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HARMO 18

PROGRESS IN URBAN AIR QUALITY ASSESSMENT: CFD MODELLING OF A WHOLE TOWN IN SPAIN

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LIFE+RESPIRA

Life

GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

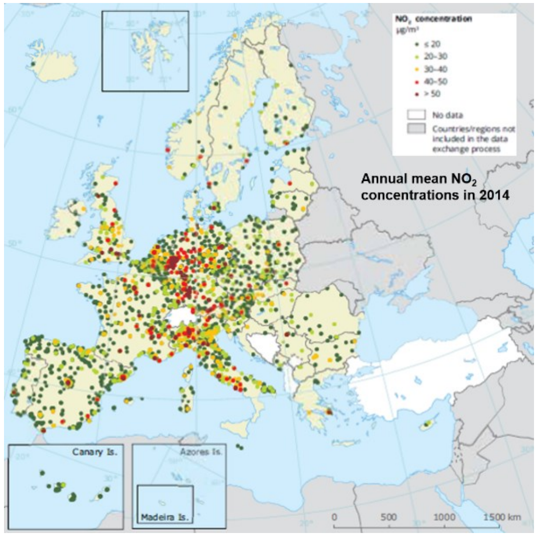
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Universidad de Navarra

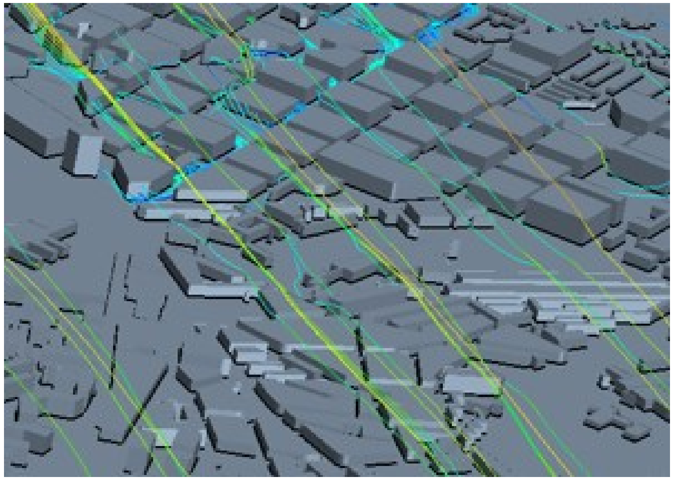
Contents

Introduction

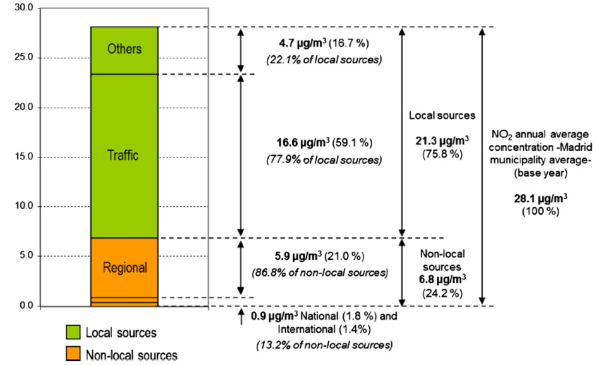
- *Urban air quality as big environmental problem*
- *Air pollution vs. human health*
- *Main source: The road traffic.*



Red and dark red dots correspond to values above the EU annual limit value and the WHO AQG (40 µg/m3). Only stations with > 75 % of valid data have been included in the map (*EEA, 2016a*).



Perspective view of the wind lines in Pamplona when the wind blows North direction.



Result of the source apportionment analysis (annual NO2 mean for the whole Madrid municipality) (*Borge et al. 2014*).

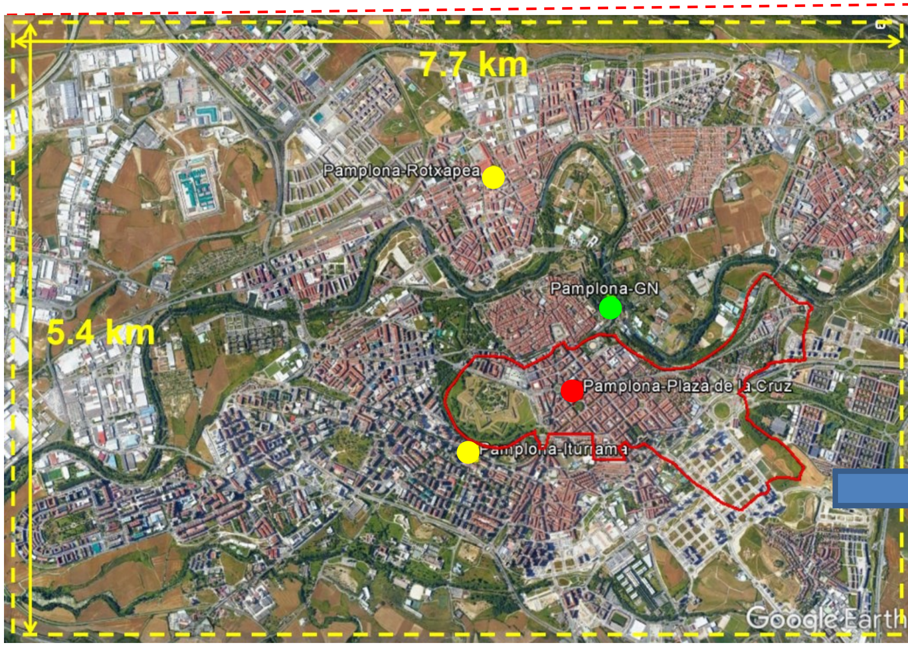
- *<u>LIFE-RESPIRA project goal:</u> To improve urban air quality and reduce exposure to air pollution by promoting healthy and sustainable mobility.*

- *<u>Our LIFE+RESPIRA project task:</u> To develop of an specific tool able to reproduce accurate pollutant maps of the Pamplona´s city (Spain).*

- ***Objective of this work**: To compute the 2016 hourly NO_2, NO and NOx maps for annual and seasonal average days by means of a CFD-RANS* methodology.

Area of Study and Experimental Data

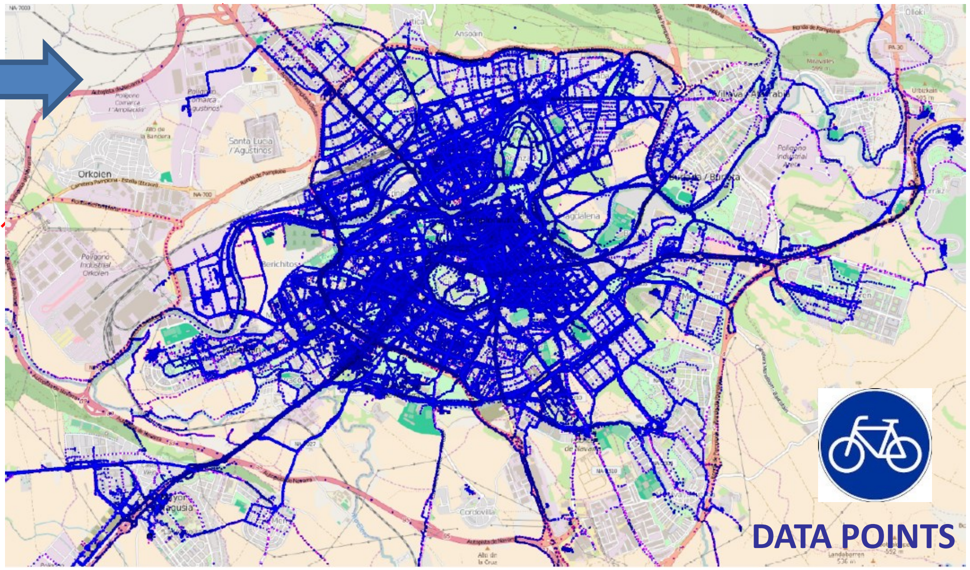
Urban Morphology and Large-scale monitoring



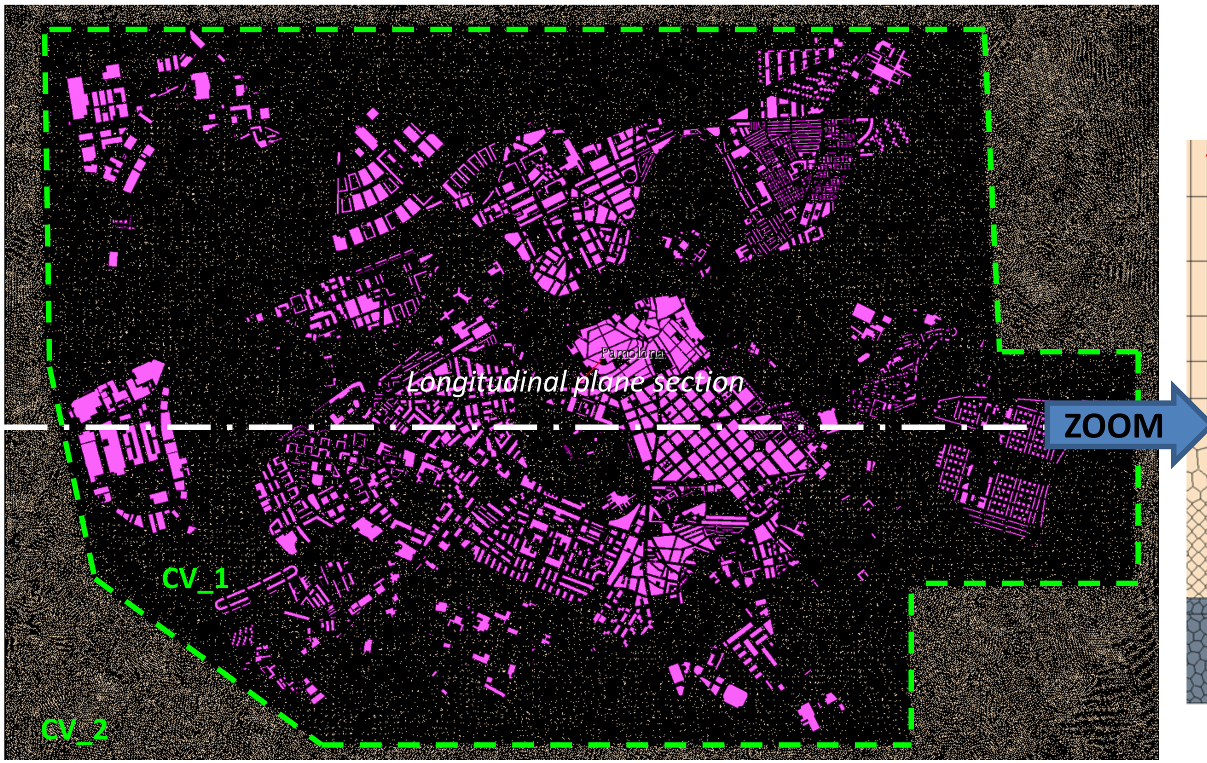
Aerial view of Pamplona´s City
(Source: Google Earth)

Pamplona
(Source: Google Earth)

Roads traveled by cyclists during 2016
(provided by University of Navarra)

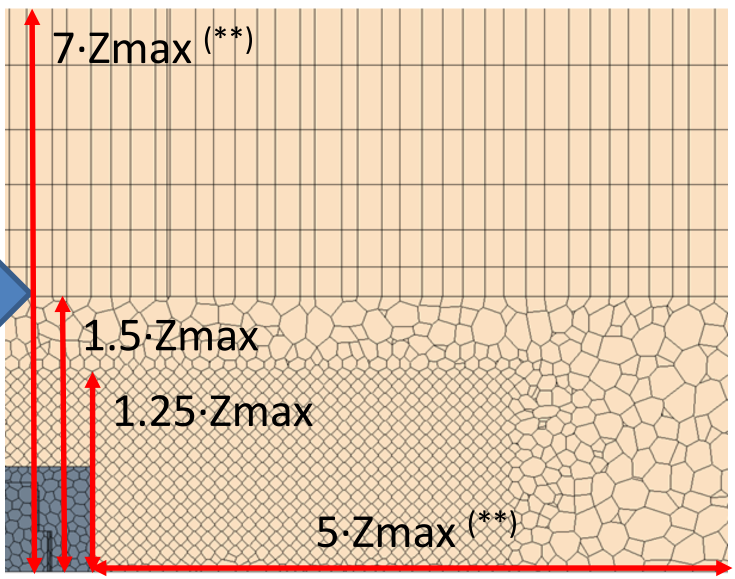


CFD model description and simulation setup: Mesh Model



CFD Mesh model (*)

Total number of cells: 44.6×10^6



Zmax = 70m

(*) CFD tool: STAR-CCM+9.04.011®

(**) Franke et al. 2007

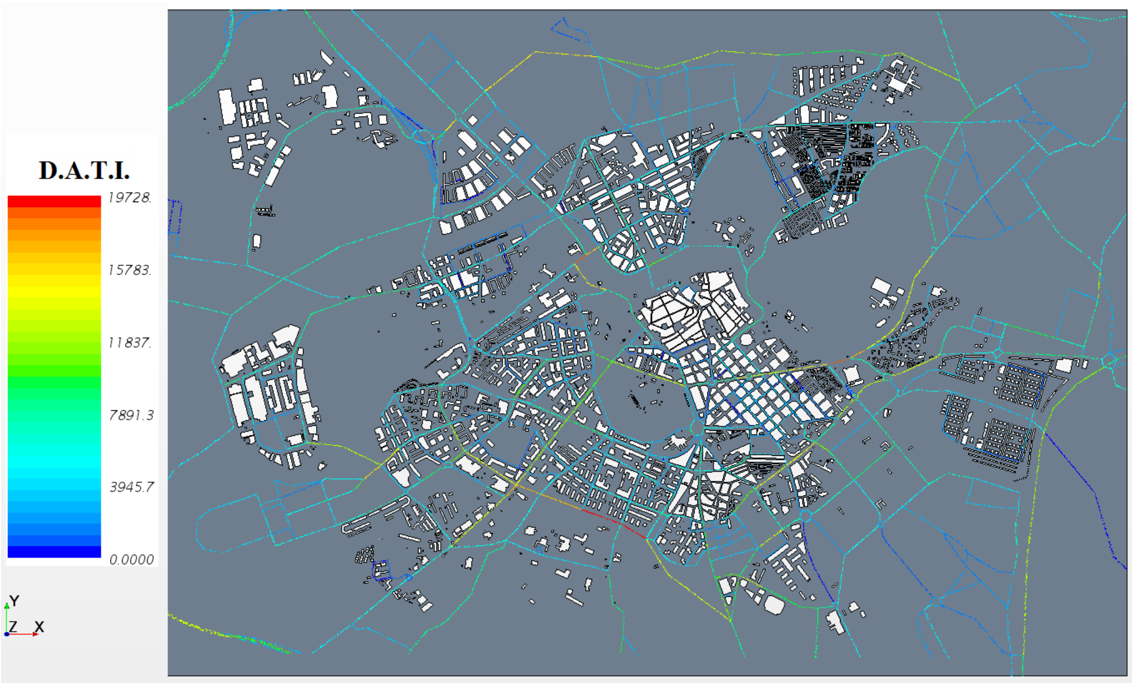
CFD model description and simulation setup: Physical Models

- *Steady State Simulations*
- *Segregated Flow Model*
- *RANS as turbulent approach:*
  - *Realizable K-ε Two-Layer model*
  - *All Y+ wall hybrid treatment*
- *Neutral atmospheric conditions*
- *Constant air density*
- *Default values of STAR-CCM + 9.04.011® as free parameters of the turbulent model*

CFD model description and simulation setup: NOx dispersion

+ *an additional passive scalar transport equation*
+ *Pollutant emissions at roads proportional to traffic intensity*
+ *Without atmospheric chemistry*

$$\left\{\partial_j\left(\rho u_j C_{CFD}(\vec{r}) - \frac{\mu_{eff}}{Sc_t}\partial_j C_{CFD}(\vec{r})\right) = S_C\right\}_{j=x,y,z}$$



Daily Average Traffic Intensity map in Pamplona's city

CFD model description and simulation setup: Boundary Conditions

- *Building*: *Solid boundary with surface specification: smooth*
- *Ground: Solid boundary with surface specification: roughness*
- *Inlet[*]:* $u(z) = \frac{u_*}{\kappa} ln\left(\frac{z + z_0}{z_0}\right); k = \frac{u_*^2}{\sqrt{C_\mu}};\ \varepsilon = \frac{u_*^3}{\kappa \cdot (z + z_0)}$
- *Outlet:* $\Delta P_{in-out} = 0$
- *Top: Symmetry boundary condition*

(*) Richards & Hoxey 1993

Numerical Methodology (*)

CFD Simulations

$\{u_M\}_{i=1,\ldots,16\,-\,scenarios}$

$\{\boldsymbol{C}_{CFD,i}\}_{i=1,\ldots,16}$

Meteorological Data: Pamplona GN Met. St.(**)

i-scenario $\rightarrow \{f_i(t), \overline{u_{ref,i}(t)}\}_{t=1,\ldots,24\,-\,hour}$

Pollutants Conc. Data: Pamplona Pza. Cruz A.Q. St. $\vec{r}_0$

$\left\{\left(\overline{C_O(\vec{r}_0,t)}\right)_{NO_x}, \left(\overline{C_O(\vec{r}_0,t)}\right)_{NO_2}, \left(\overline{C_O(\vec{r}_0,t)}\right)_{NO}\right\}_{t=1,\ldots,24}$

NO_x maps

$$\left(\boldsymbol{C_M(t)}\right)_{\boldsymbol{NO_x}} = \left[\sum_{i=1}^{16} f_i(t)\cdot C_{CFD,i}\cdot\frac{u_M}{\overline{u_{ref,i}(t)}}\right]\cdot E(t)$$

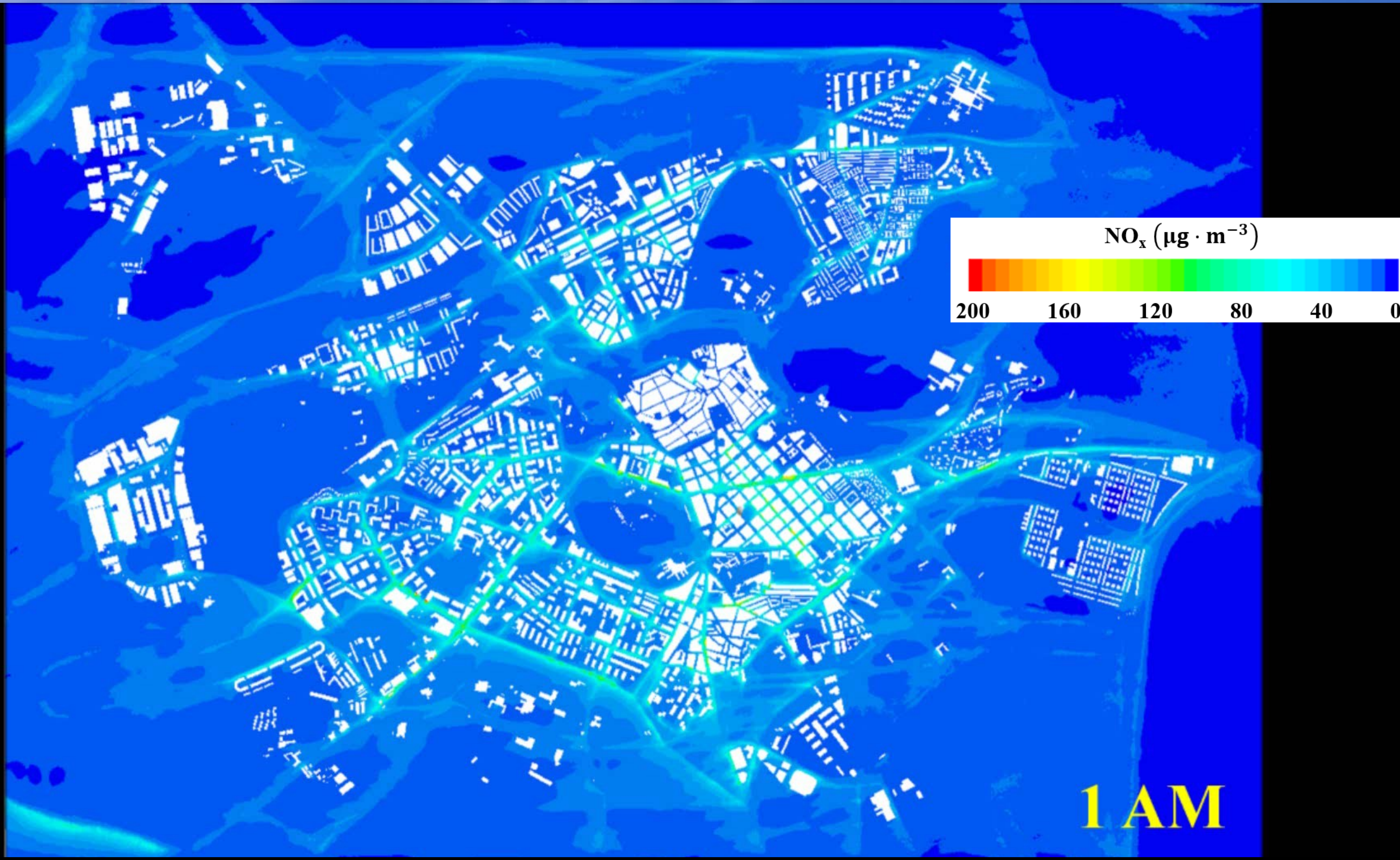
$$E(t):\left(C_M(\vec{r}_0,t)\right)_{NO_x} = \left(\overline{C_O(\vec{r}_0,t)}\right)_{NO_x}$$

NO and NO_2 maps

$$\left(\boldsymbol{C_M(t)}\right)_{\boldsymbol{NO_2\ or\ NO}} = \left(C_M(t)\right)_{NO_x}\cdot\frac{\left(\overline{C_O(\vec{r}_0,t)}\right)_{NO_2\ or\ NO}}{\left(\overline{C_O(\vec{r}_0,t)}\right)_{NO_x}}$$

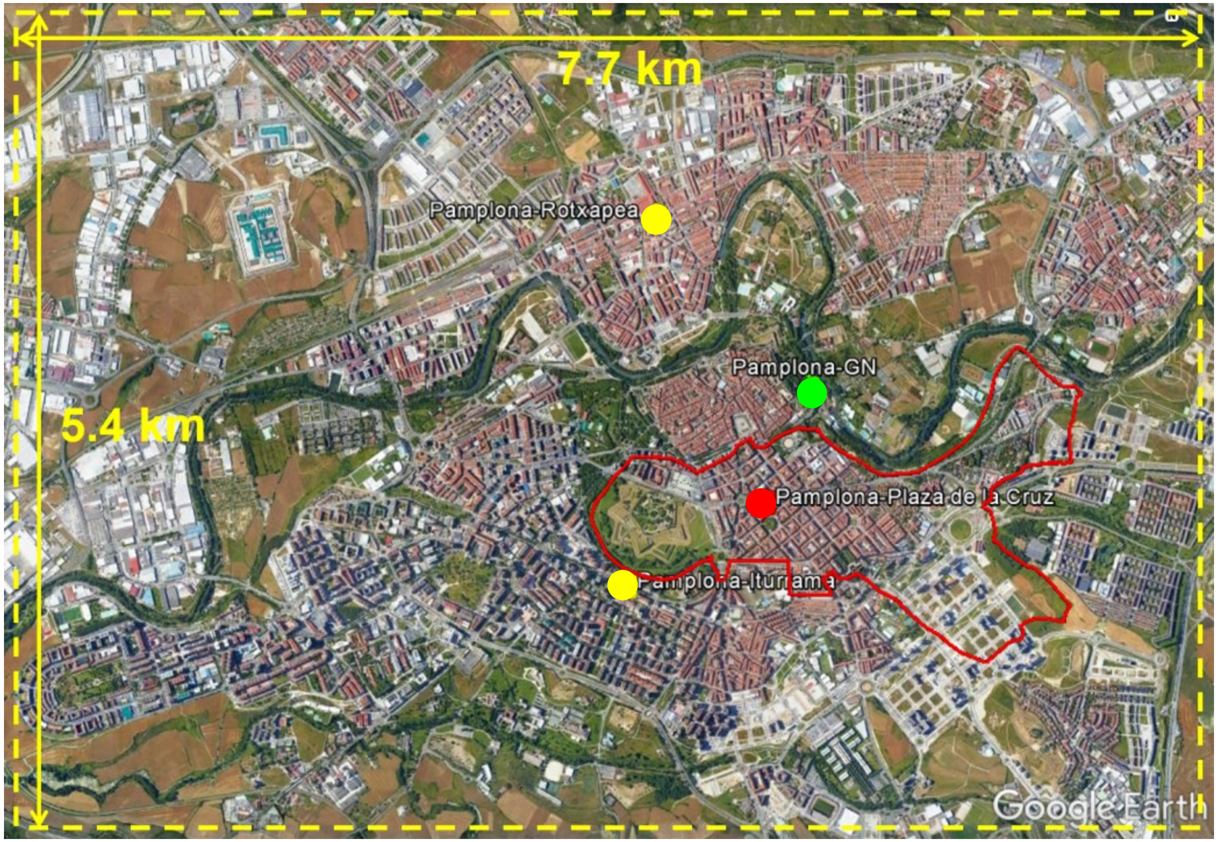
(*) Parra et al. 2010
Santiago et al. 2013
Santiago et al. 2017
(**) Source: GN

Results

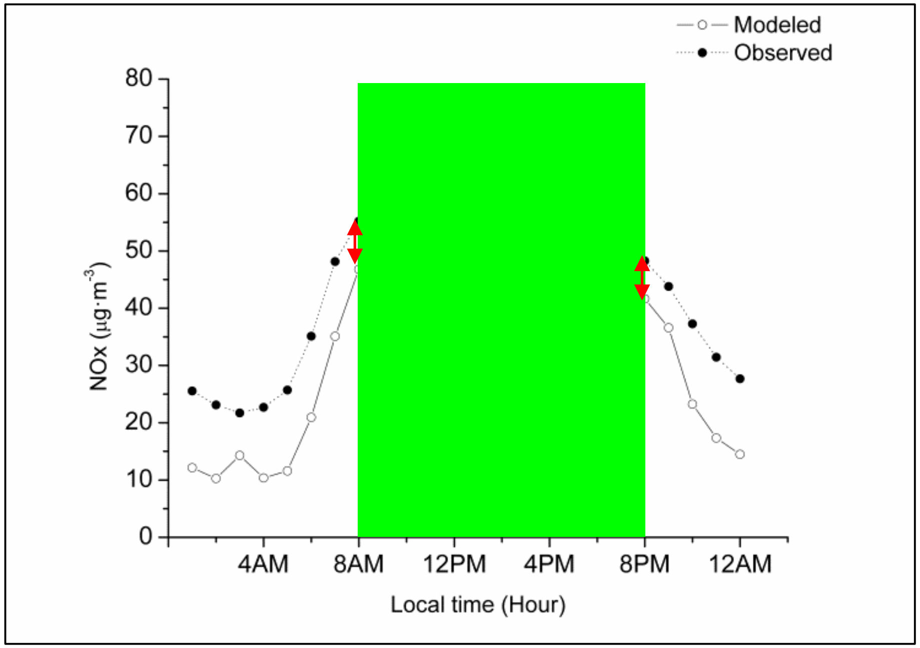


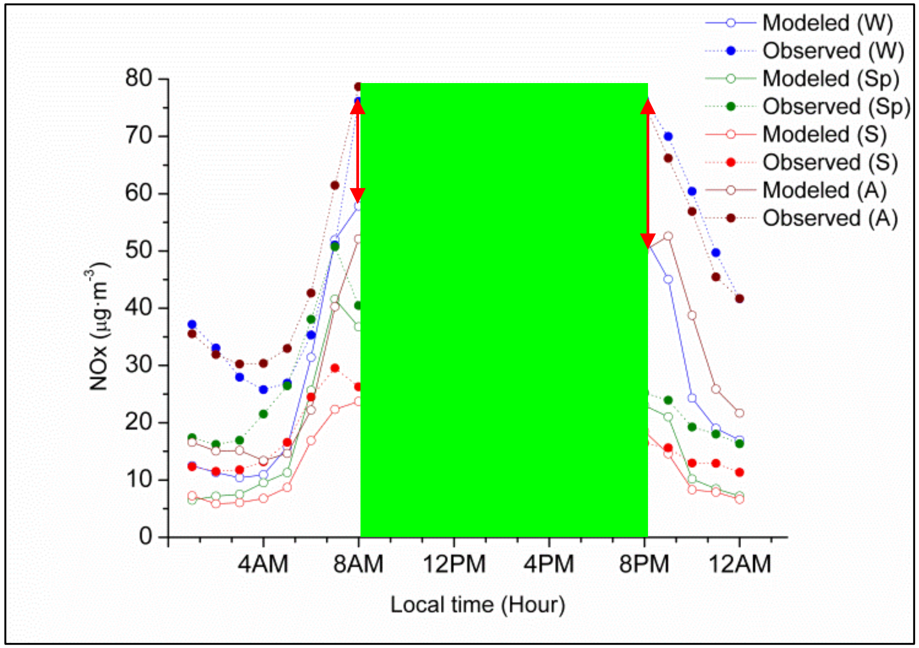
High resolution hourly maps of NO_x annual averaged concentration during 2016 at pedestrian level

Model evaluation with air quality monitoring stations



Model evaluation with air quality monitoring stations: NO_x





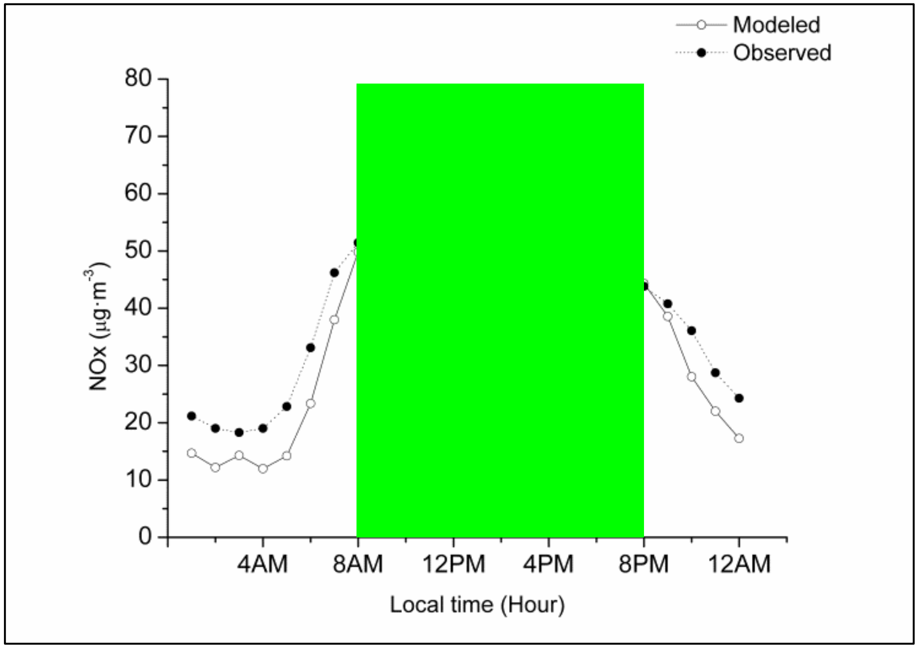
	Pamplona-Rotxapea					
	RE Max	Hour	R	NMSE	FB	FAC2
2016-average annual day	55.5	2AM	0.843	0.080	-0.282	83.3
2016-average spring day	62.7	1AM	0.807	0.108	-0.298	70.8
2016-average summer day	50.1	11AM	0.666	0.108	-0.103	100.0
2016-average autumn day	55.9	4AM	0.826	0.099	-0.325	83.3
2016-average winter day	66.4	1AM	0.814	0.161	-0.439	70.8

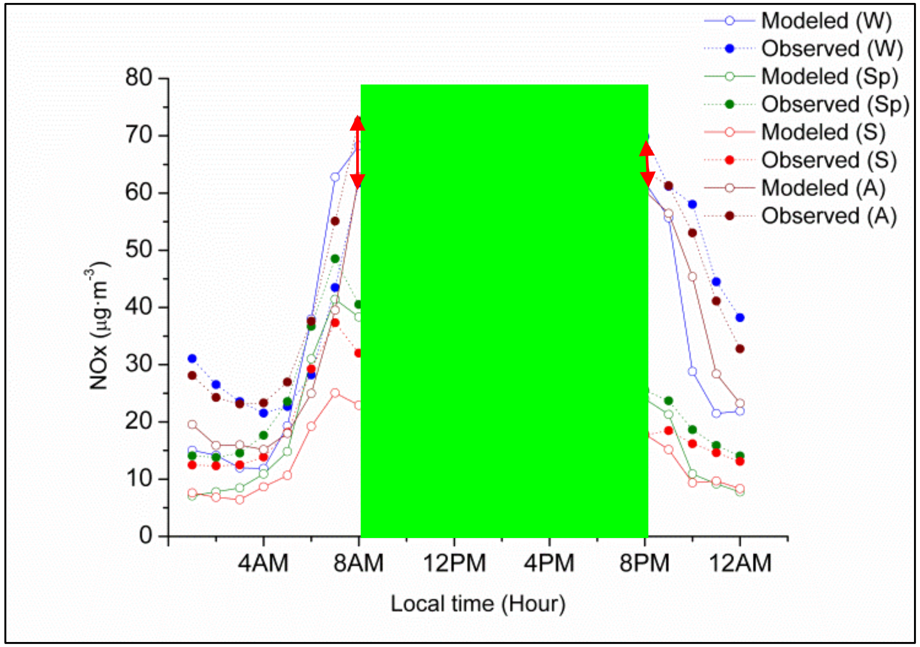
NMSE < 1.5

– 0.3 < FB < 0.3

(*) Chang & Hanna 2005
Goricsán et al. 2011

Model evaluation with air quality monitoring stations: NO_x





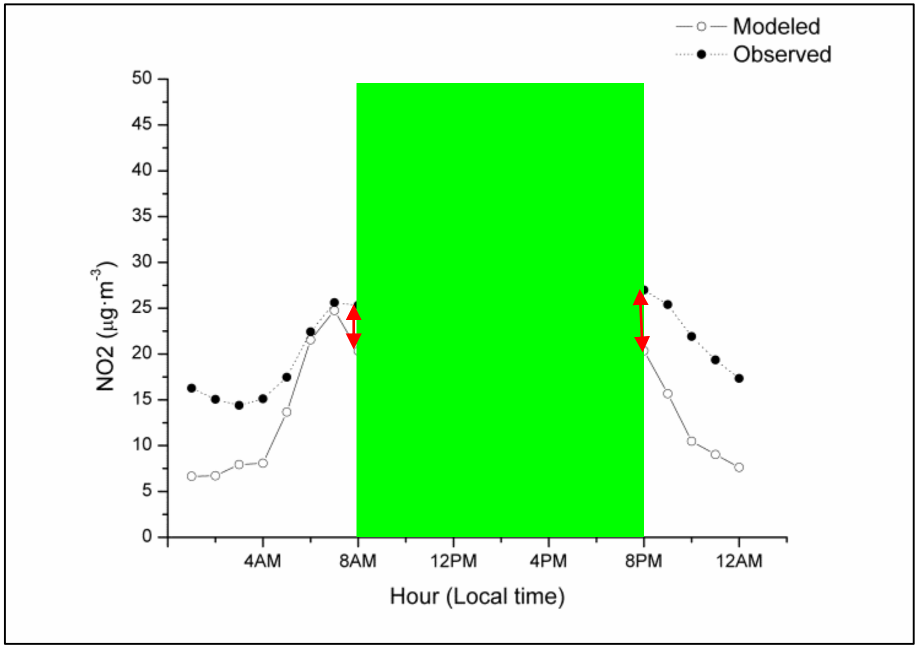
	Pamplona-Iturrama					
	RE Max	Hour	R	NMAE	FB	FAC2
2016-average annual day	37.8	5AM	0.890	0.179	-0.094	100.0
2016-average spring day	49.6	1AM	0.895	0.214	-0.173	100.0
2016-average summer day	48.5	3AM	0.811	0.247	-0.187	100.0
2016-average autumn day	47.4	5PM	0.860	0.212	-0.097	100.0
2016-average winter day	51.8	11PM	0.817	0.245	-0.193	87.5

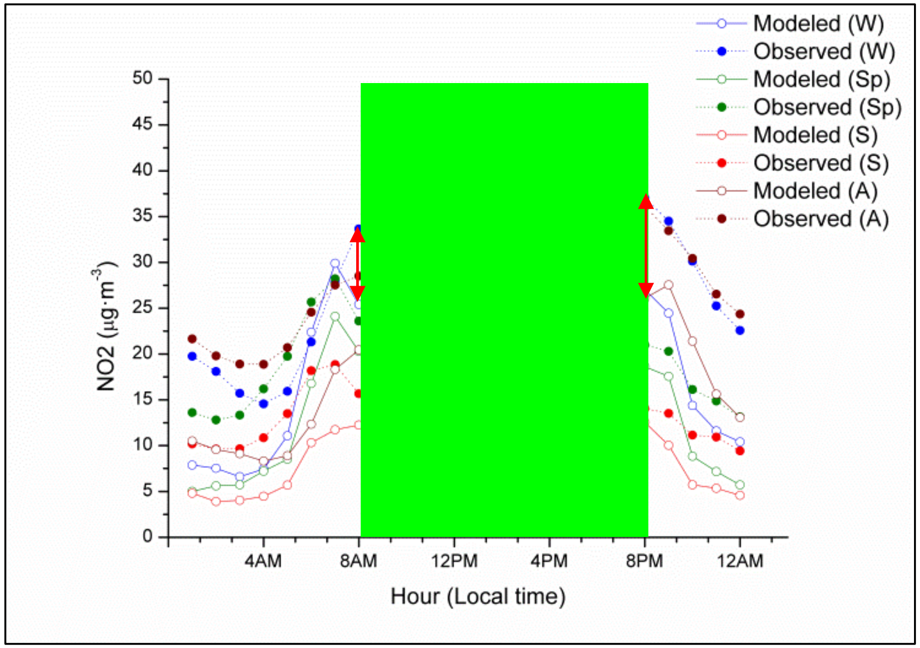
$NMSE < 1.5$

$-0.3 < FB < 0.3$

(*) Chang & Hanna 2005
Goricsán et al. 2011

Model evaluation with air quality monitoring stations: NO_2





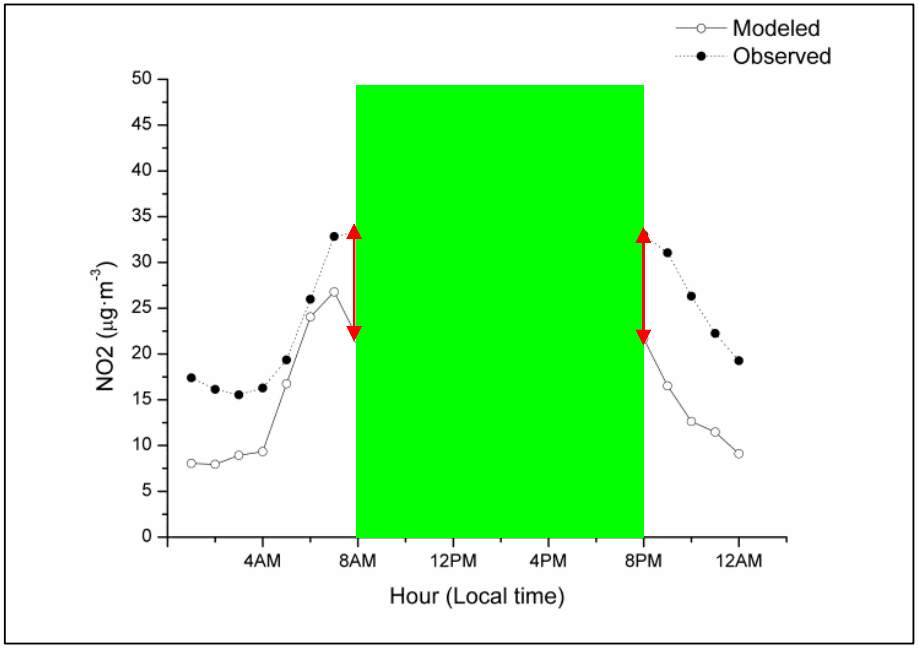
	Pamplona-Rotxapea					
	RE Max	Hour	R	NMAE	FB	FAC2
2016-average annual day	59.1	1AM	0.683	0.250	-0.310	79.2
2016-average spring day	63.1	1AM	0.699	0.268	-0.321	70.8
2016-average summer day	59.4	2AM	0.492	0.308	-0.296	70.8
2016-average autumn day	58.3	5AM	0.893	0.307	-0.396	75.0
2016-average winter day	60.1	1AM	0.780	0.286	-0.364	75.0

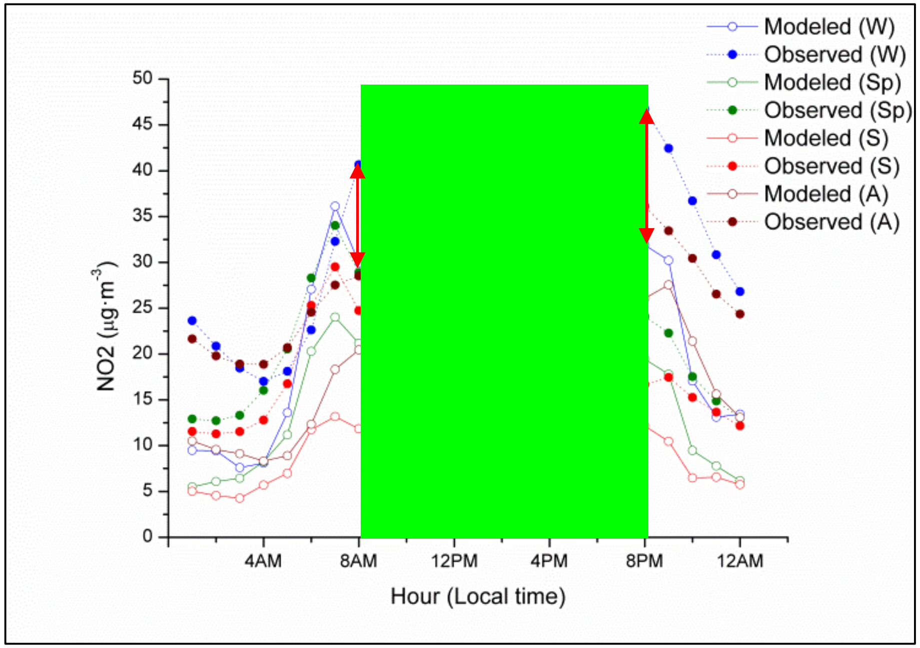
$NMSE < 1.5$

$-0.3 < FB < 0.3$

(*) Chang & Hanna 2005
Goricsán et al. 2011

Model evaluation with air quality monitoring stations: NO_2





	Pamplona-Iturrama					
	RE Max	Hour	R	NMAE	FB	FAC2
2016-average annual day	53.7	1AM	0.754	0.296	-0.375	83.3
2016-average spring day	57.4	1AM	0.880	0.292	-0.370	83.3
2016-average summer day	62.9	3AM	0.741	0.392	-0.526	54.2
2016-average autumn day	53.5	4AM	0.853	0.346	-0.440	75.0
2016-average winter day	59.9	1AM	0.770	0.350	-0.427	75.0

$NMSE < 1.5$

$-0.3 < FB < 0.3$

(*) Chang & Hanna 2005
Goricsán et al. 2011

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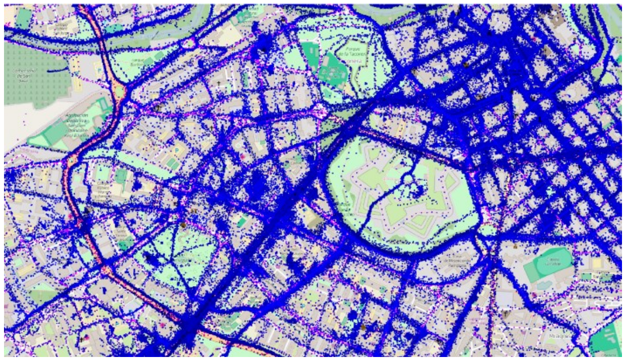
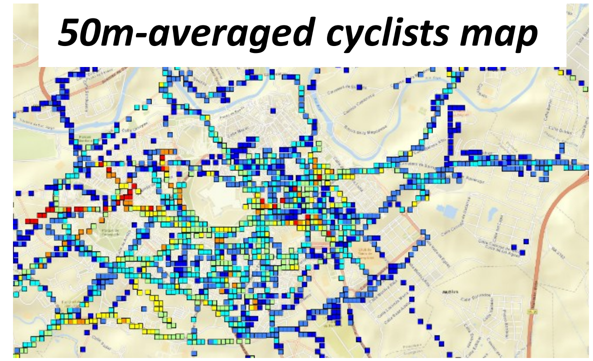
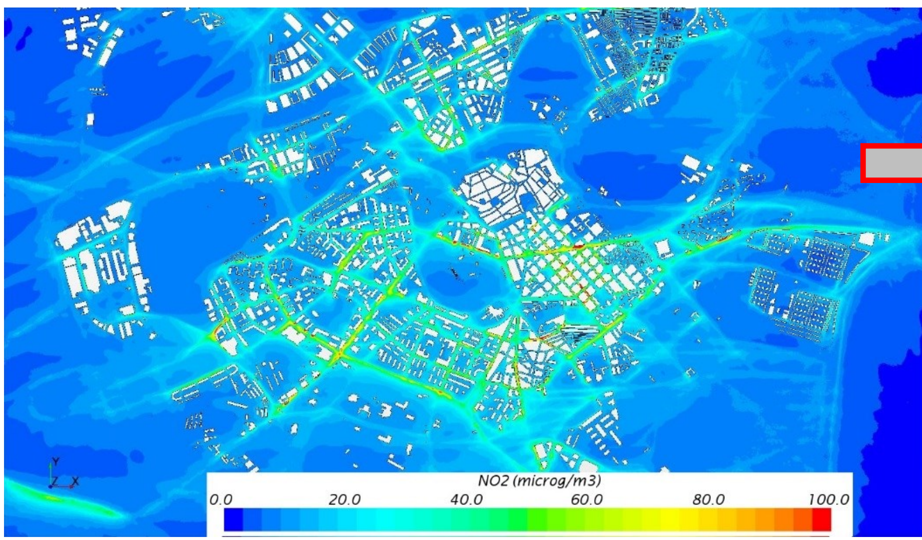
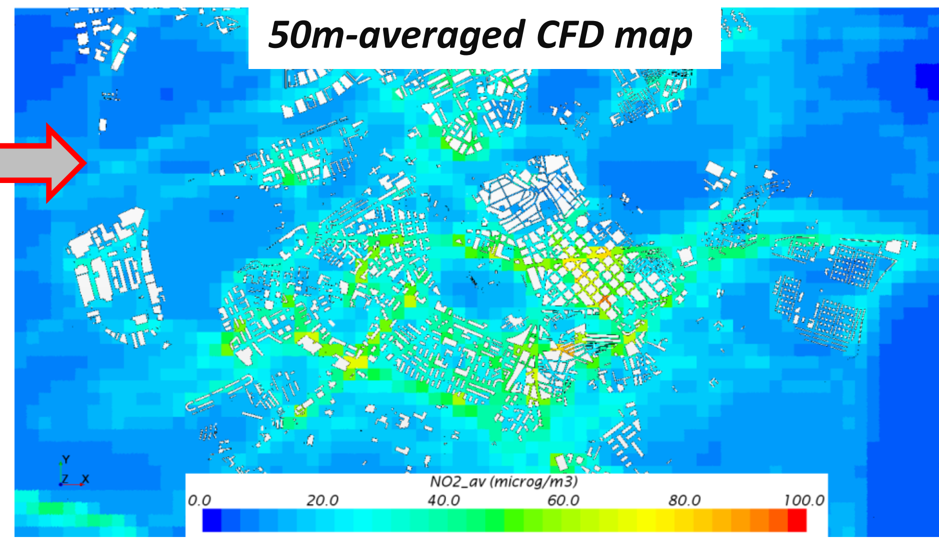
Model evaluation against experimental data from cyclists with microsensors







High resolution map of NO_2 annual average concentration during 2015 at pedestrian level(*)



Annual average concentration map of NO_2 spatially-averaged in cells of 50 x 50 m^2(*)

(*) Lechón Y. et al. *Externalities assessment of traffic related NO2 emissions in the city of Pamplona (Spain).* **14th ASAAQ Conference.** 29 - 31 May 2017 – Strasbourg, France.

Model evaluation against experimental data from cyclists with microsensors

*Comparison **50m-averaged CFD maps** vs **50m-averaged cyclists maps** presents several difficulties:*

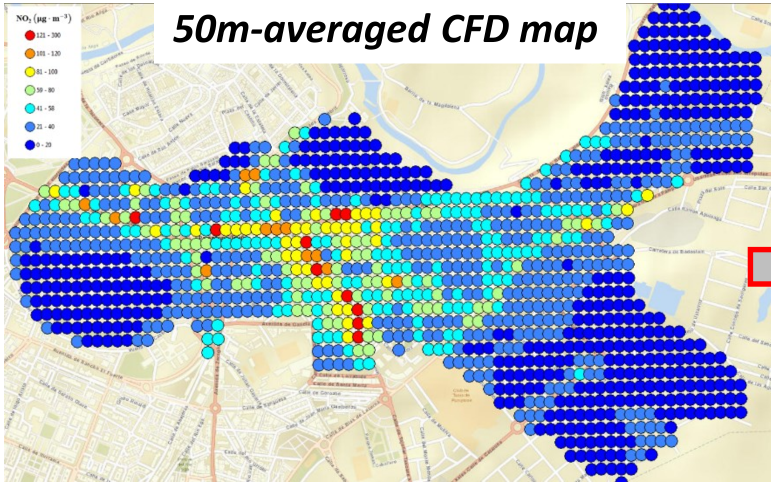
1. *In **CFD maps**, the concentration represents the average value over all cell, while in **cyclists maps,** concentration represents the average value but only over the portion of the cell where the cyclists travel.*

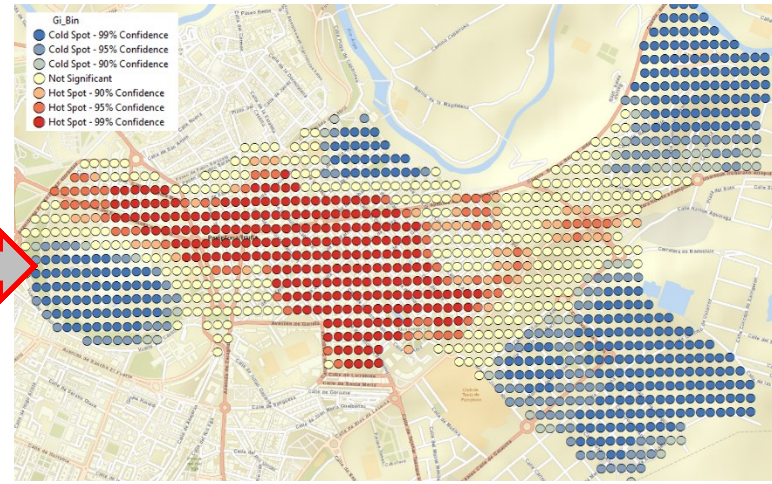
2. *Measurements from cyclists are accompanied by a certain spatial uncertainty due to: the microsensors sampling time and the movement of cyclists. These instruments send data every 10 s (time-averaged concentration and GPS position), but during this period there are uncertainties about the actual GPS positions traveled by cyclists.*

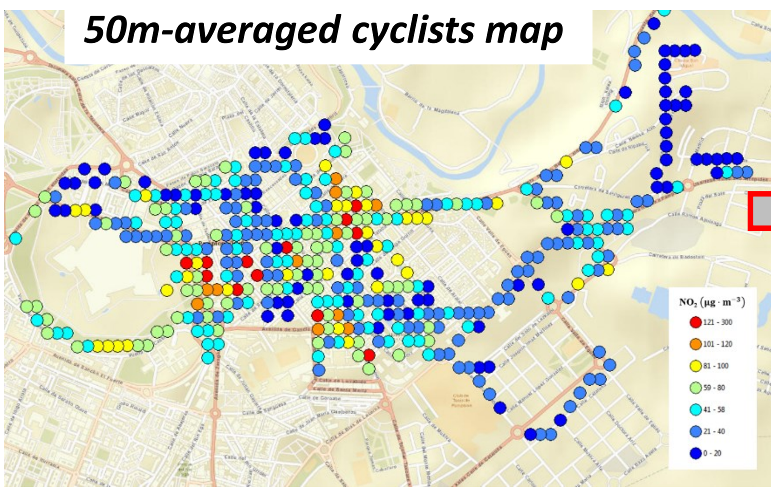
3. *The total number of cyclists in some cells could not be enough to obtain a representative average concentration value.*

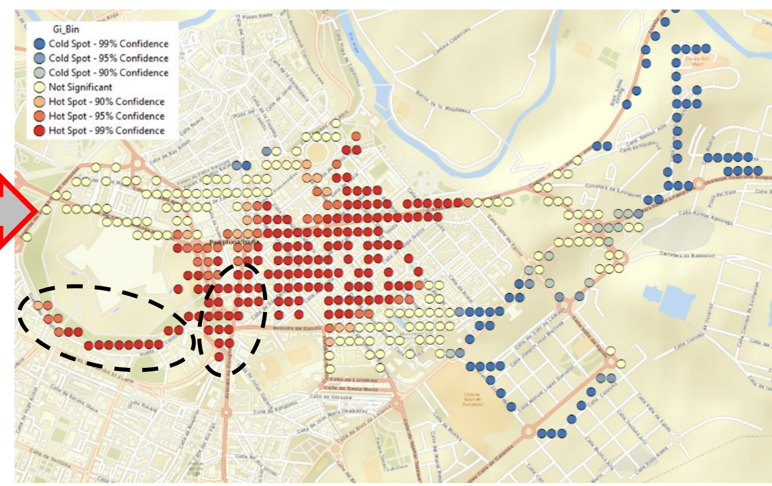
Therefore, a direct comparison (point-by-point) seems not be suitable …

Model evaluation against experimental data from cyclists with microsensors: NO_2, 8PM









Conclusions

- *A CFD-RANS methodology has been modified and applied to the entire city of Pamplona to compute high resolution NOx, NO2 and NO maps at pedestrian level.*

- *This modelling approach is able to reproduce the data from air quality monitoring stations located within the domain, especially during daytime hours (from 8 A.M. up to 8 P.M.).*

- *Data from cyclists could not be directly compared (point-by-point), therefore a comparison by using a spatial statistical method that identifies clusters of high and low values of pollutant concentrations is applied. A preliminary analysis indicates that, in general, similar locations of maxima and minima of concentration are obtained in both, experimental and numerical maps.*

- *This methodology seems to be adequate to compute high resolution concentration maps for an entire city.*

Thank you for your attention!

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