TASK FORCE ON INTEGRATED ASSESSMENT MODELLING (TFIAM)
51st session, 6-8 April 2022

The importance of multiscale model studies for the evaluation of measures to reduce NO_2 concentrations in urban areas

J.L. Santiago[1], M.G. Vivanco[1], B. Sanchez[2], E. Rivas[1], M.R. Theobald[1], J.L. Garrido[1], V. Gil[1], A. Martilli[1], A. Rodríguez-Sánchez[1], R. Buccolieri[2], F. Martín[1]

[1] Department of Environment, CIEMAT, Madrid, Spain
[2] Department of Geography, National University of Singapore, Singapore
[3] Dipartimento di Scienze e Tecnologie Biologiche ed Ambientali, University of Salento, Lecce, Italy

e-mail: jl.santiago@ciemat.es

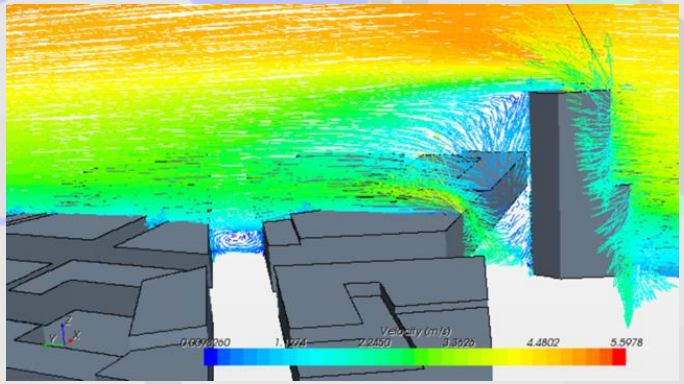
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

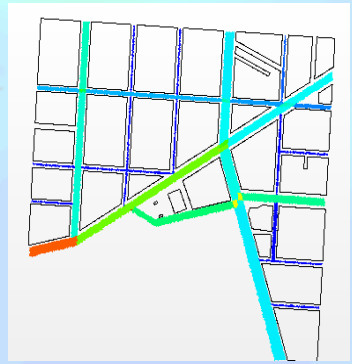
RETOS AIRE

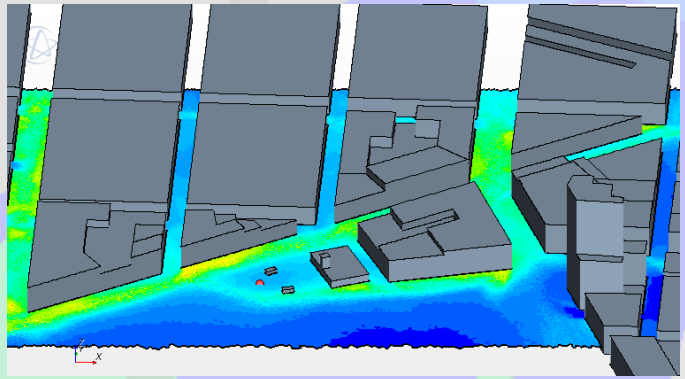
Introduction

- Atmosphere – Urban Surfaces Interactions → Complex flow circulation in city
- Reduced Ventilation in Streets
- Traffic Emission heterogeneities

High pollutant concentration and **strong gradient of concentration** (spatial and temporal)





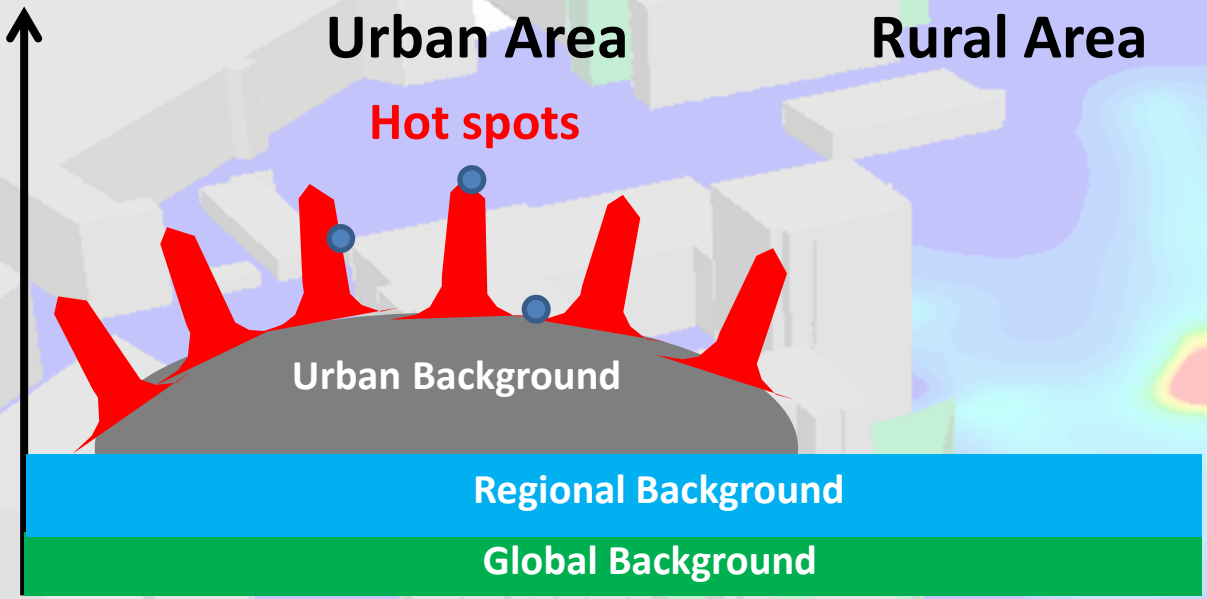


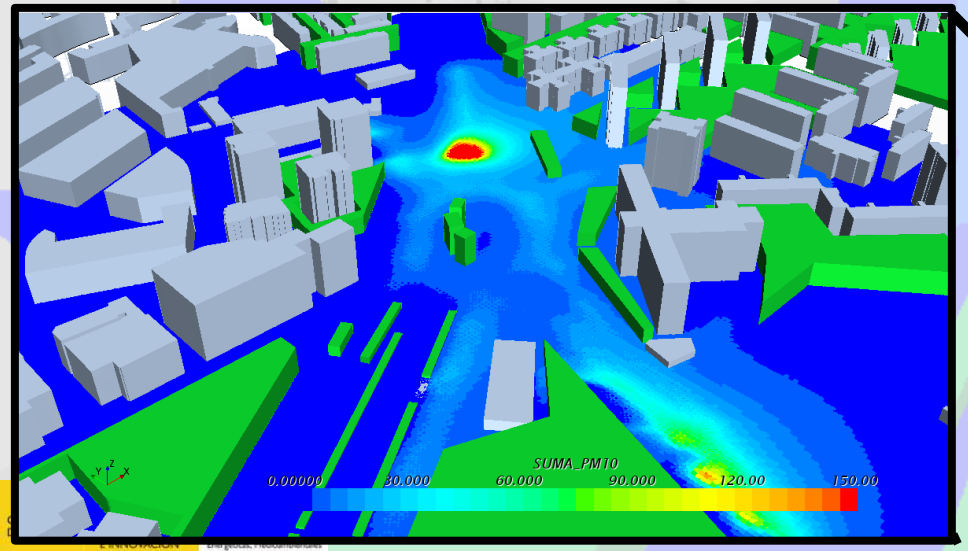
Street Scale

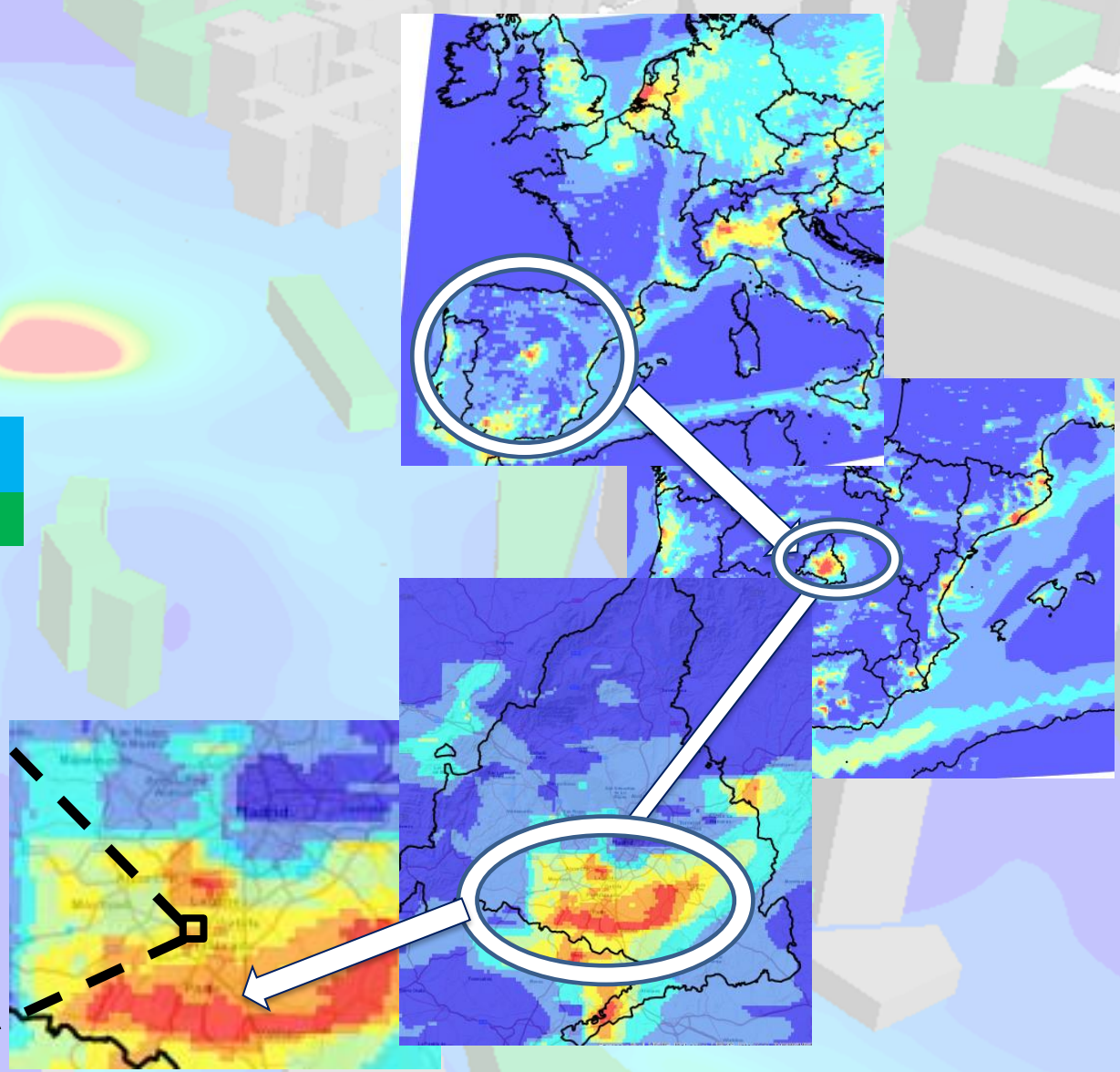
High Spatial Resolution Needed

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

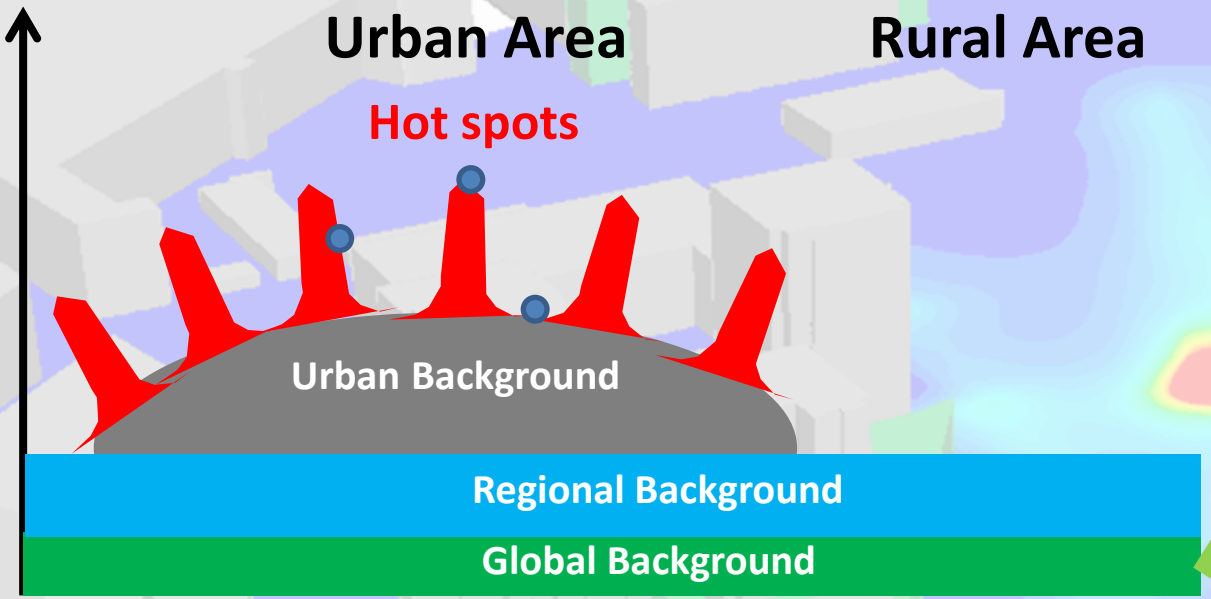
Introduction

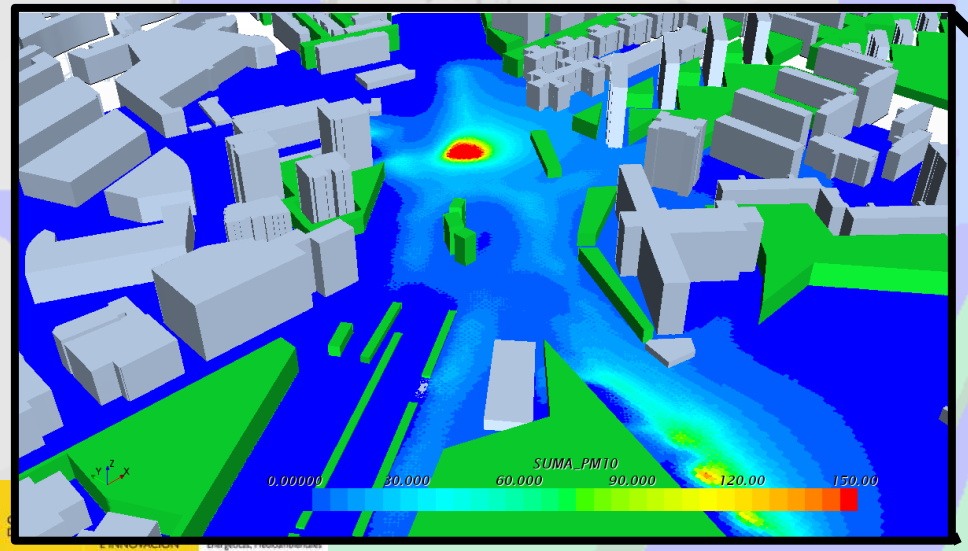


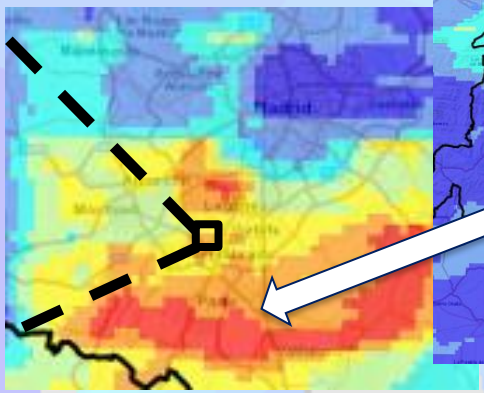


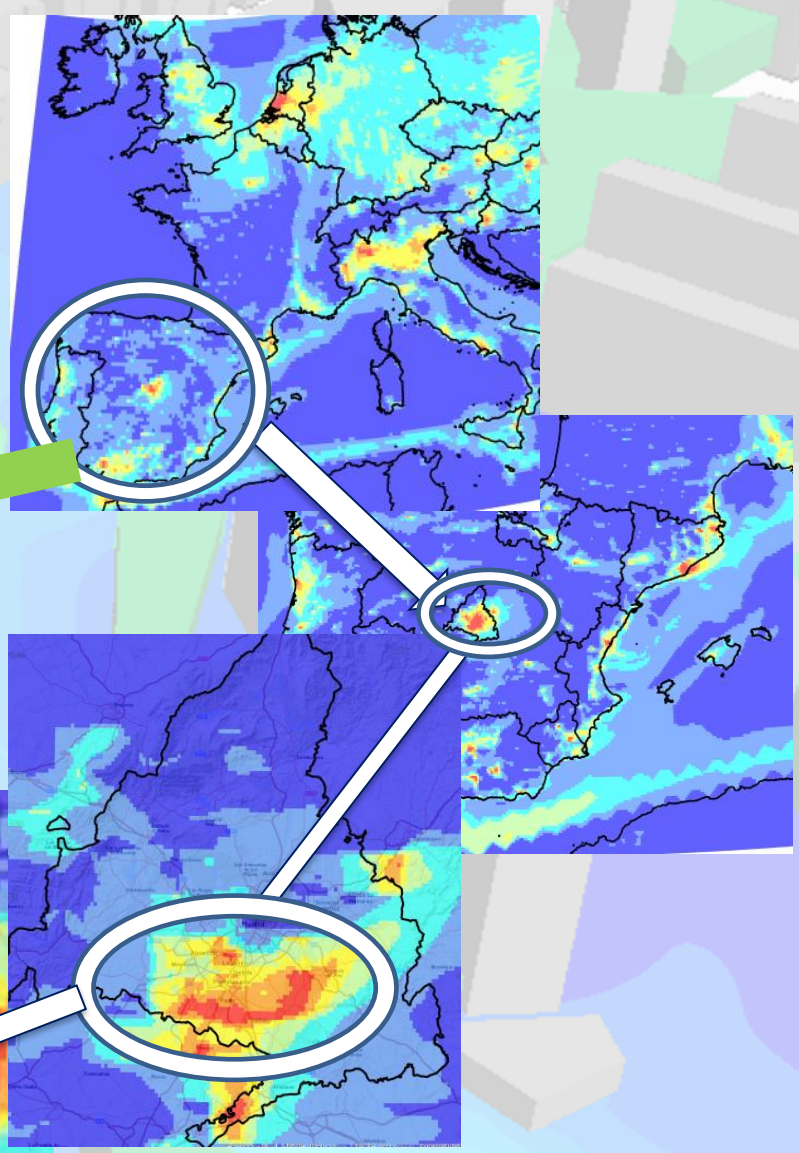


Introduction

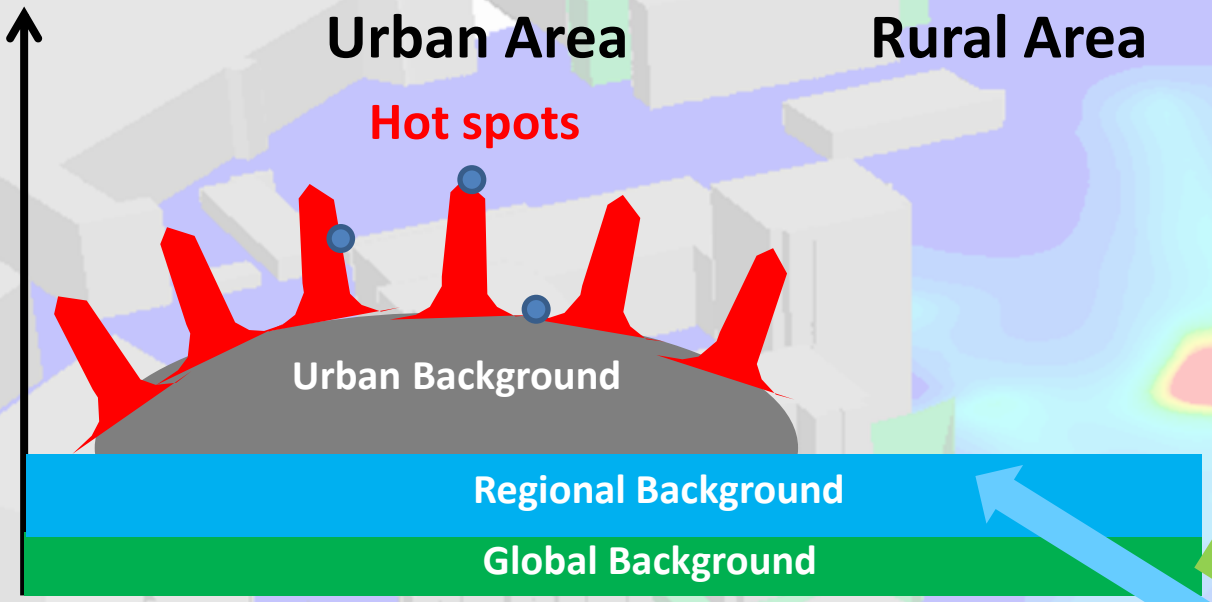


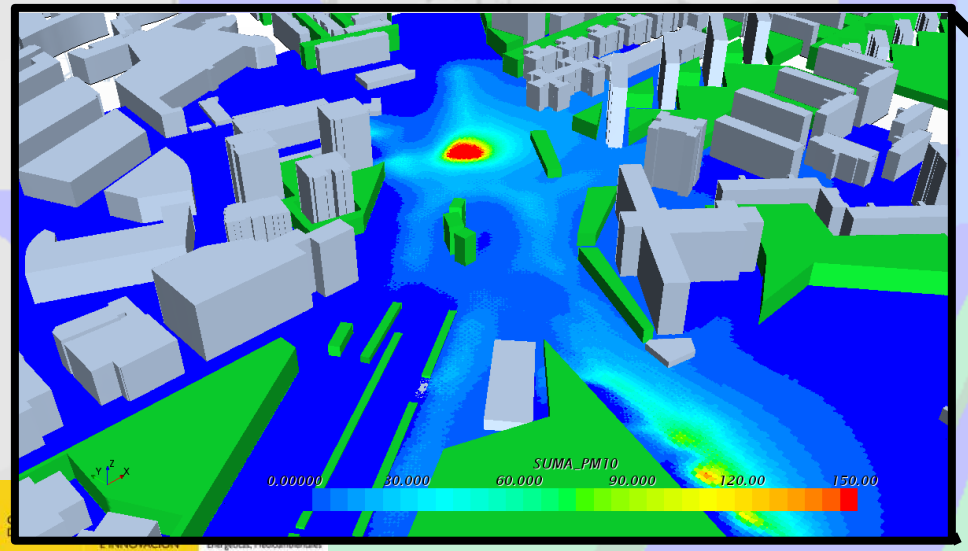


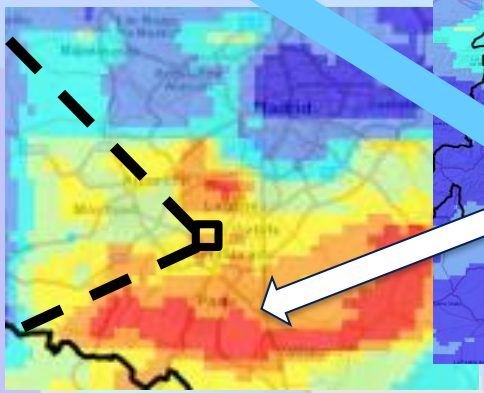


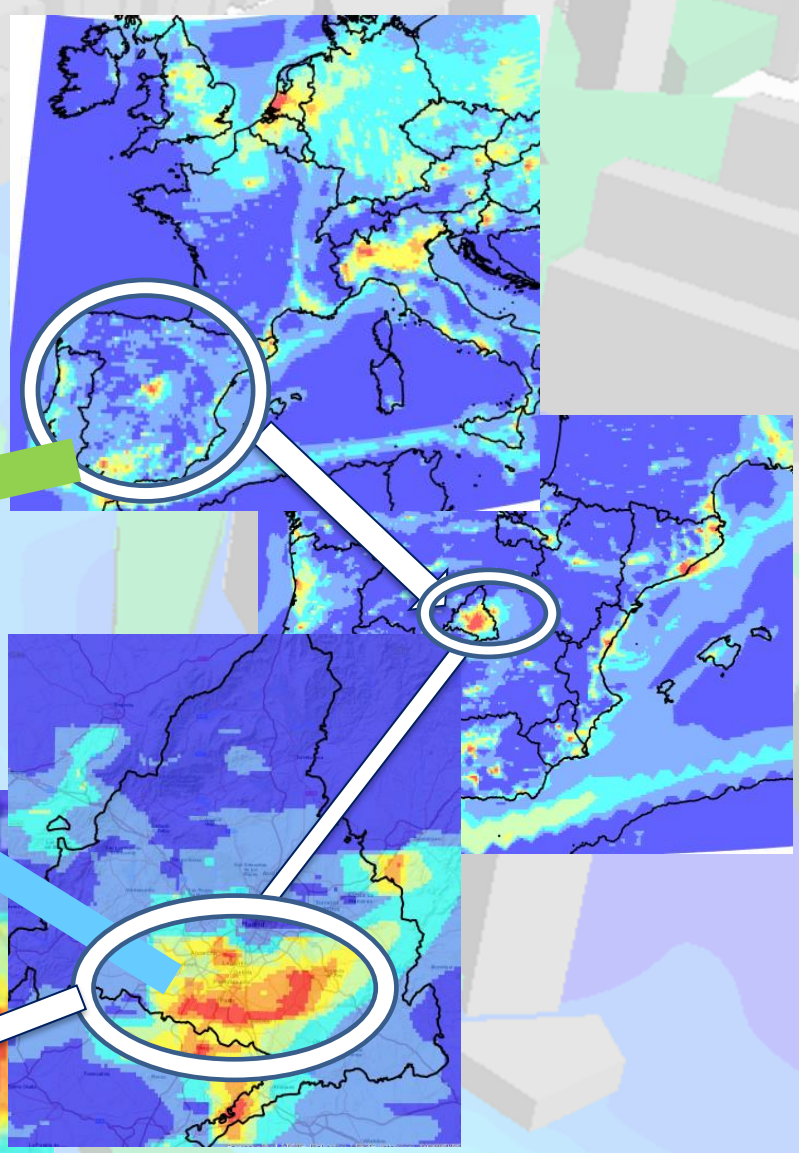


Introduction

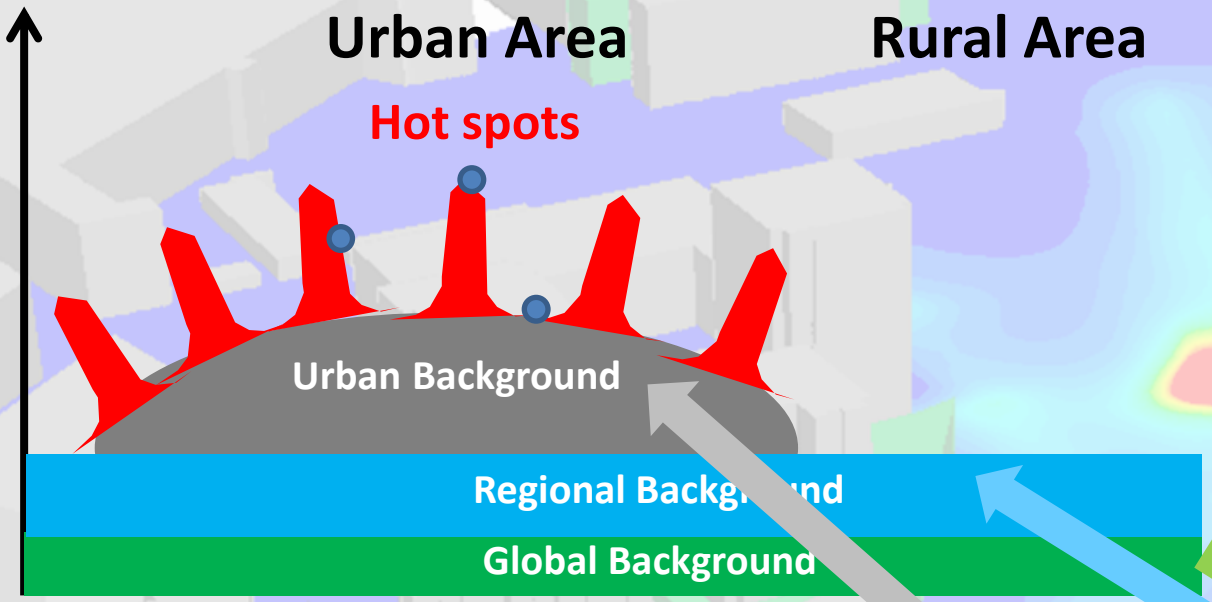


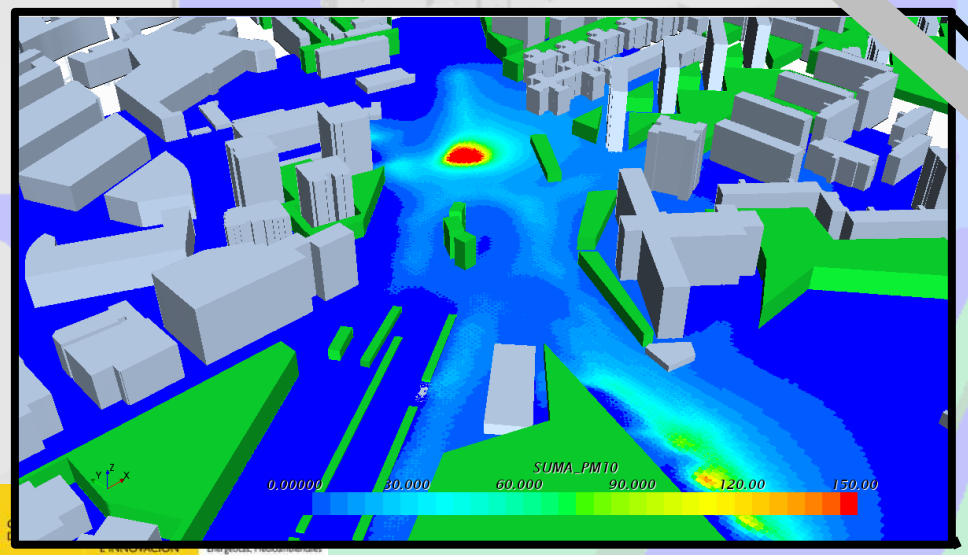


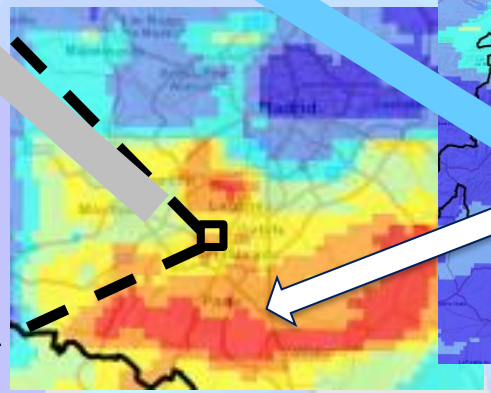


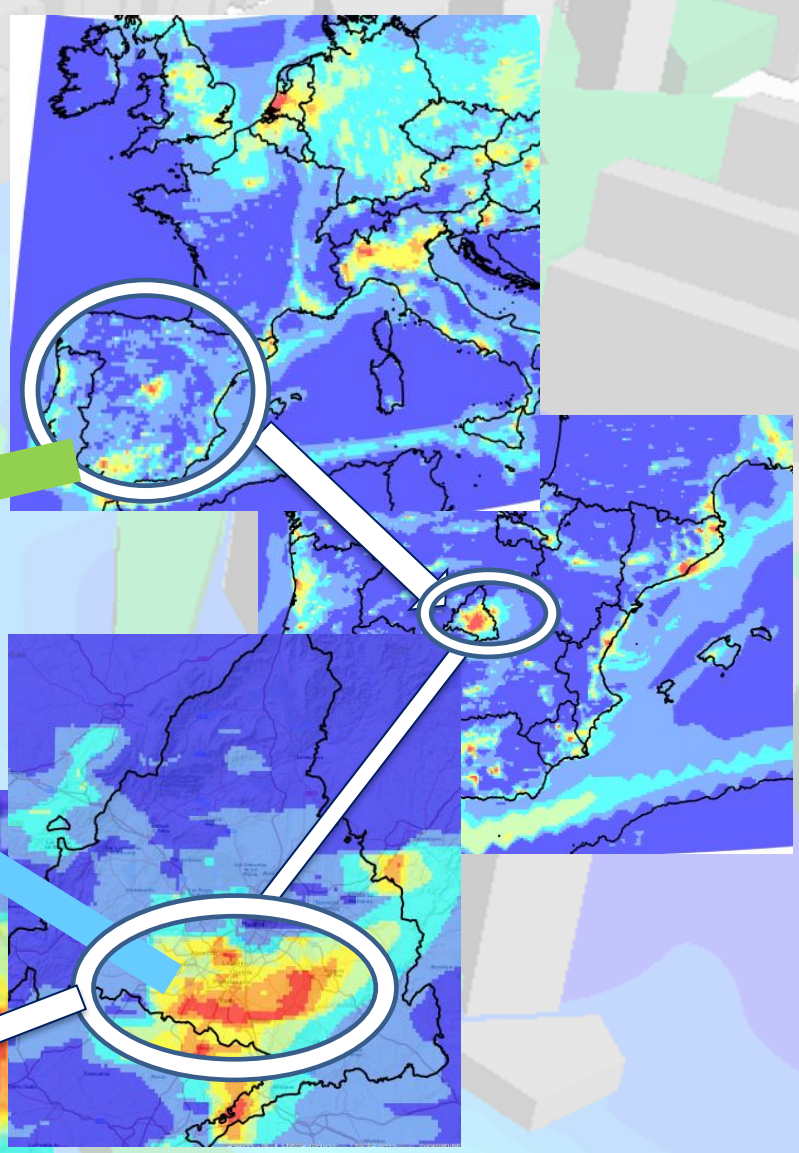


Introduction

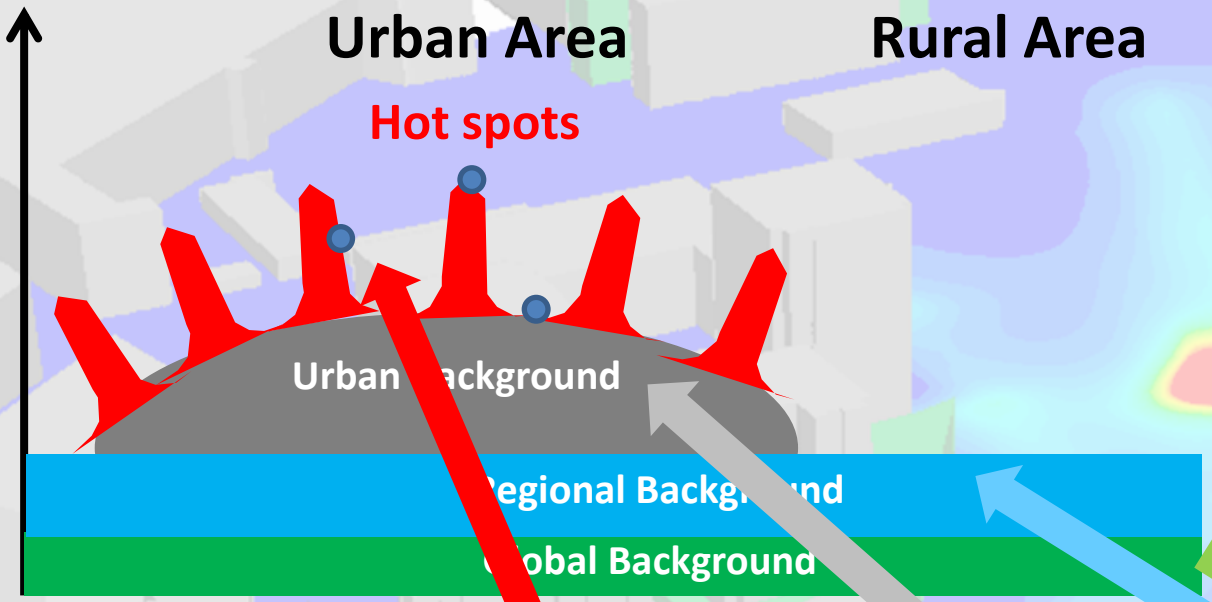


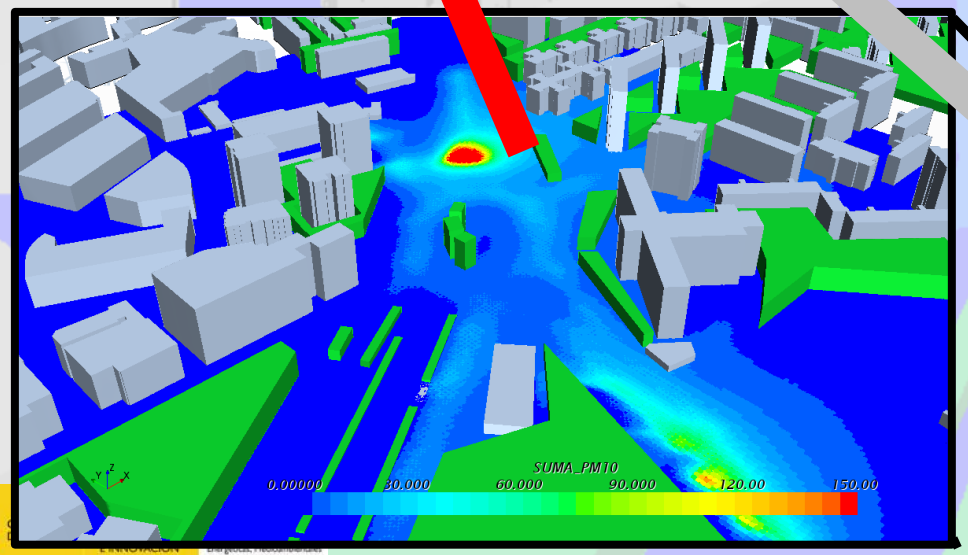


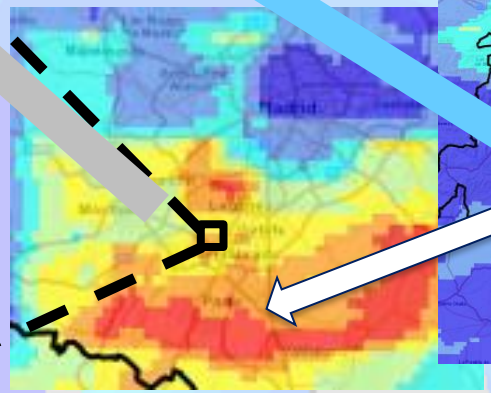


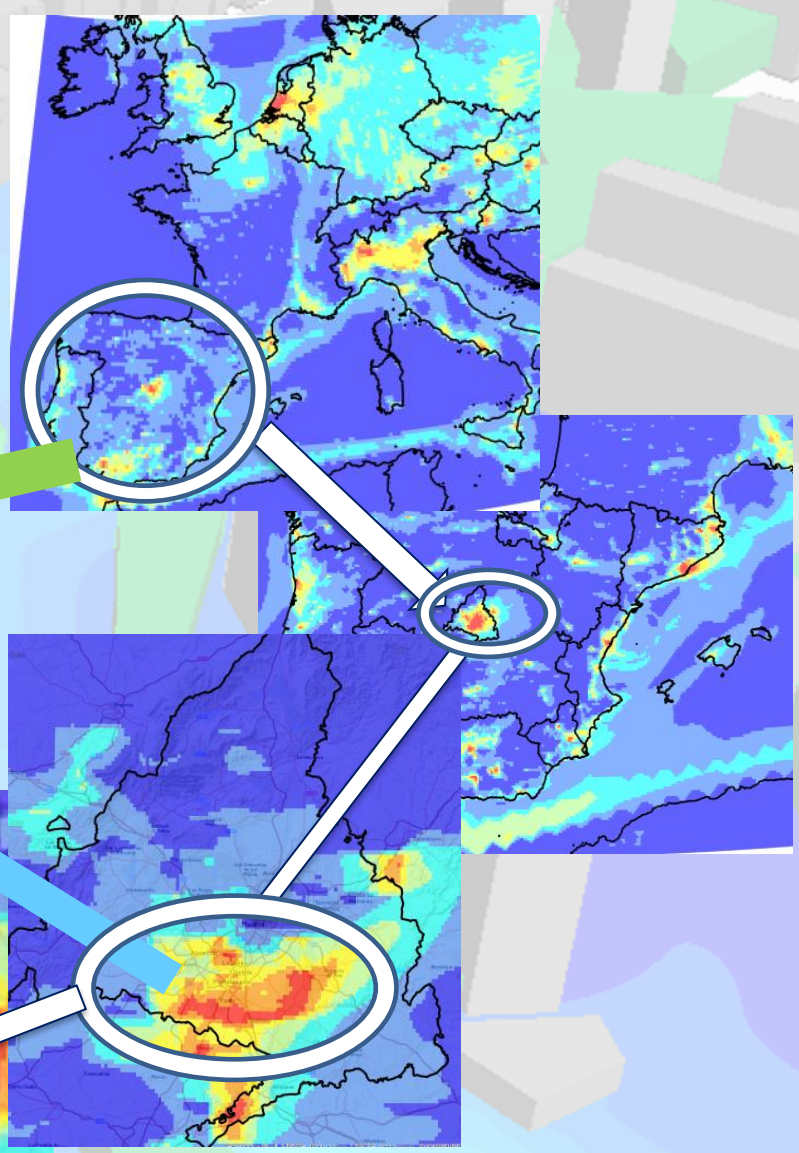


Introduction





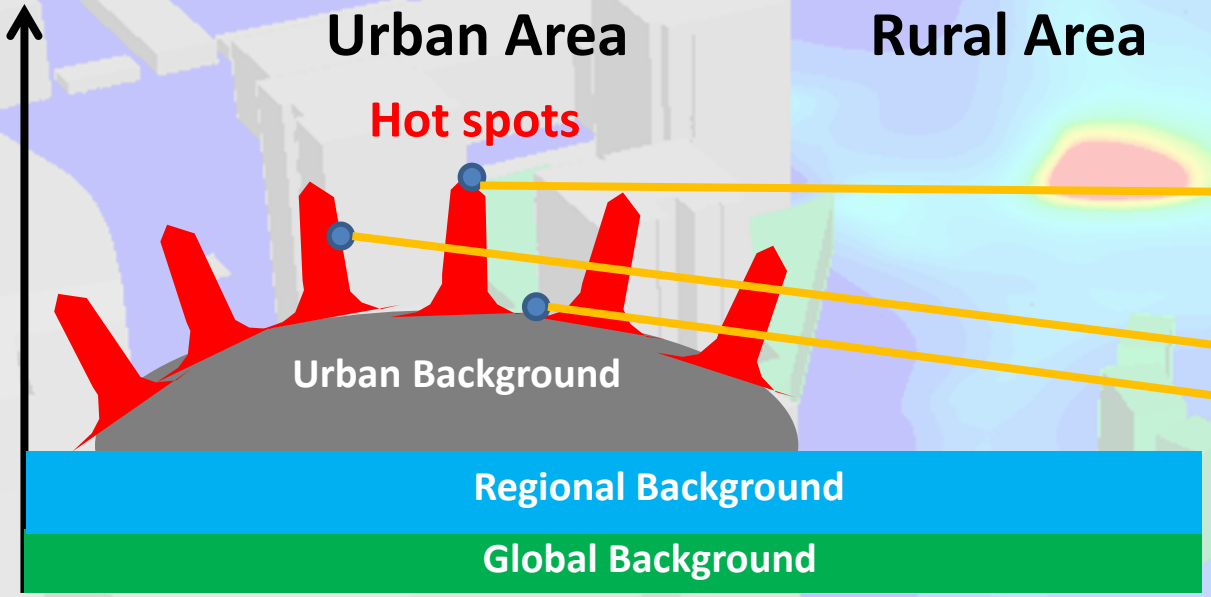


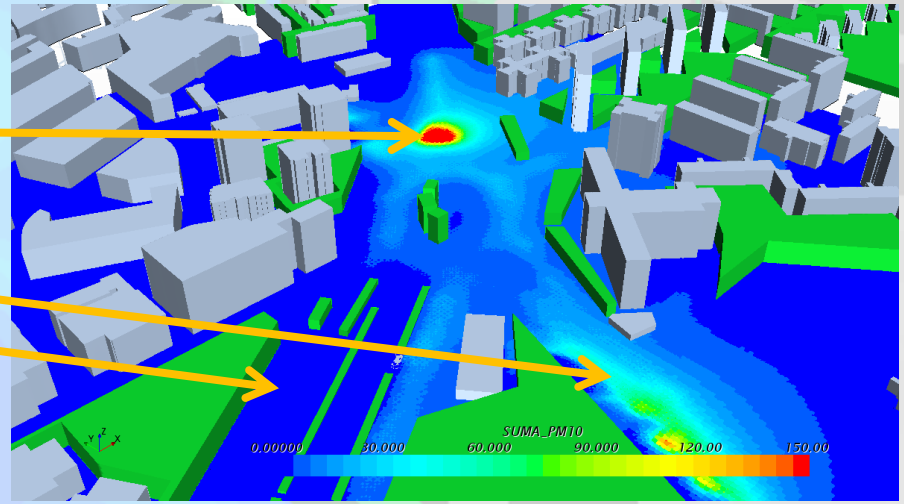


Introduction

Processes at different scales

- Concentrations at Street levels → Processes and contributions at different scale





Multiscale Modelling is needed

Objective

How much different is the model response at different scales to emission reductions at national level?

Objective

How much different is the model response at different scales to emission reductions at national level?

- **Objective**: To investigate the effects of **national emission reductions** on **street-level NO_2 concentrations** in **three neighborhoods of Madrid (Spain)** using **mesoscale and CFD modelling**.

Methodology

National emission scenarios

2016

Base Case

I Spanish National Air Pollution Control Programme (NAPCP)

Not an assessment of the NAPCP!

https://www.miteco.gob.es/images/es/primerpncca_2019_tcm30-502010.pdf

Methodology

National emission scenarios

2016

Base Case

I Spanish National Air Pollution Control Programme (NAPCP)

Scenario WEM2030

Emissions projected to 2030 assuming existing measures in the current legislation

Scenario WAM2030

Emissions projected to 2030 assuming additional measures of NAPCP

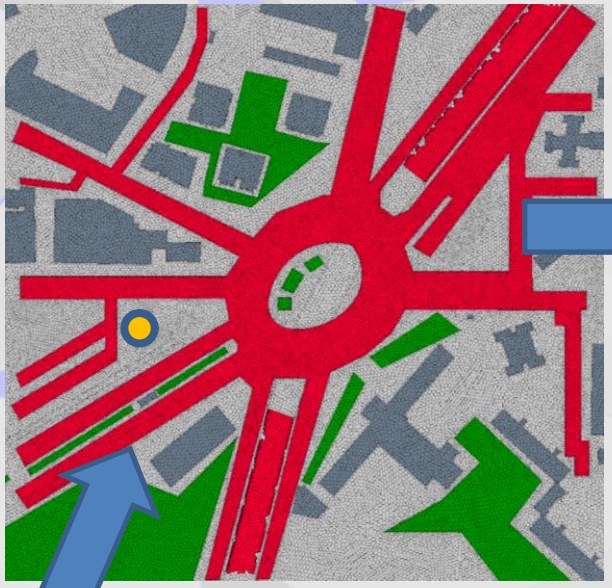
Total NOx reductions = 7% for WEM2030 and 33% for WAM2030

NOx Reduction for Road Transport = 7% for WEM2030 and 48% for WAM2030

Methodology

Multiscale modelling. WA CFD-RANS

CFD simulations



Database of simulations

- 16 wind directions
- 1 wind speed
- Neutral inlet profiles
- Traffic emissions

Hourly Meteo from mesoscale model

- V and wind direct.

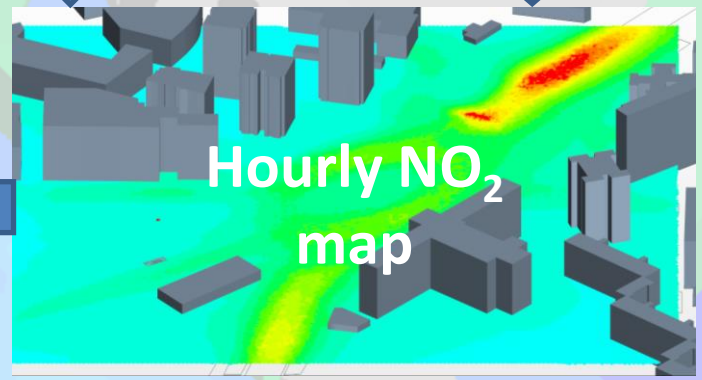
Selection of scenario

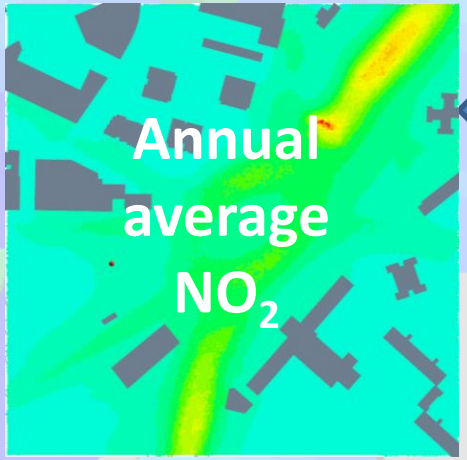
Hour and Day

Reference V

CHIMERE

- Background concentration
- Ratio NO_2/NOx
- Total NOx reductions for WEM2030 and WAM2030





Traffic emissions

(NOx reductions for road transport for WEM2030 and WAM2030)

(Santiago JL, et al, 2017. Sci Total Environ 576, 46-58)

(Santiago et al. 2022. Atmosphere 13, 248)

Methodology

Multiscale modelling. WA CFD-RANS

CFD simulations

Database of simulations

Hourly Meteo from mesoscale model

- V and wind direct.

CHIMERE

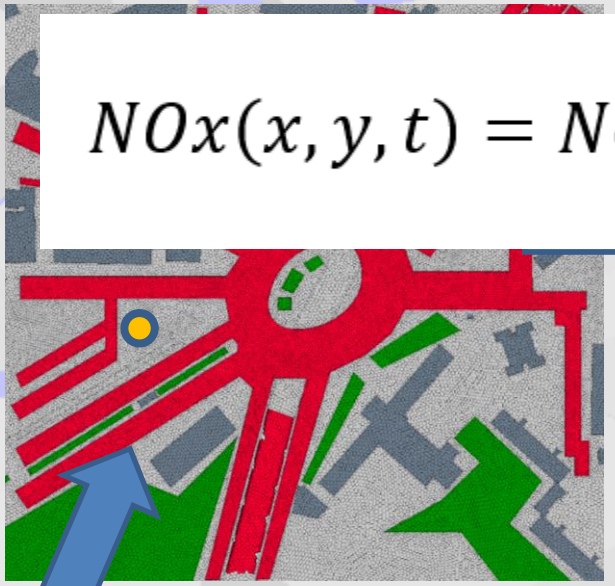
- Background concentration

$$NOx(x,y,t) = NOx\_CFD(WD(t), Em(t)) \frac{u_{ref}(CFD)}{u_{ref}(meso,t)} + NOx_{background}(t)$$

ns

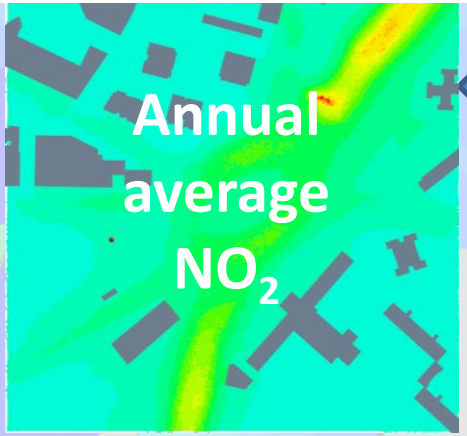
WAM2030

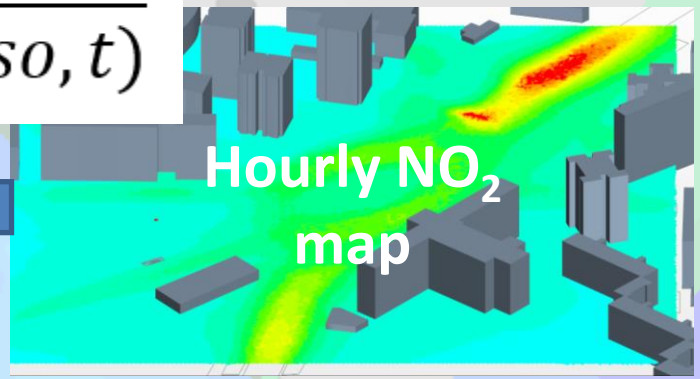
$$NO_2(x,y,t) = NOx(x,y,t) \frac{NO_2(meso,t)}{NOx(meso,t)}$$



Traffic emissions

(NOx reductions for road transport for WEM2030 and WAM2030)



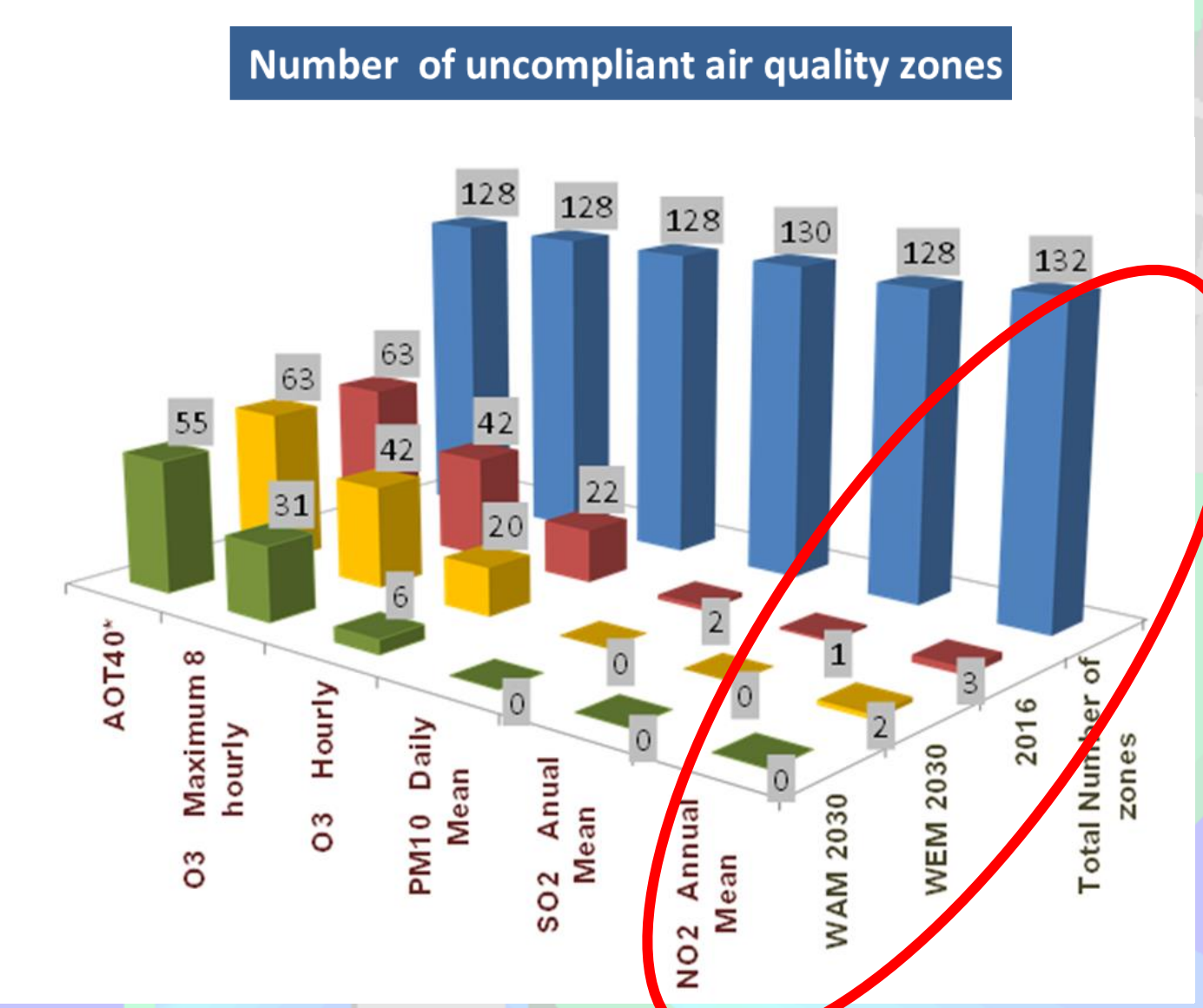


(Santiago JL, et al, 2017. Sci Total Environ 576, 46-58)

(Santiago et al. 2022. Atmosphere 13, 248)

Results of CHIMERE at national level (10 X 10 KM²)

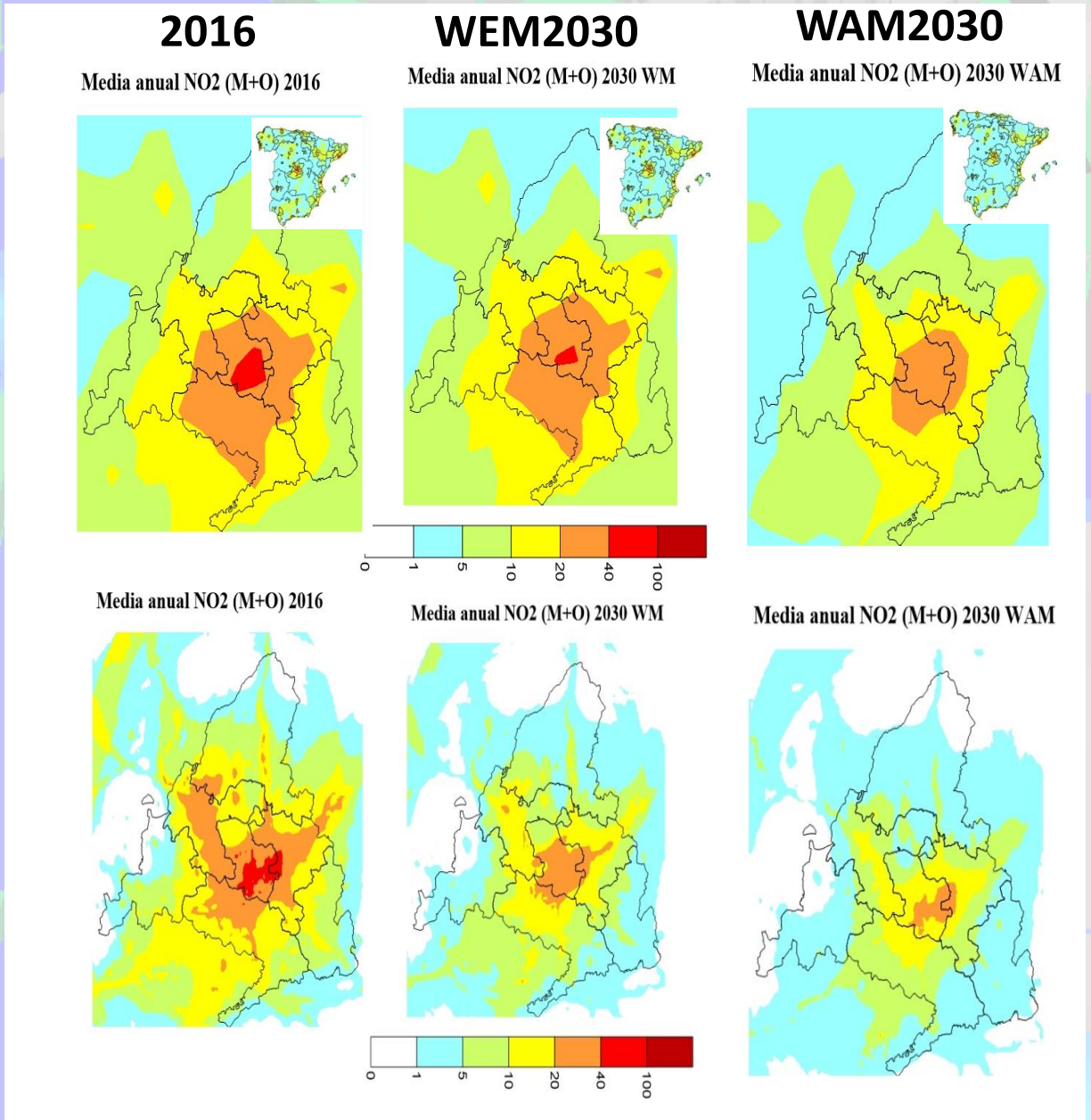
- **Scenario WEM2030**: assuming existing measures in the current legislation
- **Scenario WAM2030**: assuming additional measures of NAPCP



(*Vivanco et al., 2021, Atmosphere 12, 158*)

Results of CHIMERE at national level (10 X 10 KM²)

- **Scenario WEM2030**: assuming existing measures in the current legislation
- **Scenario WAM2030**: assuming additional measures of NAPCP



10 x 10 km²

1 x 1 km²

Results

Using the same emission reductions, what is the impact on street level NO_2 concentrations in urban hotspots at high spatial resolution?

Results

Study Urban Areas

- **3 neighborhoods** around **3 Air Quality Monitoring Stations** (AQMSs) → highest NO_2 concentrations within the city. (annual average of NO_2 concentration at these AQMSs above 40 µg m^{-3})
- **Plaza Eliptica**: A heavily trafficked roundabout with a freeway passing under it through a tunnel.
- **Escuelas Aguirre**: A large green urban area (El Retiro park) and avenues and streets with intense road traffic.
- **Plaza del Carmen**: A wide pedestrian zone, though AQMS close to avenue with intense traffic in 2016

Results

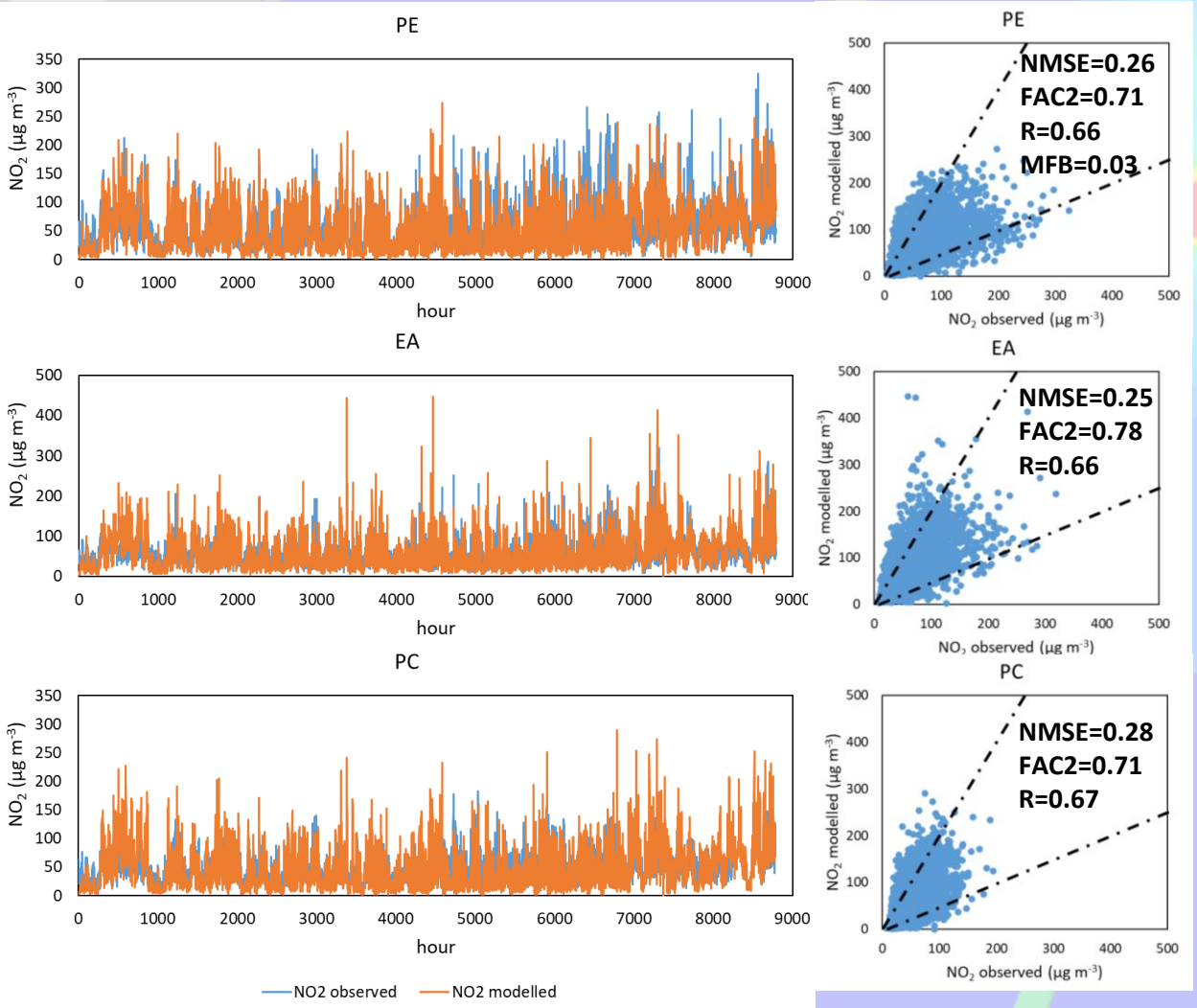
CFD modelling

- RANS equations with k-ε turbulence closure.
- Transport equation for NOx dispersion
- **Traffic emissions:**
  - Located in roads using mean daily traffic of each street.
  - For WEM 2030 and WAM2030 scenarios, only reductions of traffic emissions in CFD simulations. Reductions for the road transport sector (7% for WEM2030 and 48% for WAM2030).
- Simulations of 16 wind directions.
- Numerical domains around 1 km^2.
- Spatial resolution around 1 m close to the buildings (Several millions of cells, 3 -9 10^6 grid points)

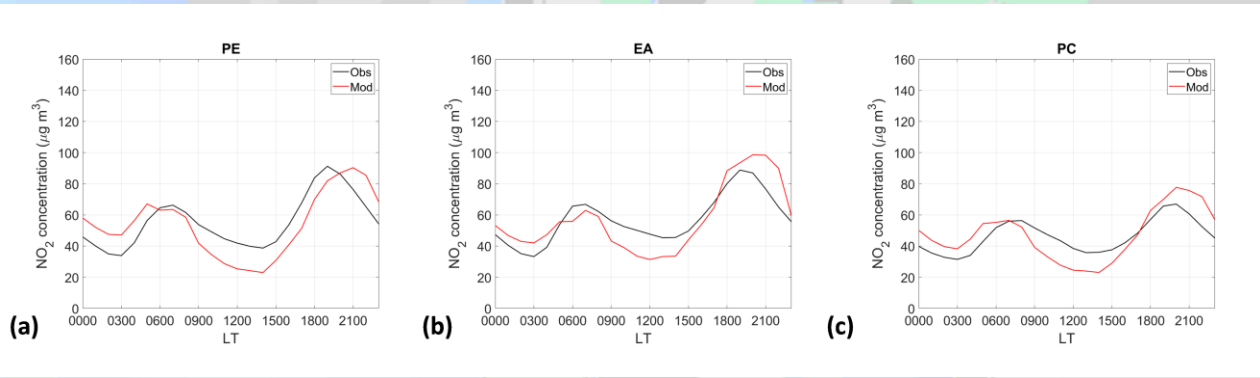
Results

Evaluation of modelling approach (evaluations in previous studies)

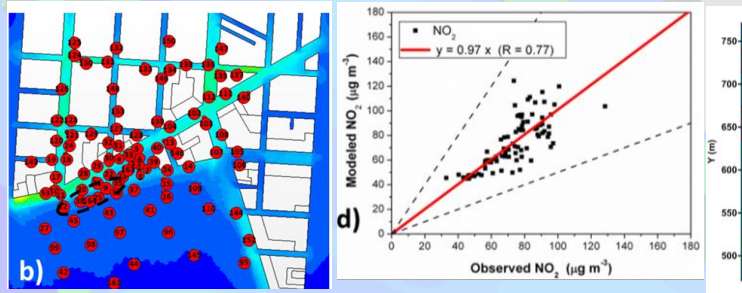
- Time series of NO_2 concentrations at AQMS

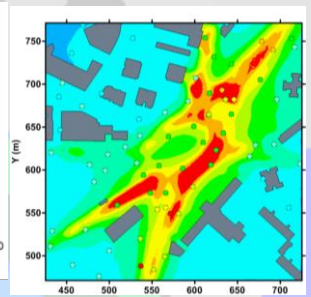


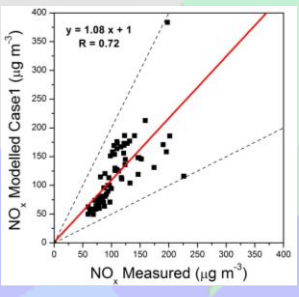
- Mean diurnal variation of NO_2 concentrations



- Evaluation of similar methodology in previous studies (campaigns of passive samplers)







EA: passive samplers campaigns in 2014

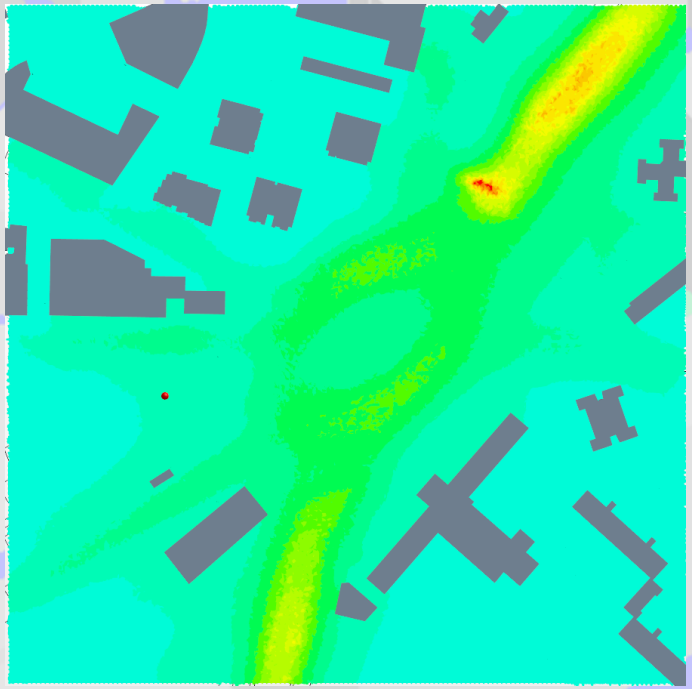
PE: passive samplers campaigns in 2015

Results

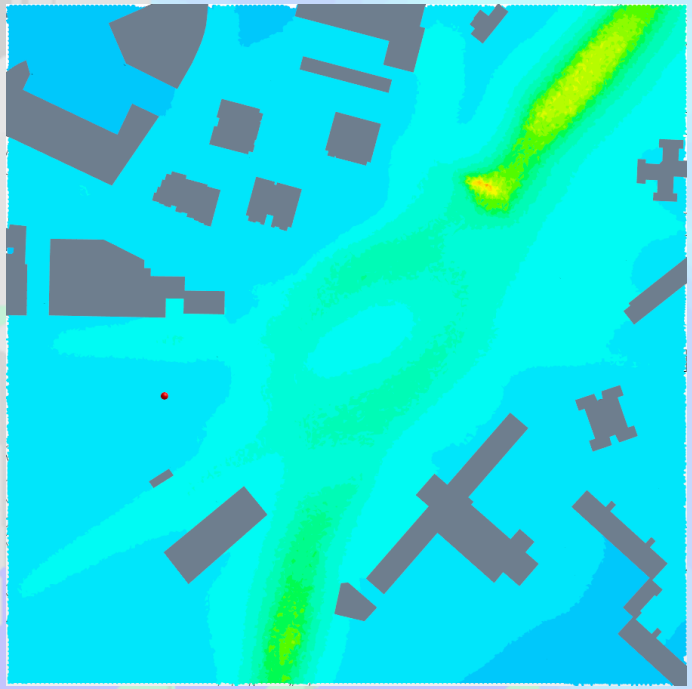
Annual average NO_2 concentrations

Plaza Elíptica (PE)

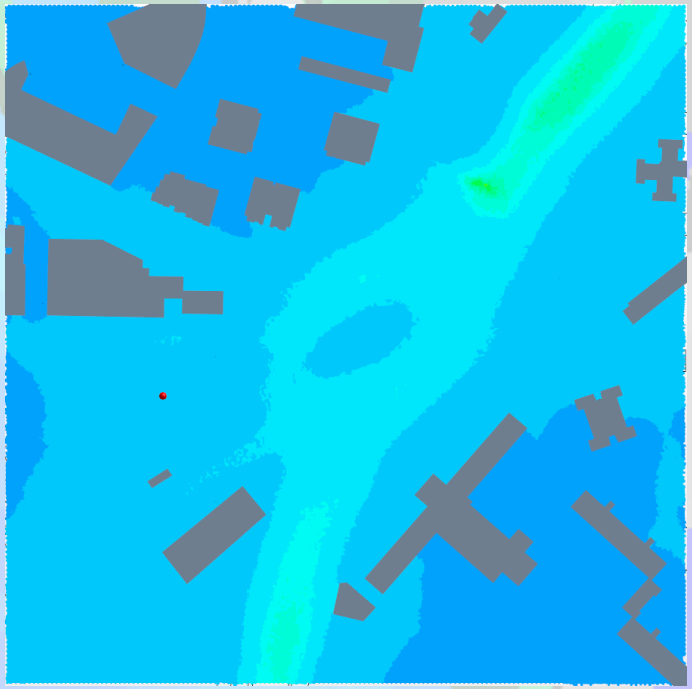
2016 scenario

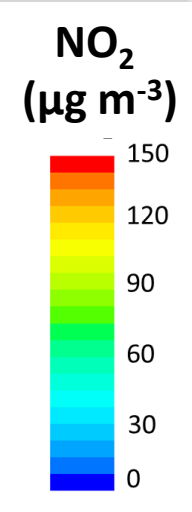


WEM2030



WAM2030



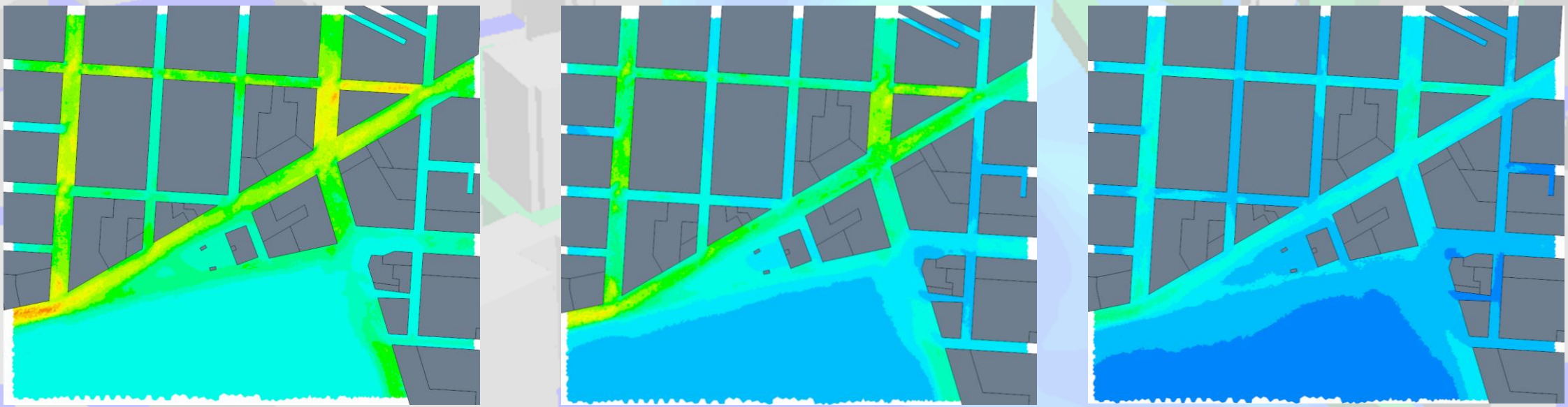


Results

Annual average NO_2 concentrations

Escuelas Aguirre (EA)

2016 scenario | **WEM2030** | **WAM2030**



Results

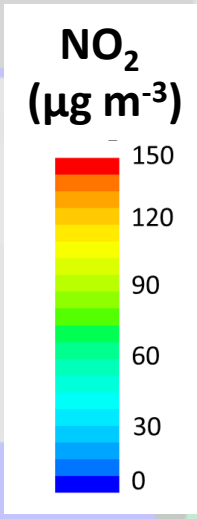
Annual average NO_2 concentrations

Plaza del Carmen (PC)

2016 scenario

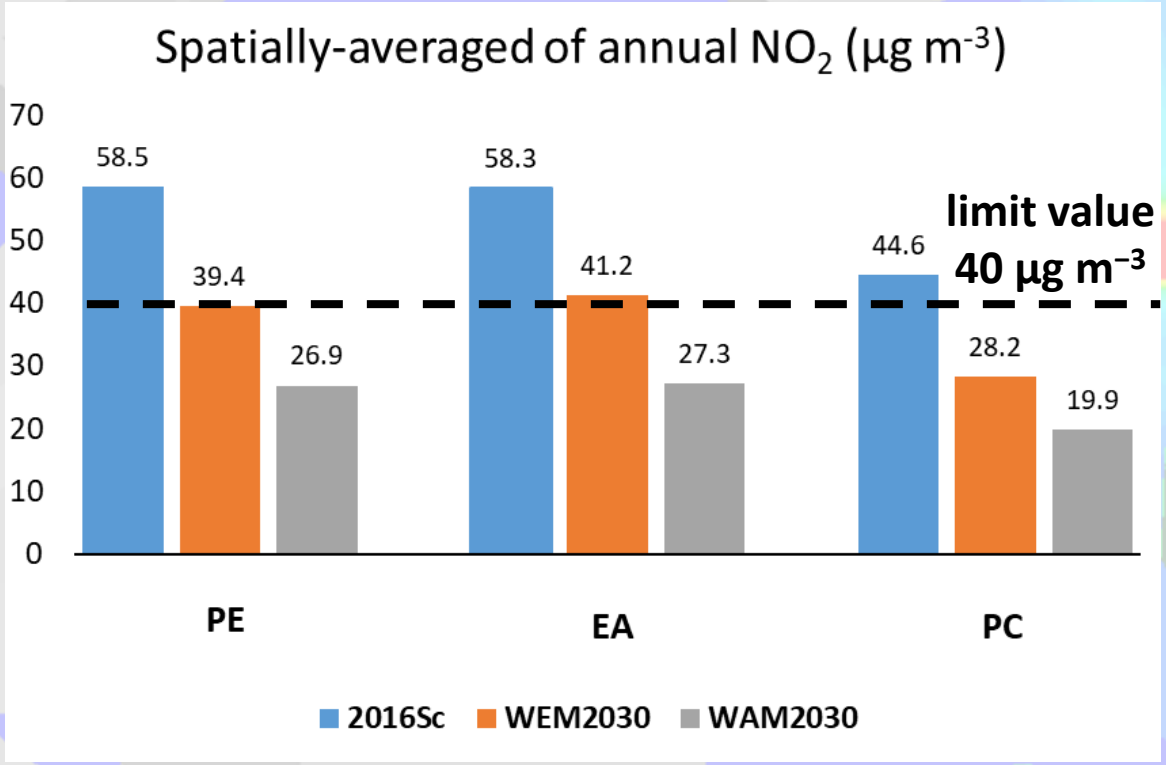
WEM2030

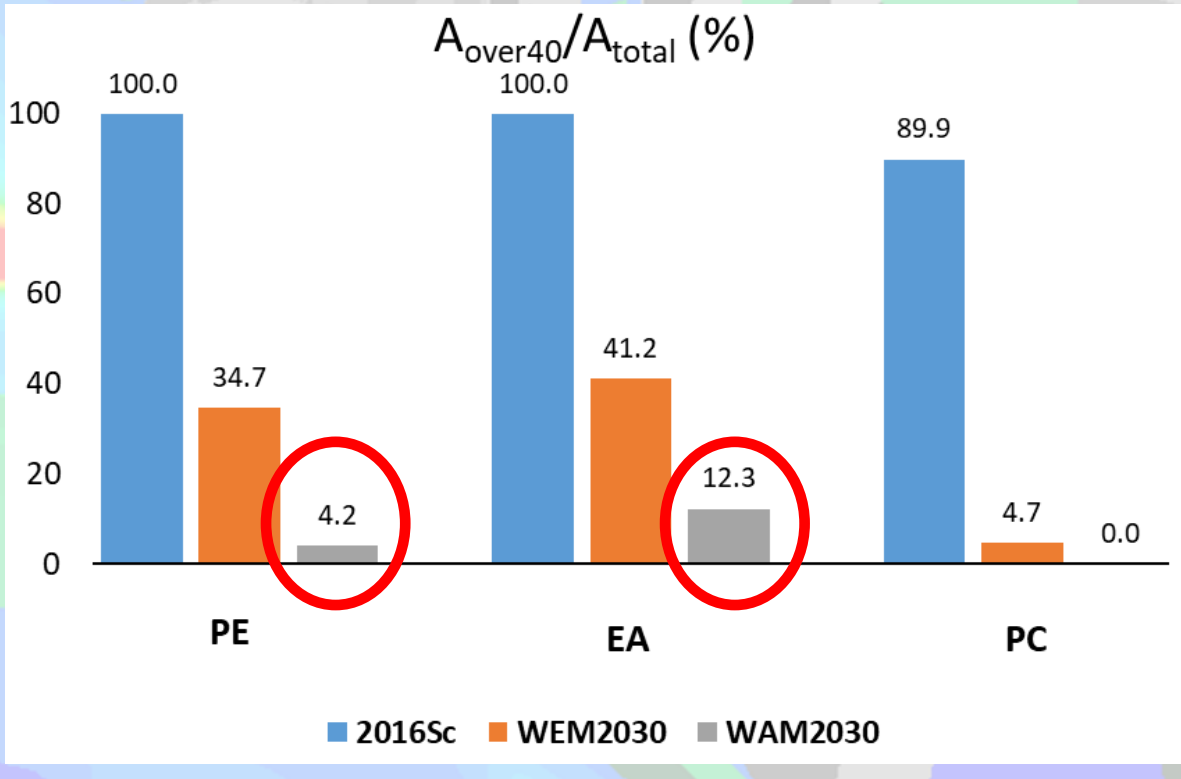
WAM2030



Results

Exceedances (anual mean limit value 40 µg m^{-3})



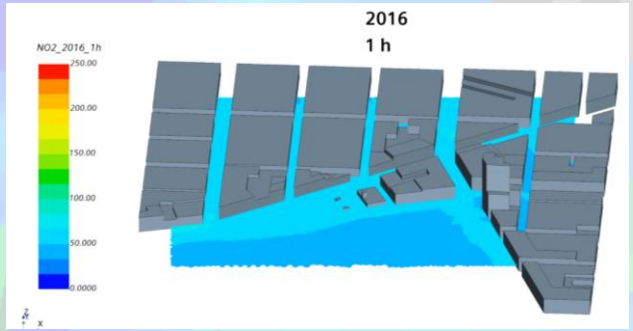


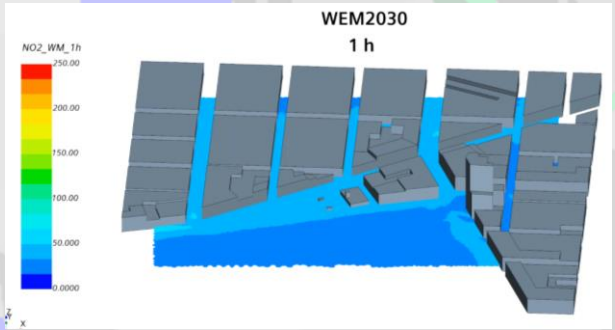
- For WAM2030, spatially-averaged of NO2 < annual average limit value for NO2 (in agreement with mesoscale simulations)
- Areas with concentrations above limit value, even for WAM2030, in PE and EA.

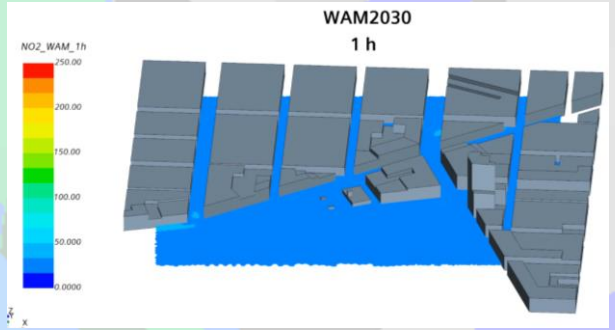
Summary and Conclusions

- High-spatial resolution maps of anual average NO_2 concentrations computed using multiscale approach (CFD models + mesoscale models).
- Objective: To investigate the model response at different scales to emission reductions at national level → Effects of national emission reductions on street-level NO_2
- Emission scenarios: **2016**, **WEM2030** (existing measures in the current legislation) and **WAM2030** (the additional measures of NAPCP).
- Despite the **annual mean limit value not being exceeded** in any of the study neighborhoods in terms of the **spatially-averaged NO_2** concentrations **for the WAM2030 scenario** (**in agreement with mesoscale study**), there are **areas with concentrations above 40 µg m^{-3} within two neighborhoods**.
- **Annual mean limit could be exceeded** in some areas **within the mesoscale cells in urban areas** in spite of the **spatially-averaged NO_2 concentration** being **below the limit value**.
- To estimate population exposure and air quality assessment, it is **important** to take into account **the spatial variability of NO_2 concentrations within each neighborhood**.

Thank you for your attention
Questions?







RETOS AIRE

http://retos-aire.ciemat.es/

More information:

High resolution study

Santiago et al. (2022). *Atmosphere* 13, 248. https://doi.org/10.3390/atmos13020248

Vivanco et al., 2021, *Atmosphere* 12, 158

Mesoscale study

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

e-mail: jl.santiago@ciemat.es