HARMO'17

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ESTIMATING THE IMPACT OF URBAN VEGETATION ON AIR QUALITY IN A NEIGHBORHOOD: REAL CASE VS NEW VEGETATION SCENARIOS

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LIFE+RESPIRA
Life

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LIFE+RESPIRA project

- *Nowadays, urban air quality is one of the most important environmental problems (in Europe, 370000 premature deaths due to respiratory diseases, with associated health care costs of 380000 M€/y).*

- *LIFE+RESPIRA project goal: To demonstrate that it is possible to improve urban air quality and reduce exposure to air pollution by promoting healthy and sustainable mobility and a better urban planning and design.*

- *Our LIFE+RESPIRA project task: Development of a specific tool able to reproduce accurate pollutant maps and estimate the impact of urban vegetation.*

- *A CFD-RANS model has been used for simulating the urban air pollution.*

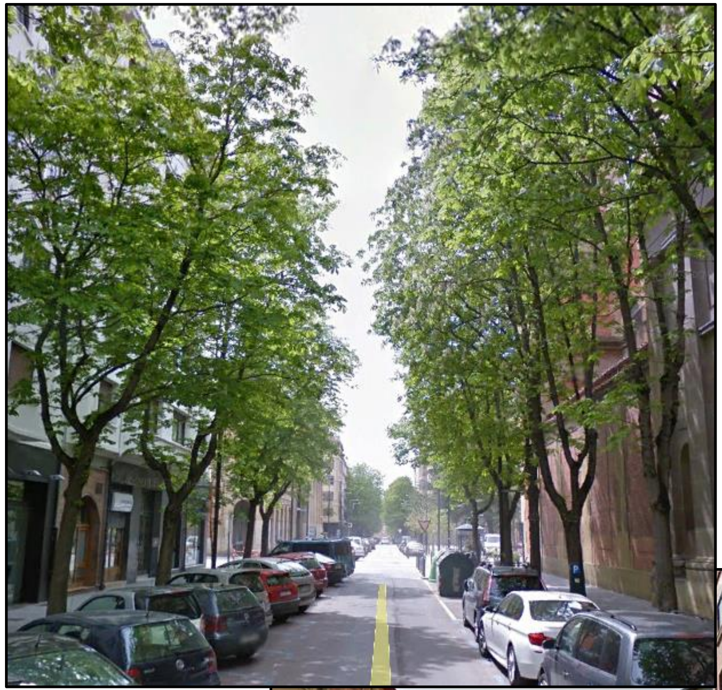
Main objective

Determine the impact of vegetation on Air Quality in a real urban environment considering:

- *The Dynamical effects*
- *The Pollutant deposition*

For this purpose, we analyze:

- ✓ *The pollutant distributions in a real neighborhood with vegetation.*
- ✓ *The effects of including new vegetation in one of the street.*



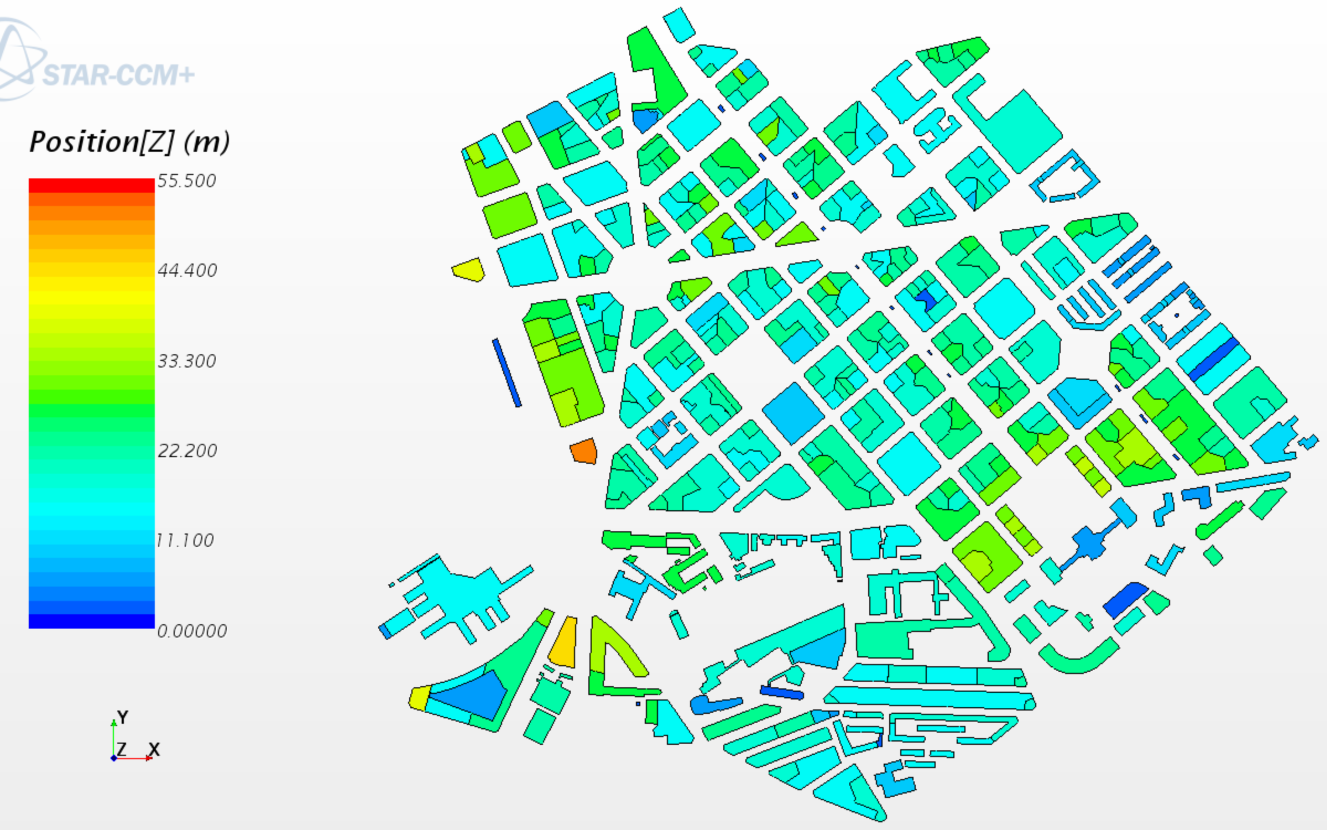
Urban Morphology

Pamplona´s neighborhood
(Source: Google Maps satellite image)

Buildings that make up the neighborhood
(AutoCAD 2016 file provided by Navarra University)

Urban Morphology

Pamplona´s neighborhood
(Source: Google Maps satellite image)

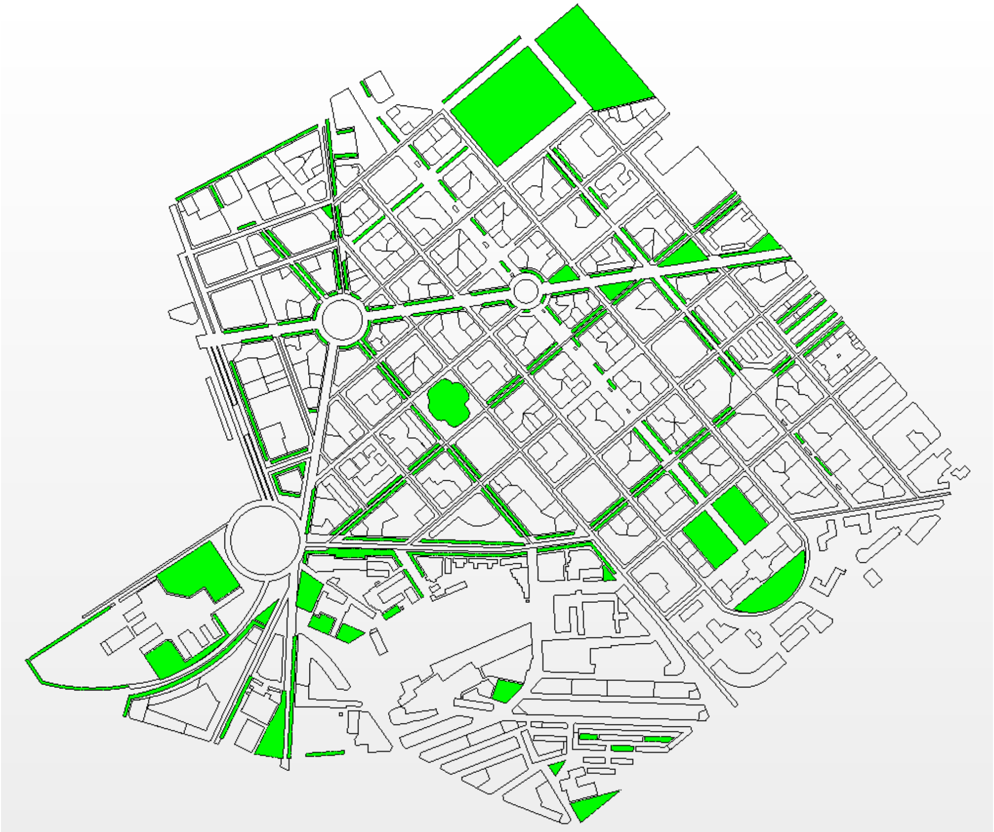


Actual heights of buildings:
CFD 3D model (*)

(*) CFD tool: STAR-CCM+9.04.011®

Geometry Model for Trees and Traffic emissions

Trees at Pamplona´s neighborhood
(Source: Google Earth satellite image)



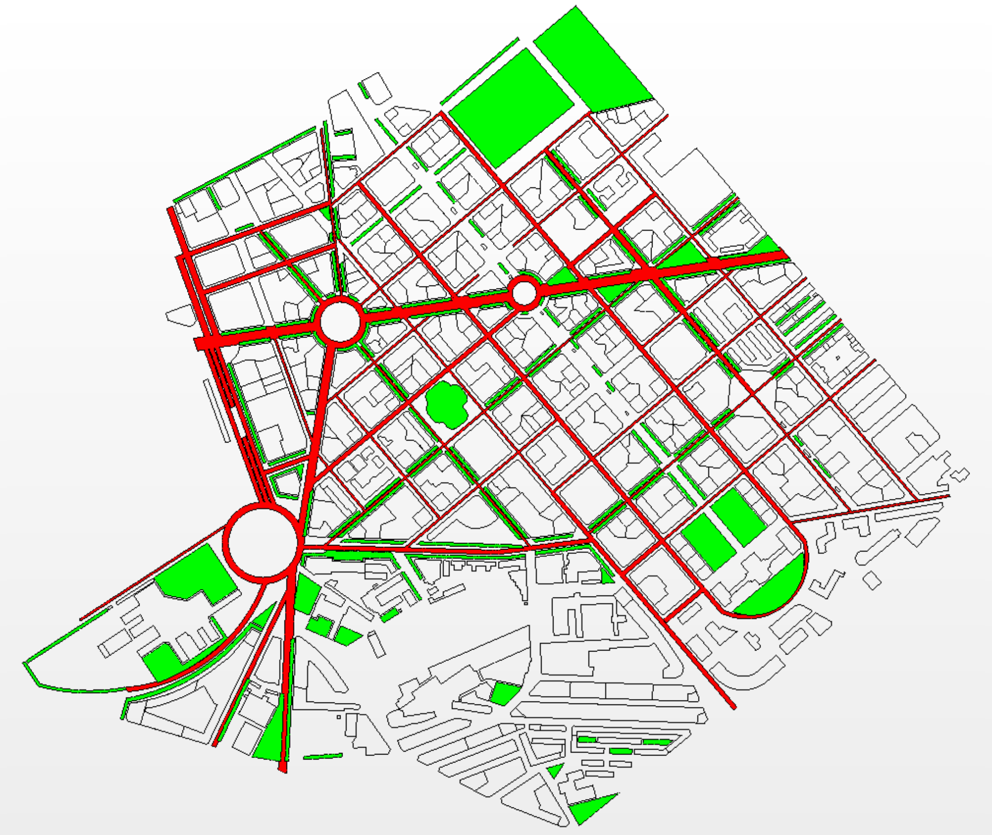
CFD 3D model (*)

(*) CFD tool: STAR-CCM+9.04.011®

Geometry Model for Trees and Traffic emissions

Roads at Pamplona´s neighborhood

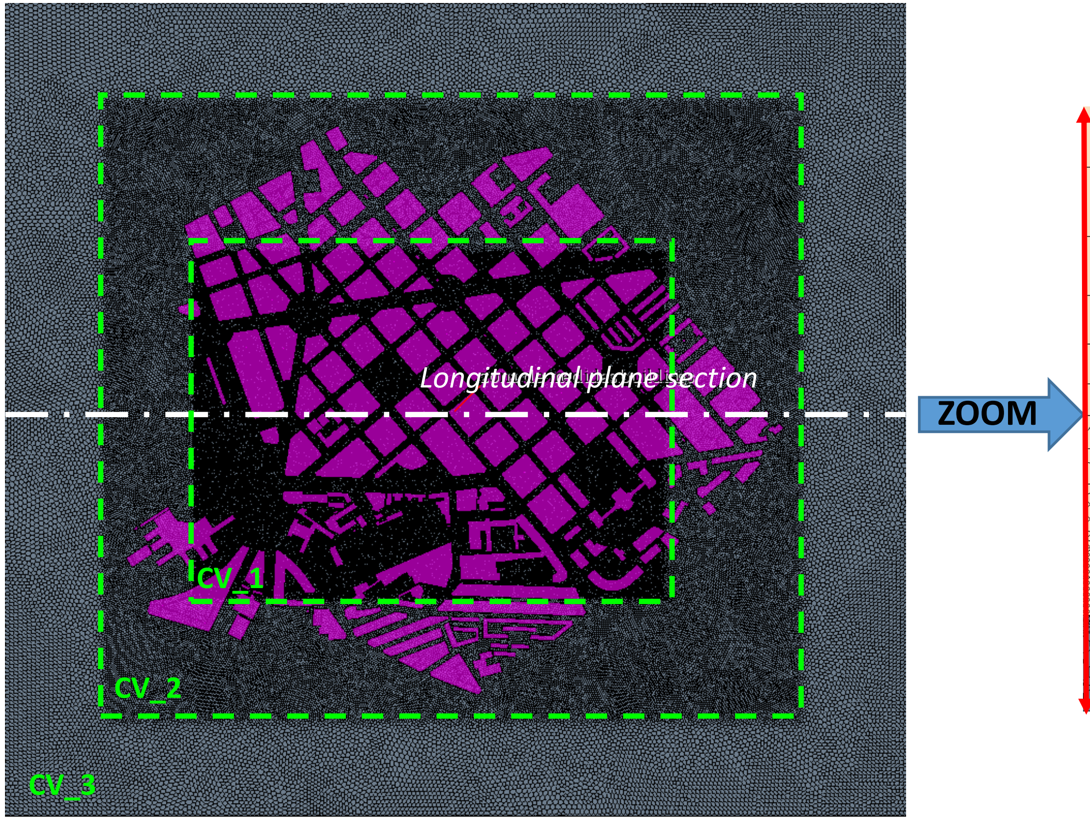
(Source: Google Earth satellite image)



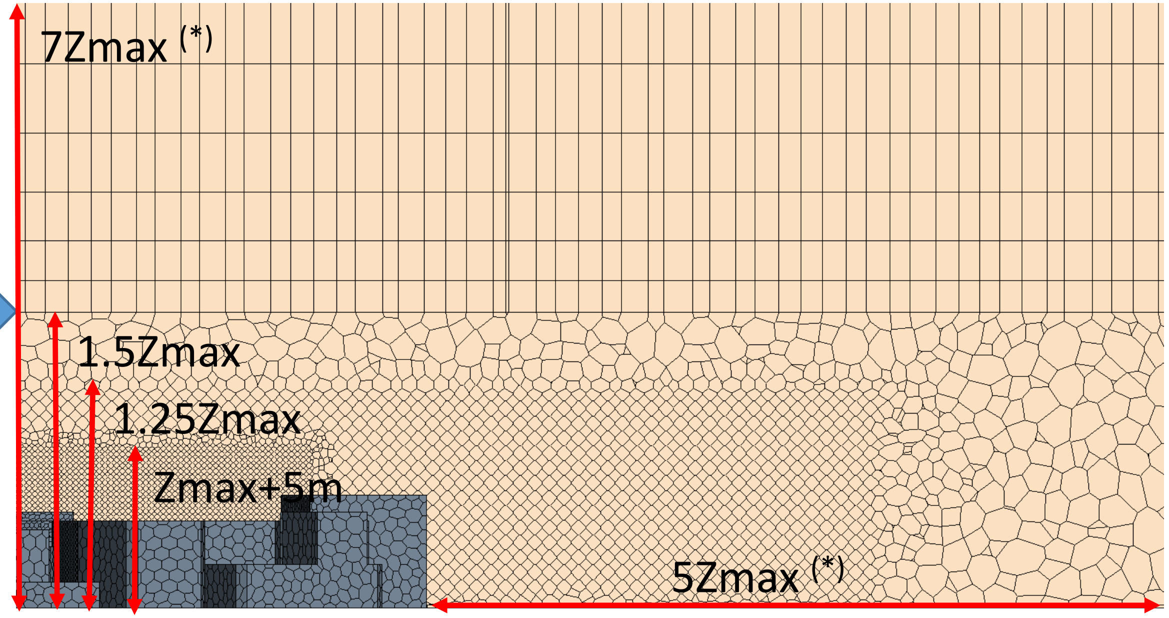
CFD 3D model (*)

(*) CFD tool: STAR-CCM+9.04.011®

Mesh Model



CFD Mesh model (*)



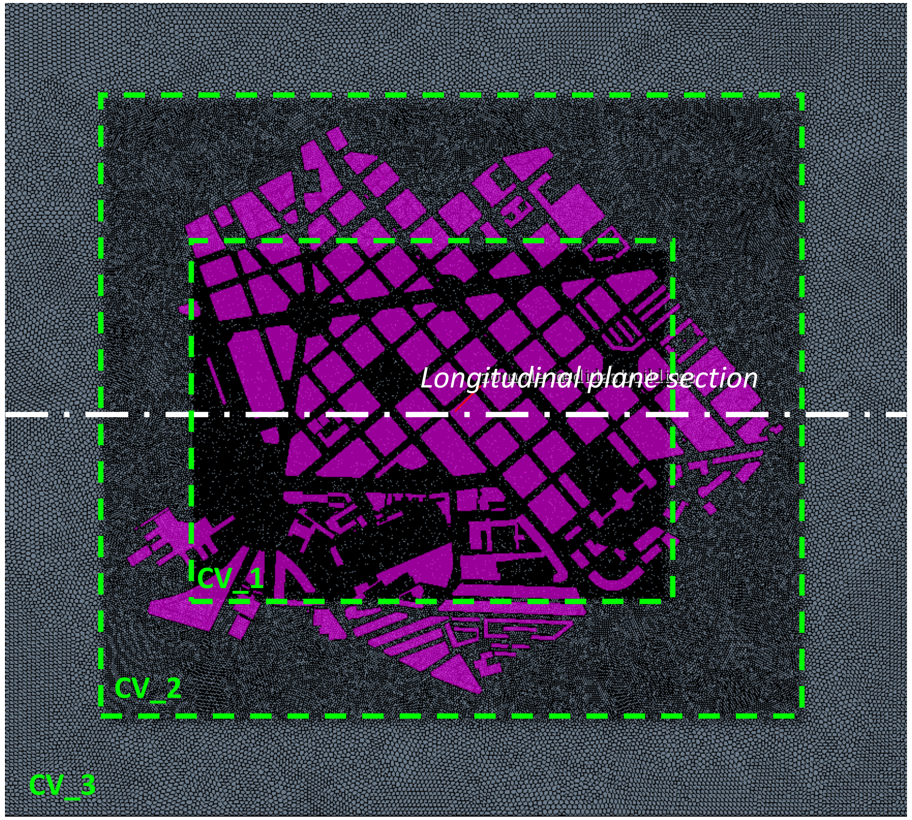
Zmax = 51m

Total number of cells: 7.4×10^6

(*) CFD tool: STAR-CCM+9.04.011®

(*) Franke et al. (2007)

Mesh Model



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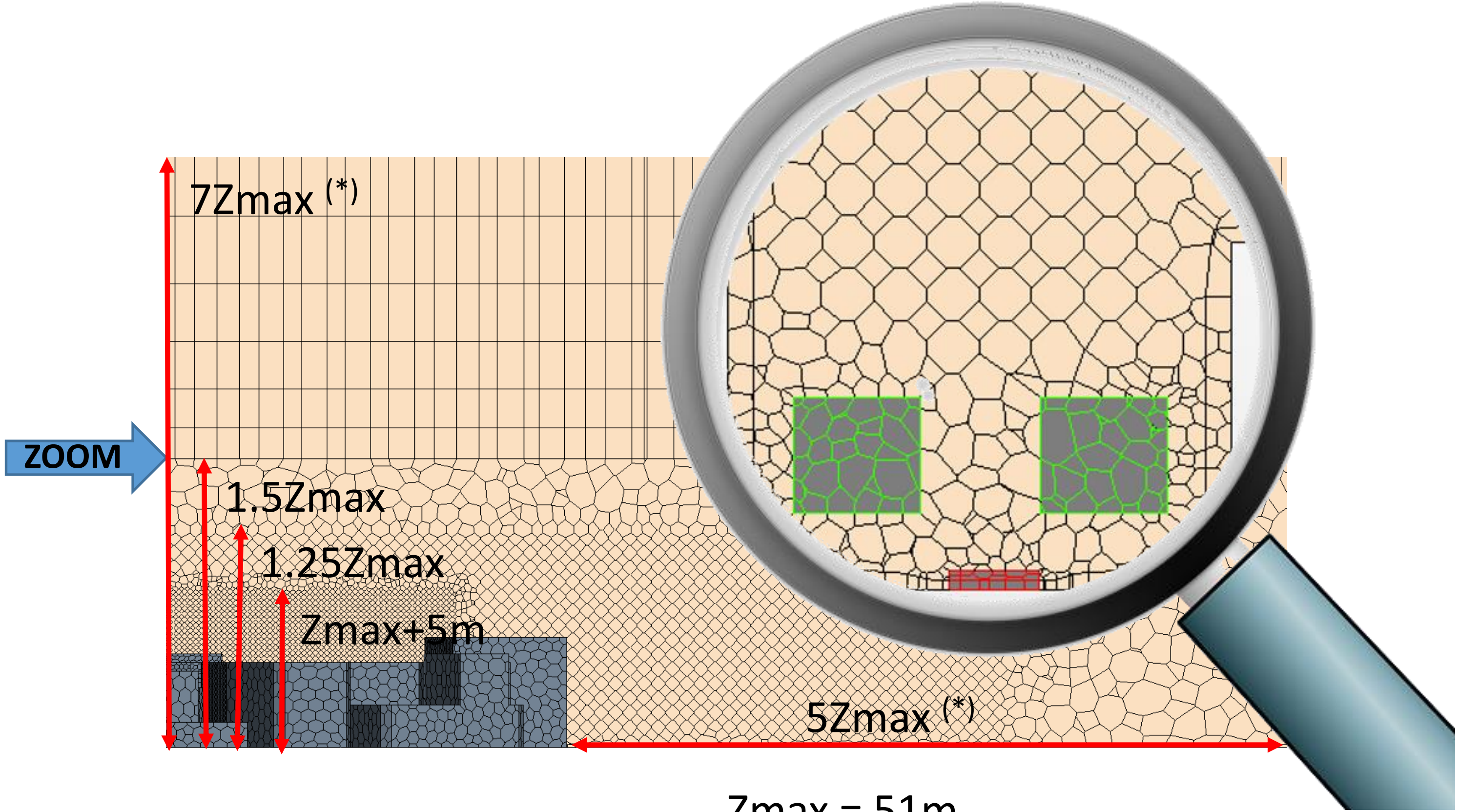

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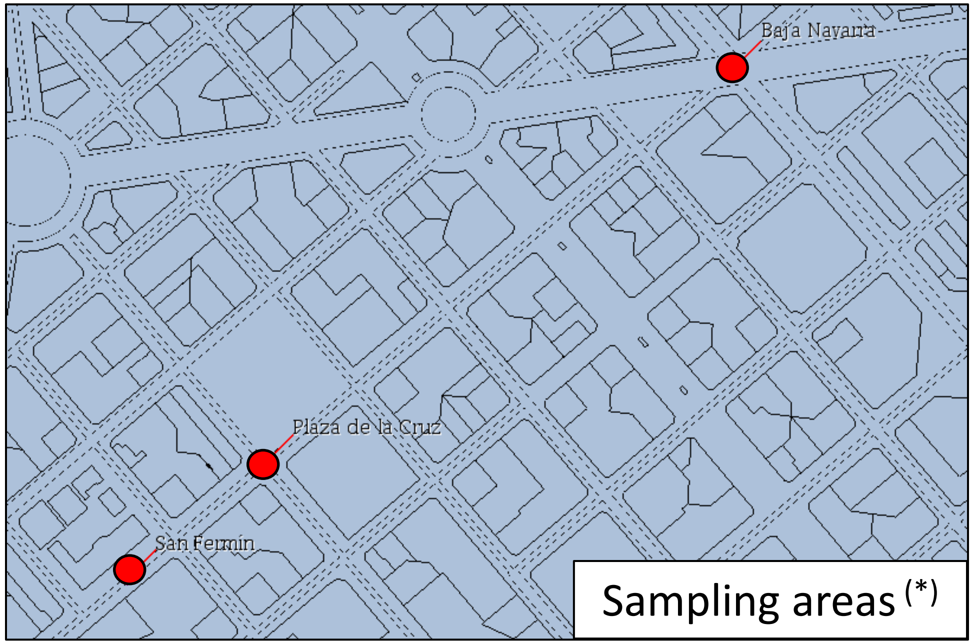
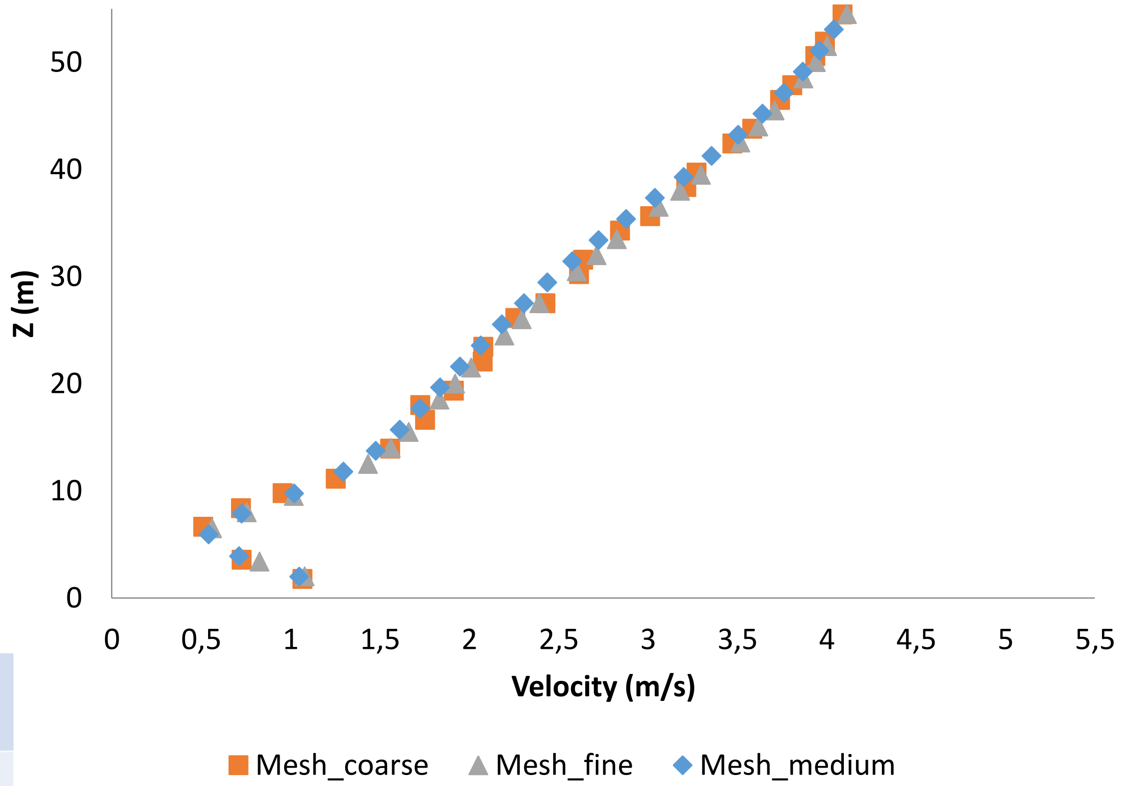
Meshing Test



Sampling areas (*)

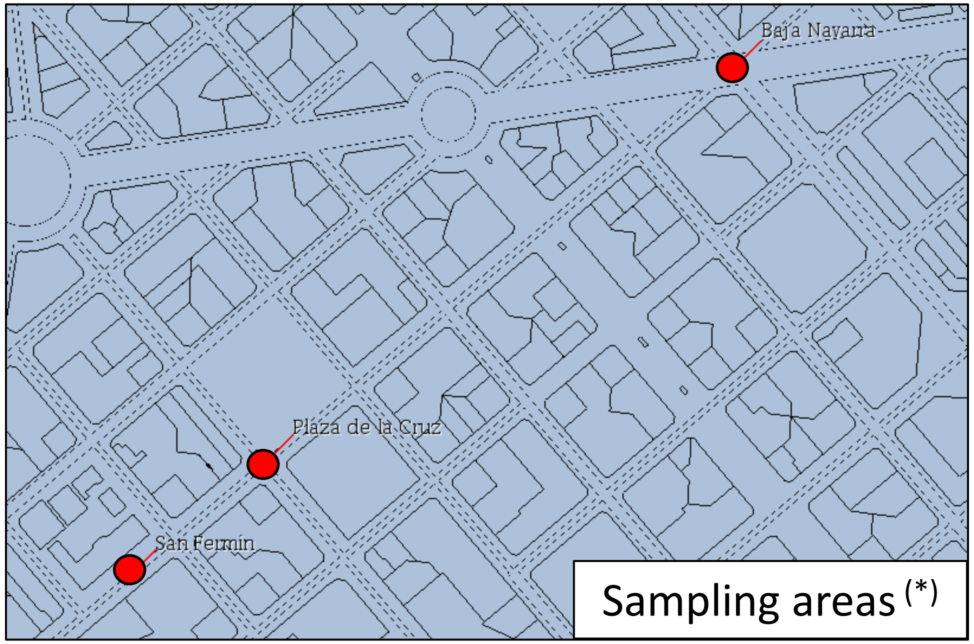
Mesh	Total number of cells ($\times 10^6$)	(CV_i) $_{i=1,2,3}$ (m)
Coarse	7.4	2.7 x 6.7 x 10
Medium	13.6	2 x 5 x 10
Fine	27.3	1.5 x 3.8 x 10



Velocity profiles in *San Fermin*

(*) CFD tool: STAR-CCM+9.04.011®

Meshing Test



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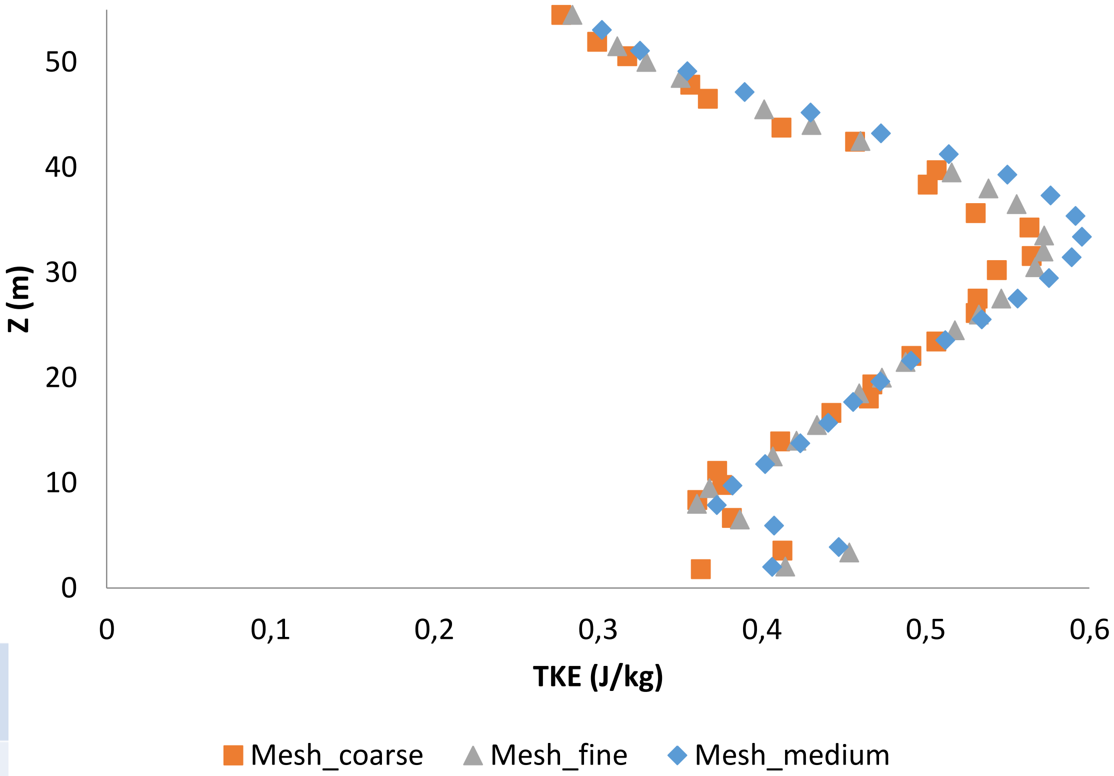


Turbulent Kinetic Energy (TKE) profiles in *San Fermin*

(*) CFD tool: STAR-CCM+9.04.011®

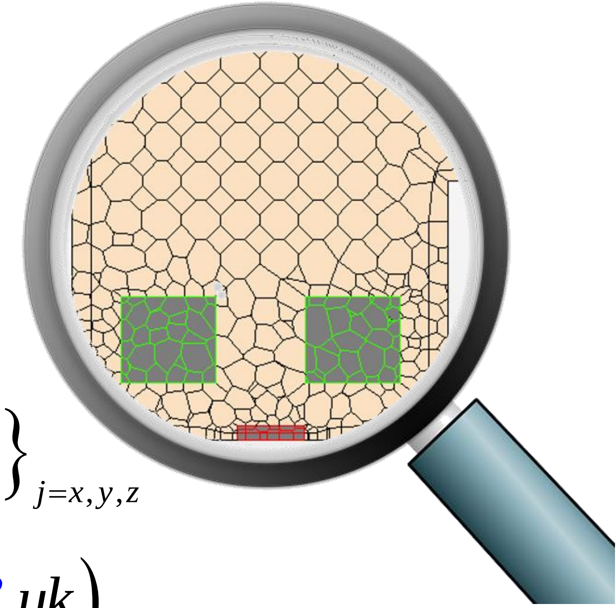
Physical Models

- ❑ *Steady State Simulations*
- ❑ *Segregated Flow Model*
- ❑ *RANS as turbulent approach:*
  - *Realizable K-ε Two-Layer model*
  - *All Y+ wall hybrid treatment*

- ❑ *Neutral atmospheric conditions*
- ❑ *Default values of STAR-CCM + 9.04.011® as free parameters of the turbulent model*

C_M	C_μ	$C\varepsilon_1$	$C\varepsilon_2$	σ_K	σ_ε	C_t	Re_y*	ΔRe
2	0.09	1.44	1.90	1	1.2	1	60	10

Physical Models: Dynamical and pollutant deposition effects of vegetation



In cells where there are vegetation

\+ *a momentum sink*

$$\left\{ Su_j = -\rho LAD\, c_d\; u\, u_j \right\}_{j=x,y,z}$$

\+ *a TKE source/sink*

$$S_k = \rho LAD\, c_d \left(\beta_p u^3 - \beta_d u k \right)$$

\+ *a TDR source/sink*

$$S_\varepsilon = \rho LAD\, c_d \left(C_{\varepsilon 4} \beta_p \frac{\varepsilon}{k} u^3 - C_{\varepsilon 5} \beta_d u \varepsilon \right)$$

\+ *a mass sink*

$$S_{Veg.} = -LAD\; Vdep\; C_{CFD}{}^{(*)}$$

c_d β_p β_d $C_{\varepsilon 4}$ $C_{\varepsilon 5}$ *from Santiago et al. (2013)*

(*) Santiago et al. (2016)

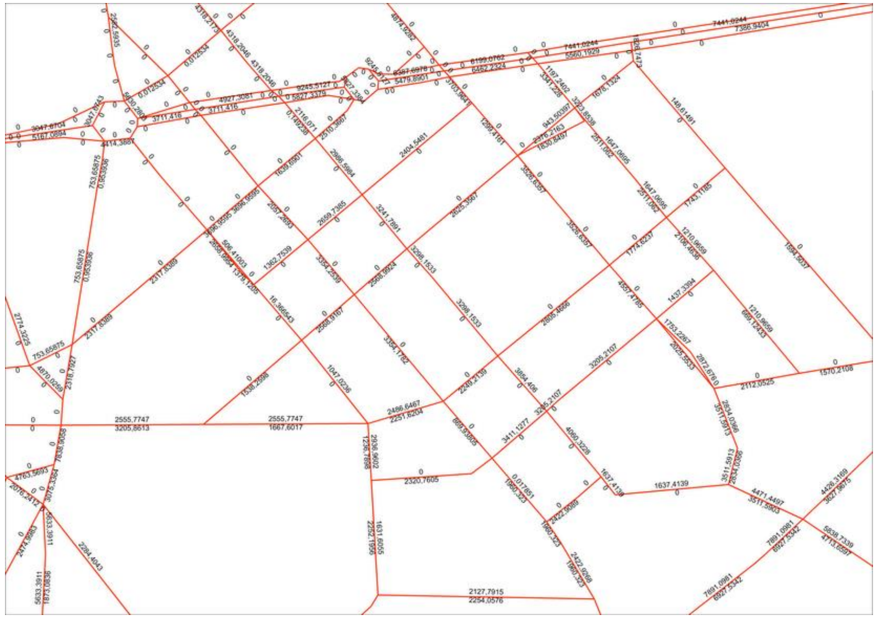
Physical Model: NOx traffic emissions

+ *an additional passive scalar transport equation*

$$\left\{\partial_j\left(\rho u_j C_{CFD}(\vec{r}) - \frac{\mu_t}{Sc_t}\partial_j C_{CFD}(\vec{r})\right) = S_C - \left|S_{Veg.}\right|\right\}_{j=x,y,z}$$

+ *Pollutant source at traffic cells proportional to traffic intensity*

+ *Without atmospheric chemistry*



i-th street

Daily average traffic intensity *at Pamplona´s neighborhood (Source: University of Navarra)*

Physical Model: NOx traffic emissions

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$$\left\{ \partial_j \left(\rho u_j C_{CFD}(\vec{r}) - \frac{\mu_t}{Sc_t} \partial_j C_{CFD}(\vec{r}) \right) = S_C - \left| S_{Veg.} \right| \right\}_{j=x,y,z}$$

+ *Pollutant source at traffic cells proportional to traffic intensity*

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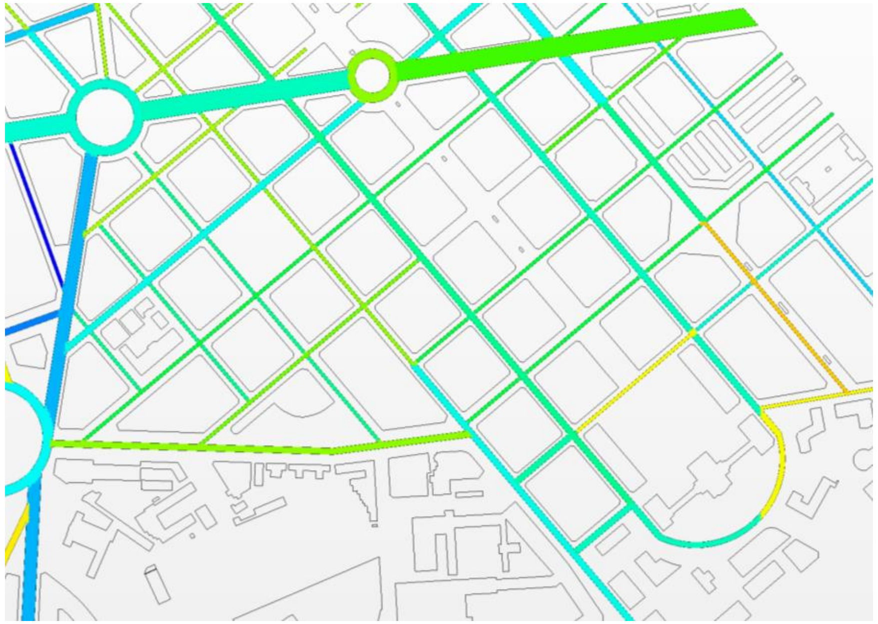


i-th street

Daily average traffic intensity *at Pamplona´s neighborhood (Source: University of Navarra)*

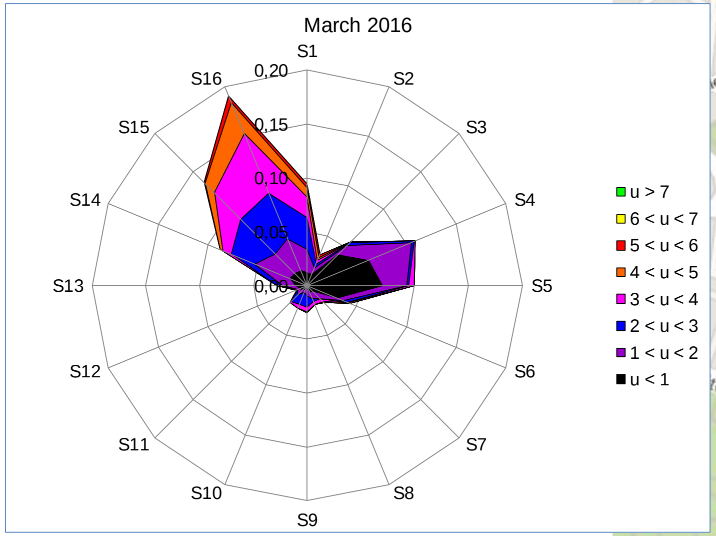
Boundary Conditions

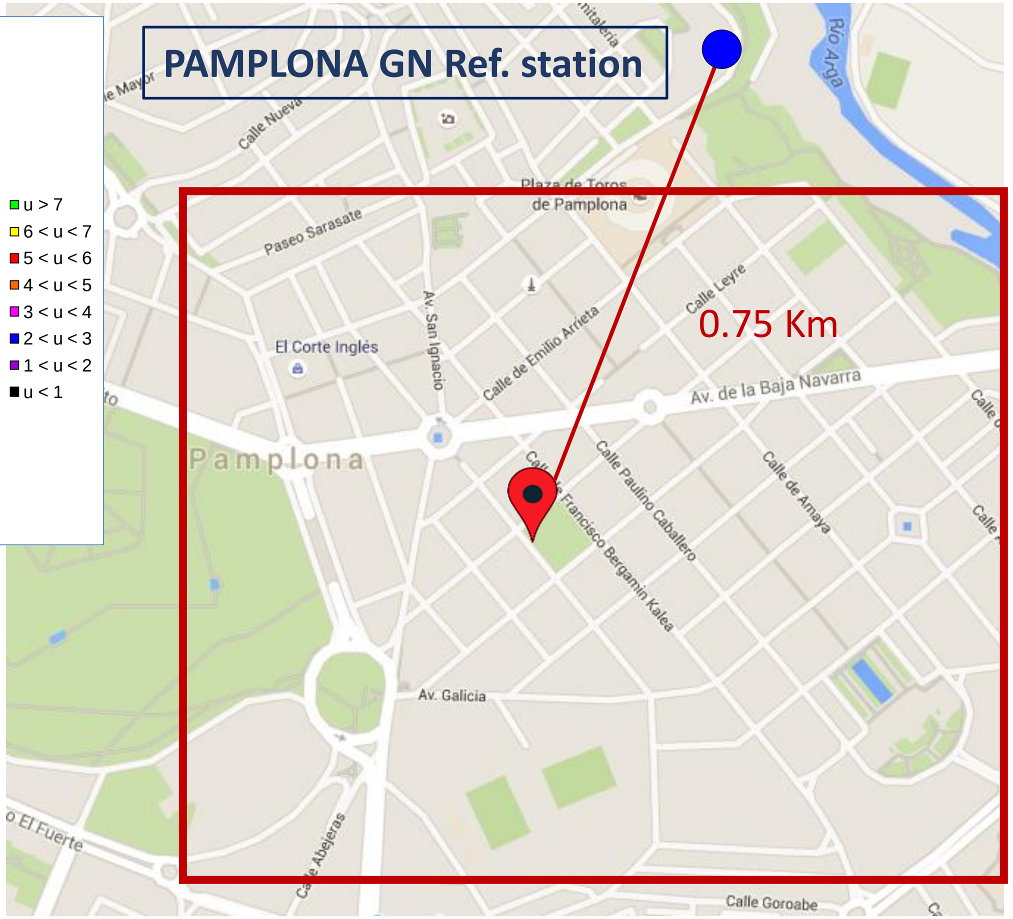
- *__Building__: Solid boundary with surface specification: smooth*
- *__Ground:__ Solid boundary with surface specification: roughness*
- *__Inlet:__* $u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z+z_0}{z_0}\right); \; k = \frac{{u_*}^2}{\sqrt{C_\mu}}; \; \varepsilon = \frac{{u_*}^3}{\kappa(z+z_0)}$
- *__Outlet:__* $\Delta P_{in-out} = 0$
- *__Top:__ Symmetry boundary condition*

Methodology (*)

- **Time period**
  - March, 1^{st} – 31^{th}
- **Meteorological Data 2016(**) :**
  PAMPLONA GN Ref. Station

$$v_{ref}(t) \quad Sector(t)$$





(Source: Google Maps satellite image)

(*) Parra et al. (2010)

(**) Source: University of Navarra

- **CFD Simulations:**
  - LAD = 0.1 $m^2\ m^{-3}$
  - 16 Sectors
  - For $v_{ref} = 3.2\ m/s$, $v_{dep} \begin{cases} 0.005\ m/s \\ 0.01\ m/s \\ 0.03\ m/s \end{cases}$

48 SIMs

$$\frac{v_{dep}}{v_{ref}} \approx \frac{v^*_{dep}}{v^*_{ref}} \Rightarrow \frac{C_{CFD}}{v_{ref}} \approx \frac{C^*_{CFD}}{v^*_{ref}} \Rightarrow \begin{cases} v^*_{ref} \le 2\ m/s \rightarrow v_{dep} = 0.03\ m/s \\ 2\ m/s < v^*_{ref} \le 4.5\ m/s \rightarrow v_{dep} = 0.01\ m/s \\ 4.5\ m/s < v^*_{ref} \rightarrow v_{dep} = 0.005\ m/s \end{cases}$$

Methodology (*)

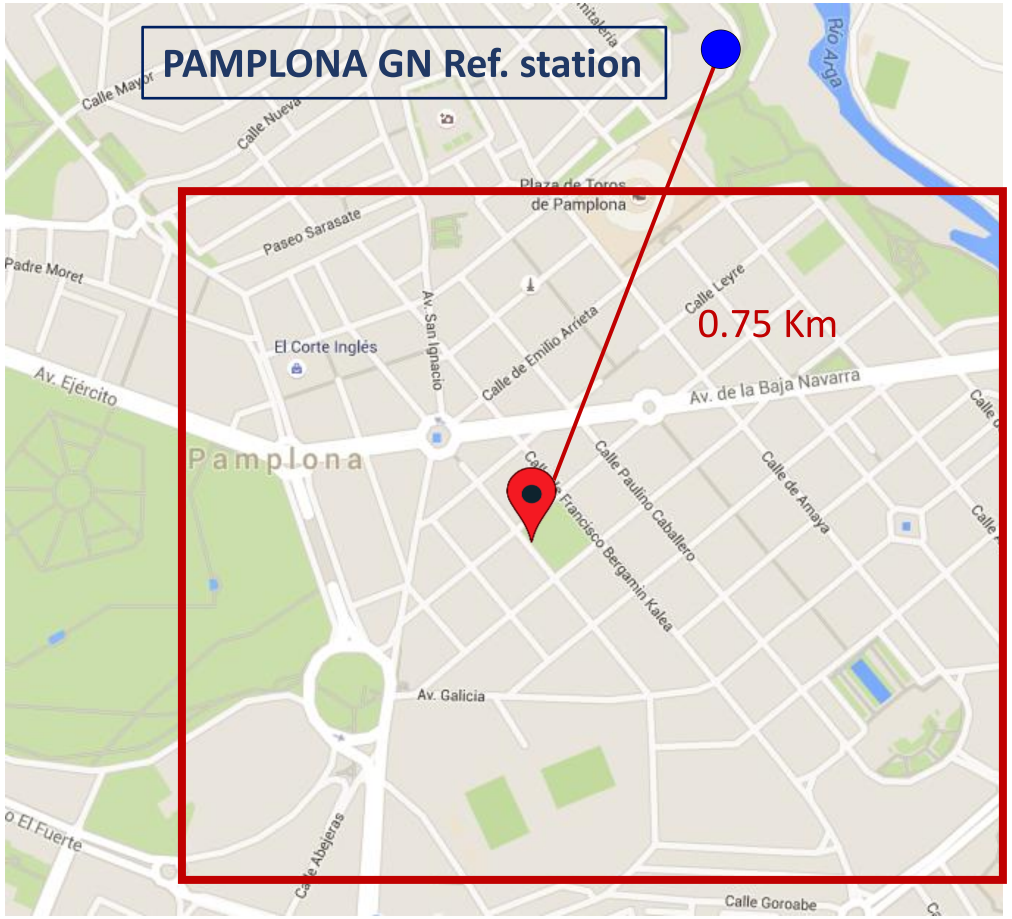
- *NOx Maps:*

$$C_{SIM}\left(\vec{r},t\right)=\frac{C_{CFD}(\vec{r},Sector(t))\cdot TF(t)}{v_{ref}\left(t\right)/v_{in}}Ct$$

$$If \quad v_{ref}\leq 1\,m/s \rightarrow v_{ref}=1\,m/s \quad \& \quad C_{CFD}(\vec{r},Sector(t))=\overline{C_{CFD}(\vec{r})}$$

$$\overline{C_{CFD}(\vec{r})}=\frac{1}{16}\sum_{i=1}^{16}C_{CFD}(\vec{r},Sector_i)$$

Ct is computed normalizing modelled concentration using time averaged concentration measured at air quality monitoring station



(Source: Google Maps satellite image)

(*) Parra et al. (2010)

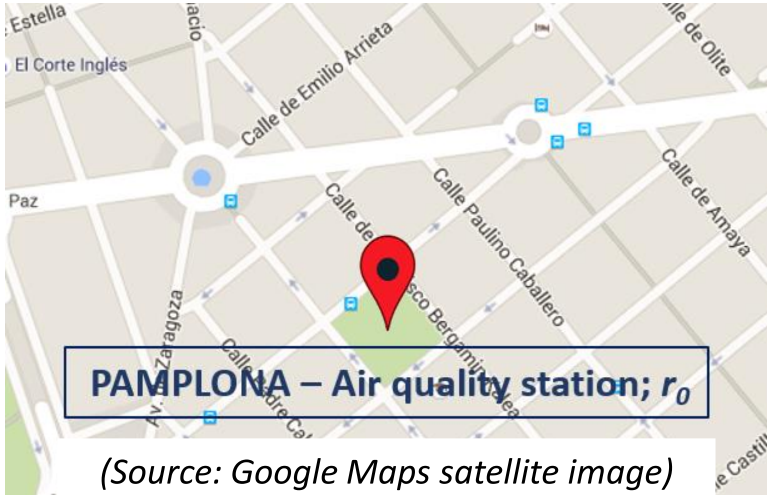
$TF\left(t\right)$ Hourly traffic evolution

- *Air Pollutants Data 2016(*) :*

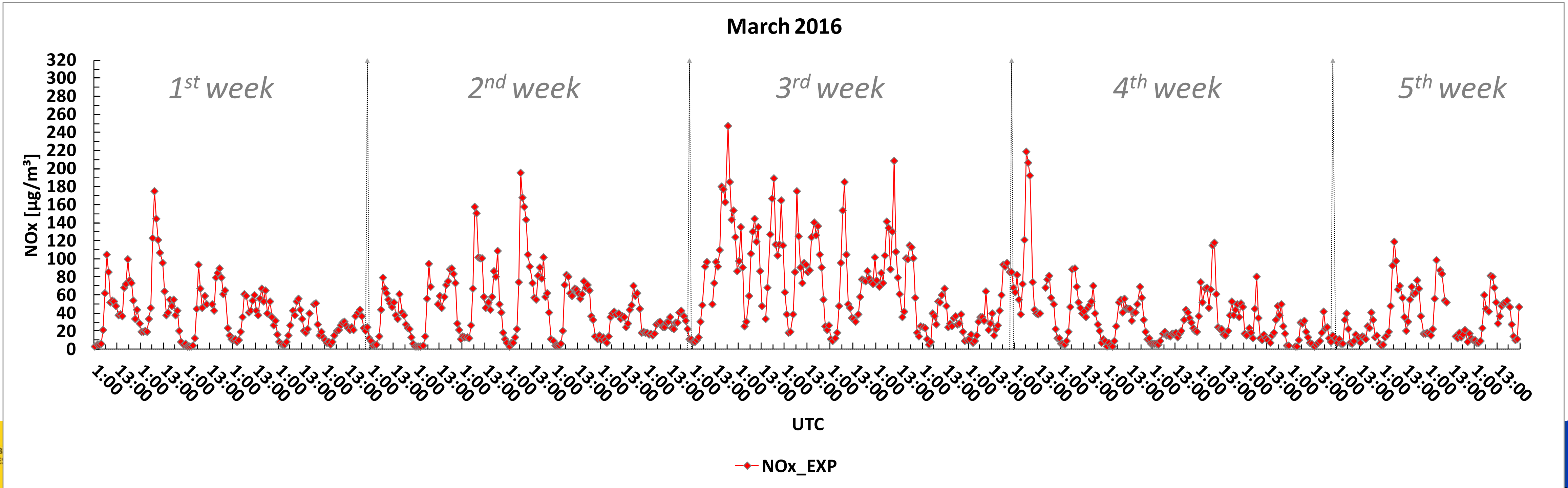
  Pamplona - Air Quality Station (NG)

  Teledyne 200E NOx analyzer

(*) Source: Gobierno de Navarra (GN)

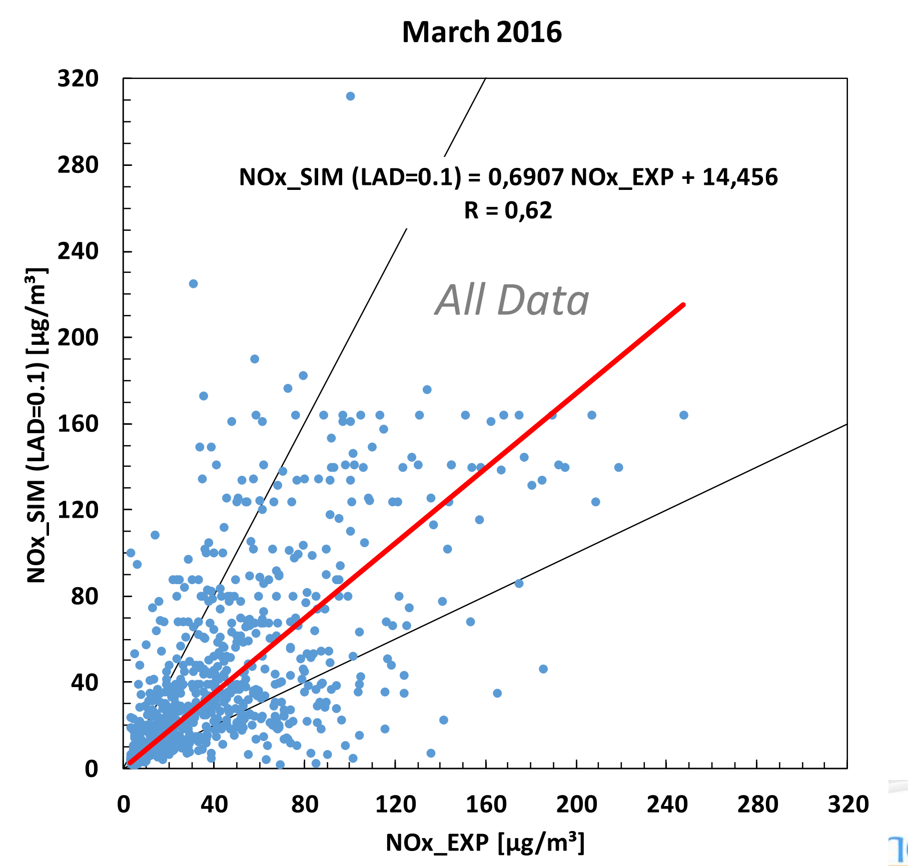


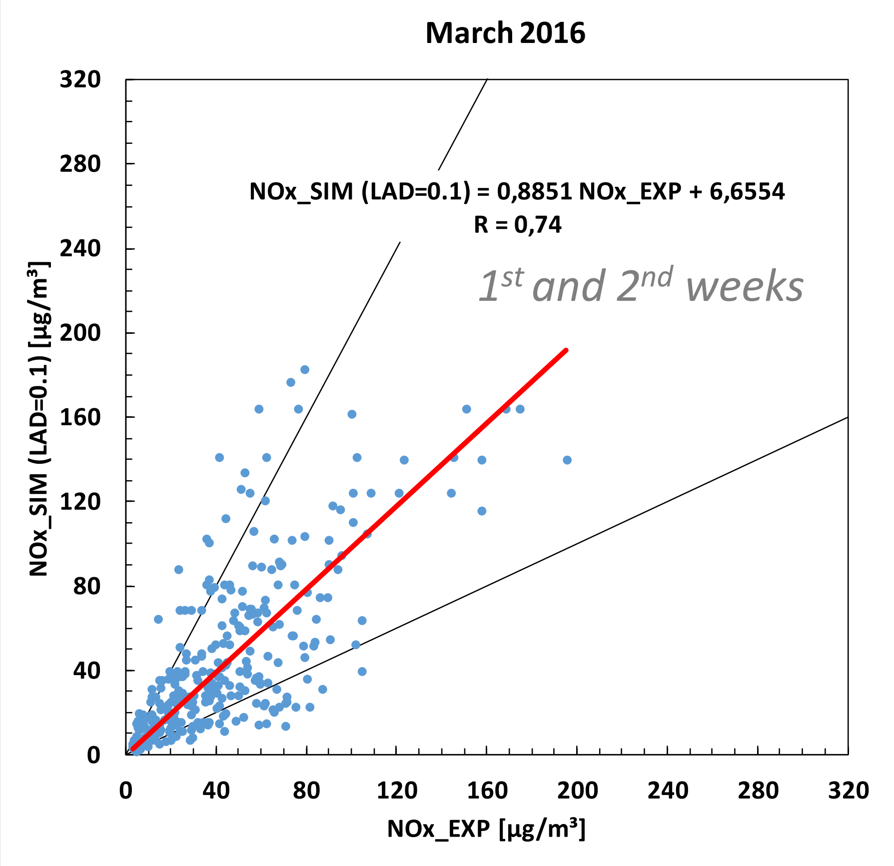
(Source: Google Maps satellite image)



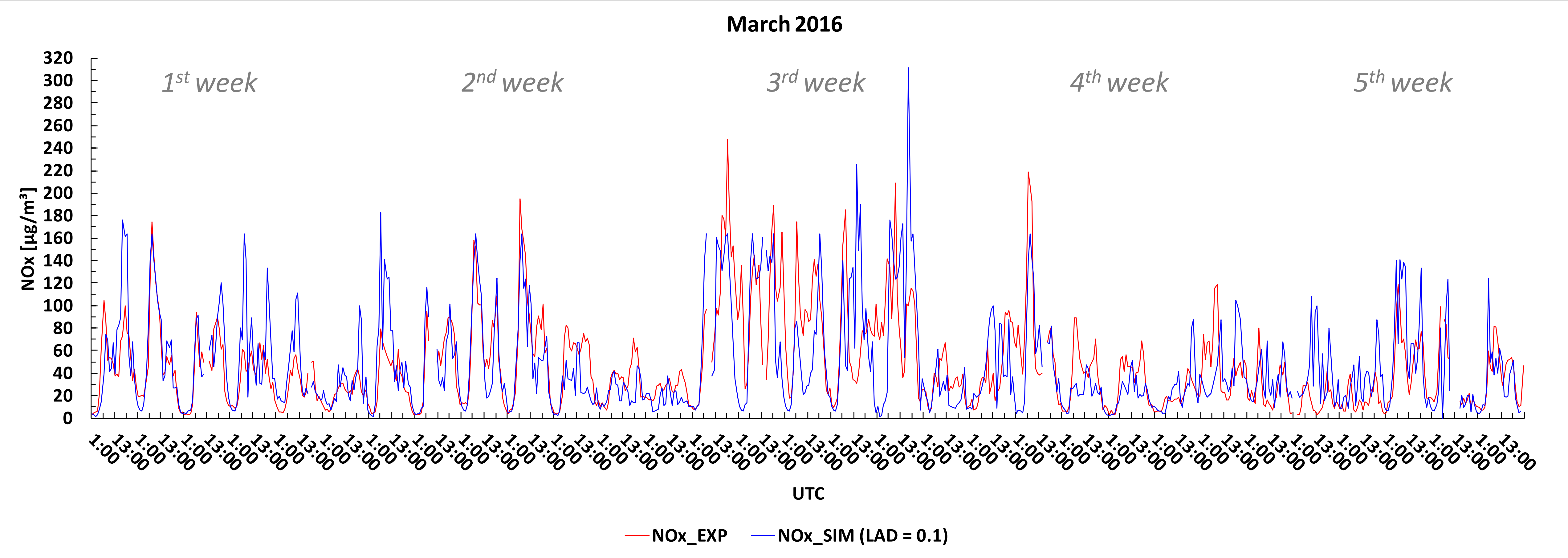
Results I: Statistical Coefficient R-squared

	All Data	*1st and 2nd weeks*
R	0.6228	0.7426
FAC2	0.6584	0.7222

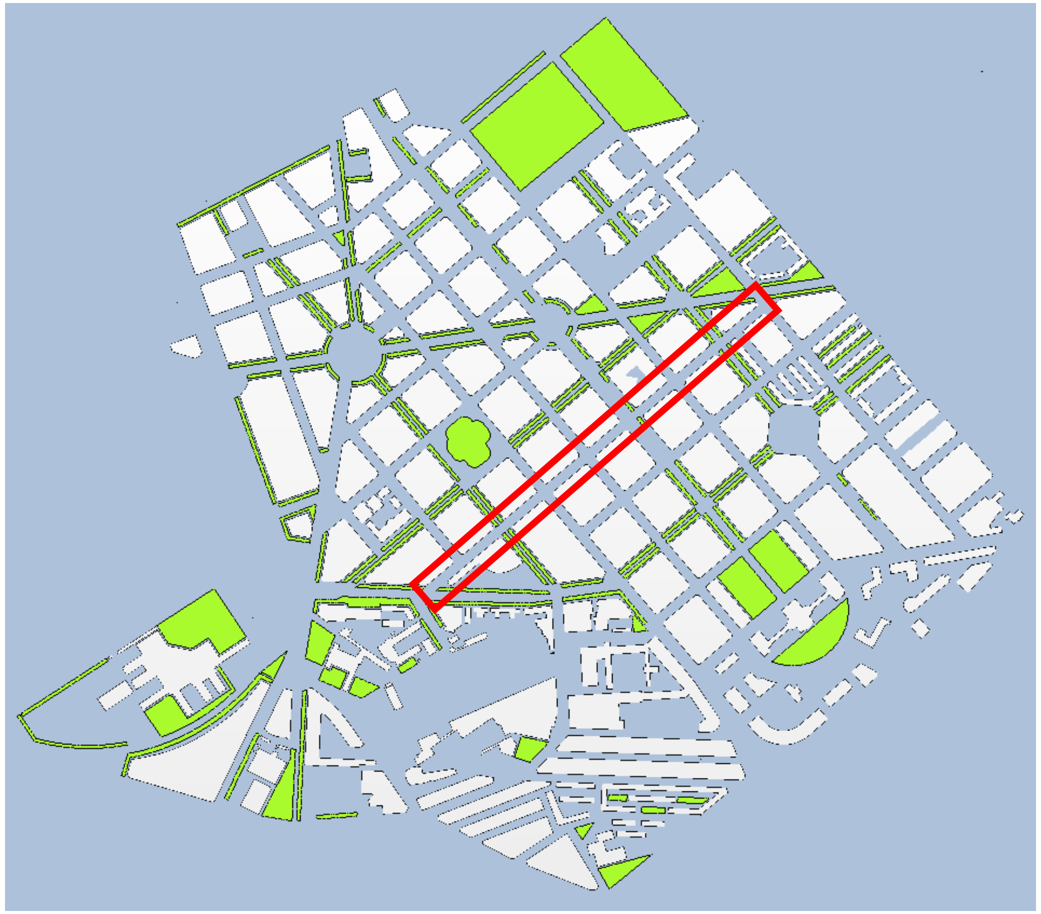




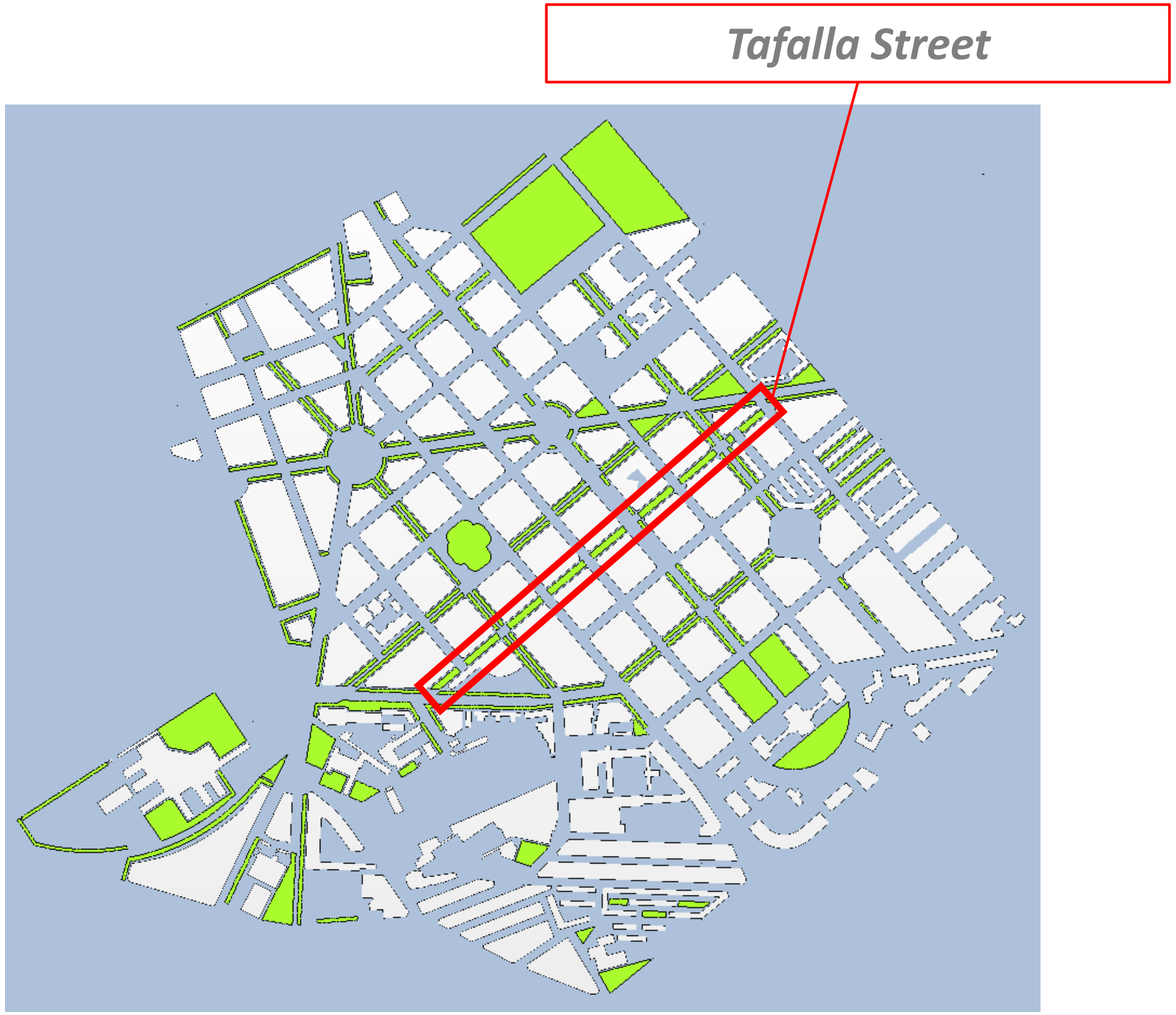
Results II: NOx time evolution



Vegetation effects on pollutant concentration

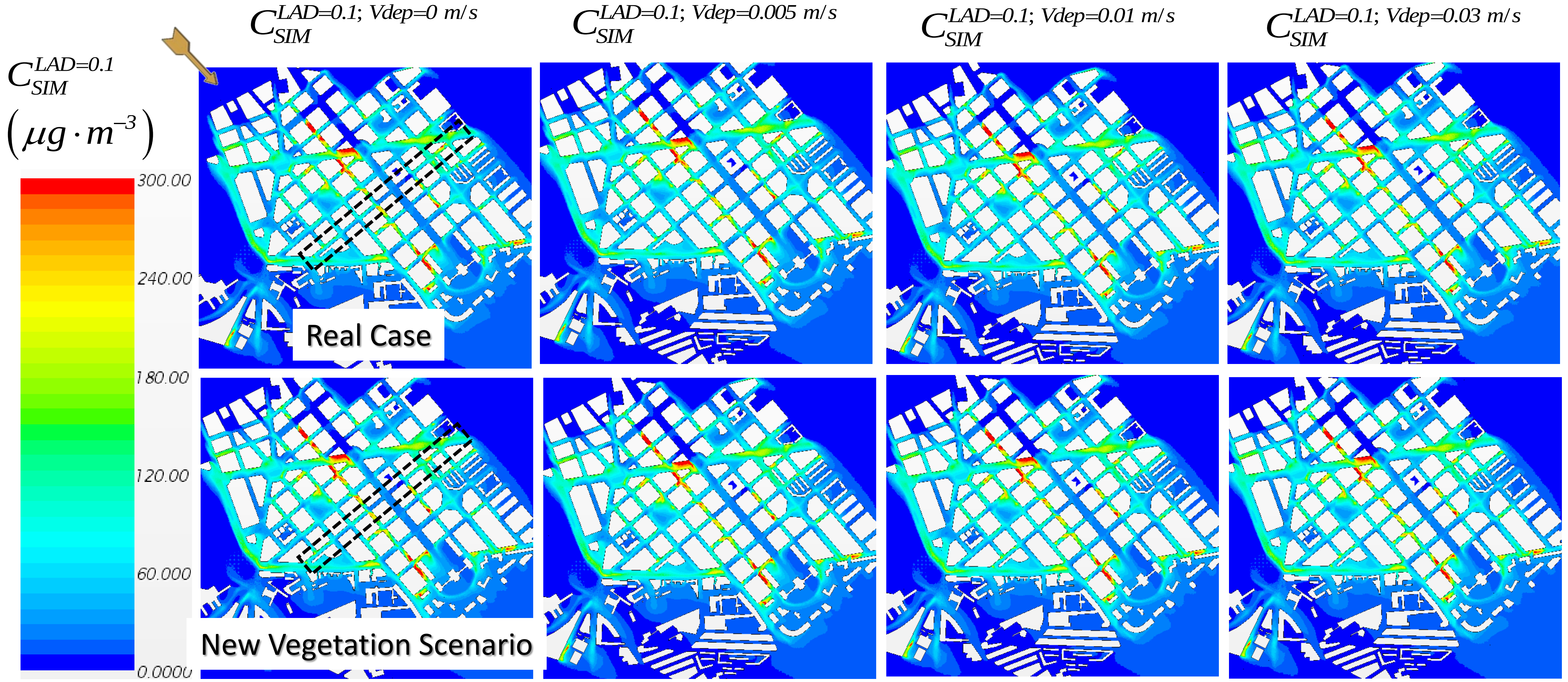


Real Case



New Vegetation Scenario

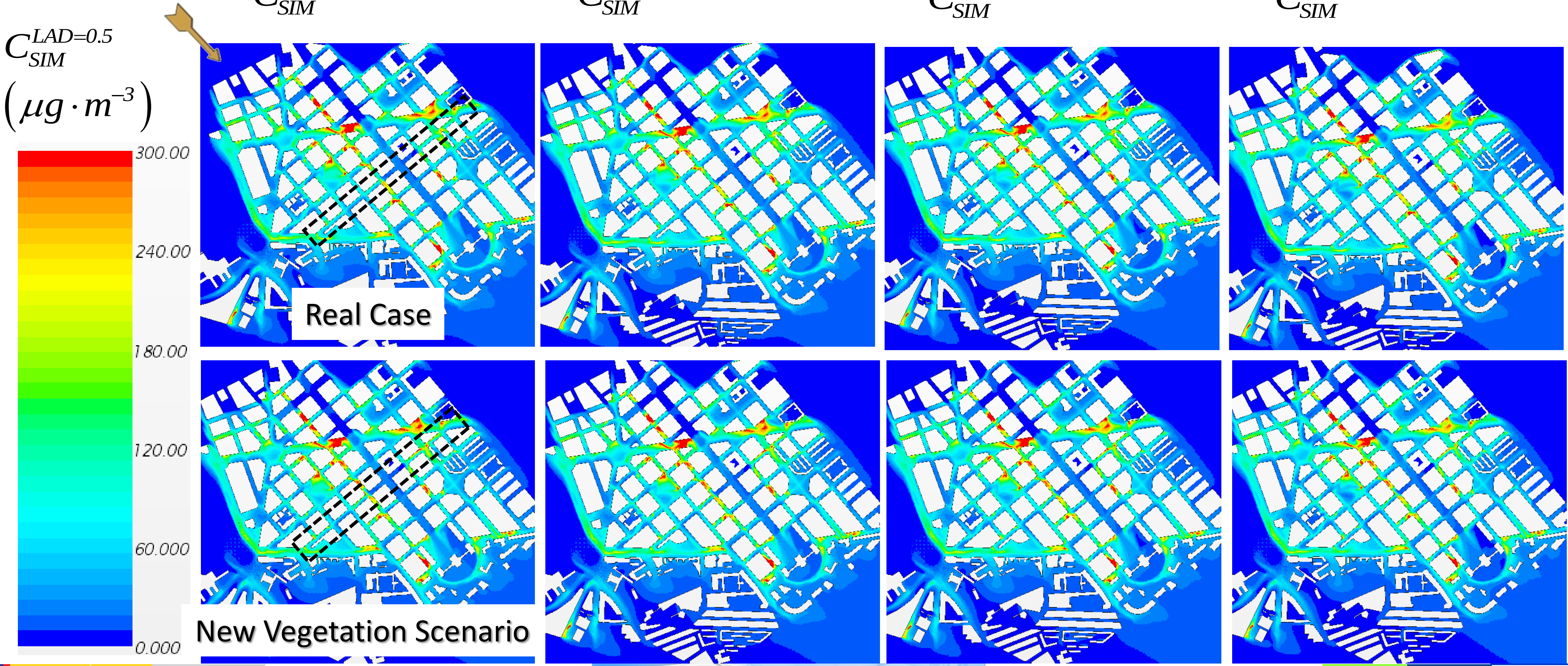
Vegetation effects on pollutant concentration



Vegetation effects on pollutant concentration

$C_{SIM}^{LAD=0.5;\ Vdep=0\ m/s}$ | $C_{SIM}^{LAD=0.5;\ Vdep=0.005\ m/s}$ | $C_{SIM}^{LAD=0.5;\ Vdep=0.01\ m/s}$ | $C_{SIM}^{LAD=0.5;\ Vdep=0.03\ m/s}$

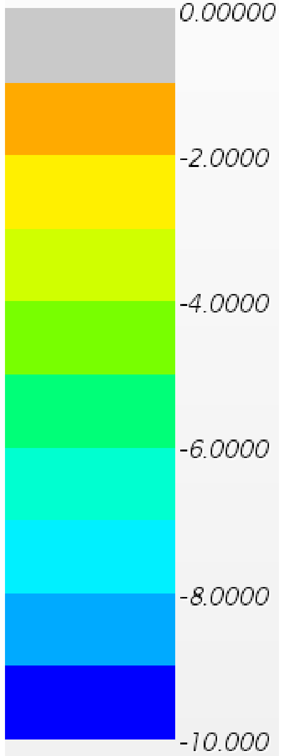
$C_{SIM}^{LAD=0.5}$ $\left(\mu g \cdot m^{-3}\right)$

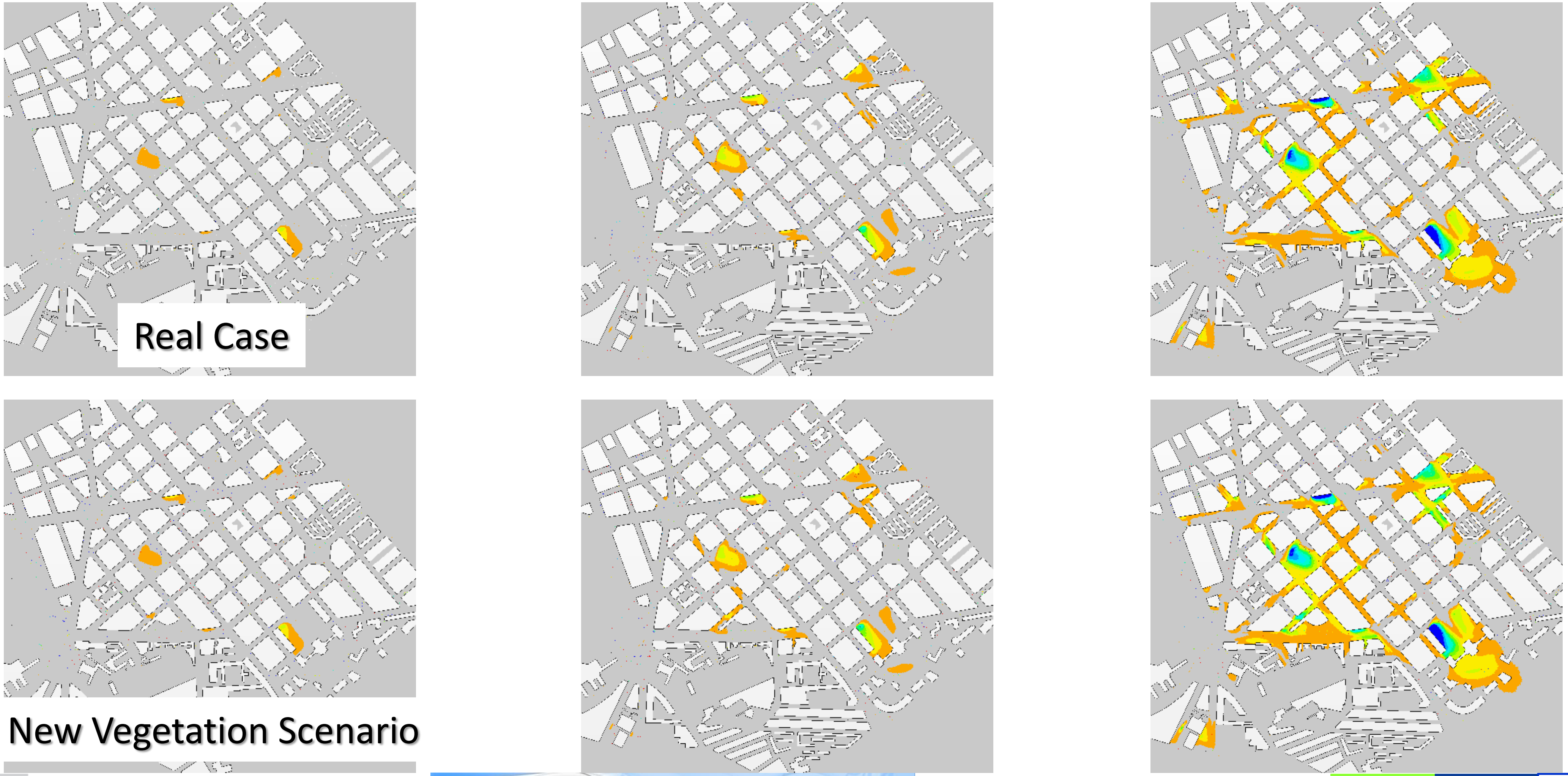


Vegetation effects on pollutant concentration: Deposition effects

$C_{SIM}^{LAD=0.1;\,Vdep=0.005} - C_{SIM}^{LAD=0.1;\,Vdep=0}$ $C_{SIM}^{LAD=0.1;\,Vdep=0.01} - C_{SIM}^{LAD=0.1;\,Vdep=0}$ $C_{SIM}^{LAD=0.1;\,Vdep=0.03} - C_{SIM}^{LAD=0.1;\,Vdep=0}$

$\Delta C_{SIM}^{LAD=0.1}$ $\left(\mu g \cdot m^{-3}\right)$



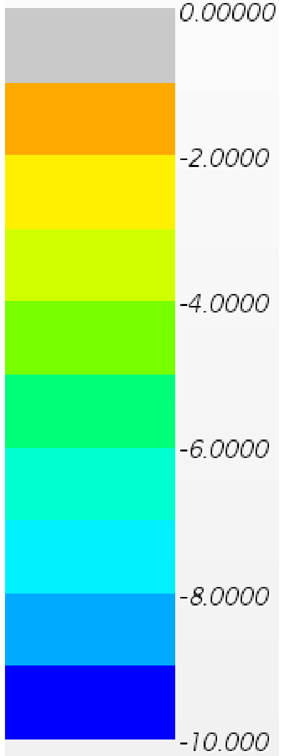


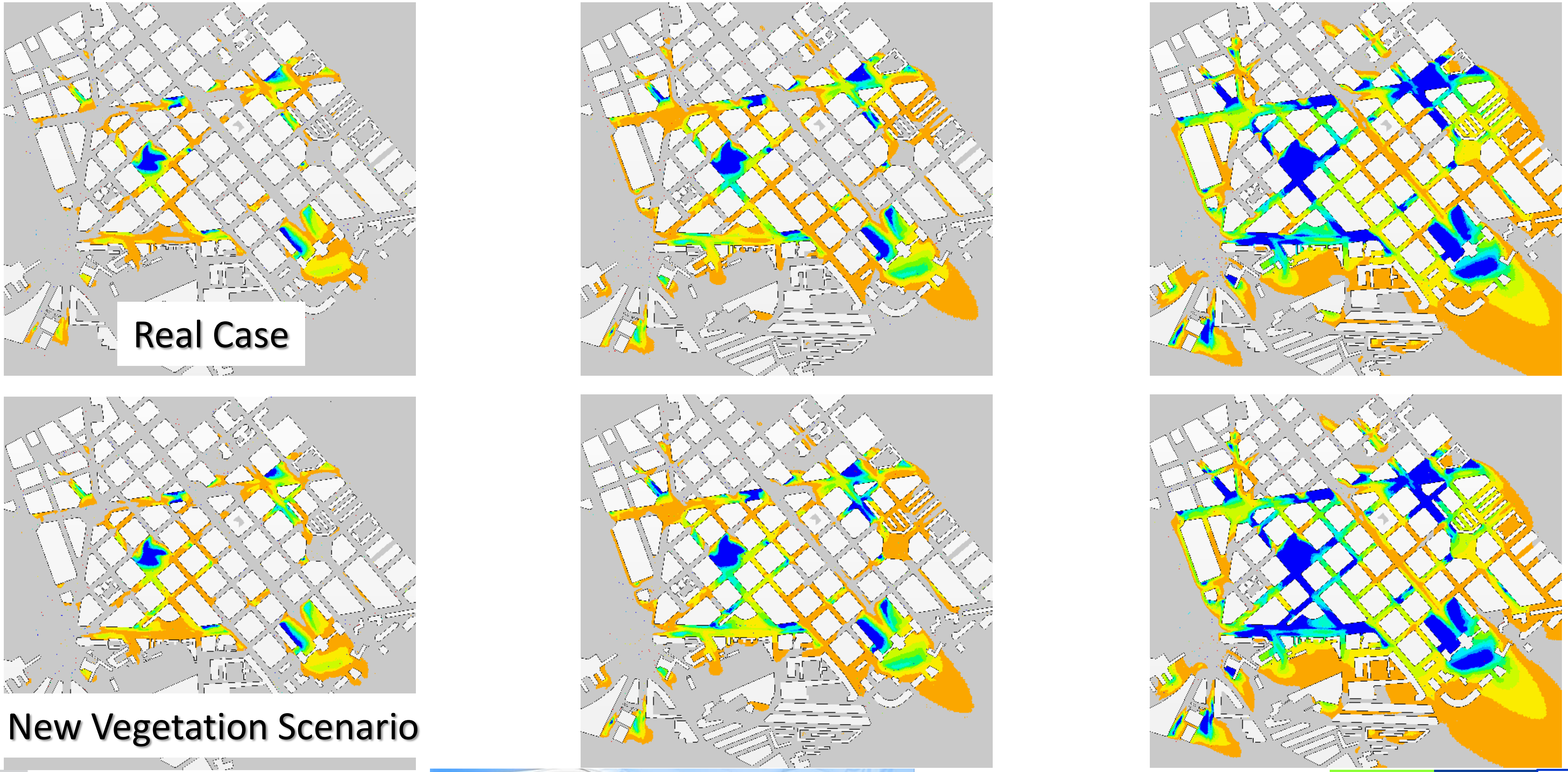
Vegetation effects on pollutant concentration: Deposition effects

$C_{SIM}^{LAD=0.5;\ Vdep=0.005} - C_{SIM}^{LAD=0.5;\ Vdep=0}$ $C_{SIM}^{LAD=0.5;\ Vdep=0.01} - C_{SIM}^{LAD=0.5;\ Vdep=0}$ $C_{SIM}^{LAD=0.5;\ Vdep=0.03} - C_{SIM}^{LAD=0.5;\ Vdep=0}$

$\Delta C_{SIM}^{LAD=0.5}$

$\left(\mu g \cdot m^{-3}\right)$

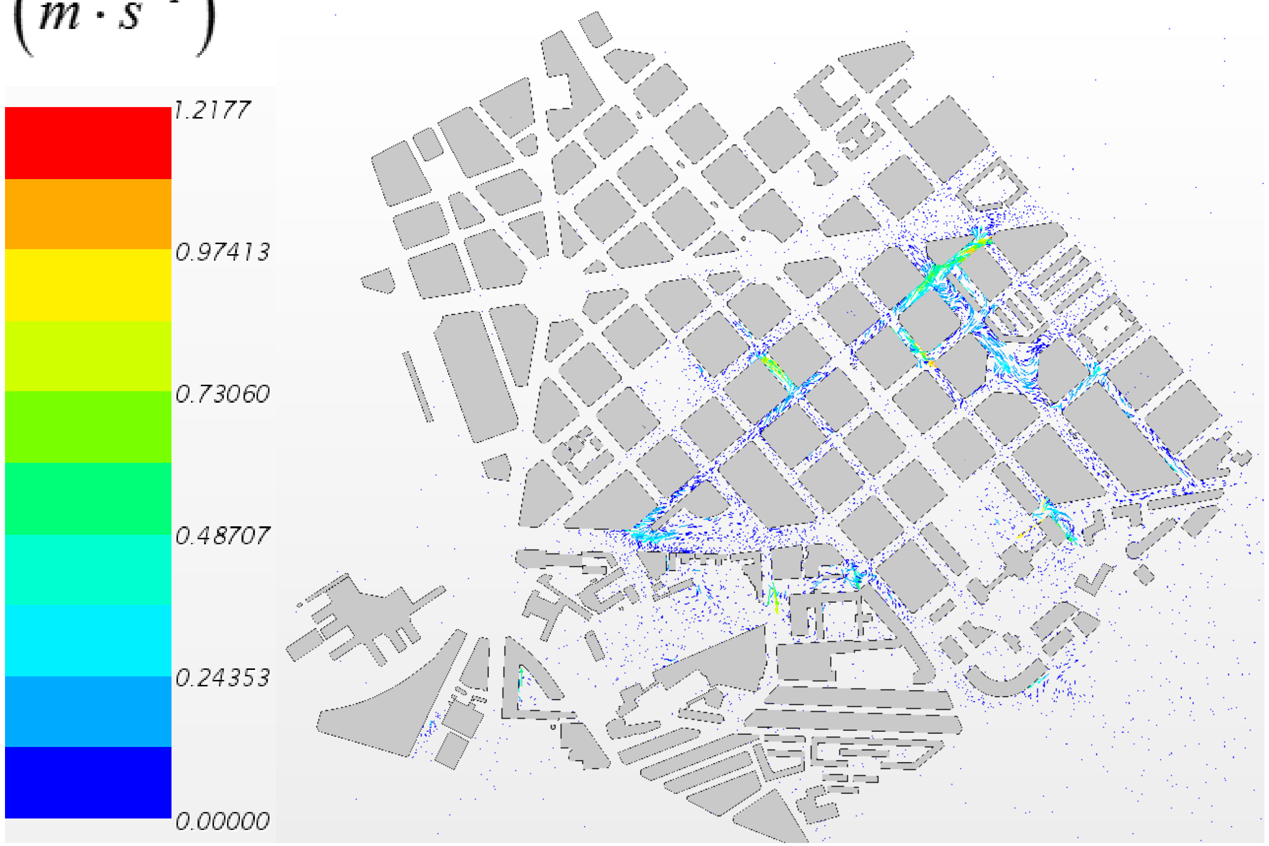




Vegetation effects on pollutant concentration: Dynamical effects

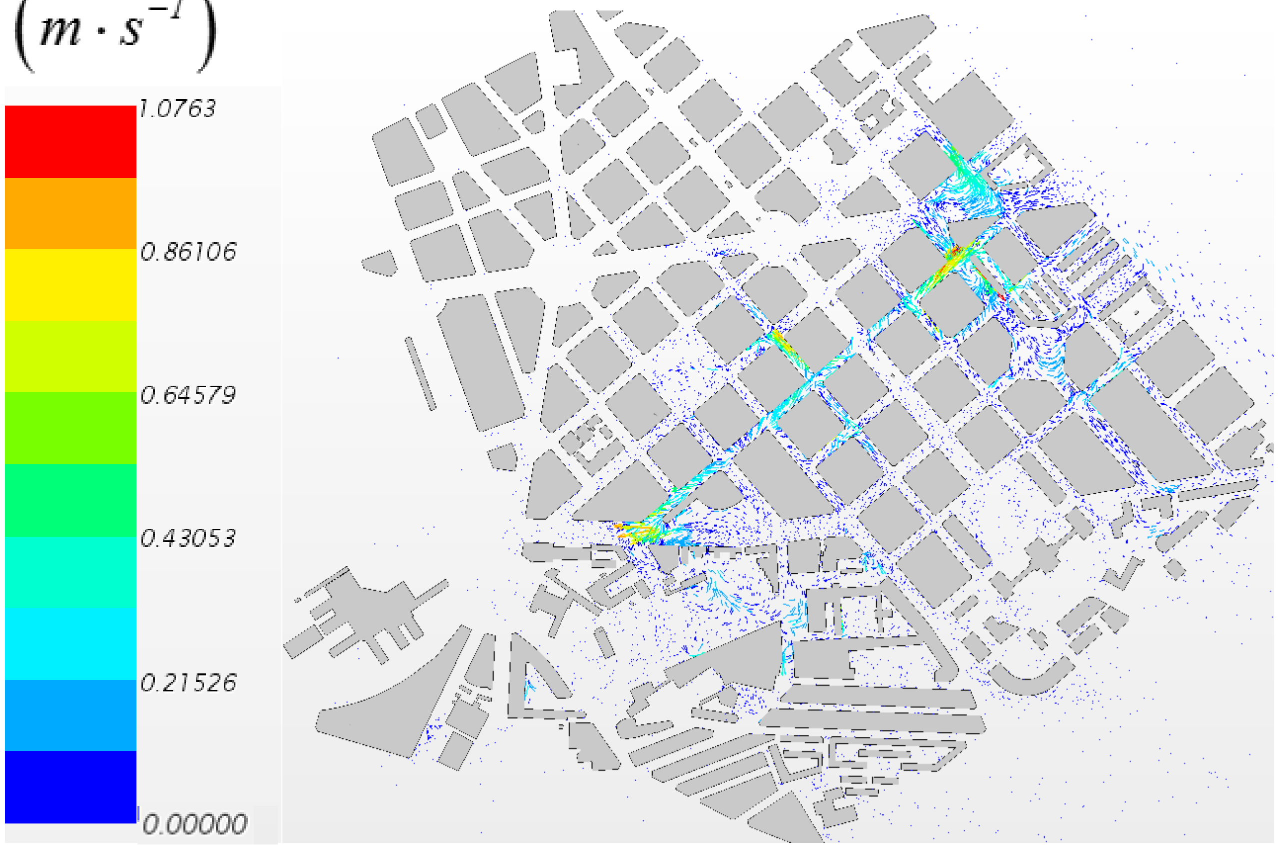
$\overrightarrow{\Delta V}_{SIM}^{LAD=0.1}$ $\left.\vec{V}_{SIM}^{LAD=0.1}\right|_{Real} - \left.\vec{V}_{SIM}^{LAD=0.1}\right|_{New\ Veg.}$

$\left(m \cdot s^{-1}\right)$



$\overrightarrow{\Delta V}_{SIM}^{LAD=0.5}$ $\left.\vec{V}_{SIM}^{LAD=0.5}\right|_{Real} - \left.\vec{V}_{SIM}^{LAD=0.5}\right|_{New\ Veg.}$

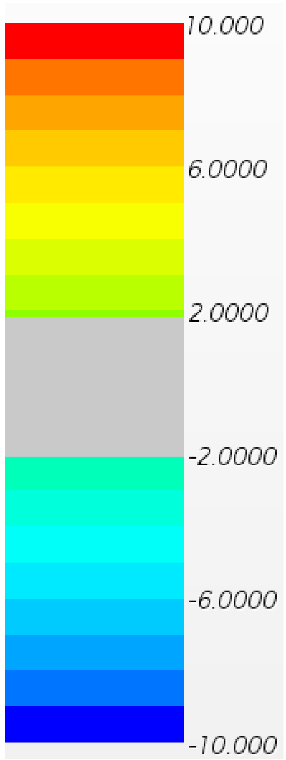
$\left(m \cdot s^{-1}\right)$



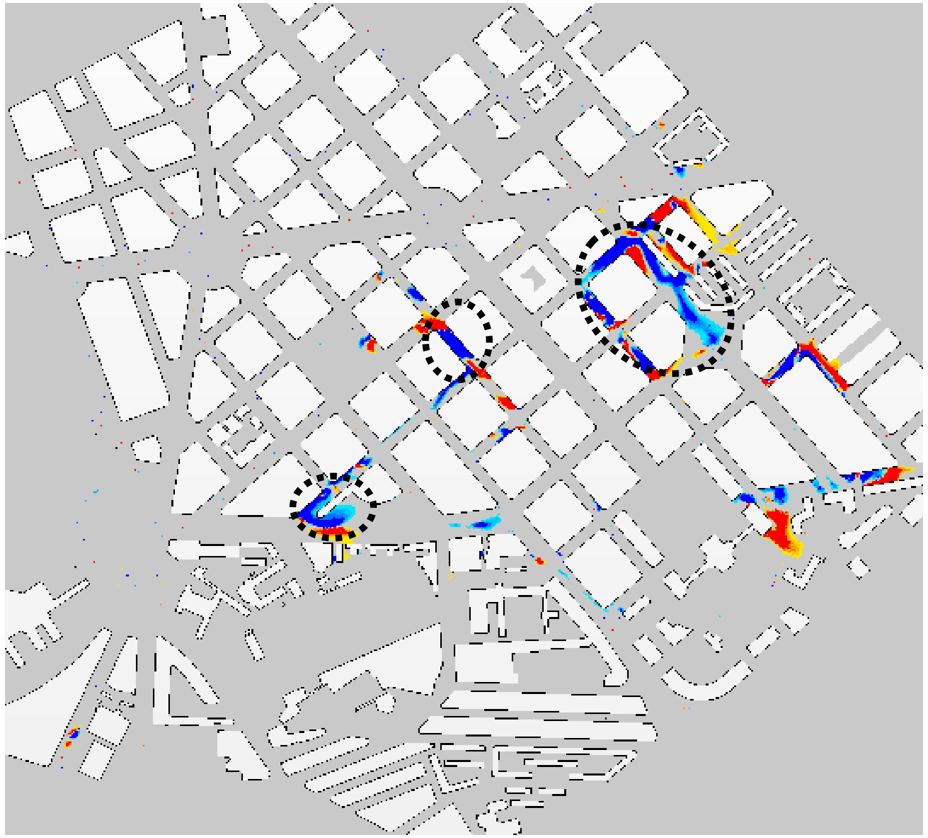
Vegetation effects on pollutant concentration: Dynamical effects

$\Delta C_{SIM}^{LAD=0.1}$

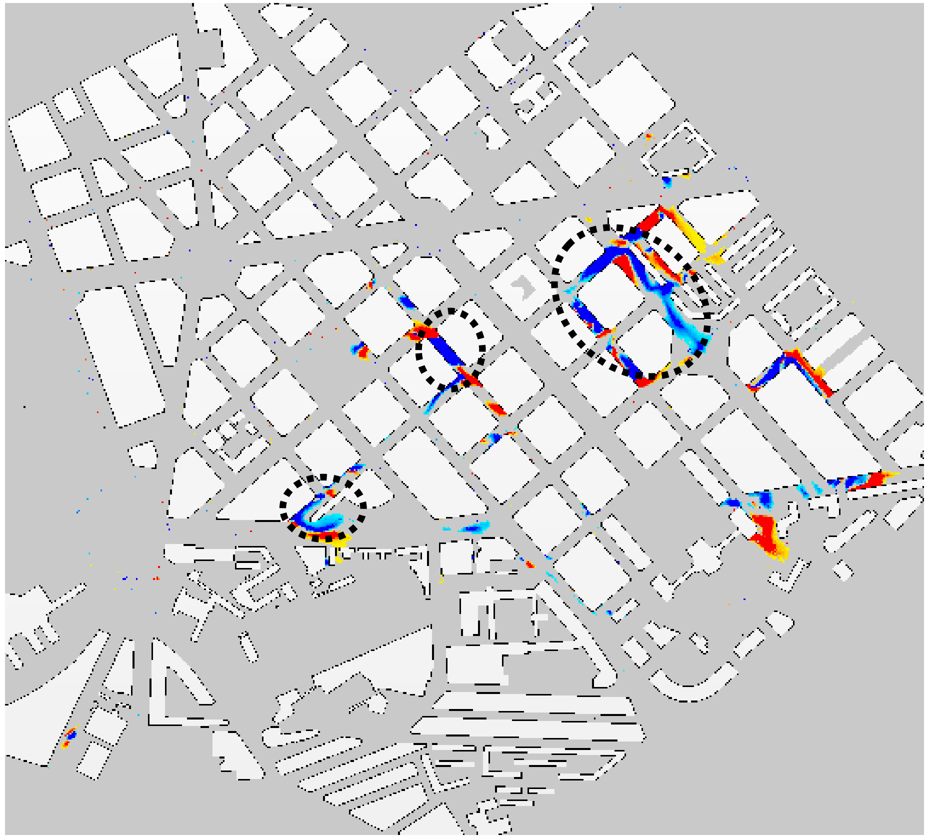
$\left(\mu g \cdot m^{-3}\right)$



$$C_{SIM}^{LAD=0.1;\ Vdep=0}\Big|_{Real} - C_{SIM}^{LAD=0.1;\ Vdep=0}\Big|_{New\ Veg.}$$



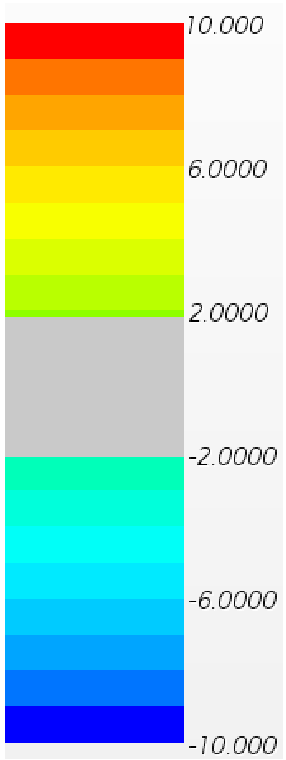
$$C_{SIM}^{LAD=0.1;\ Vdep=3}\Big|_{Real} - C_{SIM}^{LAD=0.1;\ Vdep=3}\Big|_{New\ Veg.}$$



Vegetation effects on pollutant concentration: Dynamical effects

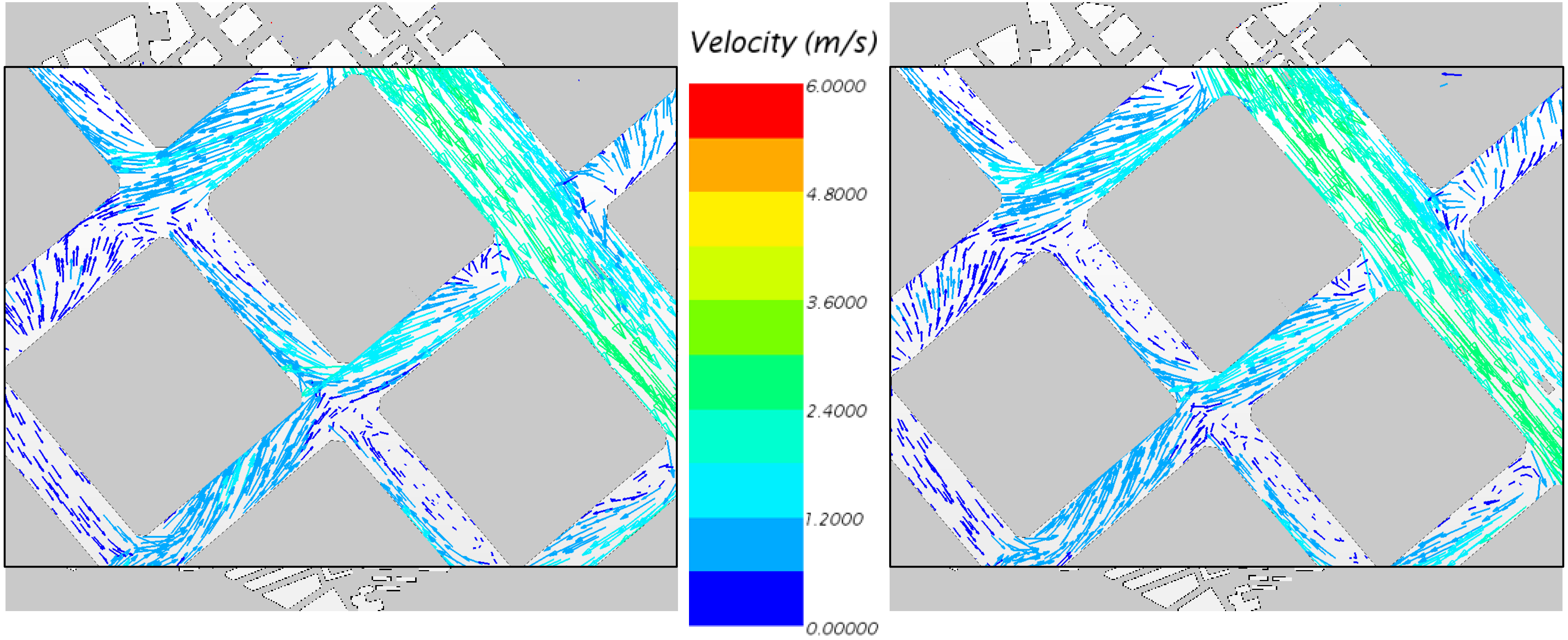
$$\Delta C_{SIM}^{LAD=0.1}$$

$$\left(\mu g \cdot m^{-3}\right)$$



$$C_{SIM}^{LAD=0.1;\ Vdep=0}\Big|_{\text{Real}} - C_{SIM}^{LAD=0.1;\ Vdep=0}\Big|_{\text{New Veg.}}$$

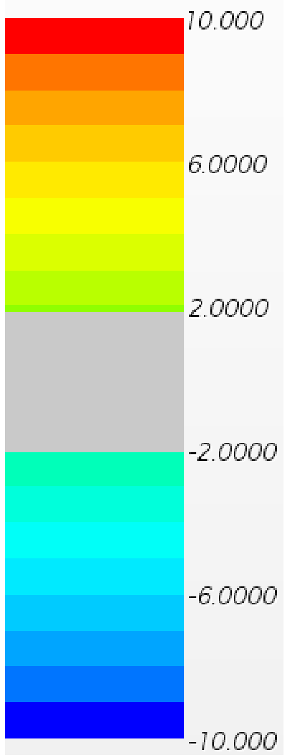
$$C_{SIM}^{LAD=0.1;\ Vdep=3}\Big|_{\text{Real}} - C_{SIM}^{LAD=0.1;\ Vdep=3}\Big|_{\text{New Veg.}}$$



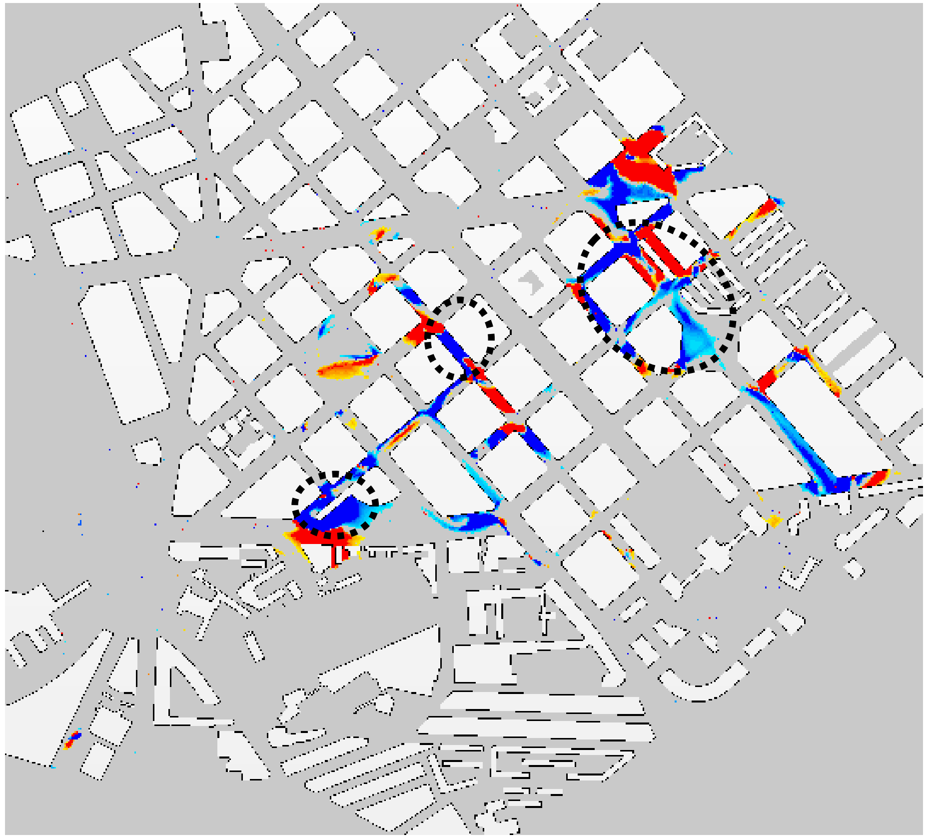
Vegetation effects on pollutant concentration: Dynamical effects

$$\Delta C_{SIM}^{LAD=0.5}$$

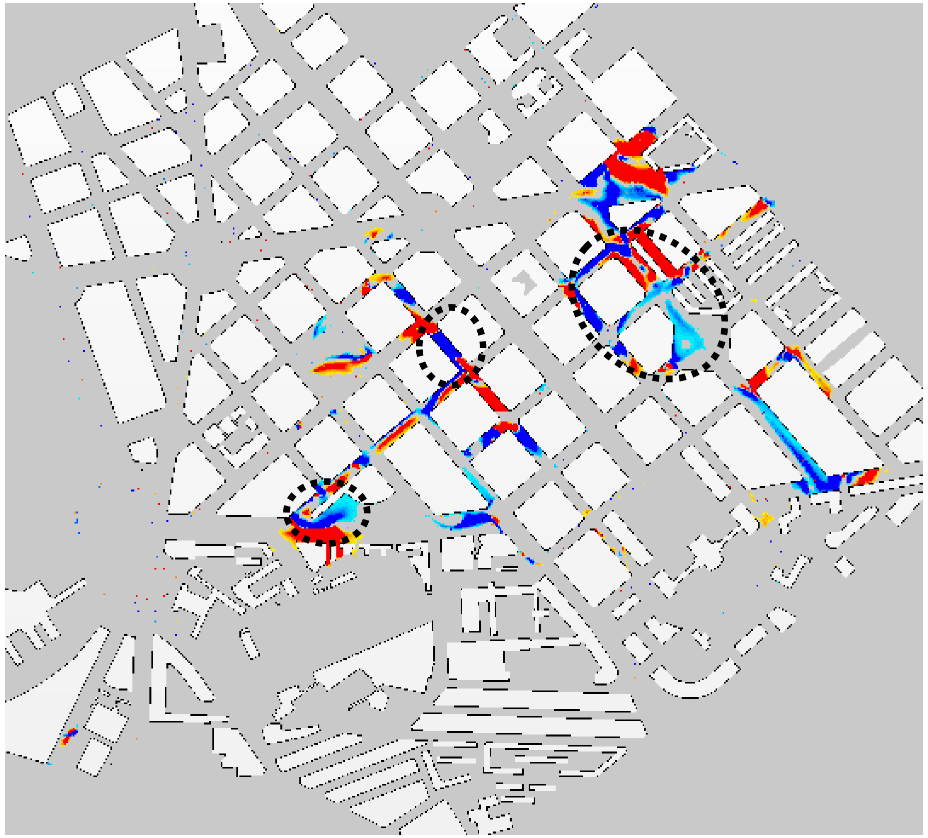
$$\left(\mu g \cdot m^{-3}\right)$$



$$C_{SIM}^{LAD=0.5;\ Vdep=0}\Big|_{\text{Real}} - C_{SIM}^{LAD=0.5;\ Vdep=0}\Big|_{\text{New Veg.}}$$



$$C_{SIM}^{LAD=0.5;\ Vdep=3}\Big|_{\text{Real}} - C_{SIM}^{LAD=0.5;\ Vdep=3}\Big|_{\text{New Veg.}}$$



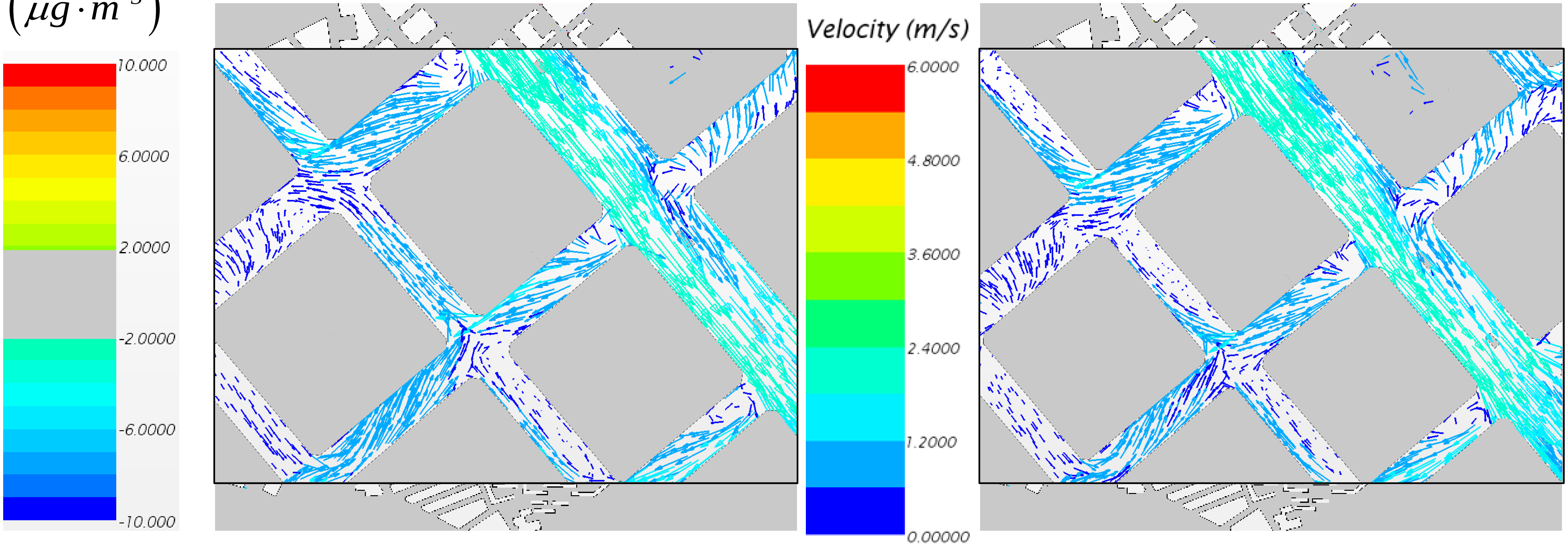
Vegetation effects on pollutant concentration: Dynamical effects

$$C_{SIM}^{LAD=0.5;\ Vdep=0}\Big|_{Real} - C_{SIM}^{LAD=0.5;\ Vdep=0}\Big|_{New\ Veg.}$$

$$C_{SIM}^{LAD=0.5;\ Vdep=3}\Big|_{Real} - C_{SIM}^{LAD=0.5;\ Vdep=3}\Big|_{New\ Veg.}$$

$$\Delta C_{SIM}^{LAD=0.5}$$

$$\left(\mu g \cdot m^{-3}\right)$$



Conclusions

- *Maps of NOx concentration in a real neighbourhood are simulated including dynamical and pollutant deposition effects of vegetation by a RANS-CFD model.*
- *Modelled concentrations are in agreement with measurements from an air quality monitoring station for March, 2016.*
- *Different vegetation scenarios are analysed considering different LAD and deposition velocities.*
- *Influence of deposition can be important* (10 µg/m³) for *LAD = 0.1 and vd=0.03 and LAD 0.5.*
- *The dynamical effects of including new vegetation in one street are more important than deposition effects.*
- *New vegetation modifies wind flow patterns and concentration maps increasing, in general, the concentration in this street. Differences are also observed in other closer areas.*
- *In order to go deeper into the knowledge about the effect of trees on the urban air quality (further works):*
  - *more experimental measurements are necessary (a field experimental campaign in RESPIRA project have been carried out and data will be analysed)*
  - *other physical processes should be taken into account in the model: turbulence induced by traffic or thermal effects or chemical reactions.*

Thank you for your attention!

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