EXPERT PANEL FOR POLLUTING EMISSIONS REDUCTION
EXPAPER 2026

CALLIOPE - Taranto Digital Twin: strumento per la valutazione dell’esposizione all’inquinamento da traffico stradale

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The Digital Twin of Taranto: CALLIOPE project

CTE (*Casa delle Tecnologie Emergenti*) **CALLIOPE** is a research project financed by the ***Ministry of Enterprises***

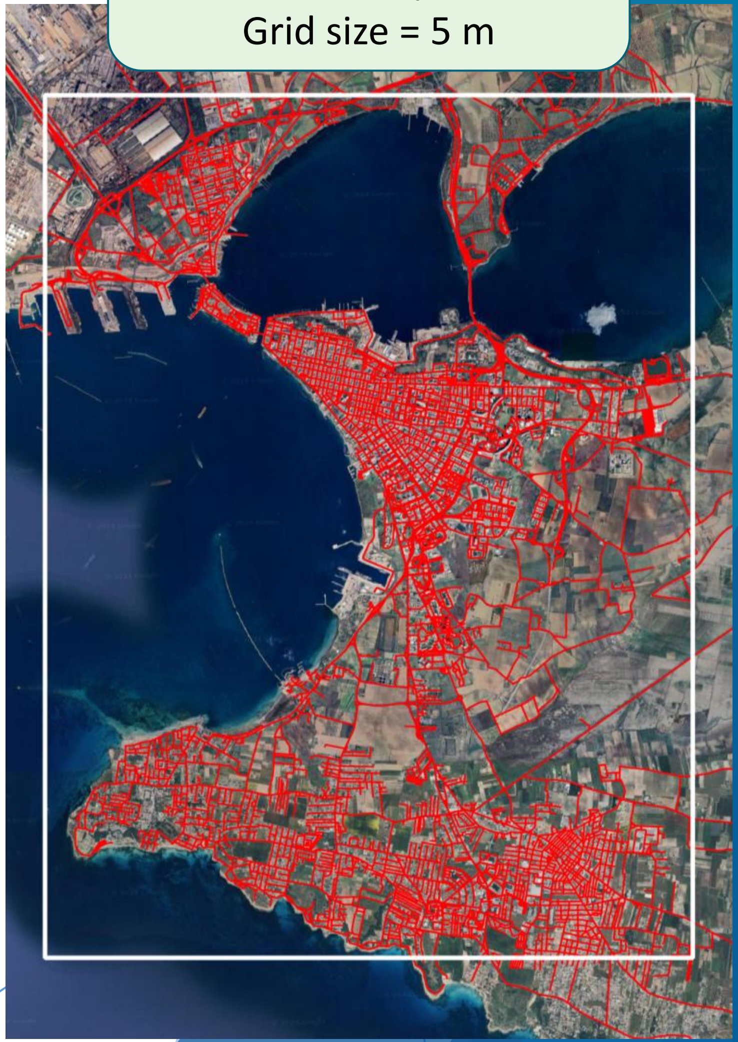
The scope of the CALLIOPE project

A sandbox platform to study and understand the relationships between environmental, chemical, physical agents and the **human health** in an **urban** context (city of Taranto).

The role of ARIANET

- Develop a **digital twin toolkit** of Taranto AQ to assess multiple exposure factors and eventually preserve the population from **sanitary risks**
- The toolkit enables the realization of ***"what if"*** *traffic* emission scenarios, allowing end users to apply mitigation actions, such as variations in the **road traffic** or the adoption of **natural based solutions** (NBS)
- Contextually, provide regional concentration background fields at 100m with data fusion techniques, for complete epidemiologic studies

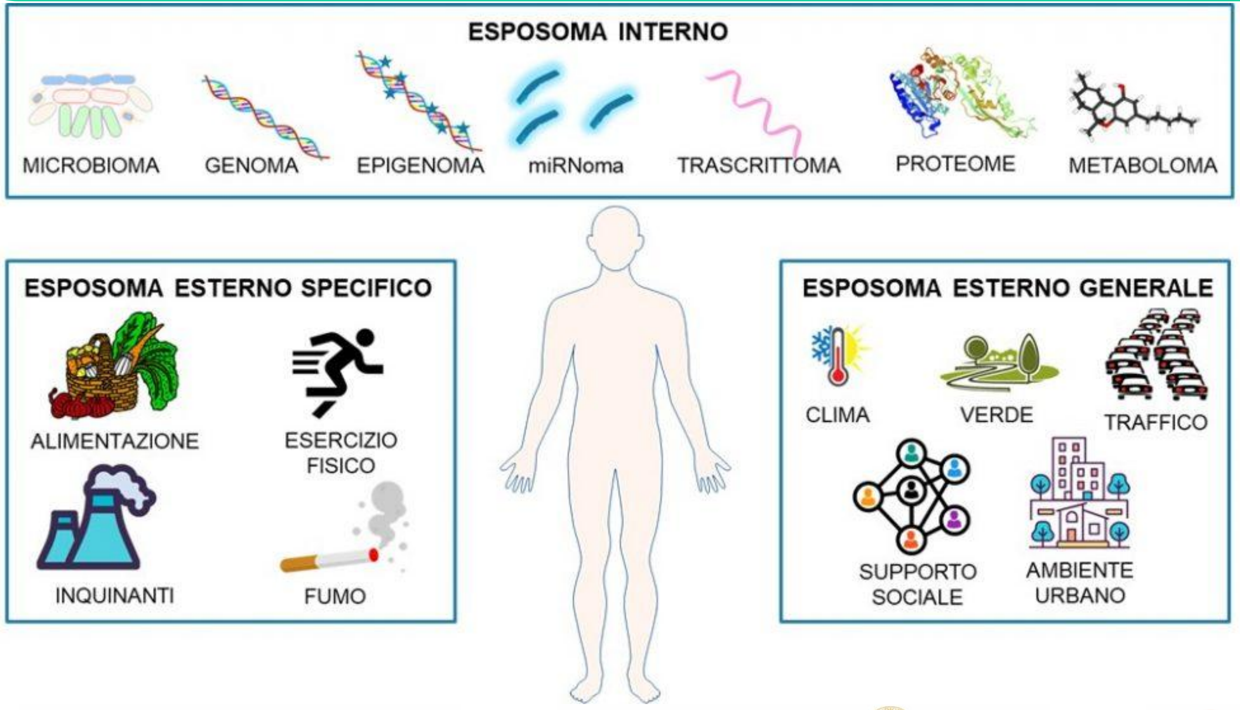
Microscale domain
Lx = 9 km - Ly = 12 km
Grid size = 5 m



CALLIOPE - the exposomic approach

The scope of the CALLIOPE project

Thanks to the AI capacity of elaborating large amounts of data, it is now more feasible to understand the relationships between environmental, chemical, physical agents and the **human health** including the totality of human disease determinants encountered throughout life, not only the major ones (**exposomic approach**).



La piaga di Taranto è [anche] ***il traffico***

Tha digital twin approach

The role of ARIANET

- The **AQ digital twin toolkit** is based on an atmospheric model and immediately enables the realization of ***"what if"*** *traffic impact* scenarios at the best spatial and temporal scale.
  The choice between a model and a digital twin depends on the representation level and the available resources

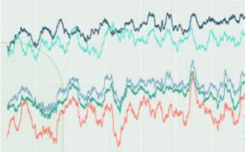
Resources	Low	High
Enough	Mo	Mo
Low	Mo	DT
	Representation	

Digital Twin

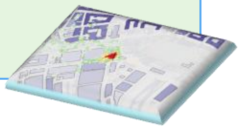
Modelling Tool

The Digital Twin: a tool for traffic emission scenarios

Meteo
Hourly time series of wind at regional scale
[ARPA PUGLIA + ARIANET]



PMSS kernels database
with normalized emissions
[ARIANET]



Emissions
Spatialised over a road network
[CUSTOMER + ARIANET]

+ Time modulations

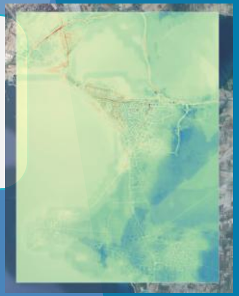
Digital Twin Toolkit

Pre-processor

CoKer
Kernel convolution on the basis of **meteo** and **emissions** hour by hour

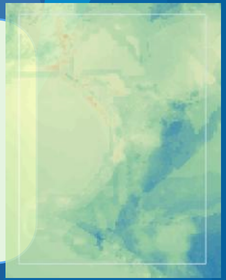
Post-processor

Mean concentration



Natural Based Solutions
Shapefile with trees features*
[CUSTOMER]

Regional background*
obtained with Data Fusion
[ARPA PUGLIA + ARIANET]

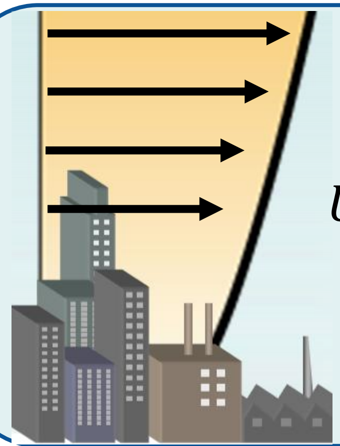


Normalized dispersion kernels construction

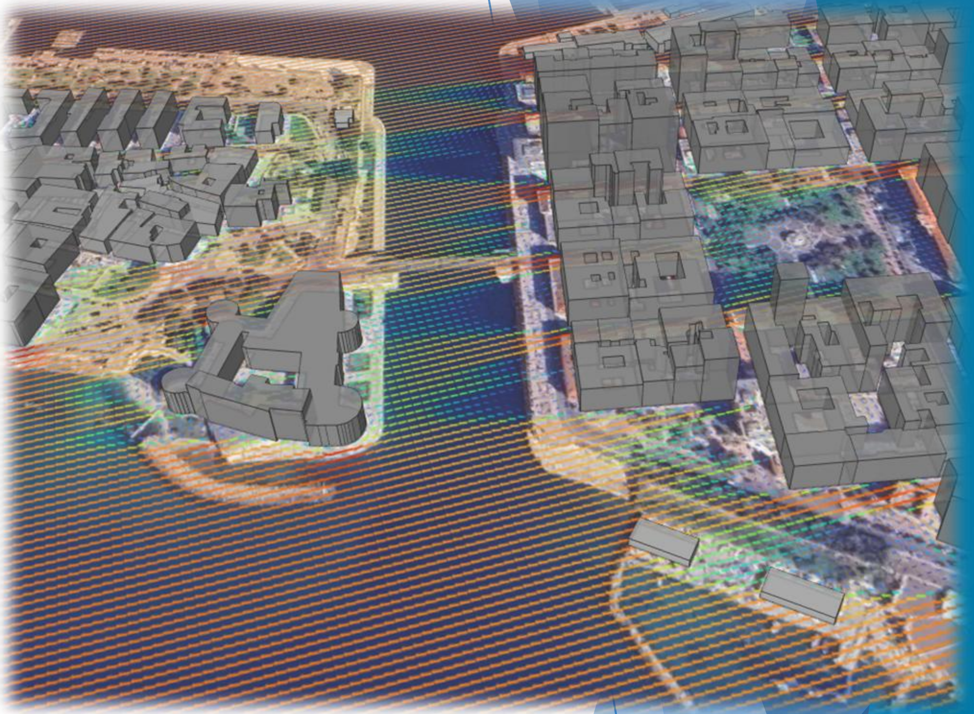
Inlet wind profiles
6 wind speeds at 10m
8 wind directions at 10m
5 stability classes
240 combinations

3D Meteo downscaling
PSWIFT
Adapt the wind profiles to buildings
240 simulations

Buildings
Vectorial Shapefile



$$U = U_{10}\left(\frac{z}{10}\right)^{\alpha}$$



Wind profiles are built raising the wind at 10 m using **power laws** which depend on **stability** and imposing **urban surface roughness**

Normalized dispersion kernels construction

Inlet wind profiles*
6 wind speeds
8 wind directions
5 stability classes
240 combinations

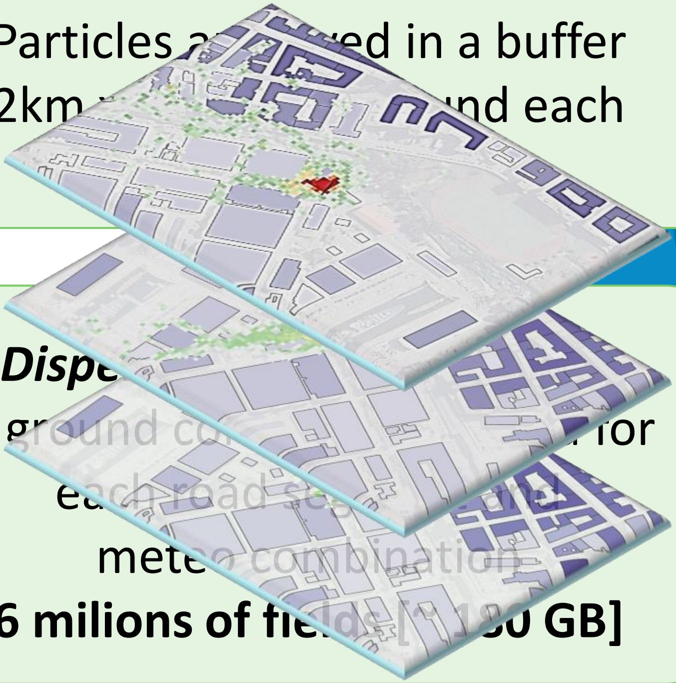
3D Meteo downscaling
PSWIFT
Adapt the wind profiles to buildings
240 simulations

3D Dispersion simulations
PSPRAY
Stationary dispersion from traffic emission at microscale
240 simulations

PMSS DRIVEN KERNELS

Buildings
Vectorial Shapefile

Particles a ed in a buffer
2km und each



Dispe
A ground co for
each road se
meteo combination
6 milions of fie [0 GB]

Street Graph
4000 polylines

Discretized graph
26000 road segments with normalized emissions

Dispersion kernels at microscale - meteo combinations

Dispersion kernels are realized performing 3D **PMSS** simulations for each **combinations** of inlet meteorological variables*

Stationary regime
Normalized emissions

Variable	Number of classes	Classes
Wind direction [degrees from North]	**8**	0° - 45° - 90° - 135° - 180° - 225° - 270° - 315 °
Wind speed at 10 m [m/s]	**6**	1 – 2 – 3 – 5 – 7 – 9
Atmospheric stability class [Pasquill]	**5**	A – B – C – D – E/F

For each meteorological combination, we extract the contribution of each **source** to the **ground concentration field**
in a ***square buffer of side 2km*** around the segment baricenter

Total meteo combination: 8 x 6 x 5 = **240**

Sources number: around **26000**

about 6 millions kernels
(concentration field at ground for street segment and meteo combination)

The kernel database built in such way weights about **180 GB**.

Dispersion kernels at microscale - examples

Kernel examples, with **fixed source** e by **varying of meteorological conditions***

* Fields cropped in a domain 600x400 m around a source are displayed to highlight the plume at the source, but kernels extend by 2000x2000 m

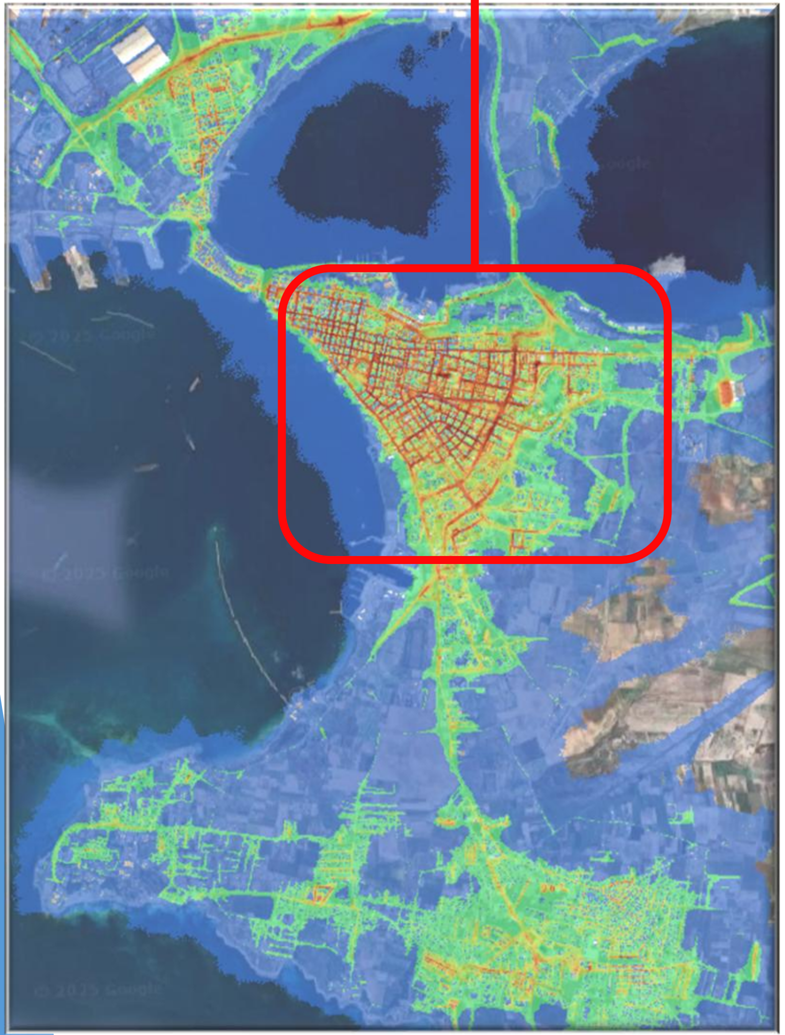
Buildings are displayed in purple scale, with intensity proportional to height

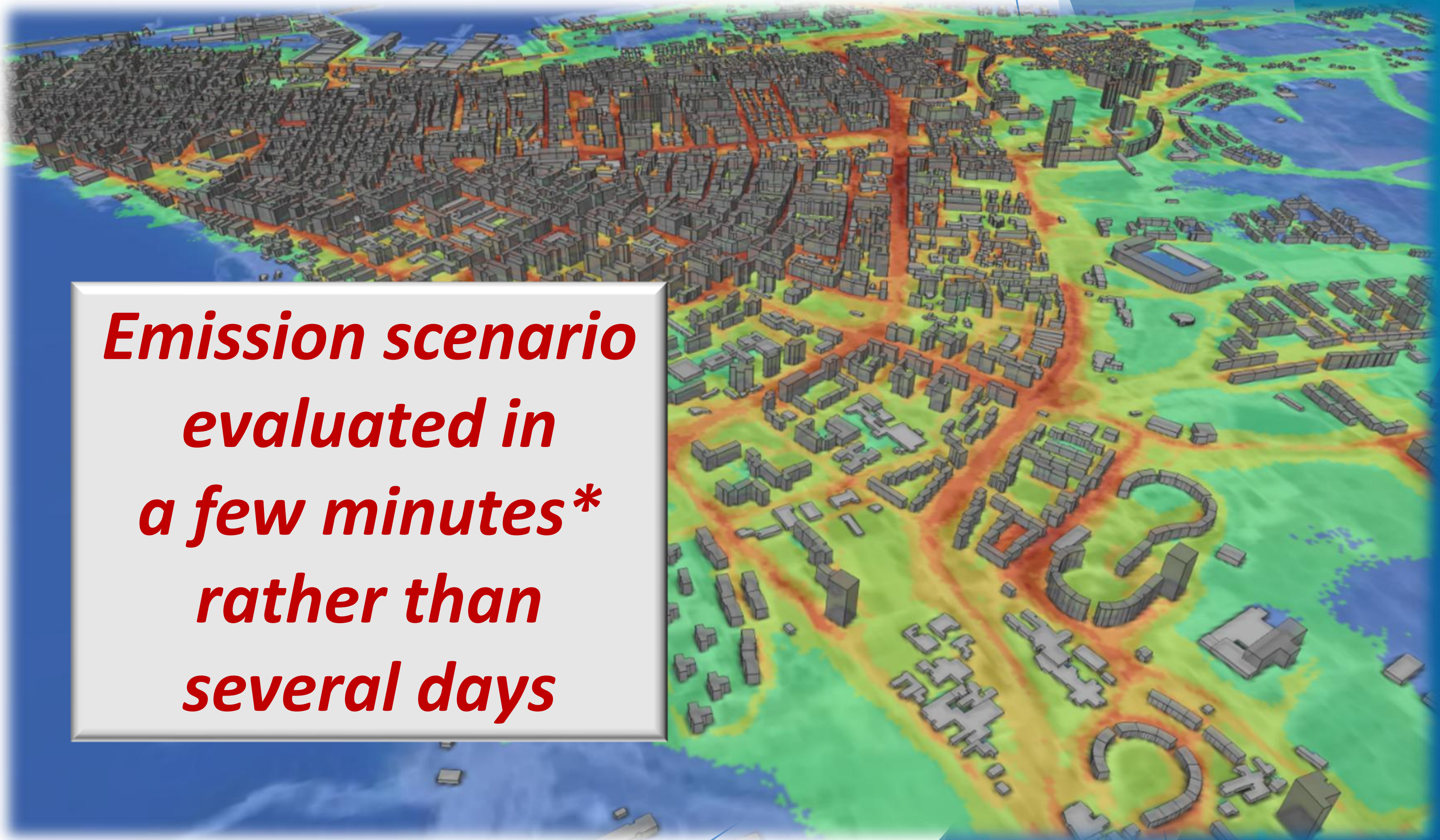
Output of CoKer - Mean NO2 annual average at microscale (2023)

Hour by hour, kernels are **selected from the database** for each source on the basis of the driving ***meteorology***, and rescaled according to ***emissions***.
The convolution and the following time average give rise to the final concentration field.

μg/m^3

0,2500 - 1,0000	
1,0000 - 2,0000	
2,0000 - 3,0000	
3,0000 - 4,0000	
4,0000 - 5,0000	
5,0000 - 7,5000	
7,5000 - 10,0000	
10,0000 - 12,5000	
12,5000 - 15,0000	
15,0000 - 40,0000	



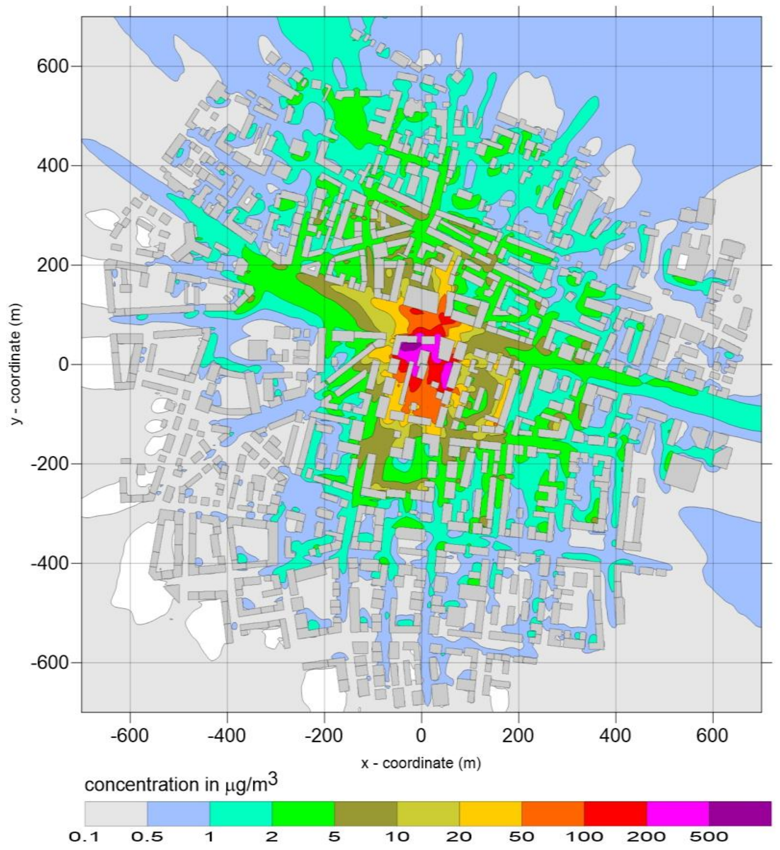


[*] OpenMP parallelization, with 192 Threads and 200+ GB RAM. For long periods, loading all kernels in memory imporeves a lot the performance. If not enough RAM is available, 1-year simulation may be 5 times

General

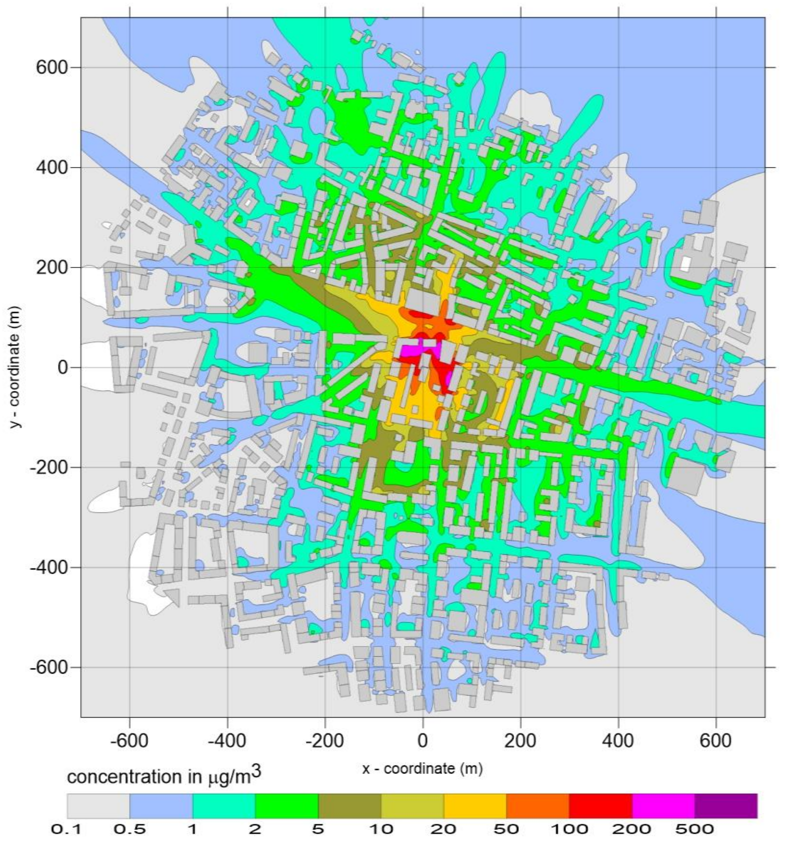
EXPO-URB - project funded by BfS aimed at comparing the performances and reliability of their Lagrangian Particle Dispersion Model **ARTM** with other LPDMs

Dresden data average - Hanna neutral - year 2019



Digital Twin

Dresden data average - Hanna neutral - 8760 hours continuous 2019



Full dispersion simulation

Validation

Data fusion with Random Forest for the regional background

PREDICTORS

Spatio-temporal

FARM concentration fields (1 km)

WRF wind and temperature (1 km)

NDVI (100 m)

Time modulated Road density (100 m)

Spatial (stationary)

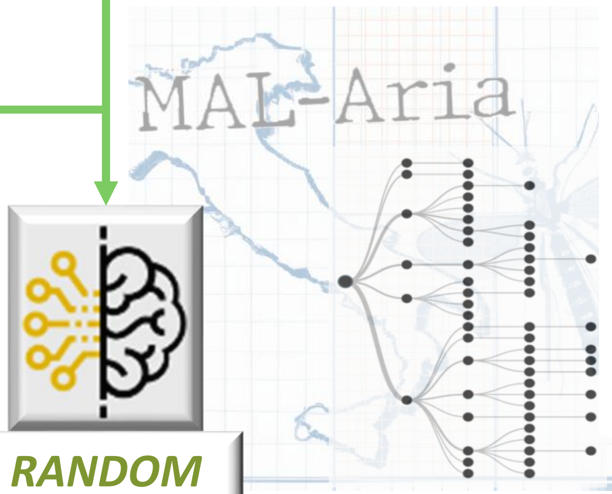
Population density (100 m)

Orography (100 m)

Land use buffered (100 m)

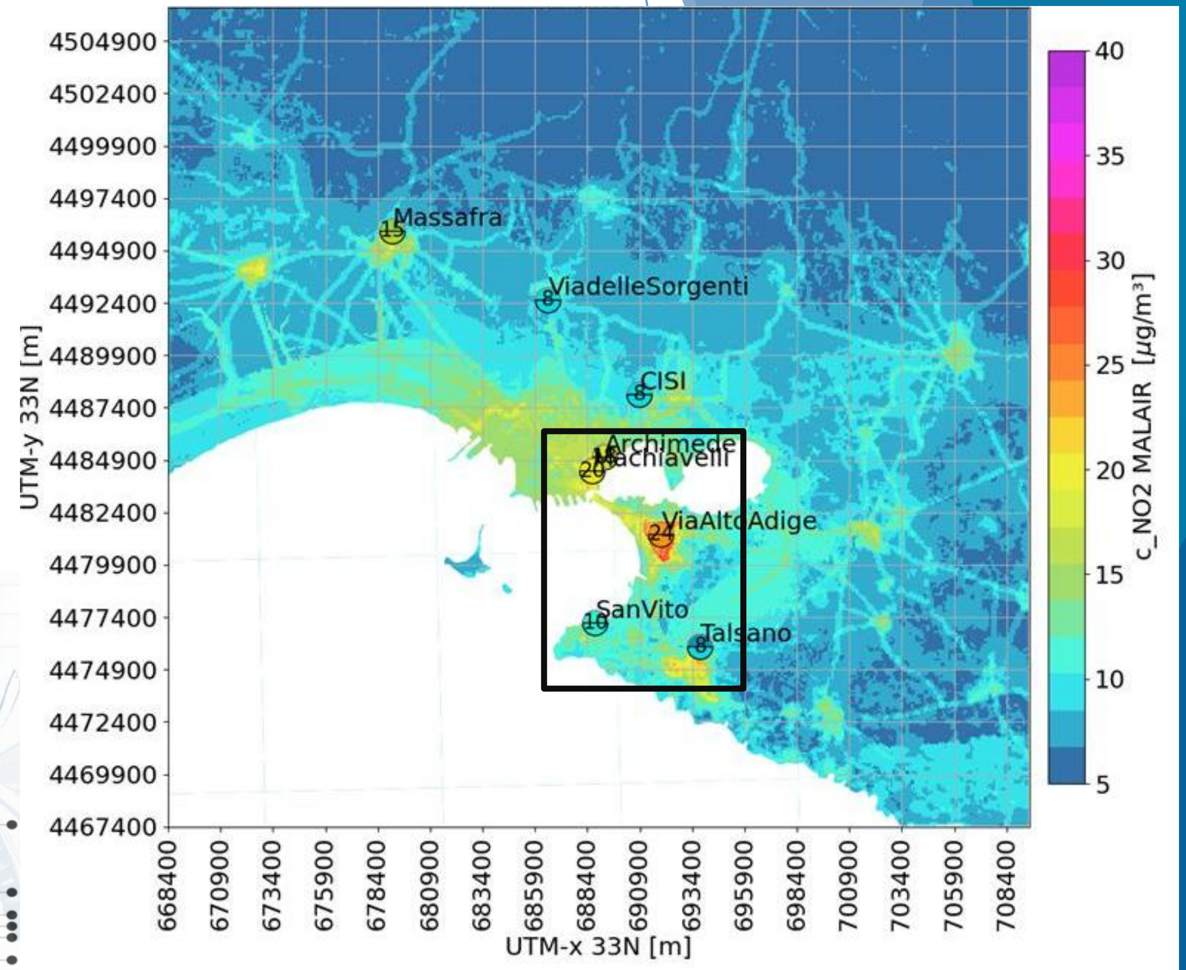
TARGET

Concentrations measured by the sensors



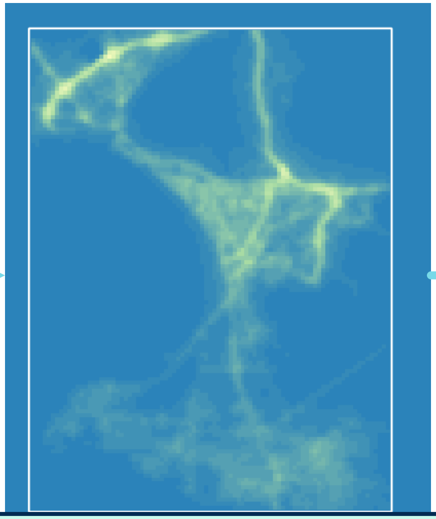
RANDOM FOREST

Background NO2 annual mean (2023)



Merge between microscale and regional background

A
Microscale convolution [5m]



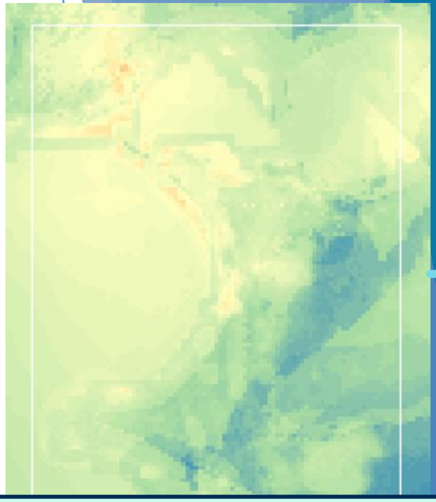
C
Microscale regridded [100m]

F
Sum A + E [5m + 100m]

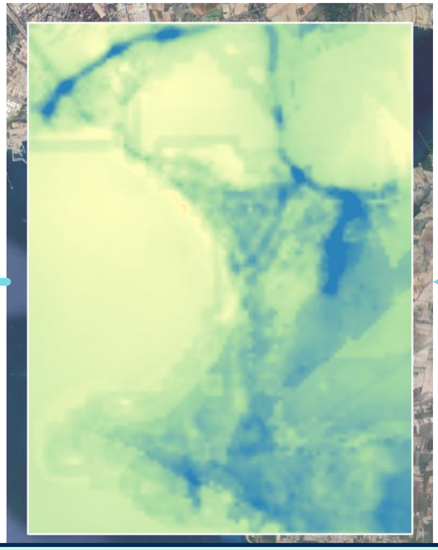
The tool combines yearly means of microscale concentration from traffic and regional background

The regional background contains all the sources, fusing **FARM** output with station observations via Machine **Learning**

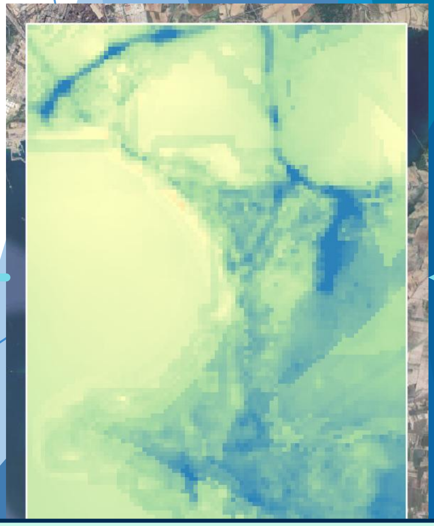
A combination procedure which avoids the **double counting** is implemented.



B
Regional background [100m]



E
Difference B-C regridded [5m]

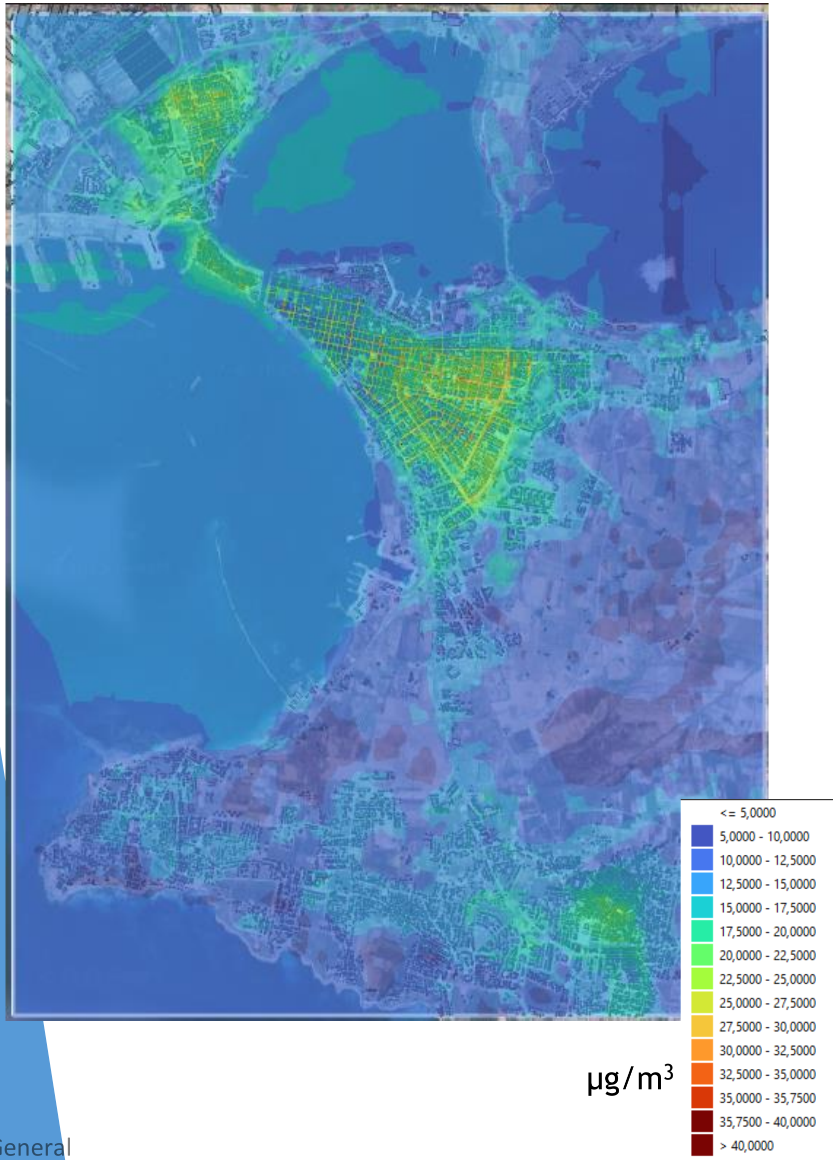


D
Difference B - C [100m]

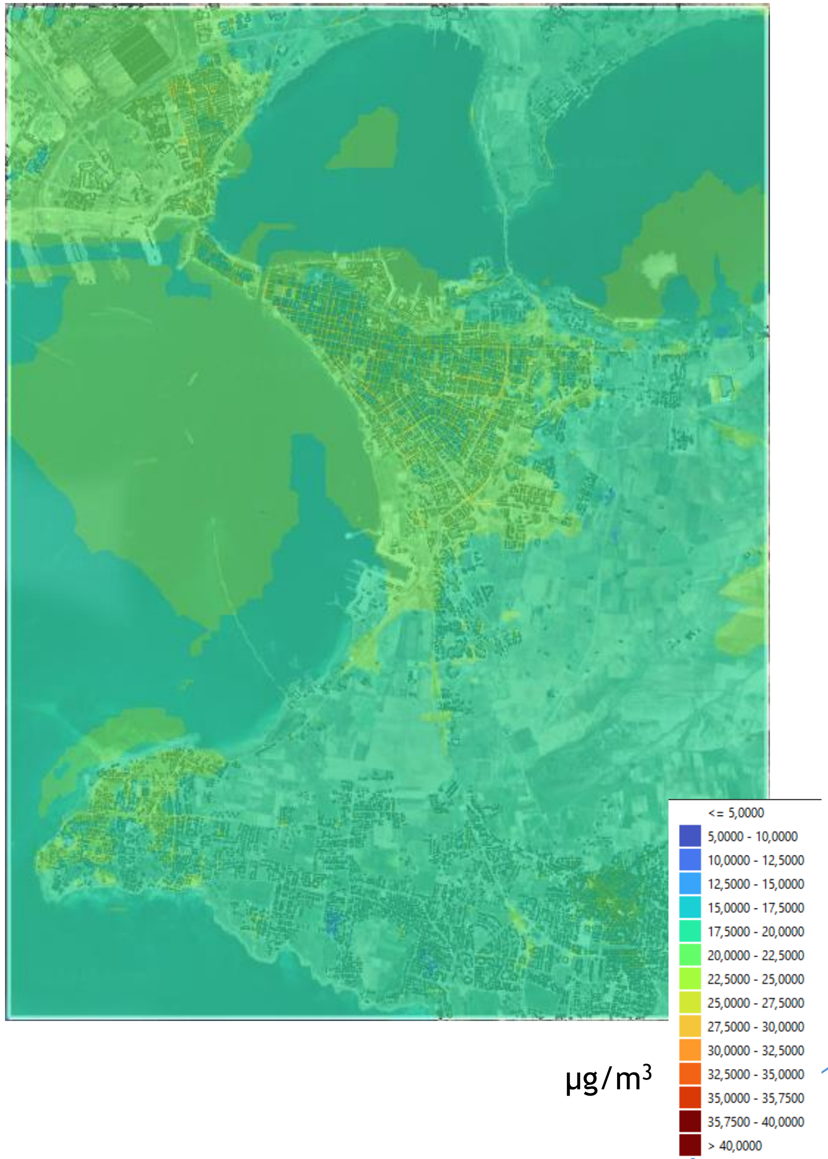
*Data refer to preliminar PM10 simulations on 2019. Traffic emission data yet to be modelled.

Merge between microscale and regional background

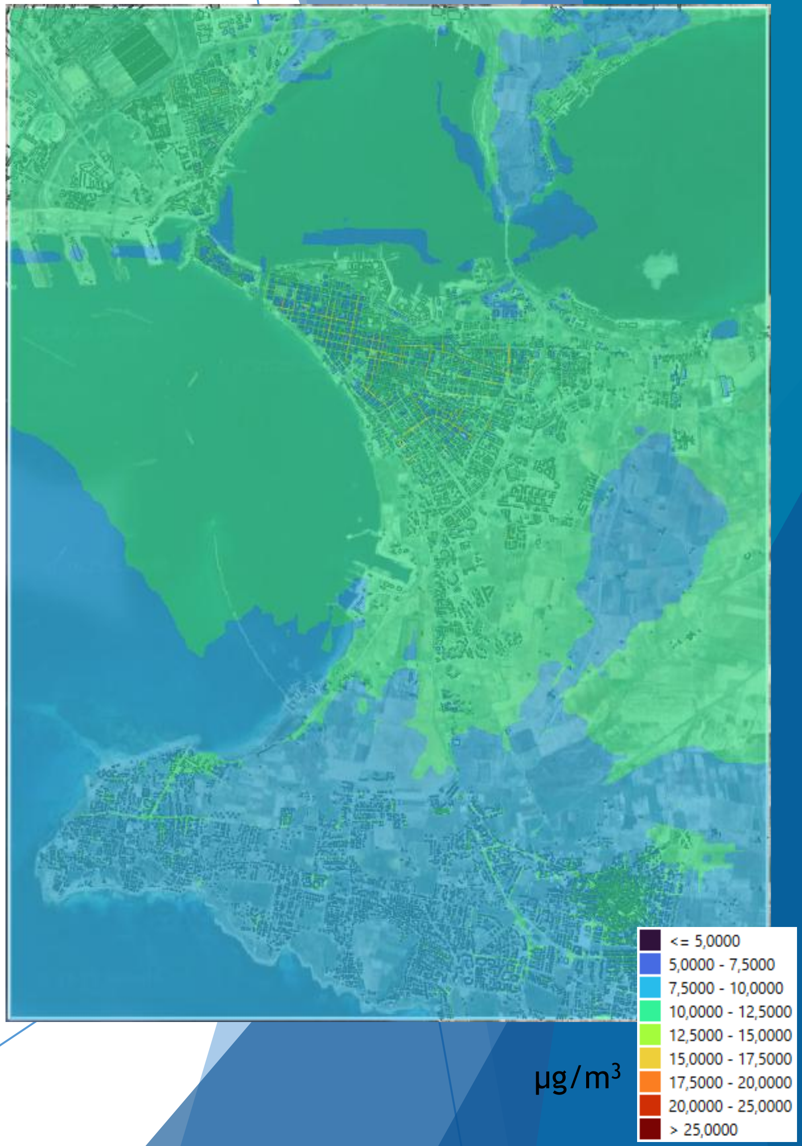
NO2 annual mean (2023)



PM10 annual mean (2023)



PM25 annual mean (2023)



Description of the whole sample according to Stroke Onset (No/Yes) over 50 years. N: 118633

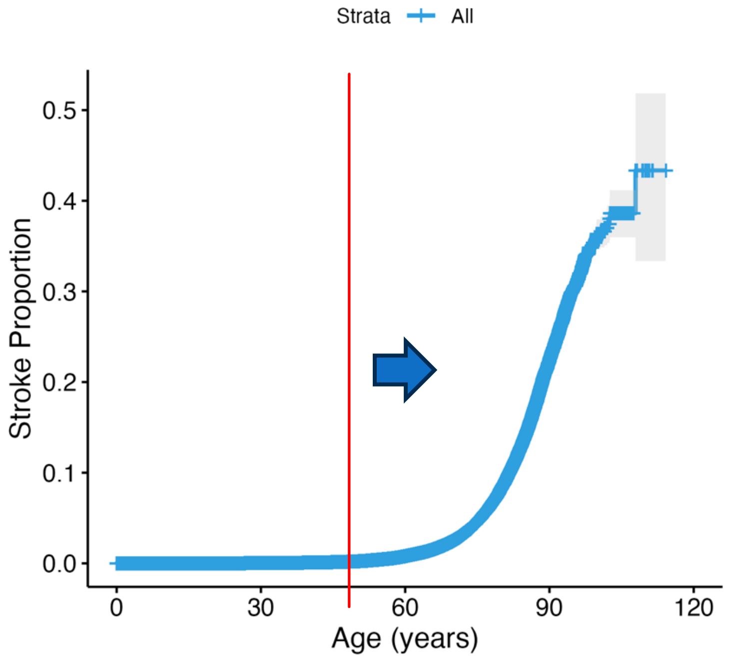
Sensitivity to cumulative vs mean exposure: +25%

	Overall	No stroke	Stroke	p
N (%)	118633	111560 (93.66)	7073 (6.34)	
Age (years)	69.53 (12.29)	69.08 (12.27)	76.70 (10.27)	<0.001
Sex (Male)	54187 (45.7)	50656 (45.4)	3531 (49.9)	<0.001
Mean Income (euro)	10988.42 (12725.81)	11080.64 (12858.81)	9533.85 (10297.69)	<0.001
Education Level score	2.55 (0.99)	2.58 (0.98)	2.13 (1.00)	<0.001
Observation Time (days)	2809.72 (922.10)	2907.00 (830.98)	1275.39 (930.81)	<0.001
Antipertensive Drugs (%)	82235 (69.3)	78104 (70.0)	4131 (58.4)	<0.001
Diabete (%)	26001 (21.9)	23634 (21.2)	2367 (33.5)	<0.001
Atrial Fibrillation (%)	60520 (51.0)	55413 (49.7)	5107 (72.2)	<0.001
Mean Income (Log2)	11.31 (4.55)	11.35 (4.53)	10.78 (4.94)	<0.001
Cumulative Exp. NO2 (ug/m3)	66751.00 (24231.83)	68719.84 (22915.61)	35697.07 (23249.89)	<0.001
Mean Exp. NO2 (ug/m3)	24.82 (6.33)	24.42 (5.94)	31.26 (8.48)	<0.001
Cumulative Exp. PM10 (ug/m3)	57746.19 (19057.08)	59701.19 (17291.30)	26910.72 (19090.48)	<0.001
Mean Exp. PM10 (ug/m3)	20.77 (1.35)	20.71 (1.30)	21.63 (1.67)	<0.001
Cumulative Exp. PM2.5 (ug/m3)	30573.12 (10042.87)	31604.82 (9104.59)	14300.43 (10131.59)	<0.001
Mean Exp. PM2.5 (ug/m3)	10.99 (0.65)	10.96 (0.62)	11.46 (0.83)	<0.001

*t test for independent sample for continuous variable and Chi Squared Test for categorical ones.

Legend: Max Family Educational Level Score: 0: Uneducated, 1: Elementary School, 2: Middle School, 3: High School, 4: University+.

Disease Cumulative Curve according to age



Napoli
Top-down traffic emission modelling

Emissions from municipal inventory (For PM accounted for resuspensions)

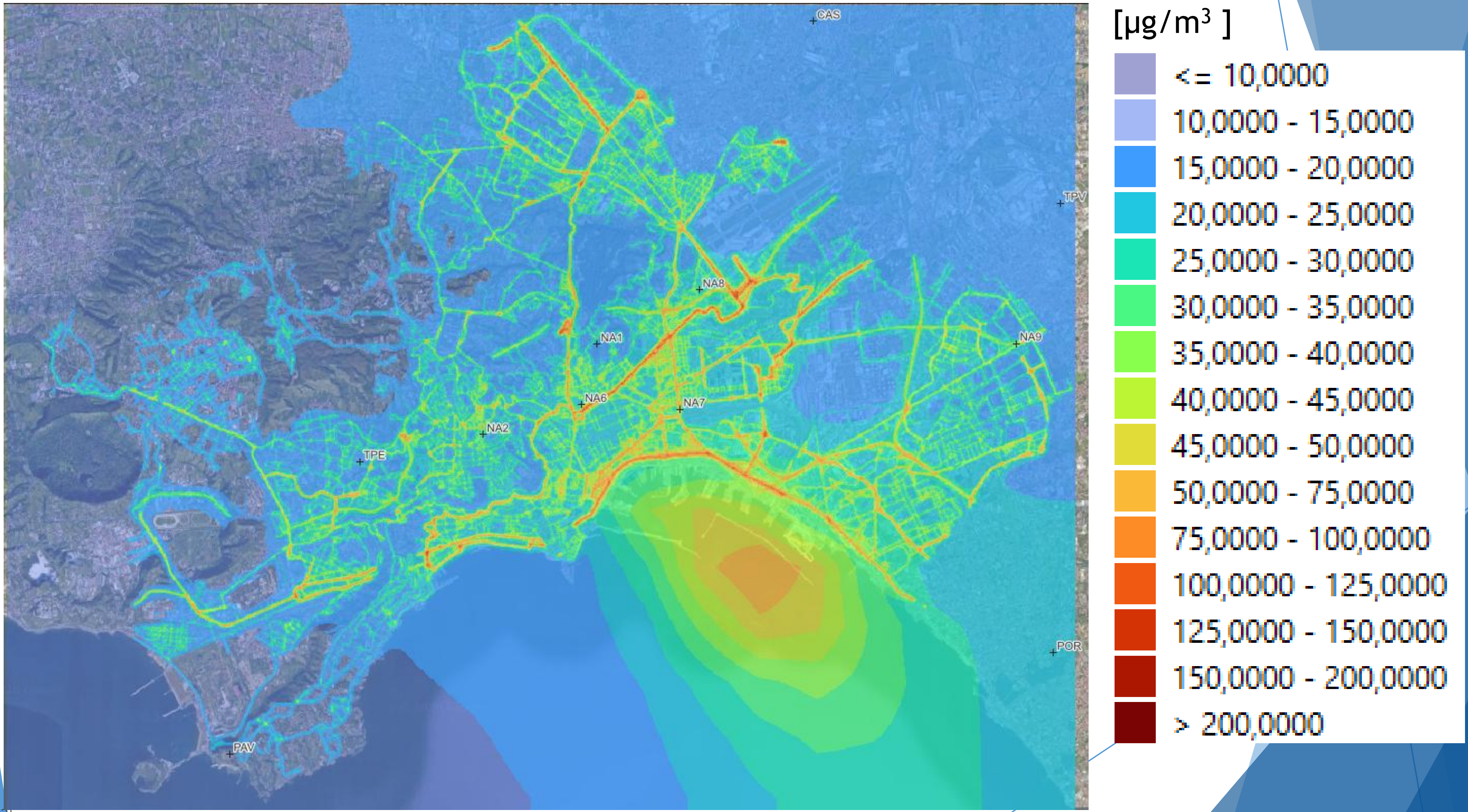
	NOx	PM2_5	PM10	CO
urbane + extraurbane [ton/year]	3685,124	293,021	407,016	2678,433
autostrade [ton/year]	287,950	17,384	21,808	199,320

Spatialization over street network according with road type weights

TYPE	*DESC*	*WEIGHT*
UNCLASSIFIED	strade non classificate (comunali)	0.05
UNKNOWN	strade non classificate (comunali)	0.05
MOTORWAY_LINK	svincolo autostrada	0.1
TERTIARY_LINK	svincoli terziarie	0.1
TRUNK_LINK	svincolo tronco	0.1
SECONDARY_LINK	svincolo provinciale	0.2
PRIMARY_LINK	svincolo statale	0.3
RESIDENTIAL_ROAD	strada provinciale/medio scorrimento	0.5
TRUNK_ROAD	tronco (strada statale/super strada)	0.7
TERTIARY_ROAD	rotonde/strade provinciali medie	0,5
SECONDARY_ROAD	strada provinciale	1
PRIMARY_ROAD	statale	3

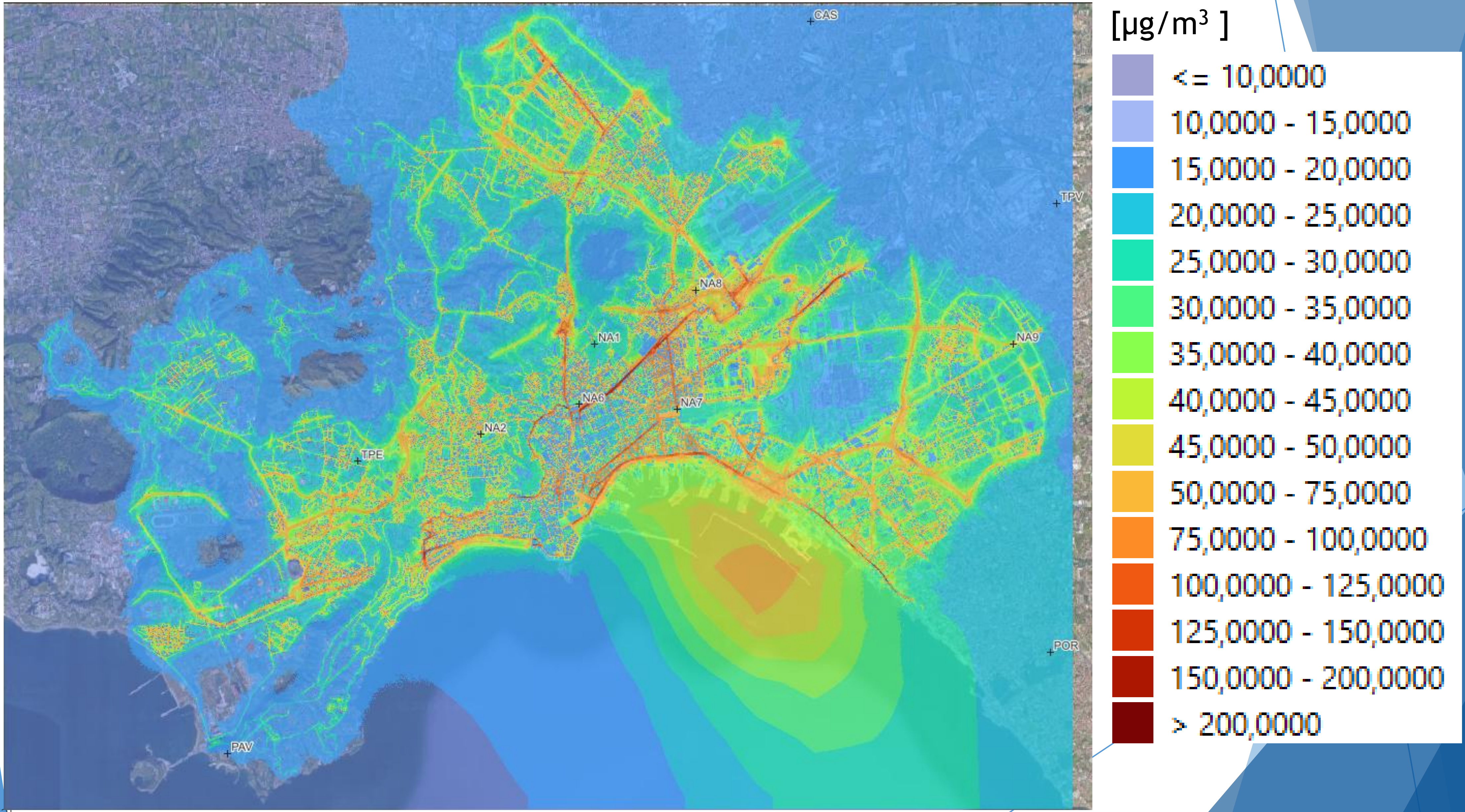
Napoli hybrid modelling

NO2 yearly avg: Background 1km + traffic without obstacles 20m



Napoli hybrid modelling

NO2 yearly avg: Background 1km + traffic with obstacles 5m



THANK YOU