XII giornata sulla modellistica in aria(net)
Milano, 26 marzo 2025

CoKer [Convolutor of dispersion Kernels]

A microscale PMSS-based tool for **Digital Twins**

Application on the city of **Taranto** in the context of **CALLIOPE** project

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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***

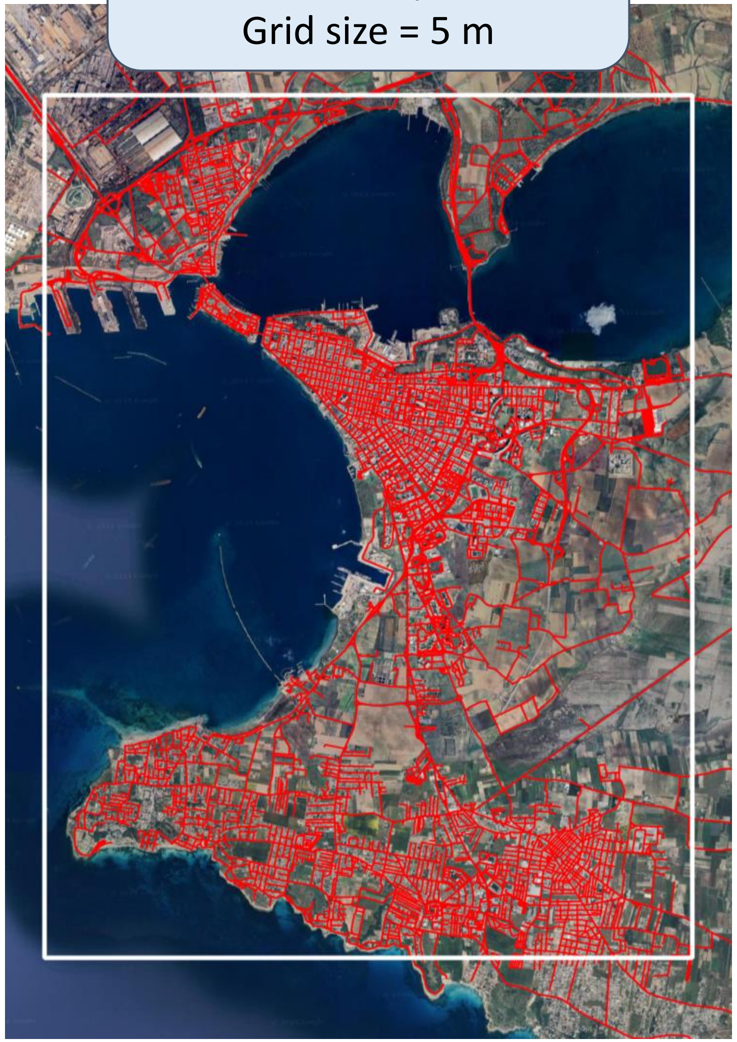
The scope of the CALLIOPE project

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).

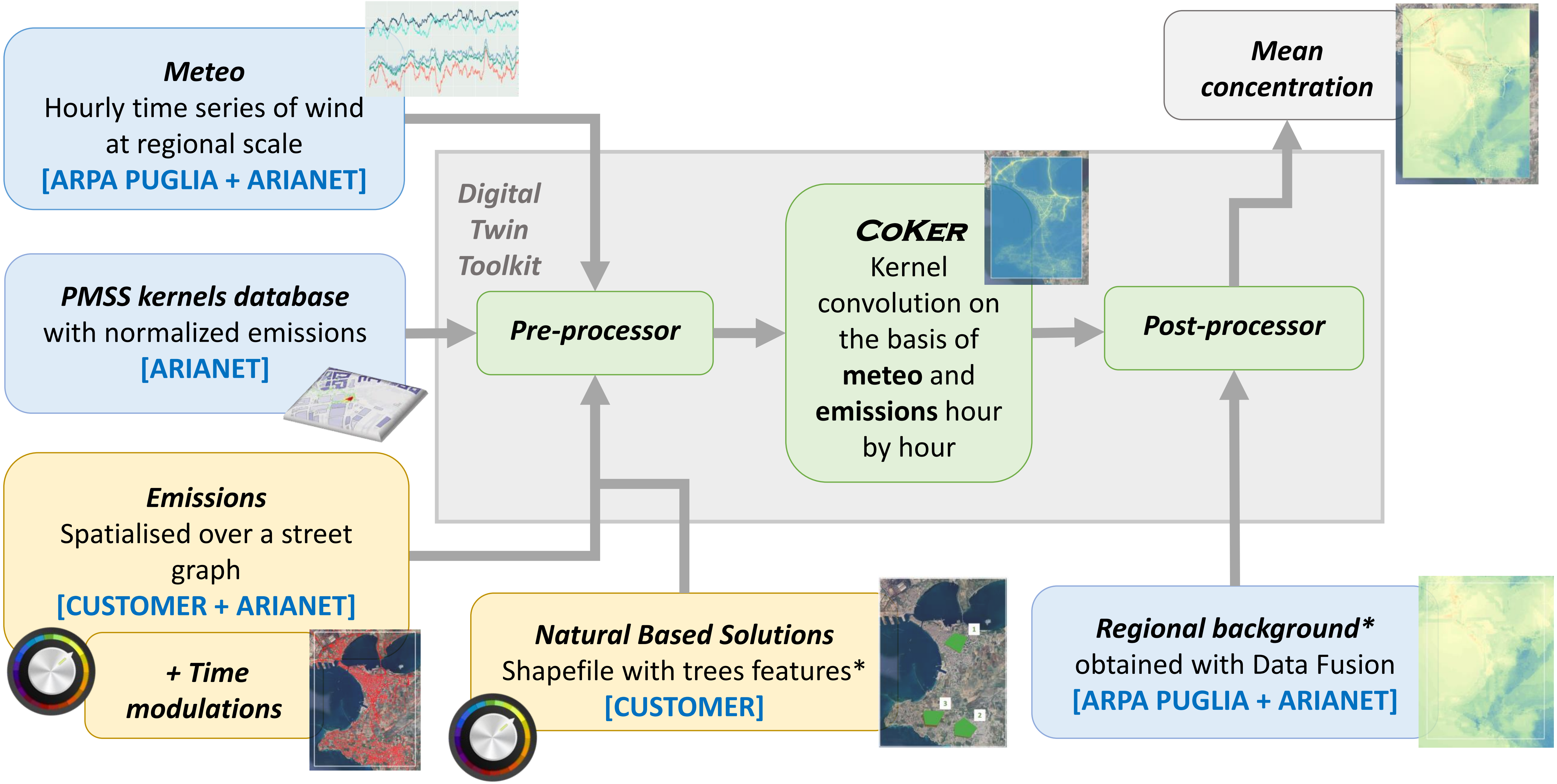
The role of ARIANET

- Develop a **digital twin toolkit** of the city of Taranto to assess multiple exposition 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 factors, 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 epidemiologic studies

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



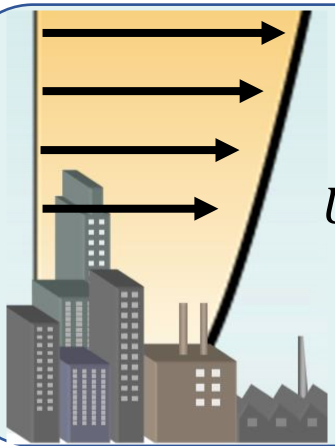
The Digital Twin: a tool for traffic emission scenarios



Normalized dispersion kernels construction

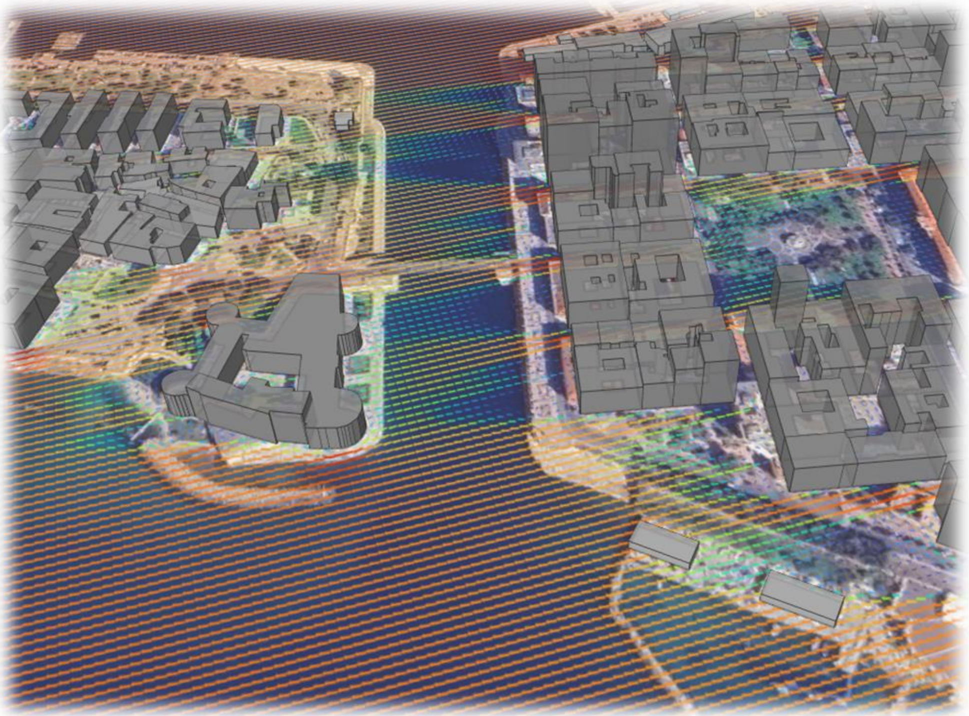
Inlet wind profiles
6 wind speeds at 10m
8 wind directions at 10m
5 stability classes
240 combinations

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



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

Buildings
Vectorial Shapefile



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

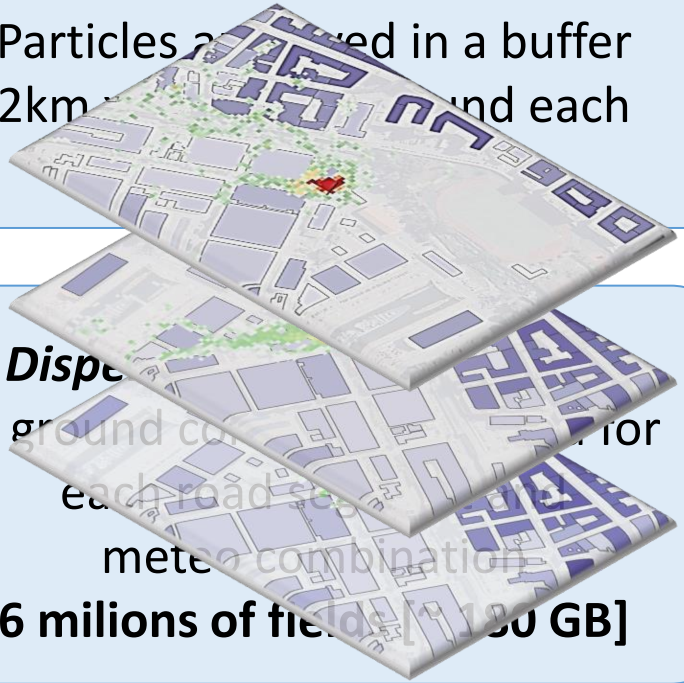
PMSS DRIVEN KERNELS

Buildings
Vectorial Shapefile

Street Graph
4000 polylines

Discretized graph
26000 road segments with normalized emissions

Particles a… …ed in a buffer
2km … …nd each



Dispe…
A ground co… …for
ea… …and
mete… combination
6 milions of fie… […0 GB]

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

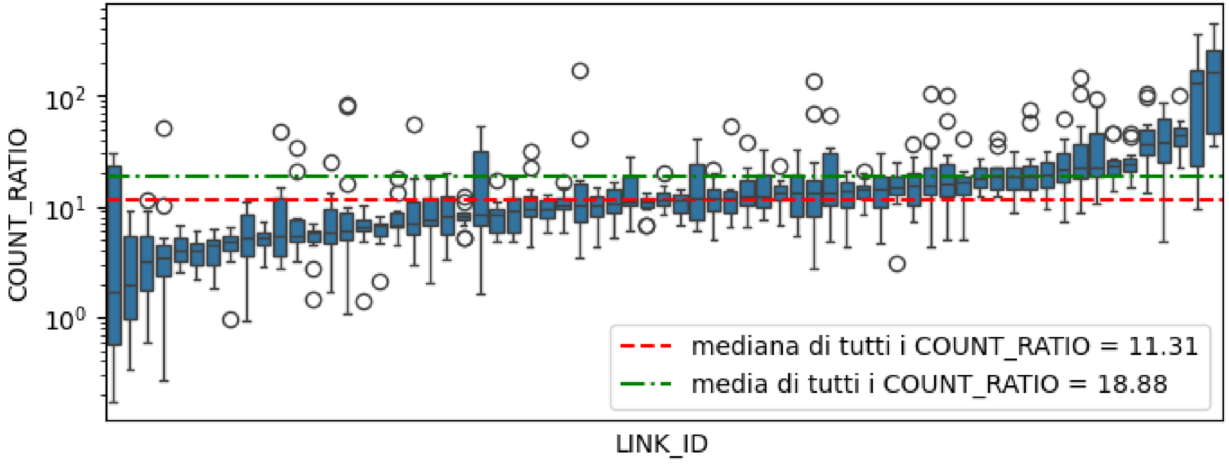
Traffic emissions: calibration of traffic flows

HERE Historical data

- ***Vehicle counts***
- ***Vehicle speeds***
- Frequency 5 mins
- Years 2022/2023
- Spatialized over the street graph

Traffic light observations

- ***Vehicle counts***
- Hourly frequency
- One week (jan 2024)
- Localized over few streets



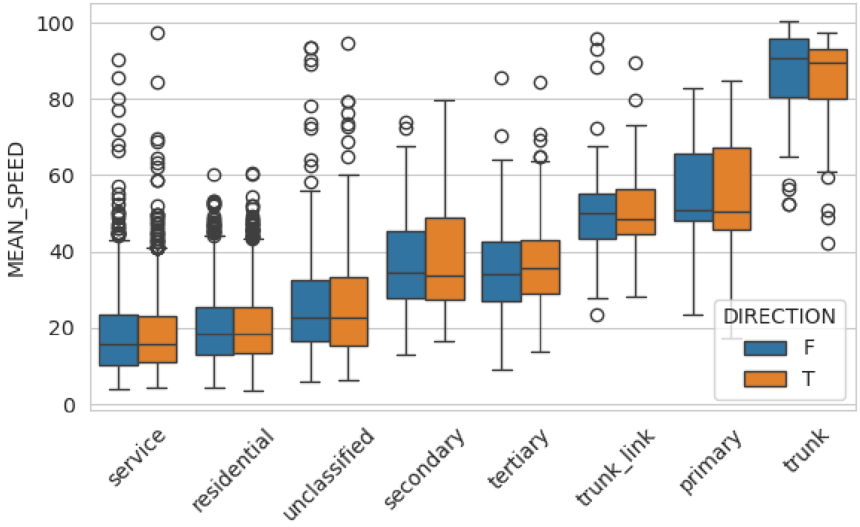
- Average ***HERE*** observations and ***traffic light observations*** have been compared in the same reference week (but different years)
- The ratio between traffic light and HERE observations shows a ***homogeneous bias*** with median equal to **11**.
- Such bias is used to rescale HERE counts over the whole street network

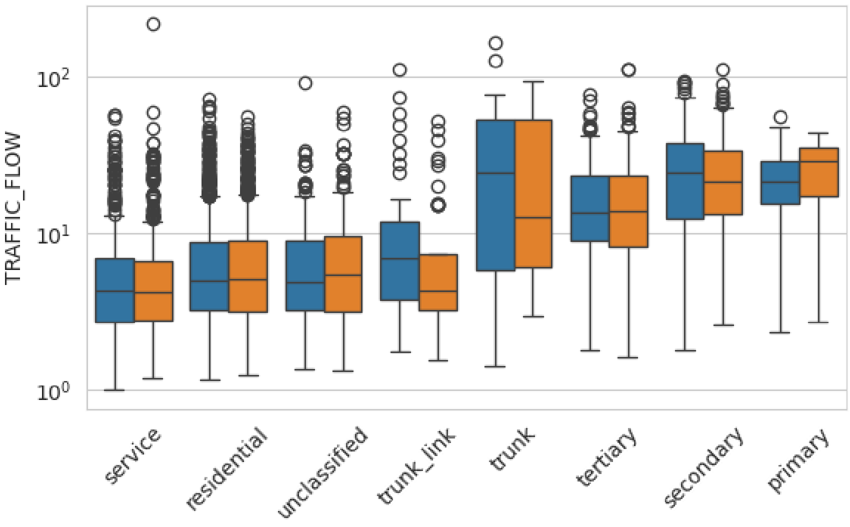
- Streets with HERE measurements
- Traffic lights

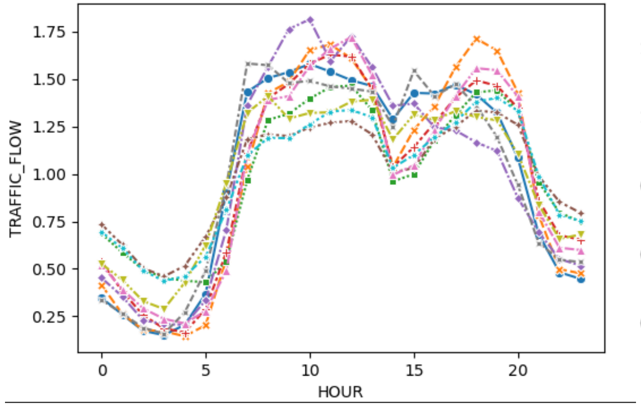
Traffic emissions: Distribution of traffic flows and speeds

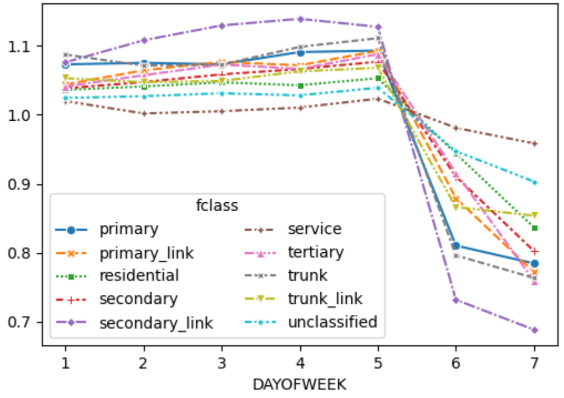
HERE data, properly re-calibrated are used to build the input of the emission model (TREFIC)

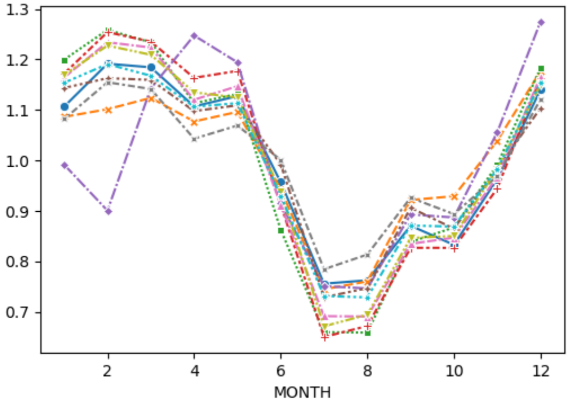
Flows and speeds are *averaged across time* and spatialized over the OSM network.
For each street type, **time modulations** are computed.



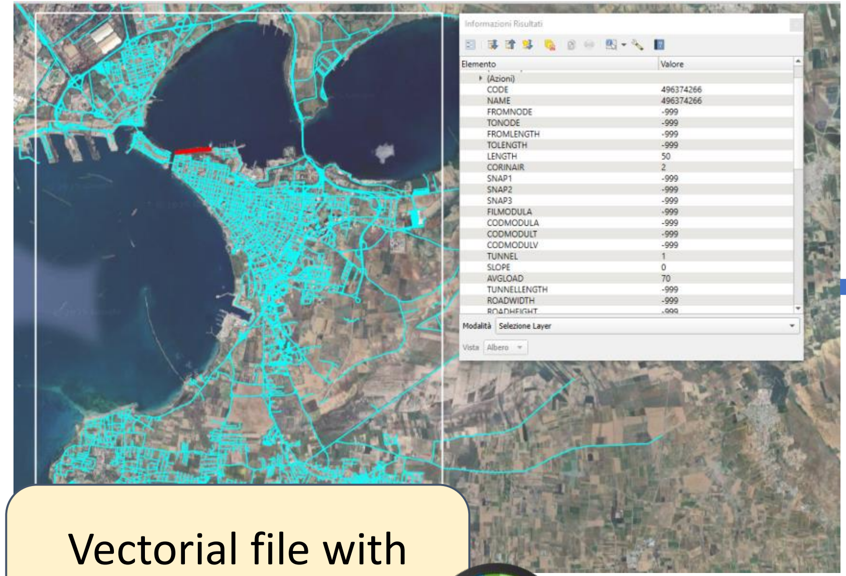








Traffic emission: calculation with TREFIC



Vectorial file with
flows and speeds

*			urb	%
cars	1	Petrol Mini Euro 4	0	0.00
	2	Petrol Mini Euro 5	0	0.00
	3	Petrol Mini Euro 6 up to 2016	0	0.00
	4	Petrol Mini Euro 6 2017-2019	0	0.00
	5	Petrol Mini Euro 6 2020+	0	0.00
	...	....	......	....
	36	Petrol Large-SUV-Executive PRE ECE	0	0
	37	Petrol Large-SUV-Executive ECE 15/00-01	0	0
	38	Petrol Large-SUV-Executive ECE 15/02	0	0
	39	Petrol Large-SUV-Executive ECE 15/03	0	0
	40	Petrol Large-SUV-Executive ECE 15/04	0	0
	41	Petrol Large-SUV-Executive Euro 1	0	0
	42	Petrol Large-SUV-Executive Euro 2	0	0
		Large-SUV-Executive Euro 3	21062269	0.1
		Large-SUV-Executive Euro 4	53122291	0.25
		Large-SUV-Executive Euro 5	14244499	0.07
		...e Euro 6 up to 2016	13115574	0.06

Table file with
Vehicular fleet

Traffic flows and speeds are formatted in a **vectorial format** (.mif).
Together with the **vehicular fleet**, they are an input for the emission scenario ***tunable by the customer***

Time modulation (*)

TREFIC

Vectorial file with ***Pollutant mass flow*** (kg/h) for each arc of the street network OSM

***CoKER**, etc*

Digital Twin Toolkit

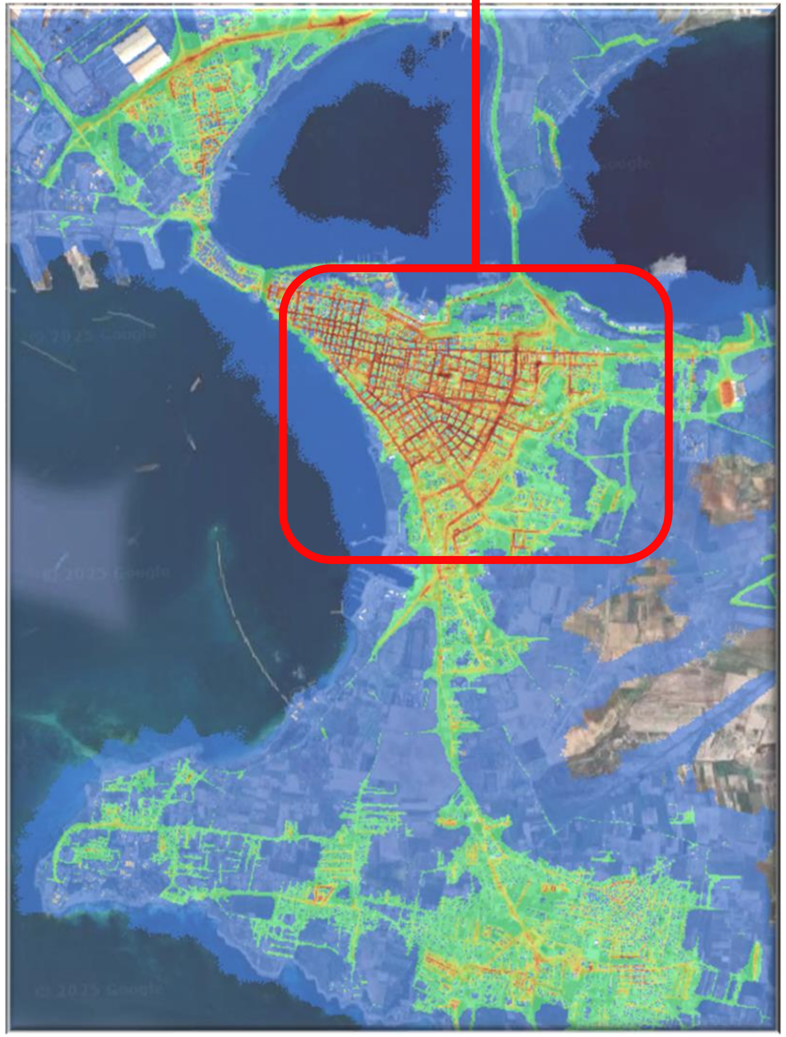
(*) Time modulation for different road categories are another tunable input

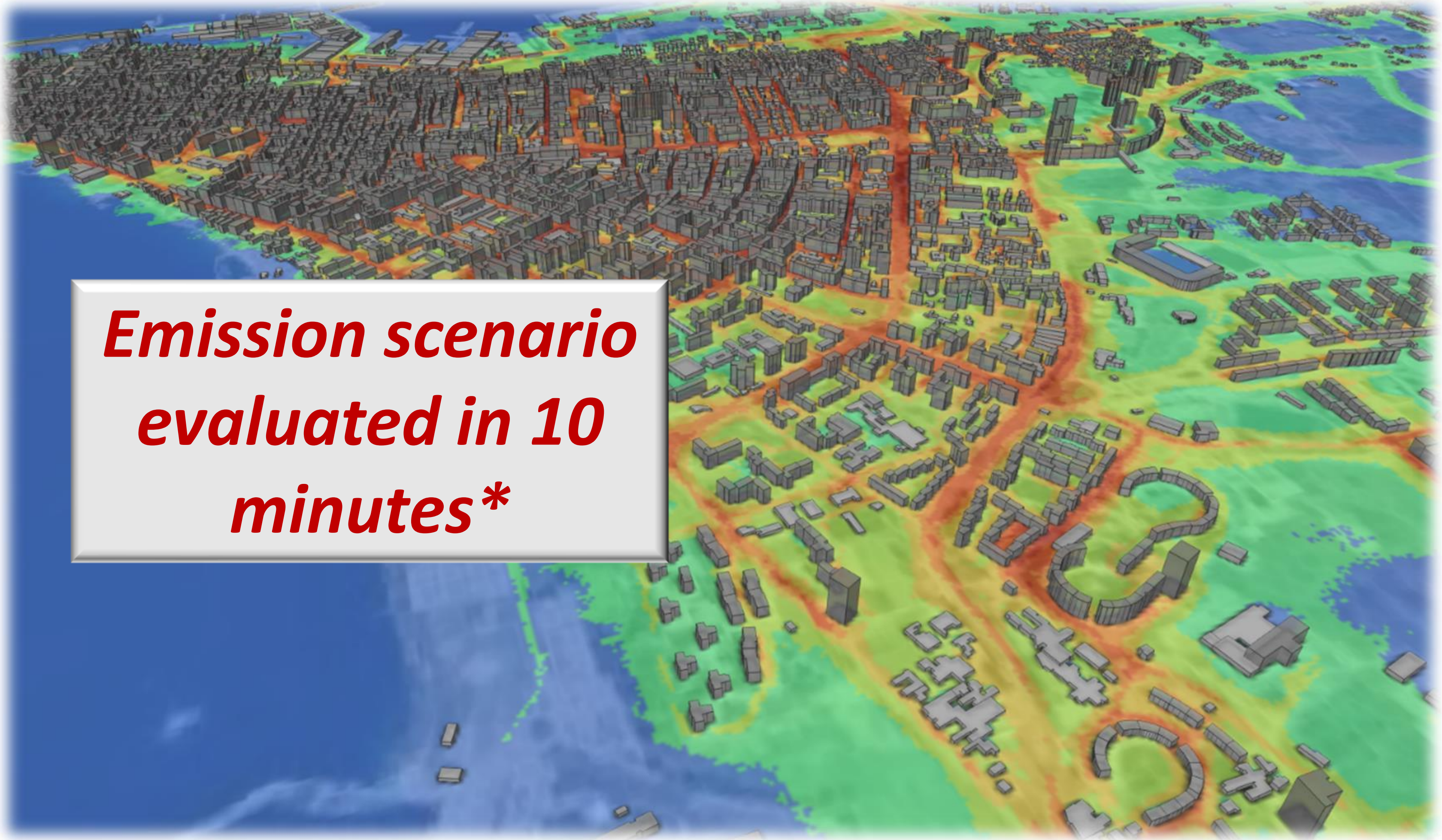
Output of CoKer - Mean NO2 annual average at microscale (2023)

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





Emission scenario evaluated in 10 minutes*

[*] 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 slower.

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)

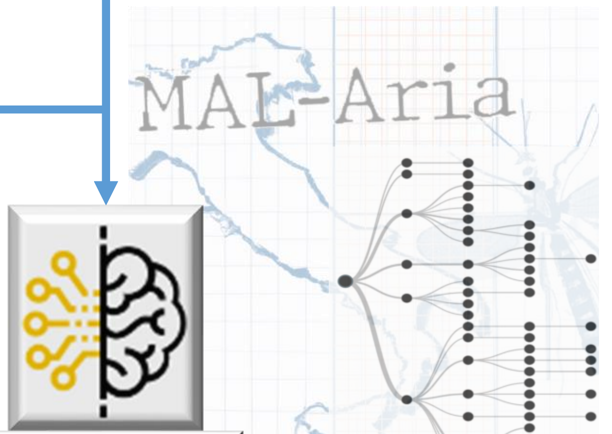
Population density (100 m)

Orography (100 m)

Land use buffered (100 m)

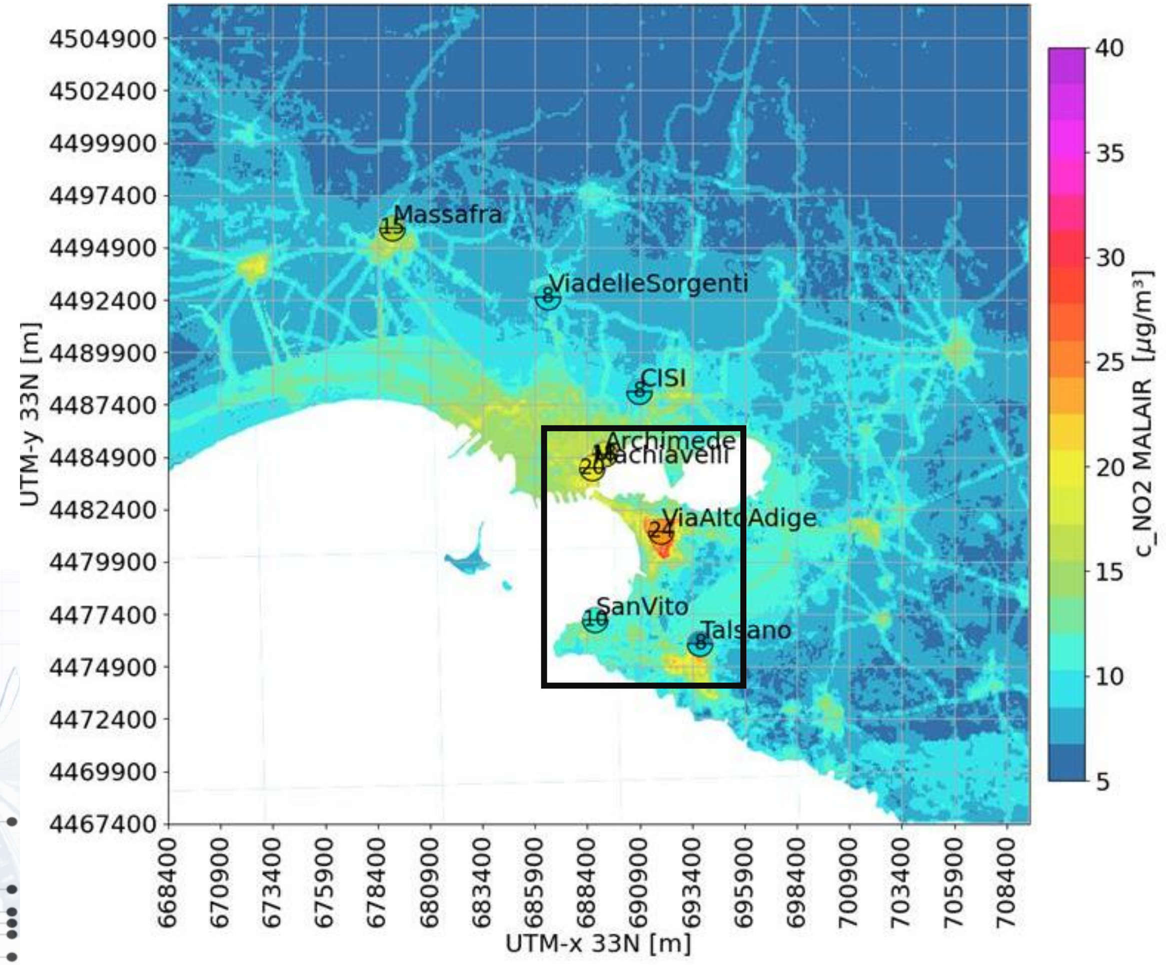
TARGET

Concentrations measured by the sensors



RANDOM FOREST

Background NO_2 annual mean (2023)

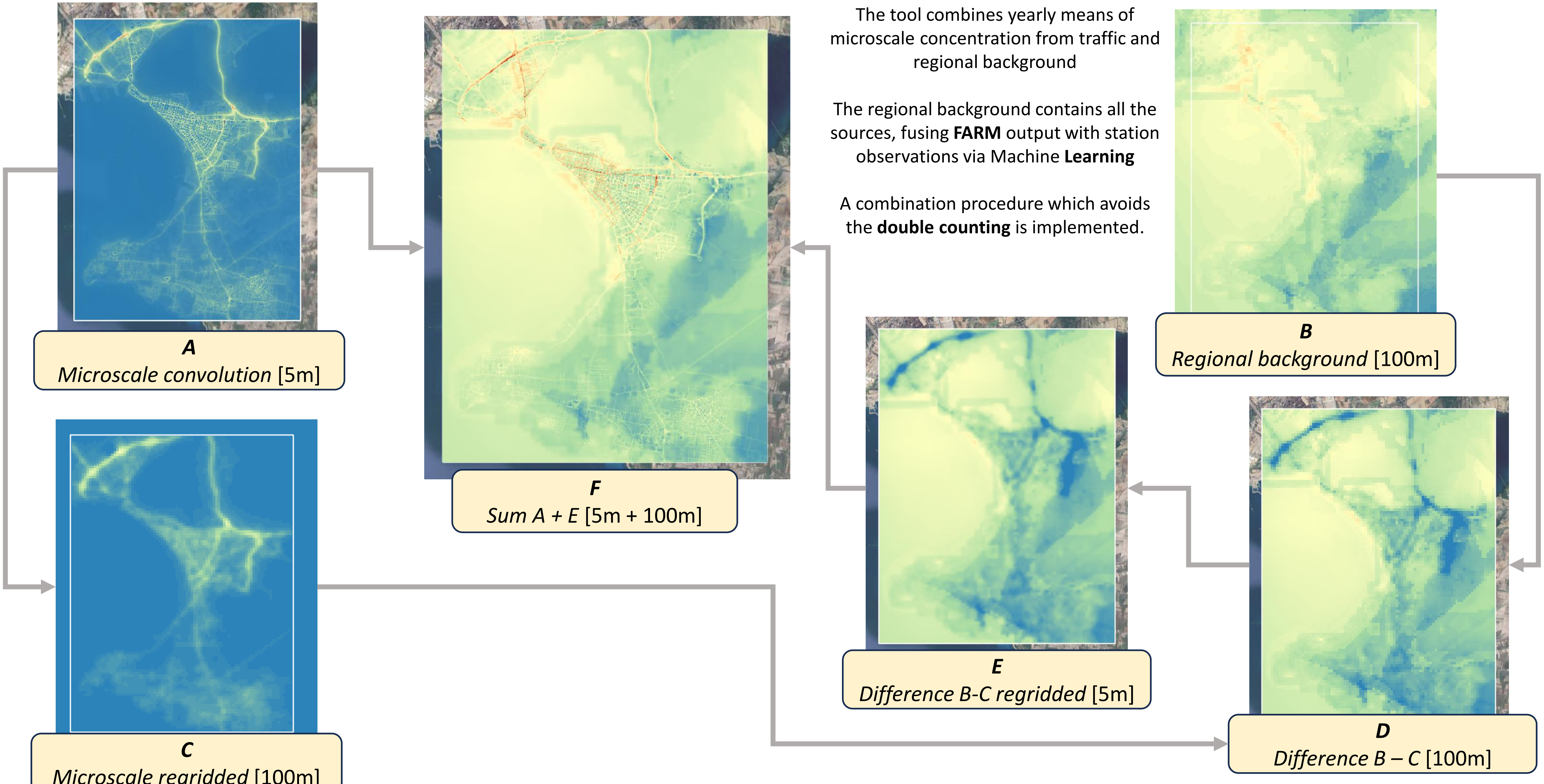


Merge between microscale and regional background

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**

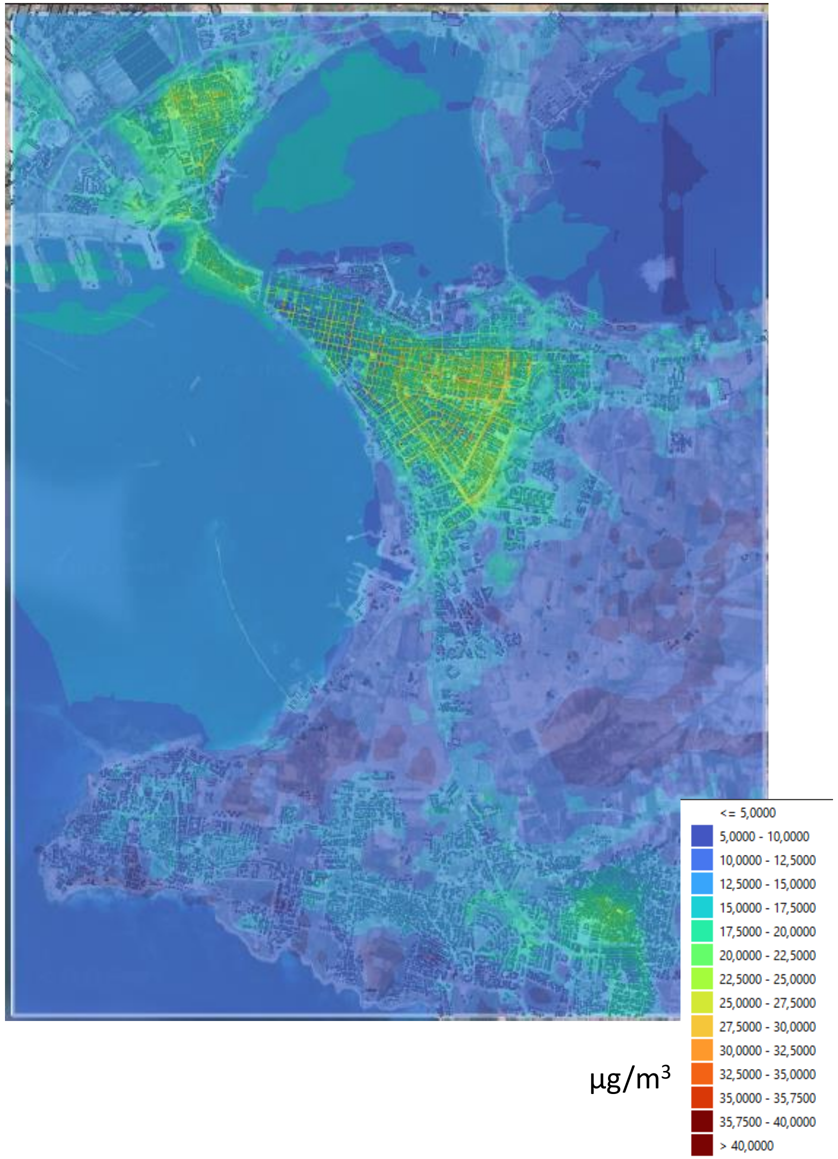
A combination procedure which avoids the **double counting** is implemented.



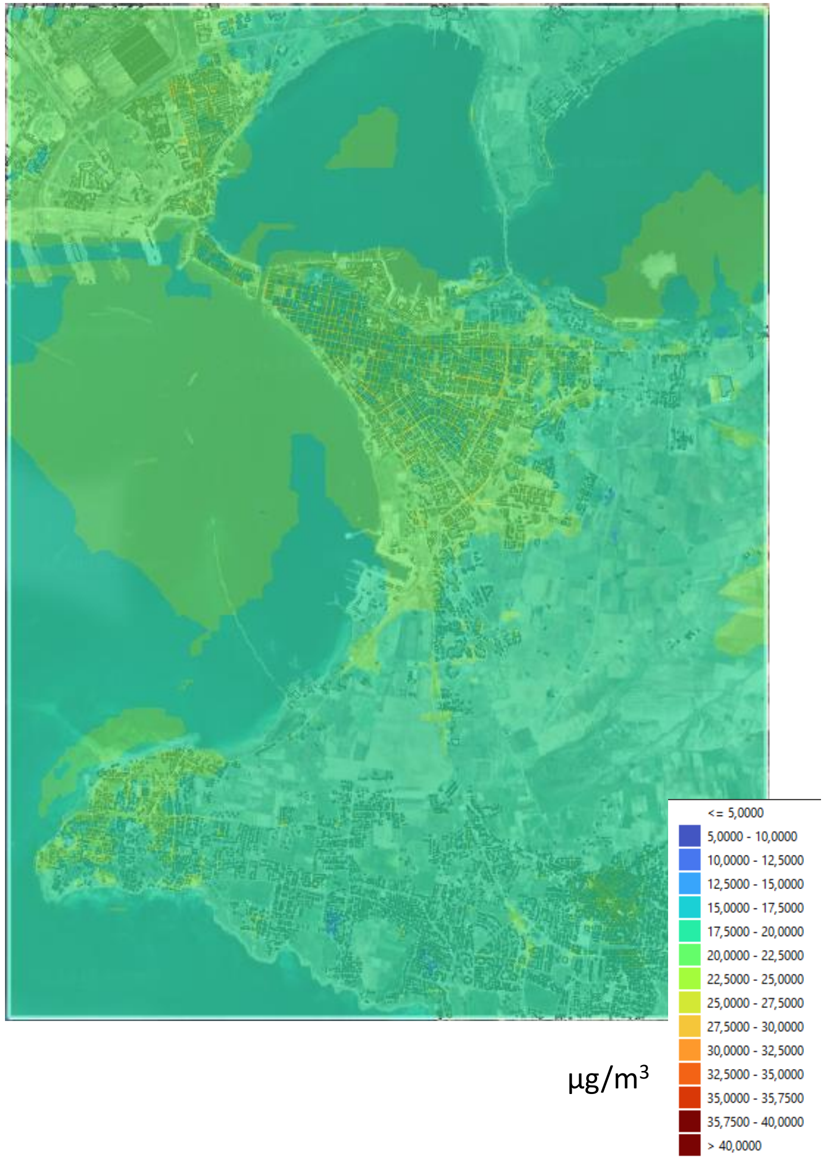
*Data refer to preliminar PM10 simulations on 2019. Traffic emission data yet to be modelled.

Merge between microscale and regional background

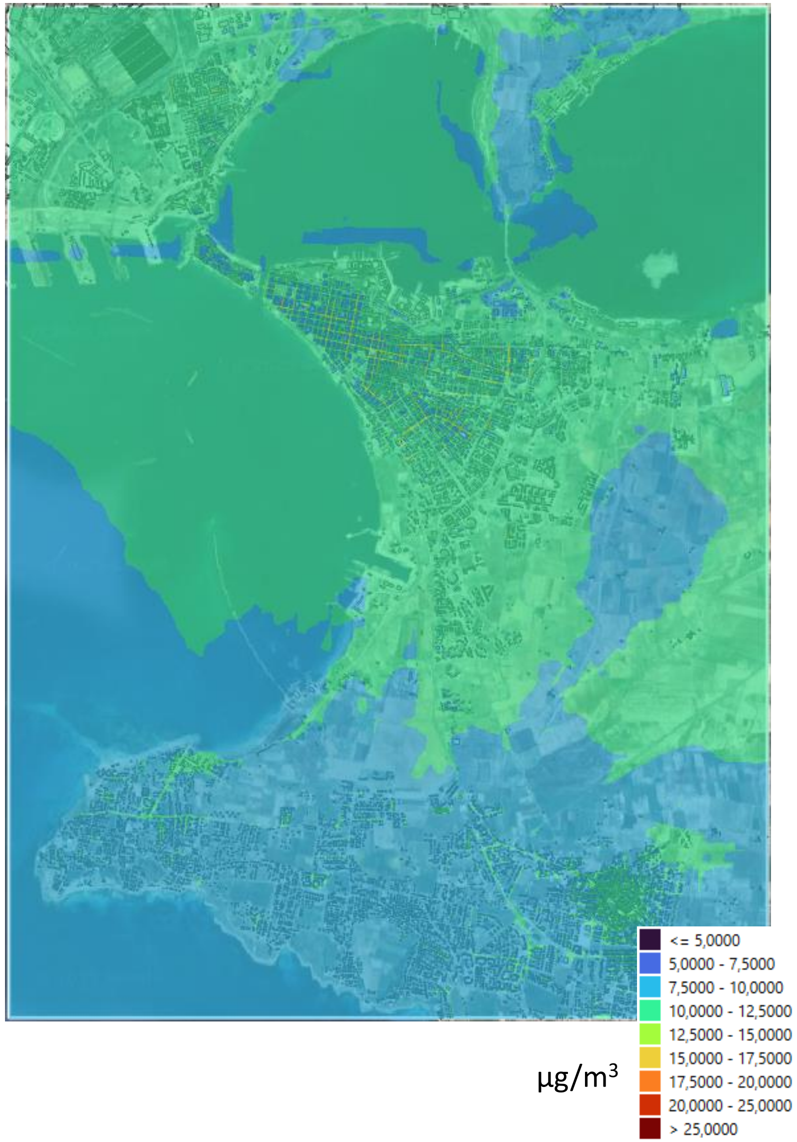
NO2 annual mean (2023)



PM10 annual mean (2023)



PM25 annual mean (2023)



THANK YOU