATMOSYS Air quality models

RIO Model
(smart spatial interpolation)



Domain size: Continental/ country size
Resolution: KM

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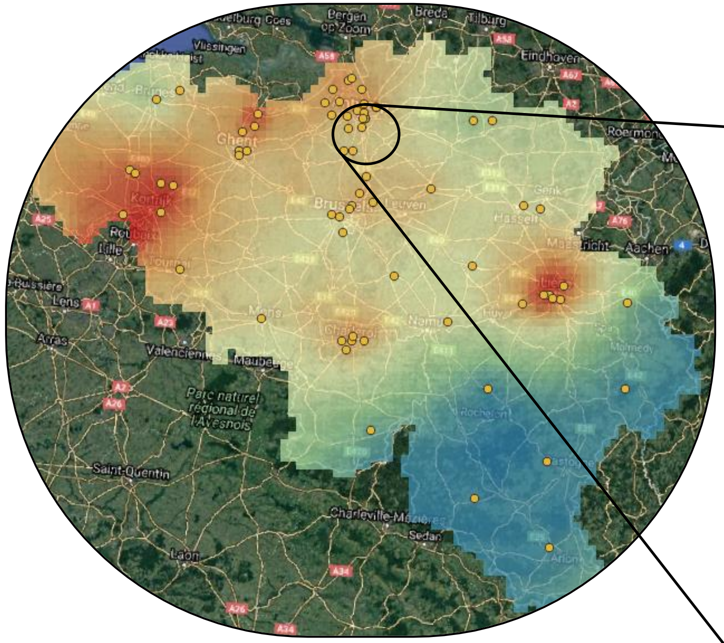

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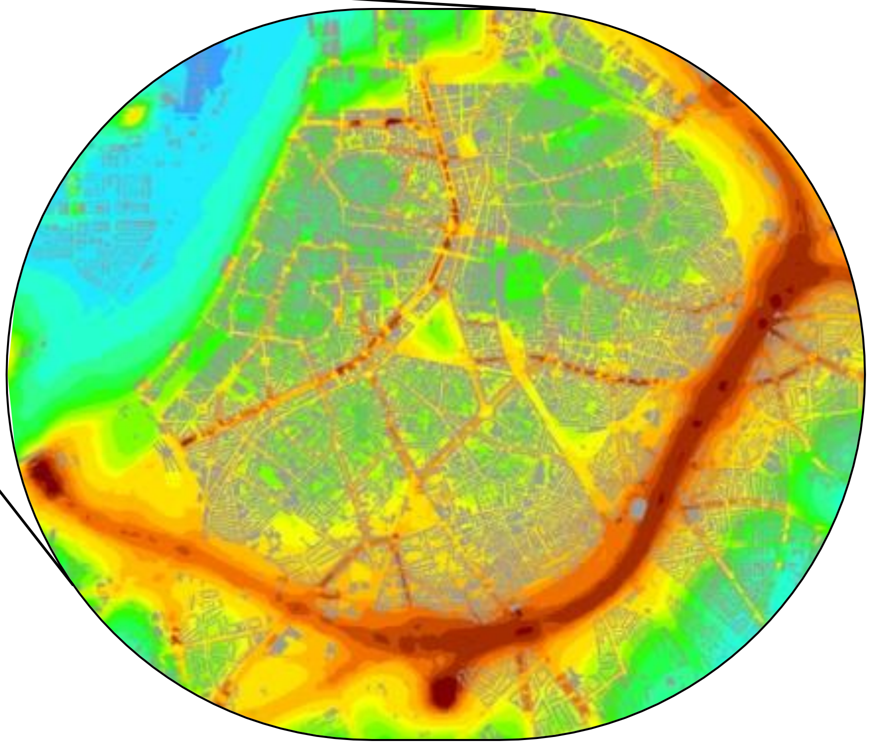
IFDM + OSPM

(Gaussian plumes + parameterizations)



Domain size: urban areas
Resolution: 10-100 meters

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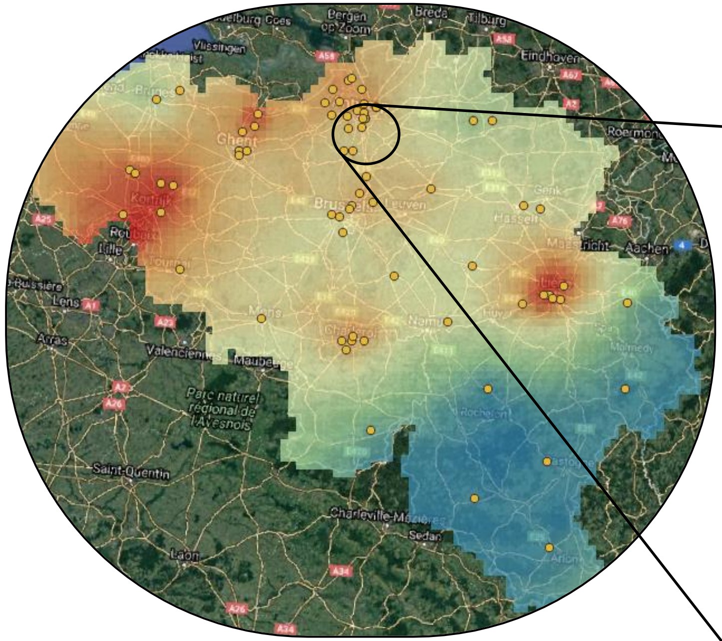

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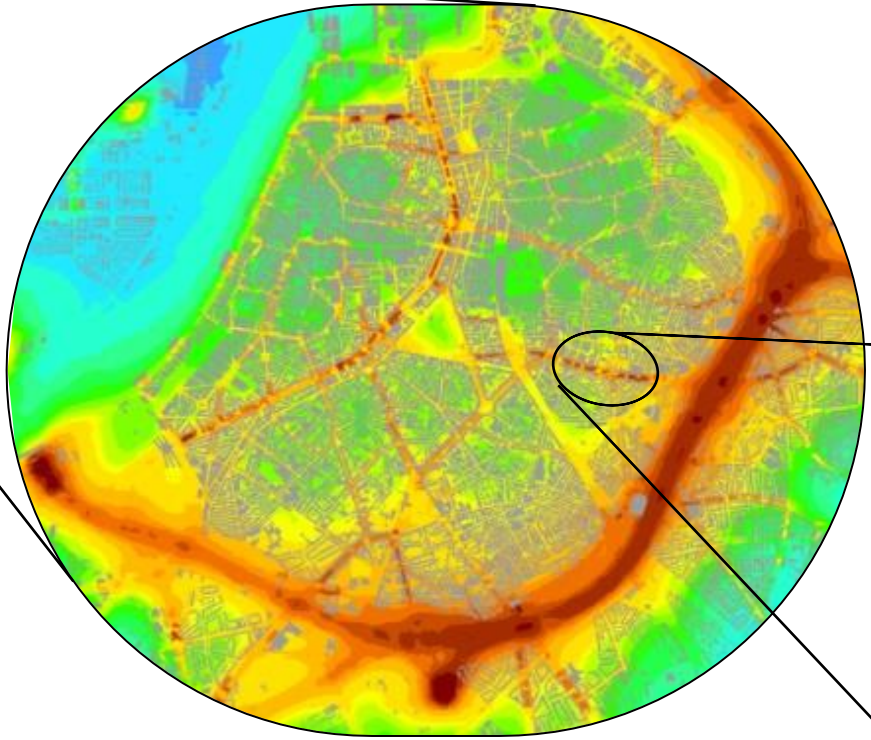
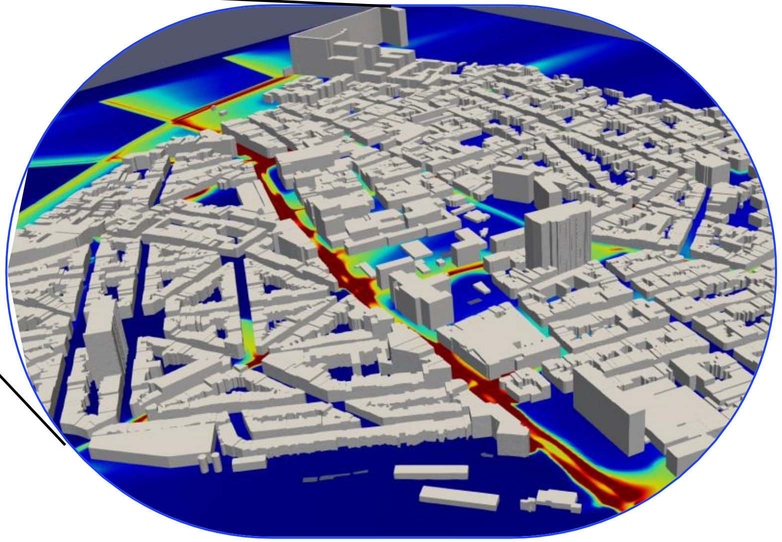


Domain size: urban areas
Resolution: 10-100 meters

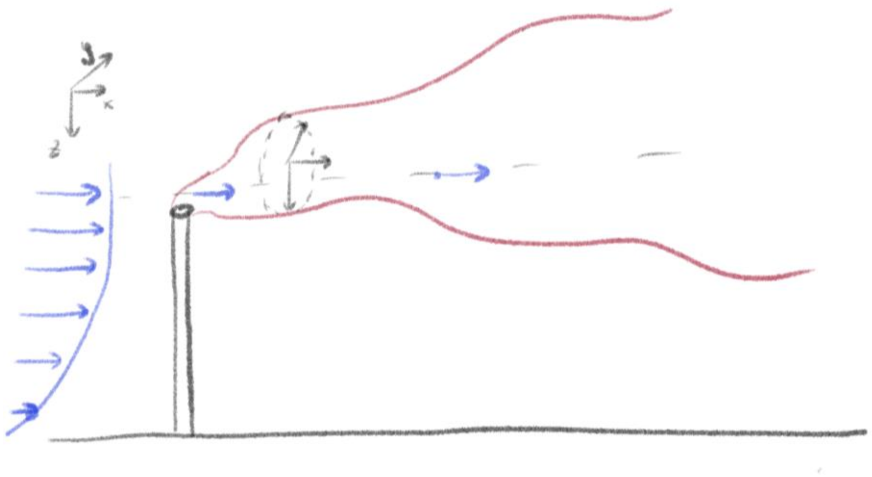
CFD
(Reynolds average Navier-Stokes equations)



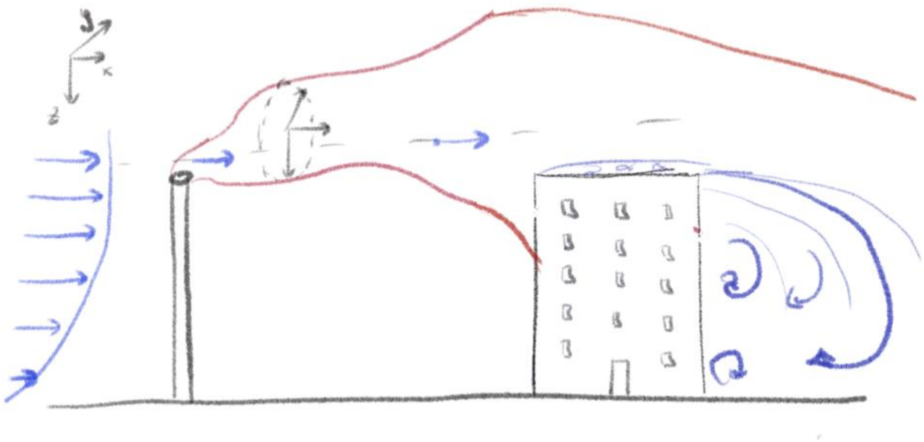
Domain size: neighborhood
Resolution: 1-5 meters

Gaussian Plumes vs CFD

Simple situation



Complex situation



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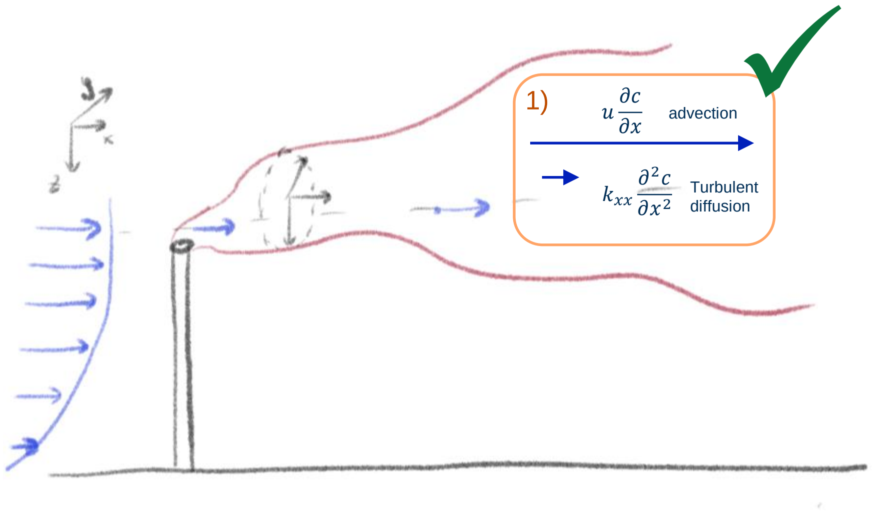

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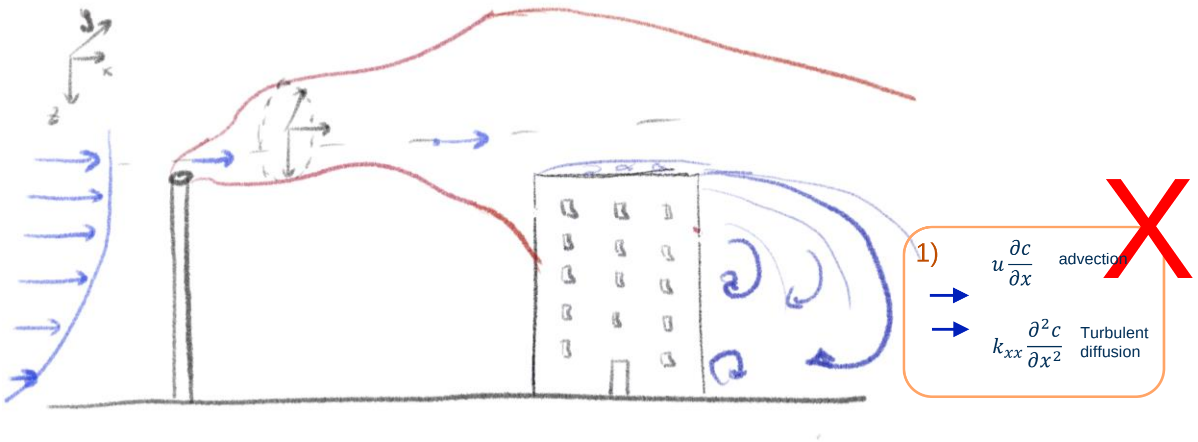

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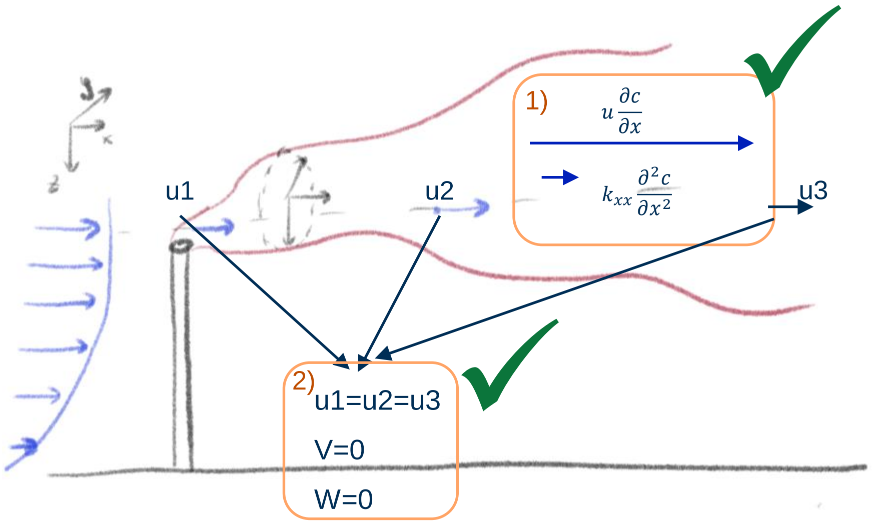

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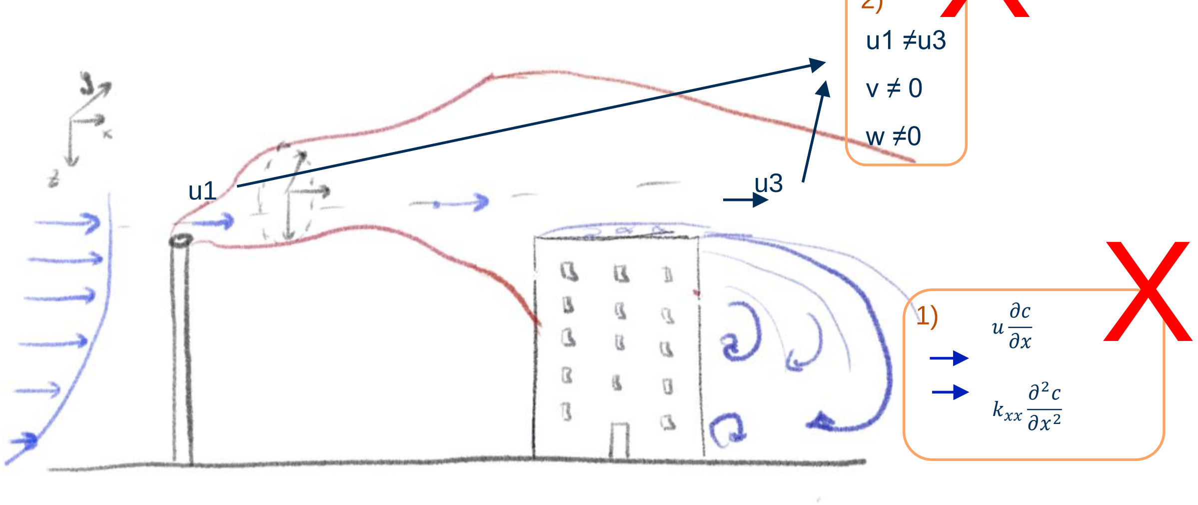

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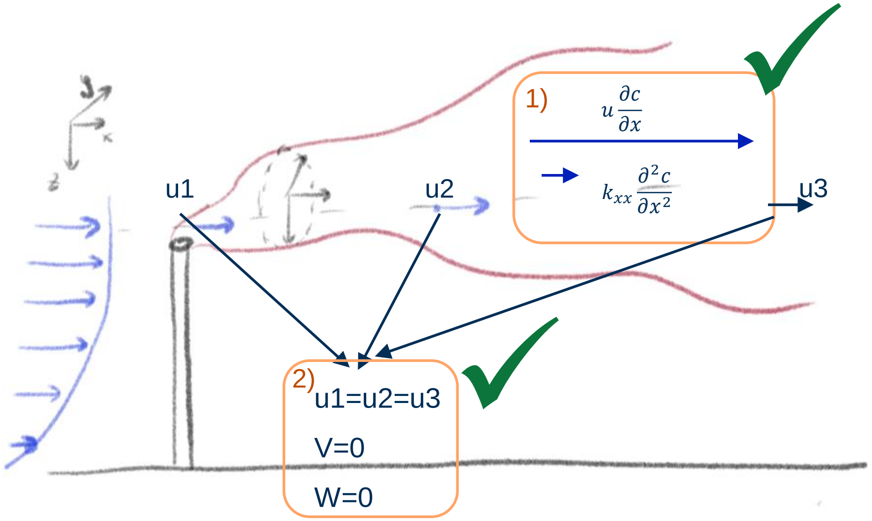

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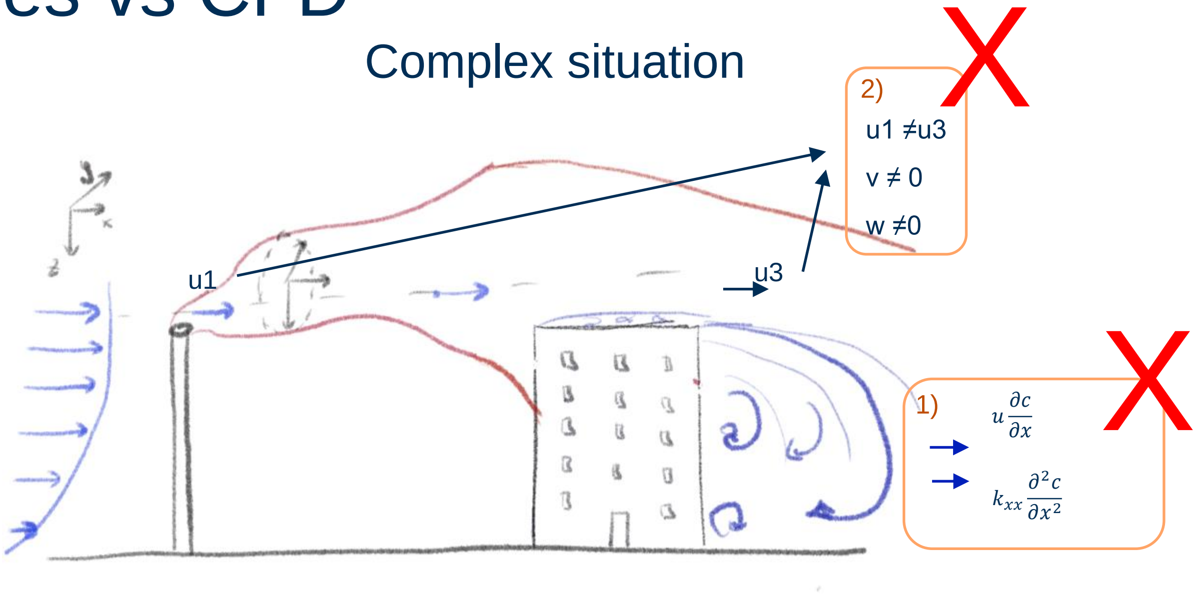


Gaussian plume model

Algebraic equation:

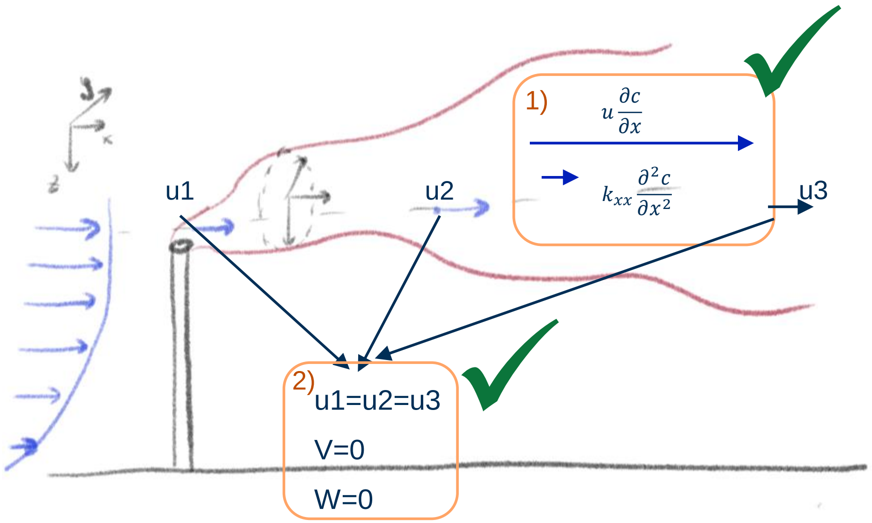
$$C(x,y,z) = \frac{Q}{2\pi u \sigma_{yy}\sigma_{zz}} e^{-1/2\left(\frac{y^2}{\sigma_y^2}+\frac{(Z-H)^2}{\sigma_z^2}\right)}$$

Parameterizations:

- Stability, chemistry, building downwash, plume rise …

Gaussian Plumes vs CFD

Simple situation



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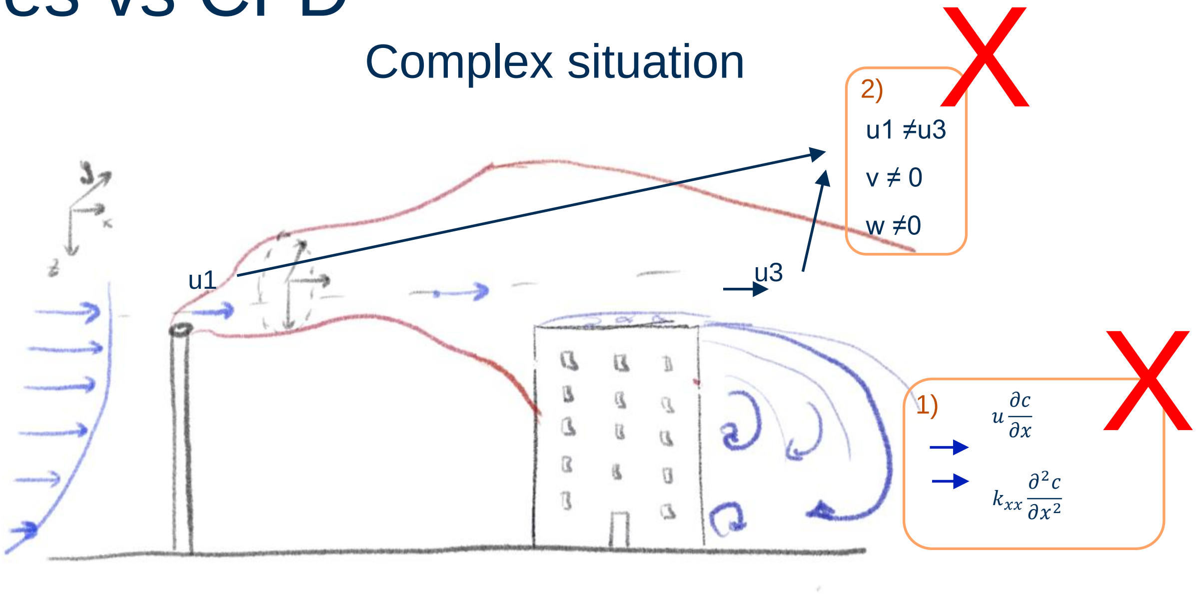

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Parameterizations:

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Computational Fluid dynamics model

Advection diffusion equation:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial x} = -[D+k_{xx}]\frac{\partial^2 c}{\partial x^2} - [D+k_{yy}]\frac{\partial^2 c}{\partial y^2} - [D+k_{zz}]\frac{\partial^2 c}{\partial z^2}$$

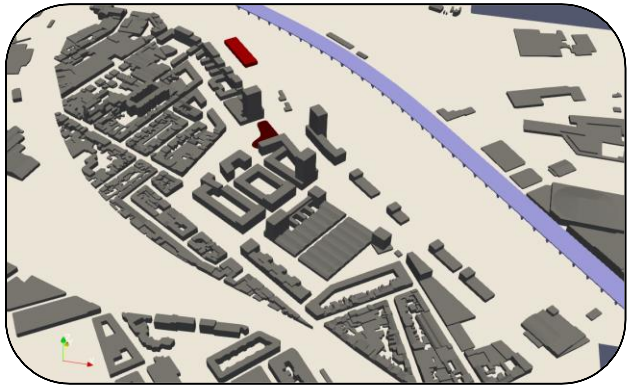
Navier Stokes equation:

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = \rho g - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$
$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = \rho g - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$
$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

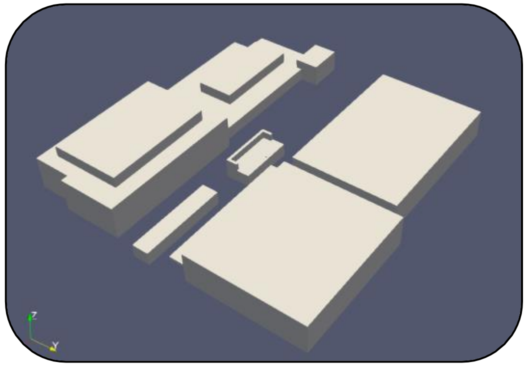
+ parameterizations: turbulence

Situations where CFD is best suited

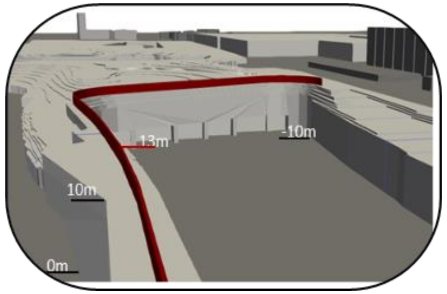
Complex urban sites

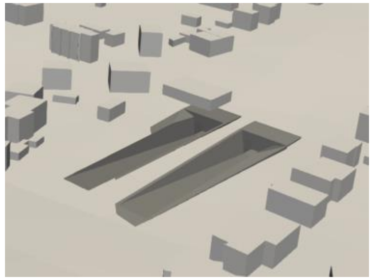


Industrial sites

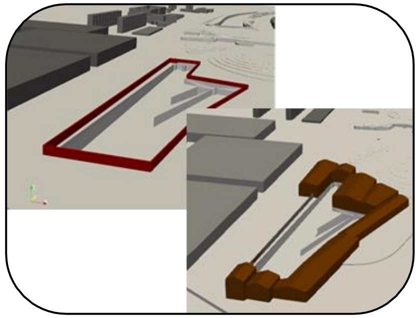


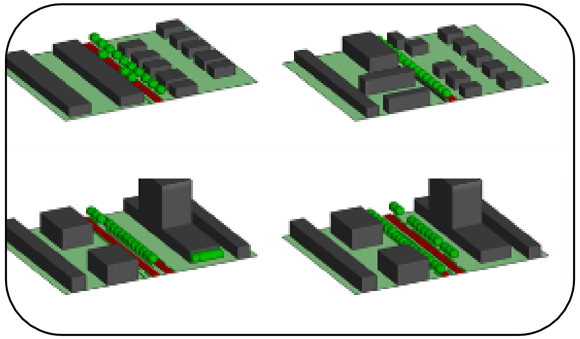
Tunnel mouths





Mitigation measures

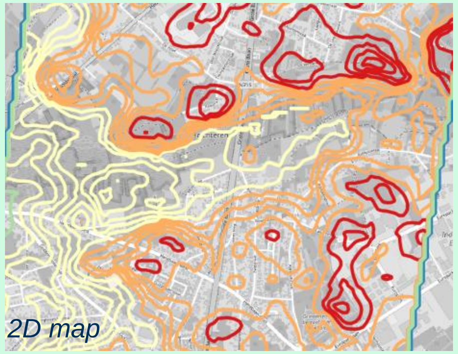


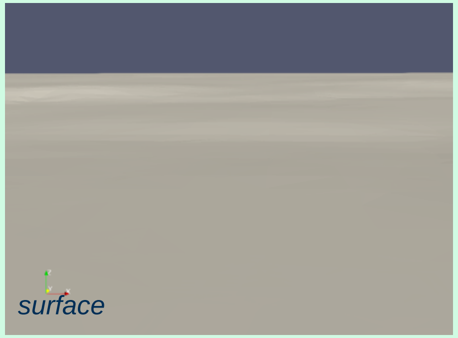


Geometrical methodology

Geometrical methodology

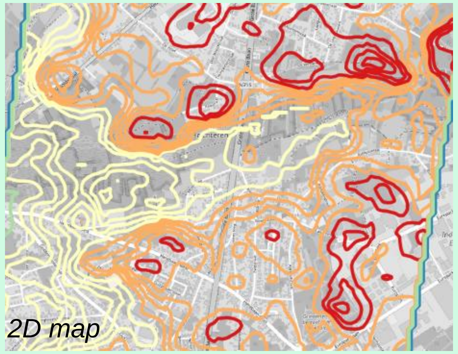
Topography





Geometrical methodology

Topography



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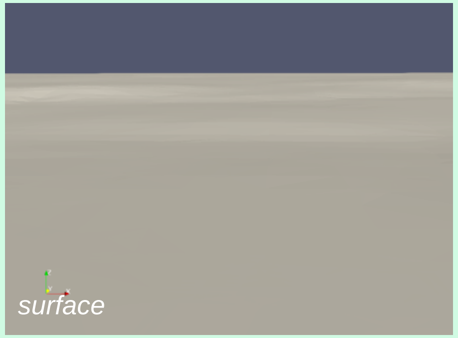
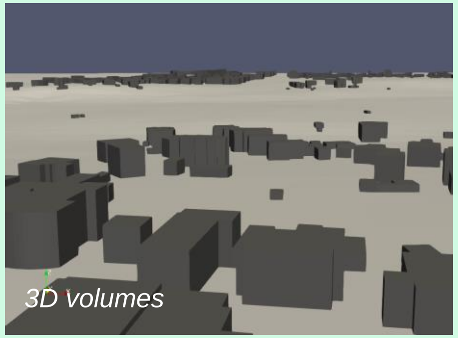


Buildings



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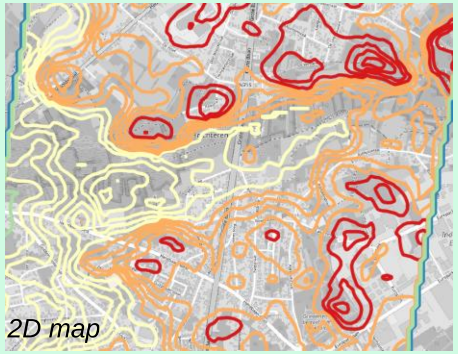

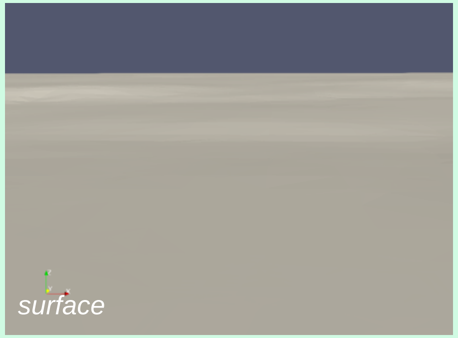

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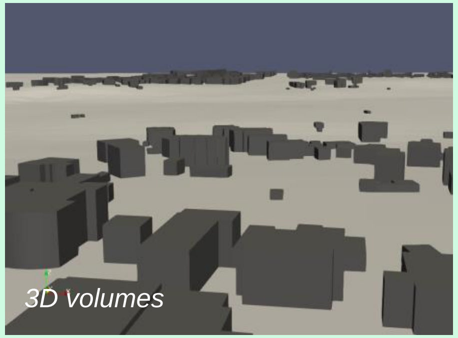
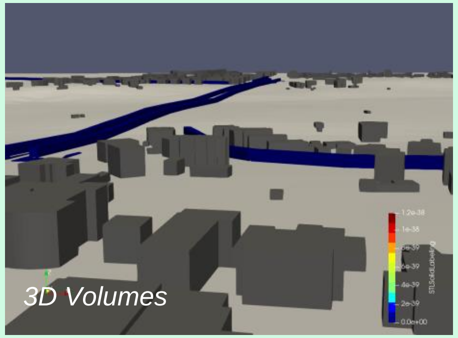


Emissions



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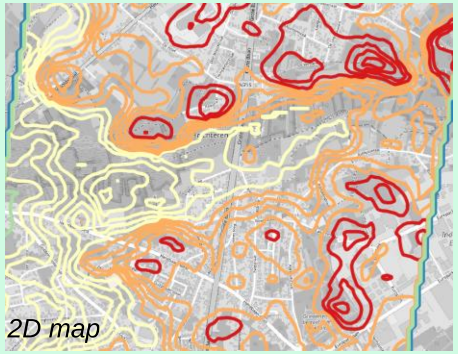

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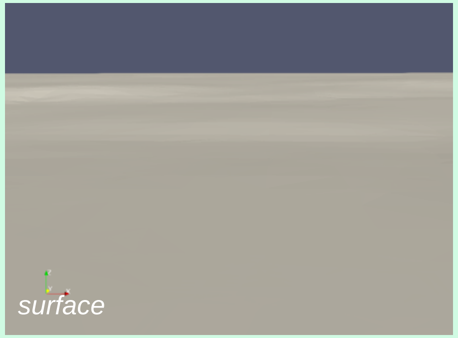

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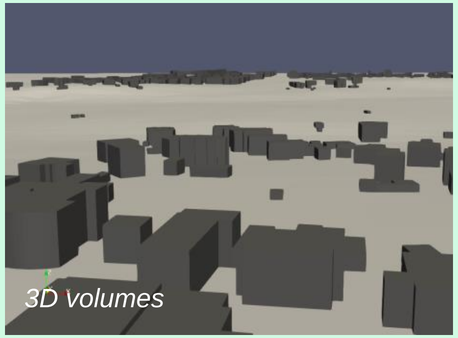

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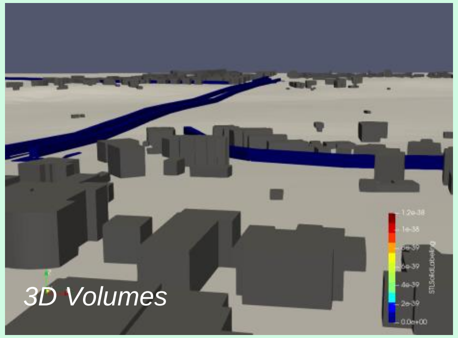
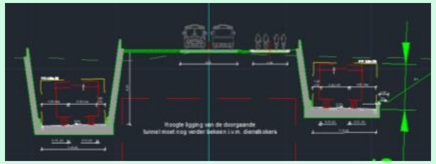
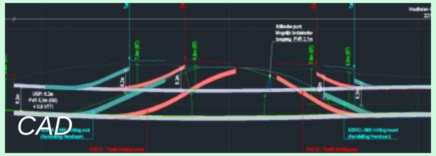
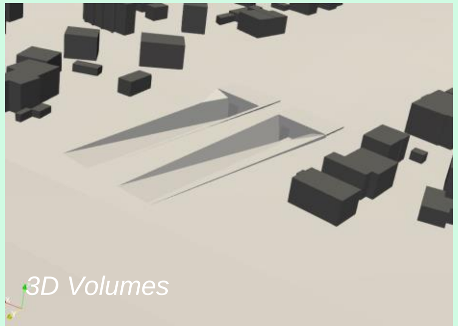


3D Details







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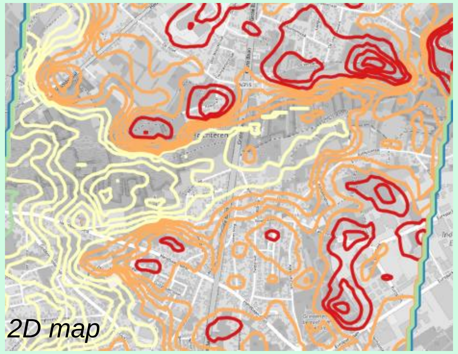

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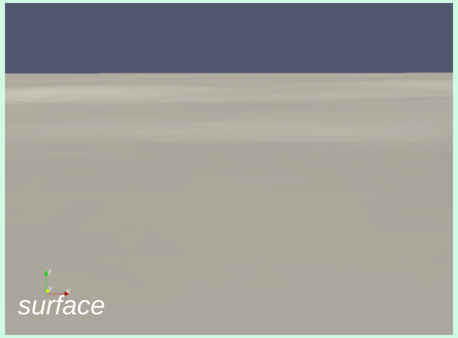

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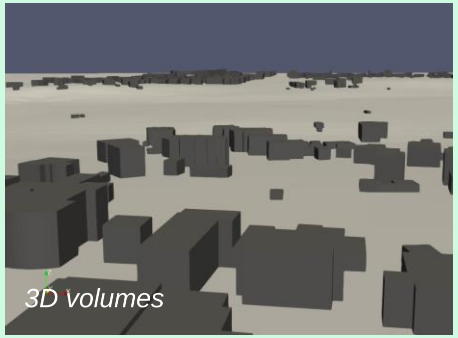

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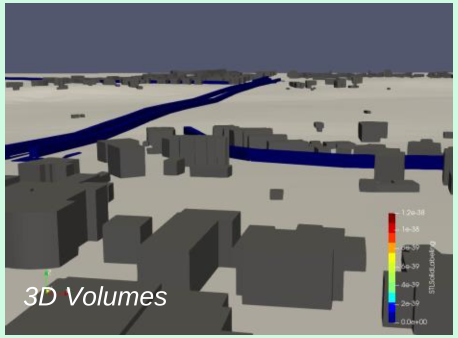

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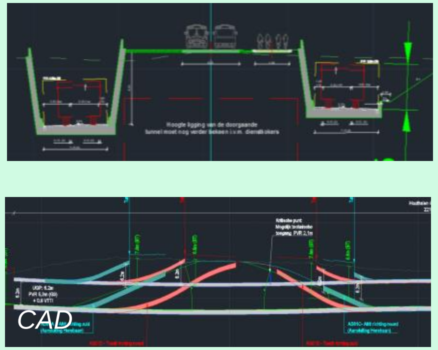

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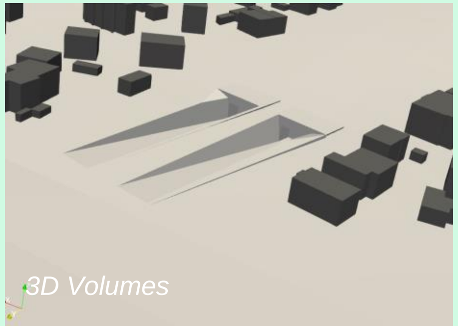
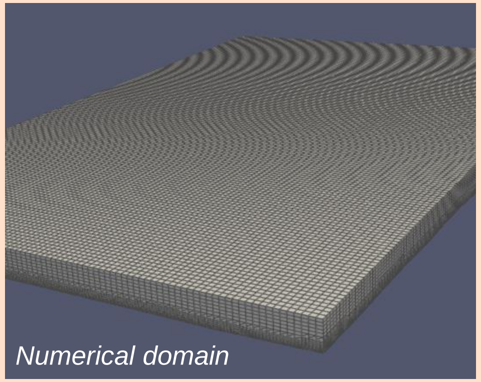
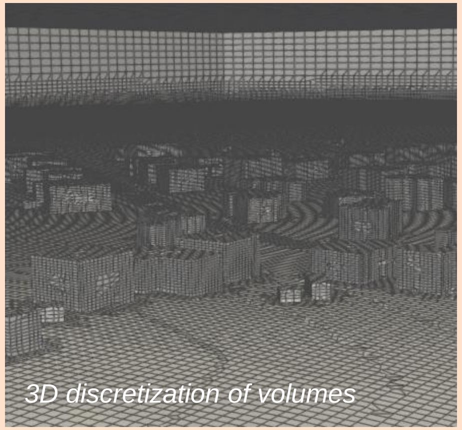


Mesh

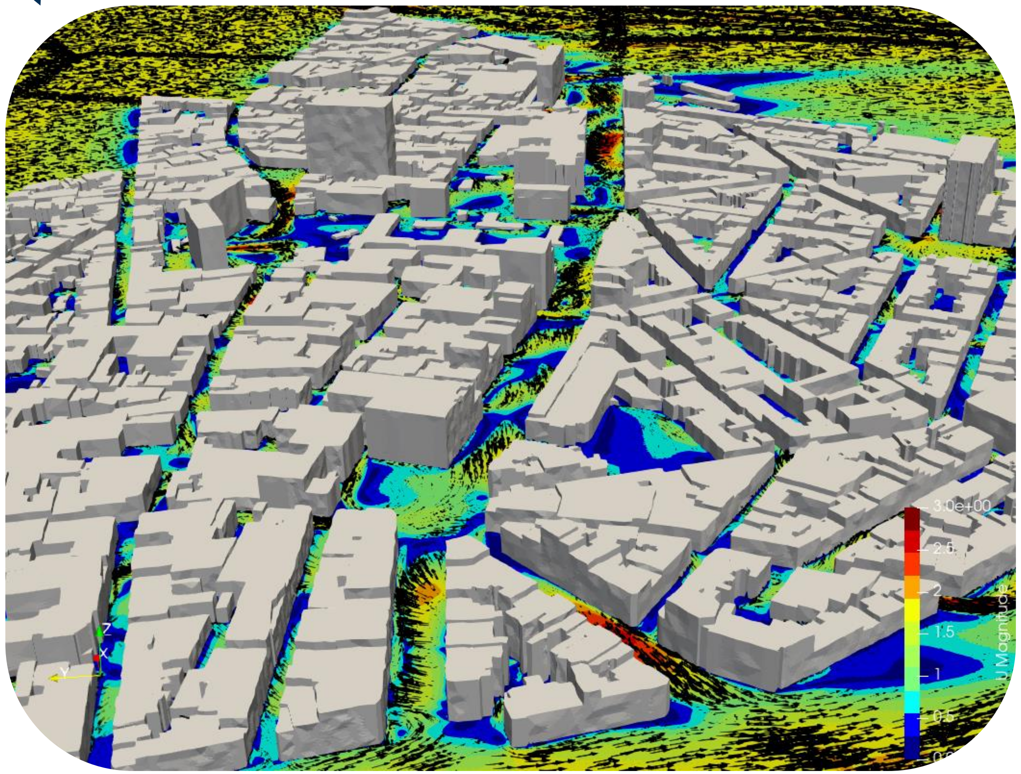




Numerical Solution

Meteo data

Velocity Field



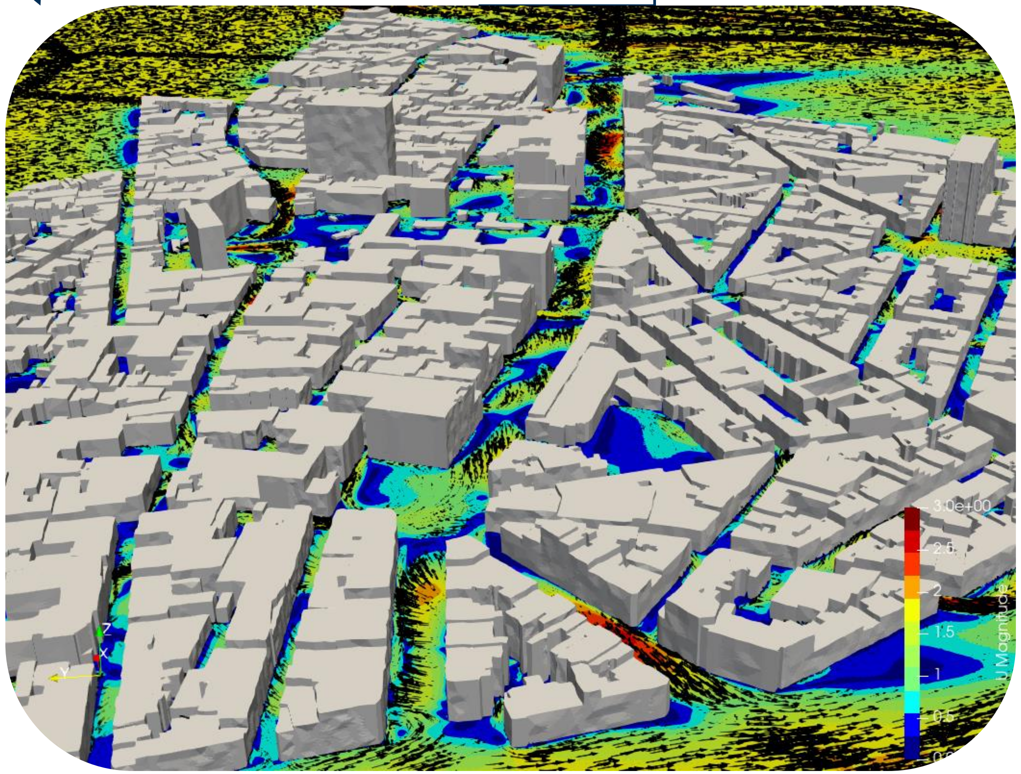
Numerical Solution

Emissions

Advection-diffusion equation

Meteo data

Velocity Field



Numerical Solution

Emissions

Advection-diffusion equation

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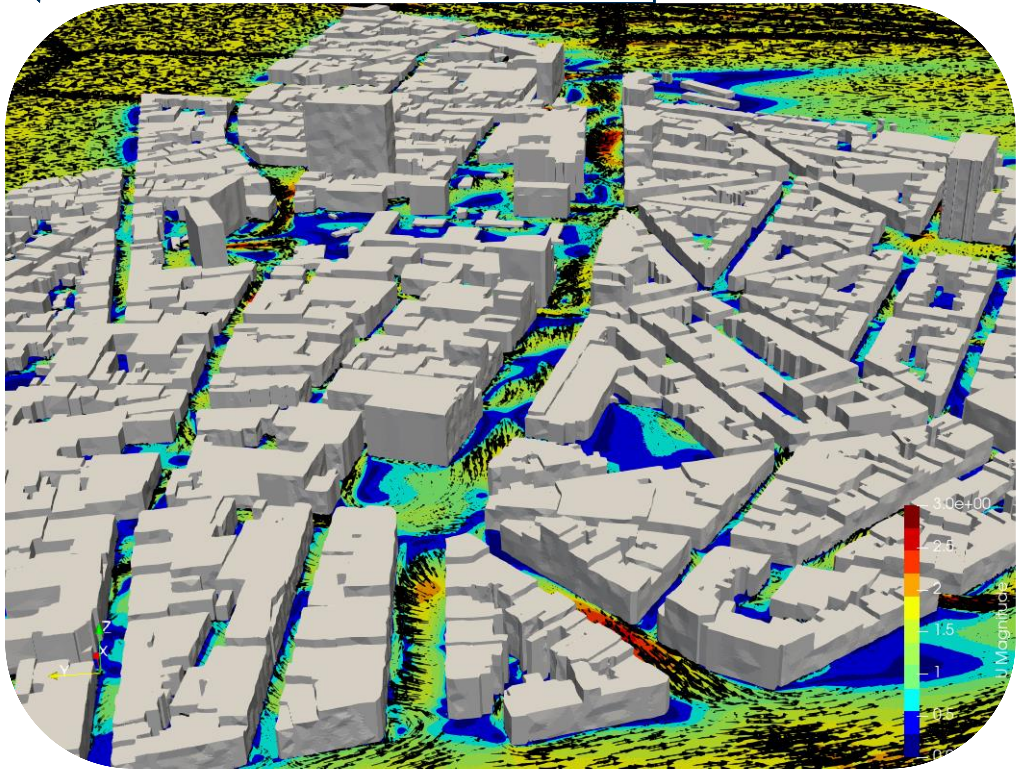
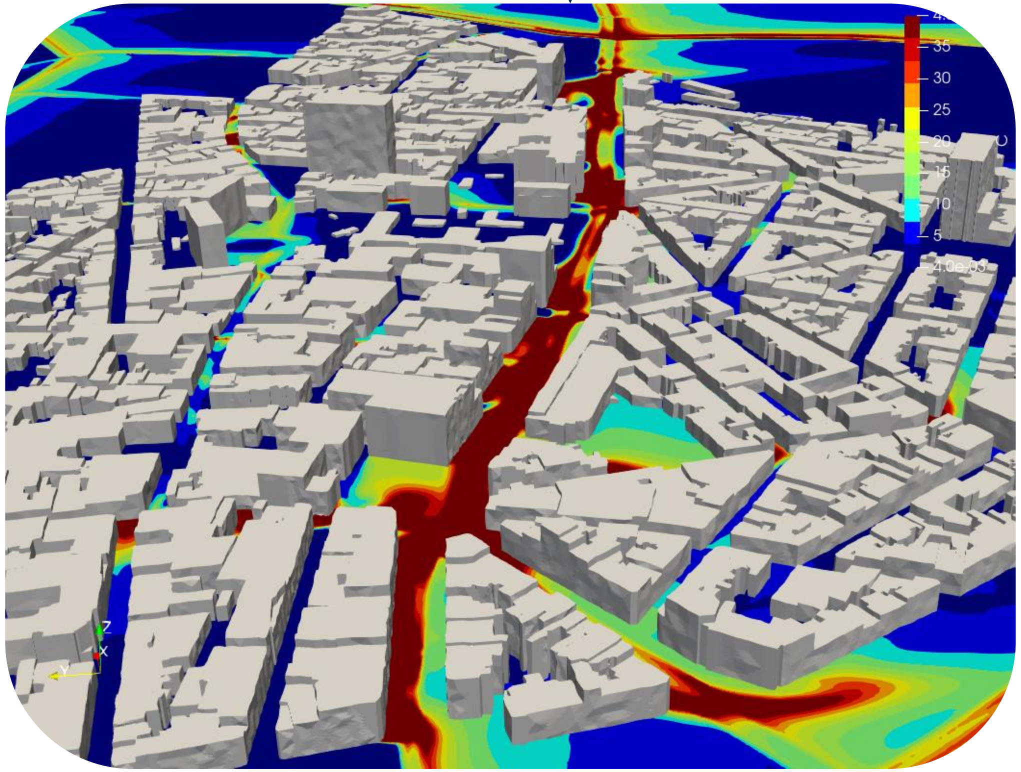
Velocity Field

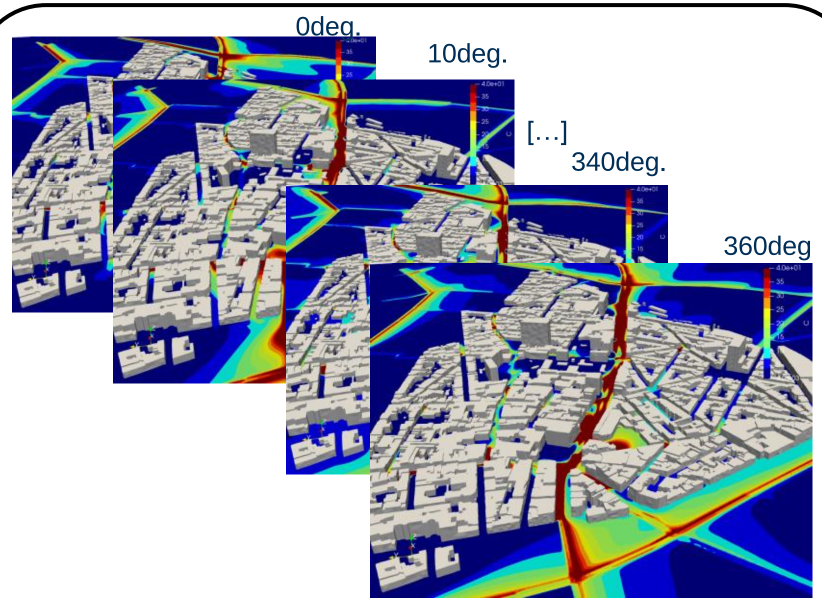
Concentration field



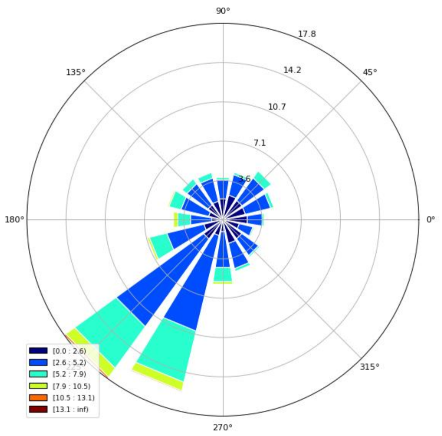


Post processing methodology:

1) Data base of simulations



2) Wind statistics



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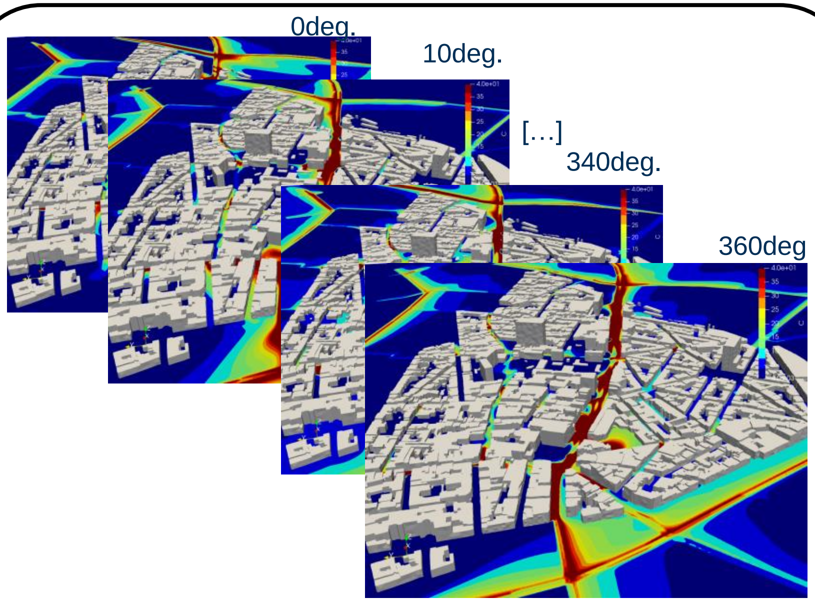

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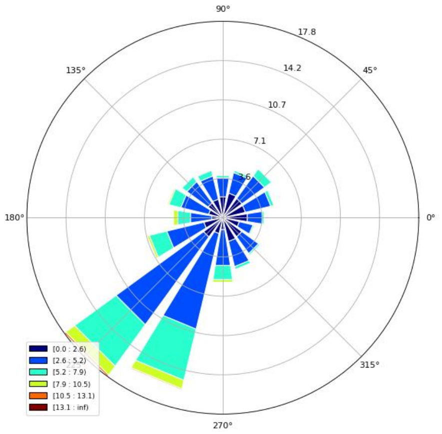
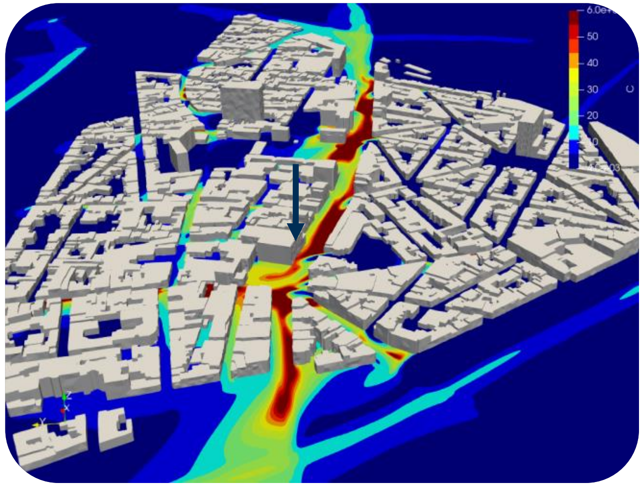


3) Annual means:

Data base, Emission, probability, background

$$\bar{C}(x,y) = \sum_{U_{inlet}} \sum_{\theta_{inlet}} \frac{C^{*}_{traffic}(\theta_{inlet})U_{ref}}{U_{mean}} E_{mean}(P(\theta_{inlet},U_{inlet})R_{\text{NO2/NOX}} + C_{bck}$$



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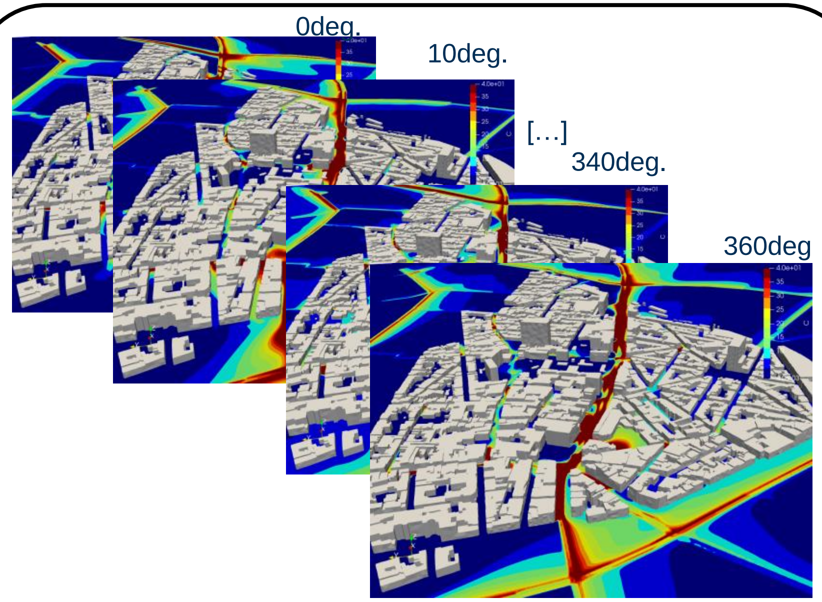

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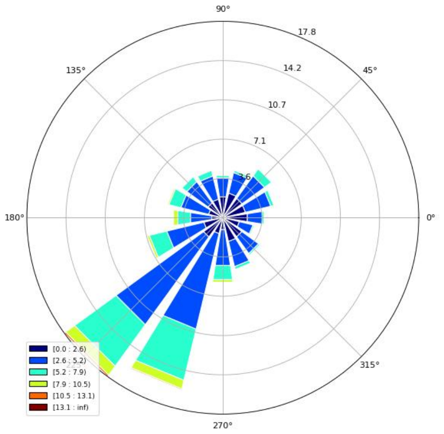

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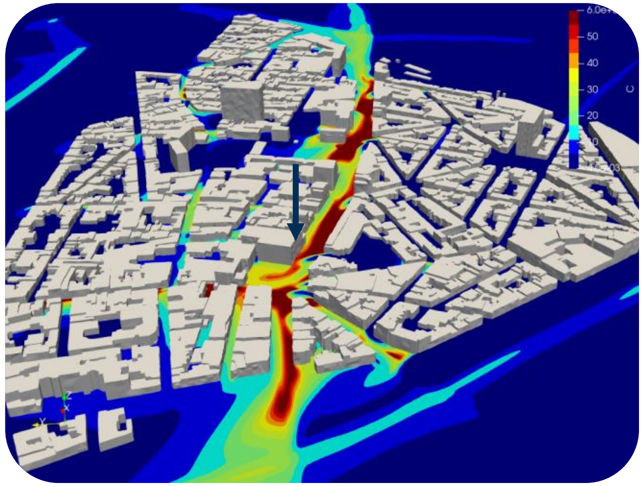
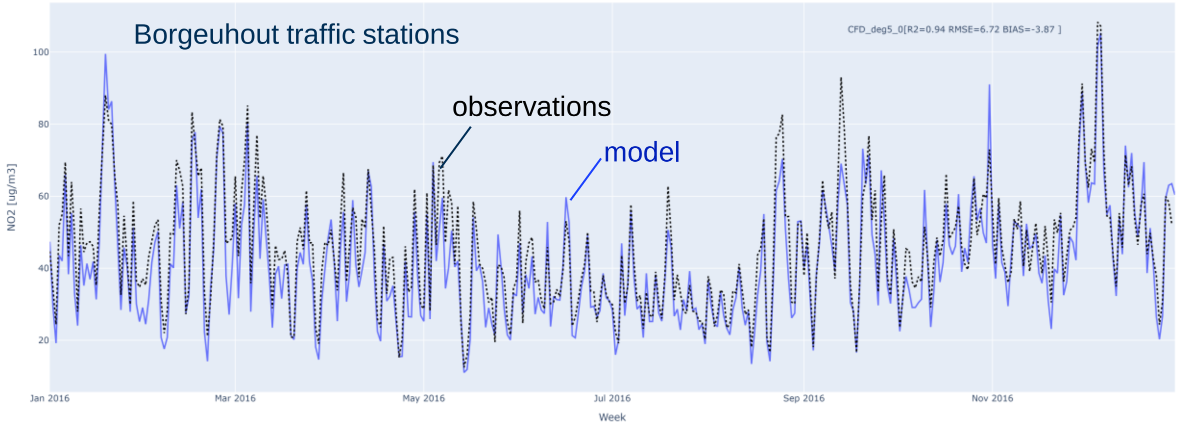


3) Hourly outputs:

Closest to the data base, Time factor

$$\bar{C}(x,y) = \frac{C^*_{traffic}(\theta_{t=t1})U_{ref}}{U_{t=t1}} E_{t=t1} T_{factor} R_{\mathrm{NO2/NOX}} + C_{bck}$$

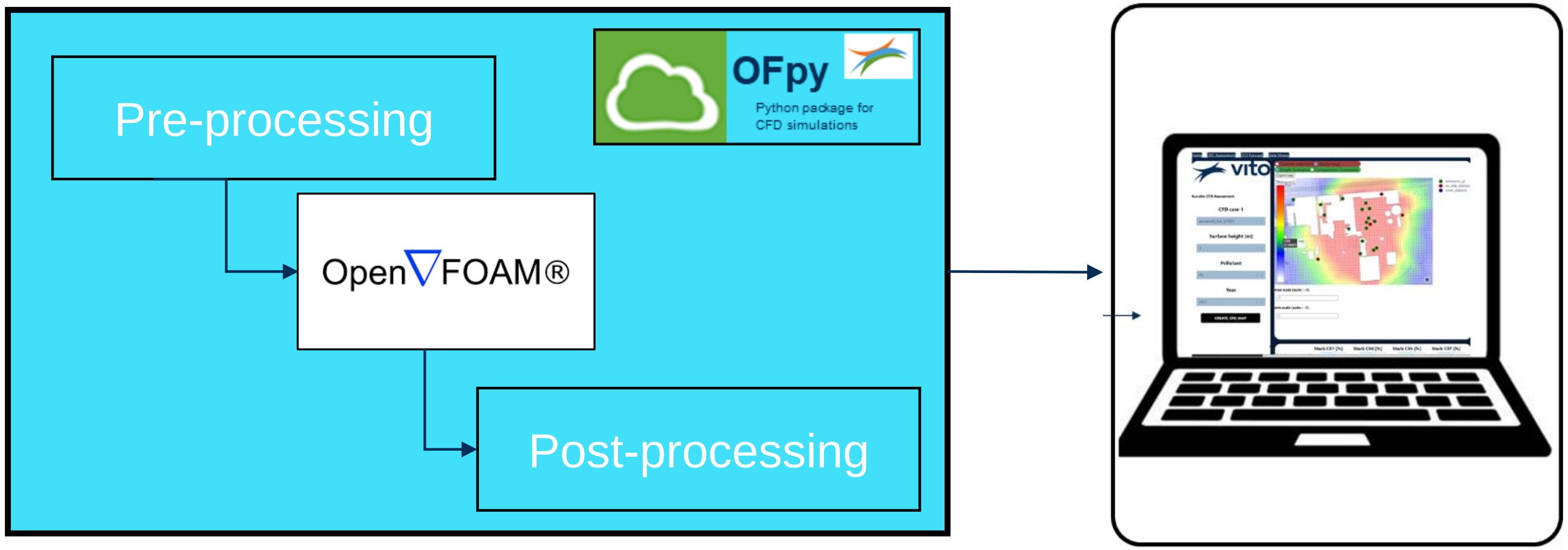


Running:

- For a typical run there are about 10-20 million fluid elements
- Very expensive computationally:
  - The domain is spitted in several regions
  - Each region runs in parallel in a dedicated CPU
  - Example: 128 [CPU] * 6 [hours] * 72 [wind sectors] ≈ 55000 cpu hours

Ofpy manages all the process

Interactive dashboard



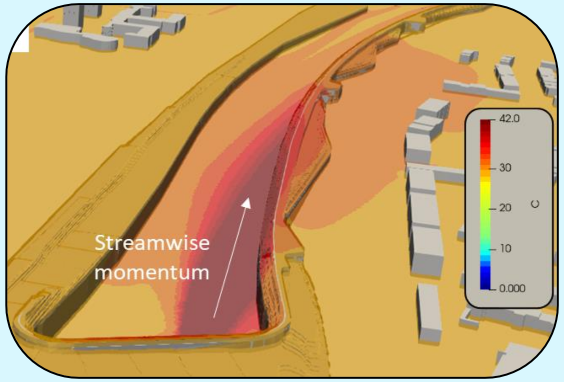
Applications

Applications: Complex tunnels (MER)

Applications: Complex tunnels (MER)

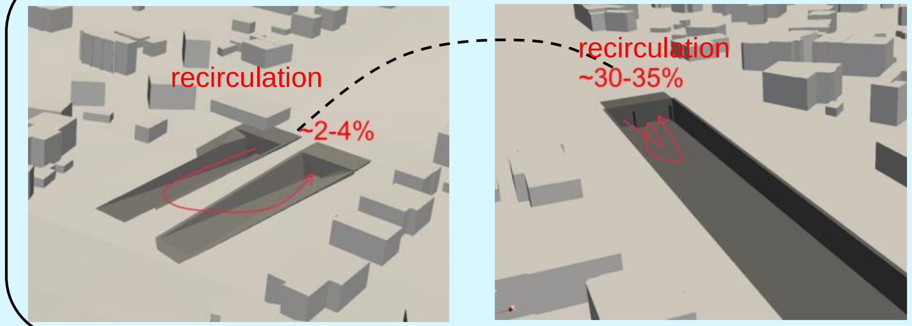
Tunnel mouths:

Depressed road + screens



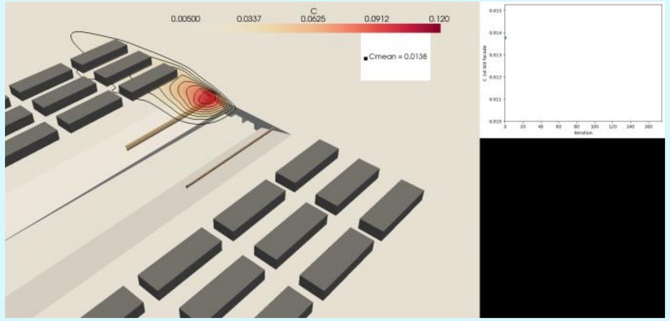
- good mitigation strategy

Nonsymmetrical tunnel mouths



- Accumulation on one side

Parametric/ optimization study

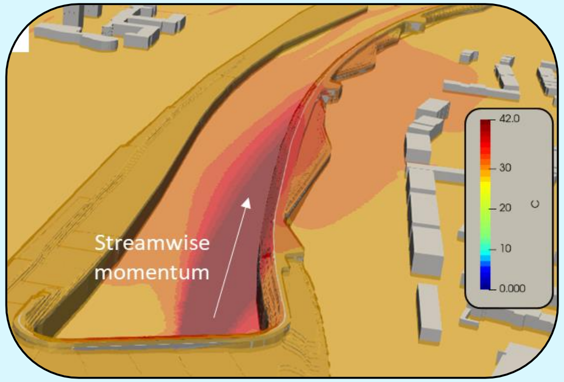


- Next talk: Tunnel model

Applications: Complex tunnels (MER)

Tunnel mouths:

Depressed road + screens



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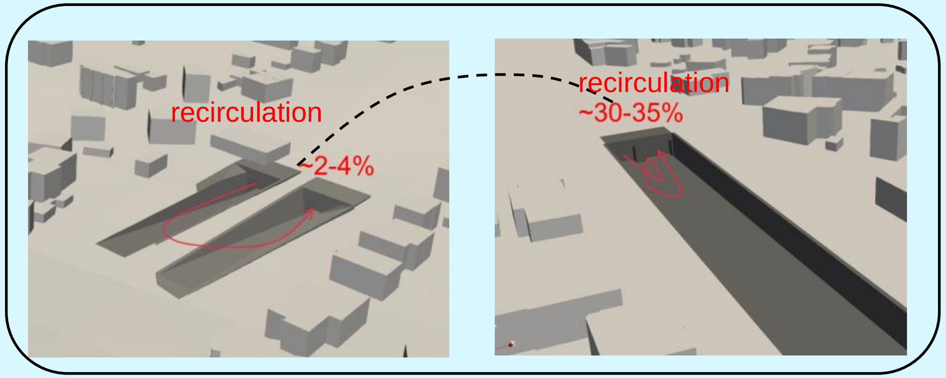

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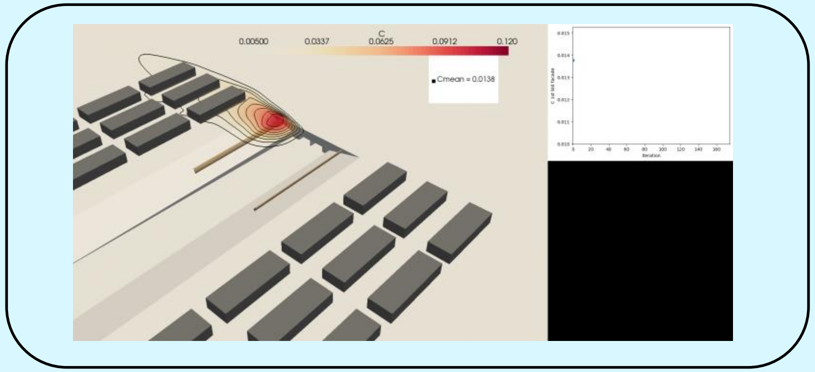
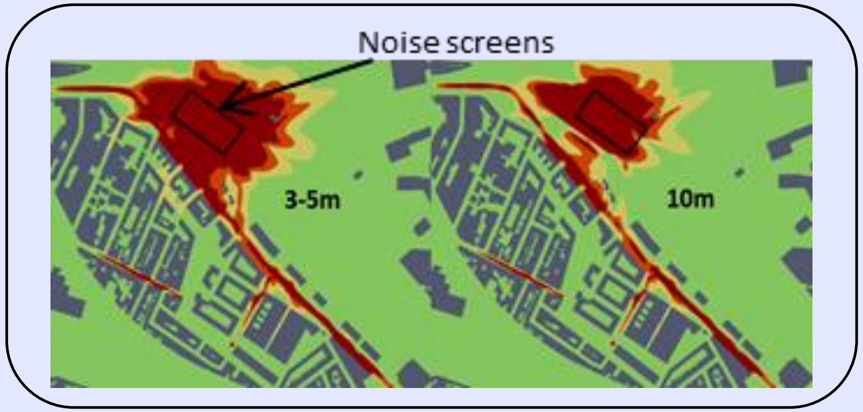


- Next talk: Tunnel model

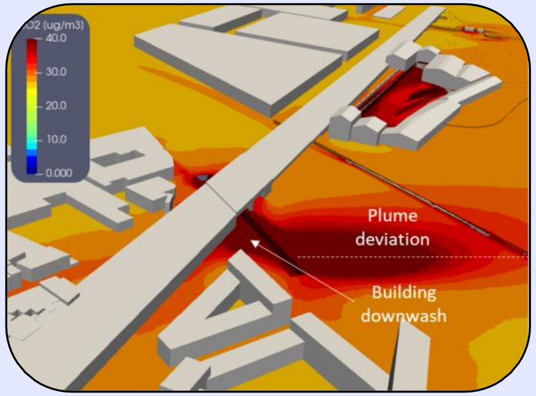
Tunnel openings:

Tunnel openings



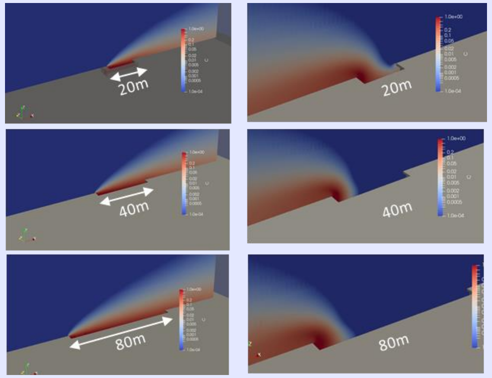
- Remove pollutants from the tunnel. But create hot spots

Proximity of buildings



- accumulation at the facade

Parametric study



- Next talk: tunnel model

Applications: Industrial sites

Modeling of guided emissions

Modeling of Non-Guided emissions

Applications: Industrial sites

Modeling of guided emissions

Modeling of Non-Guided emissions

Diffused emissions inference based on sensor networks

Applications: Industrial sites

Modeling of guided emissions

Diffused emissions inference based on sensor networks

Modeling of Non-Guided emissions

Impact of 3D features

Applications: Industrial sites

Modeling of guided emissions

Modeling of Non-Guided emissions

Diffused emissions inference based on sensor networks

Impact of 3D features

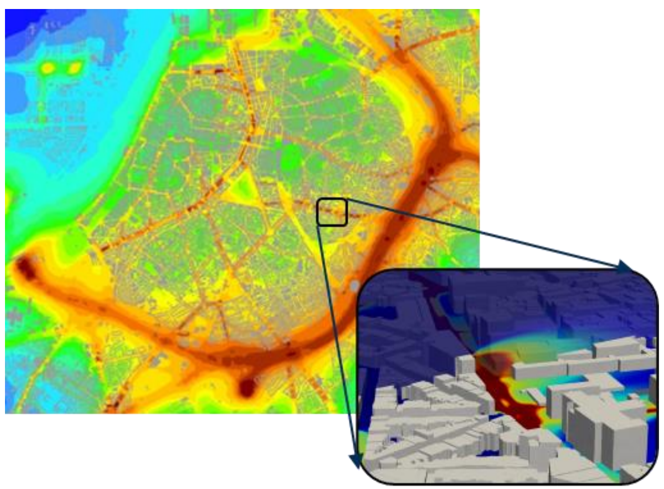
Interactive dashboard

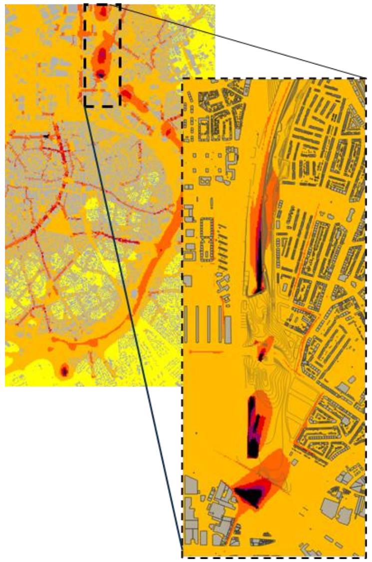
- Forecast analysis
- Scenario analysis

Conclusion:

1) CFD model is used to complement AtmoStreet by zooming into complex situations

- Street canyons
- tunnels
- Industrial sites





Conclusion:

1) CFD model is used to complement AtmoStreet by zooming into complex situations

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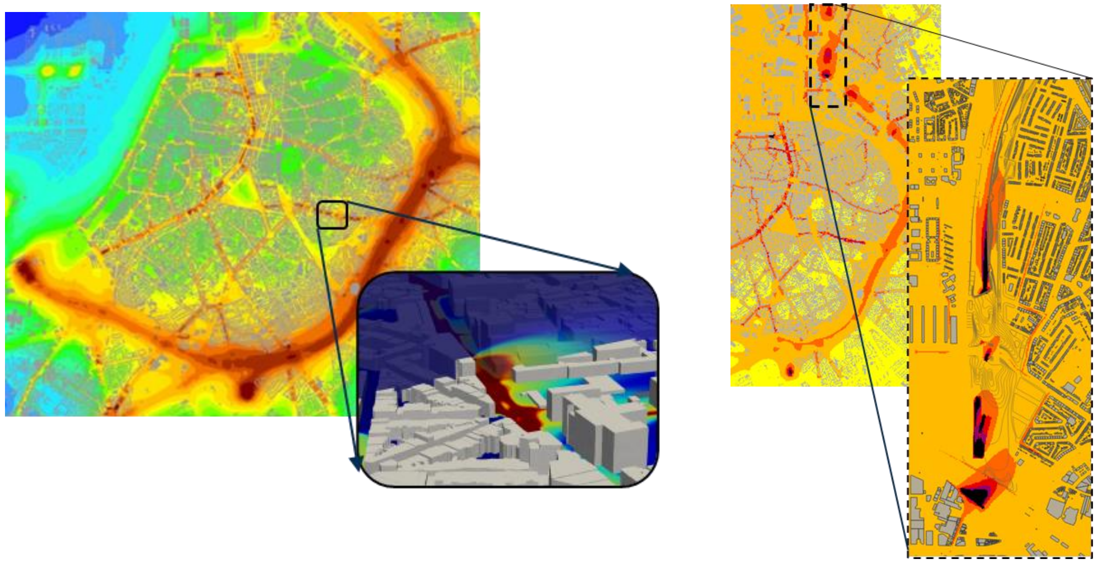

2) Use correction factors in AtmoStreet derived from CFD:

Next talk by Stijn Vranckx