Modeling real-world traffic pollutant emissions and urban Air quality at high spatial and temporal resolution

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

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Introduction

Microscopic AIRMES methodology:

- **Pollutants emitted by road traffic represent a major contributor to the pollution in urban areas.**

- Current air quality management tools always rely on macroscopic estimates of road traffic emissions (COPERT methodology). They are adapted to large spatial scales and an average driving profile, but do not characterize local driving patterns in real use.

- *Our study presents a microscopic estimate of road traffic emissions (AIRMES), and their impact on the air quality characterization for a district of Marseille.*

- The large modelled domain covers an area of 3.4km wide by 4.5km high and a small one 400m by 800m.

Construction of an emissions inventory

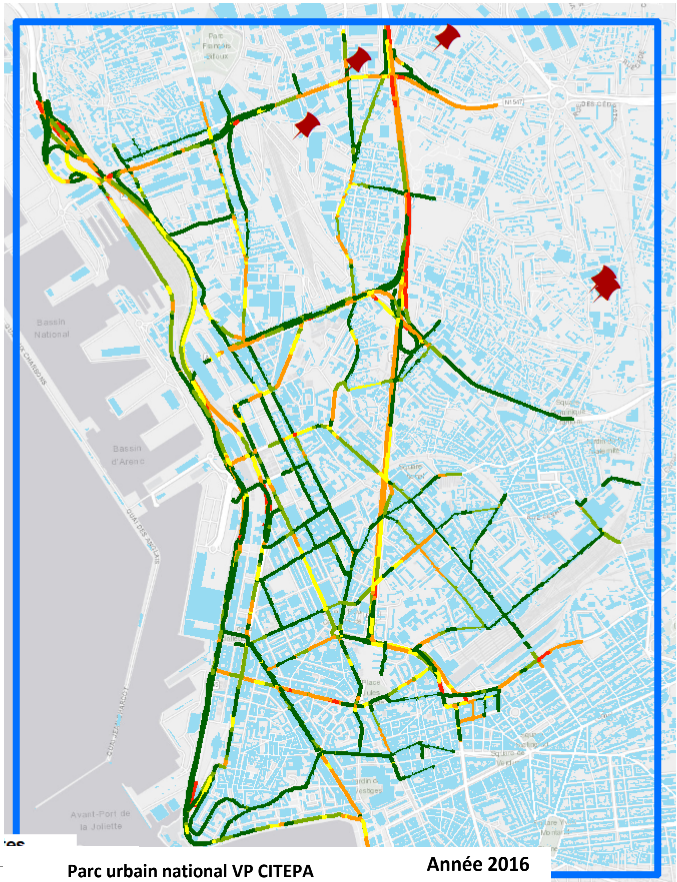
Construction of a *microscopic & macroscopic* emissions inventory:

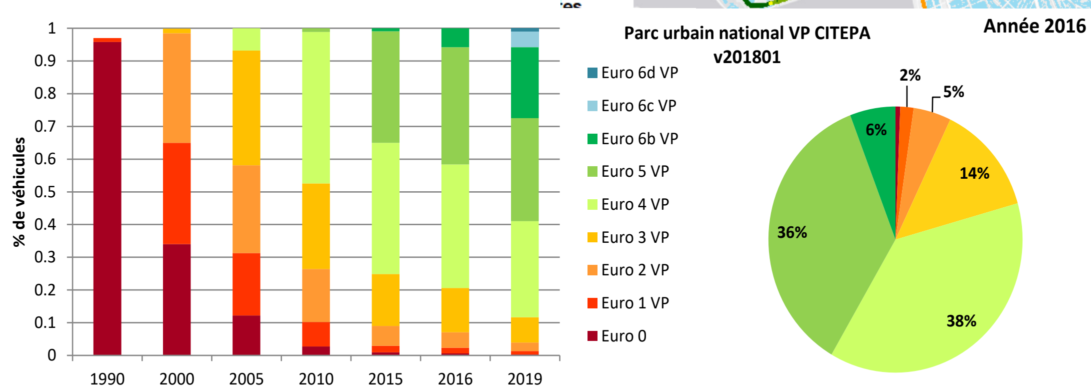
- The roads are described in segments of 42m on average, but their length varies from a few meters to several hundred meters.

- An adjustment by AtmoSud to the vehicle fleet description by CITEPA is used to catalog the vehicles in Marseille.

- An hourly modulation of the annual average daily traffic (AADT) is established by AtmoSud, based on annual vehicle flow counts in the city center.

- An AADT is assigned to each segment and is distributed among the vehicle categories: passenger cars (PC), light commercial vehicles (LCV), heavy goods vehicles (HGV), buses and 2-wheelers.





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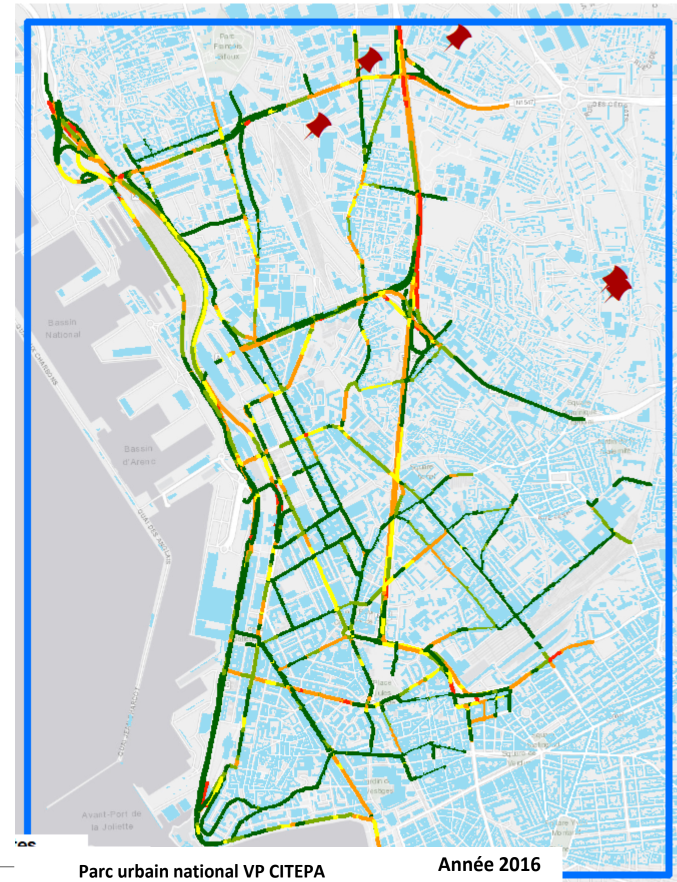

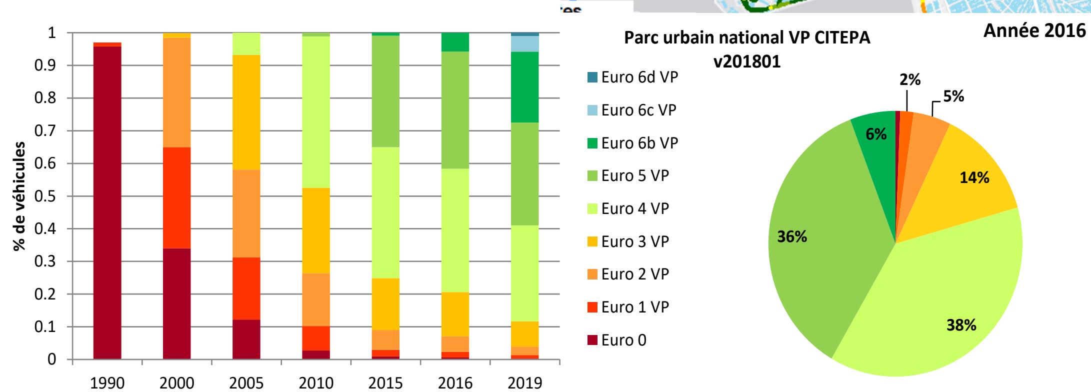

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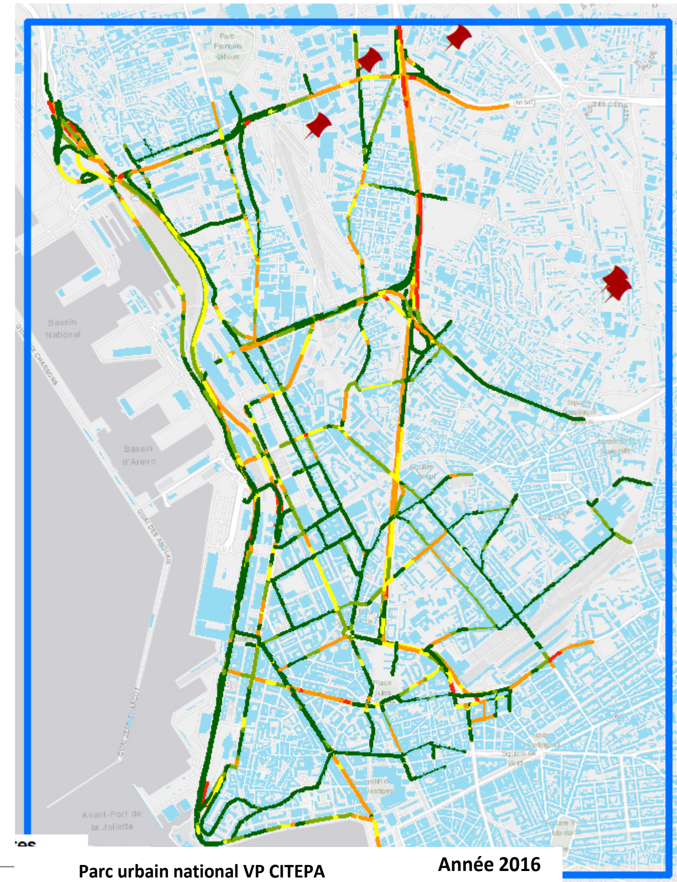
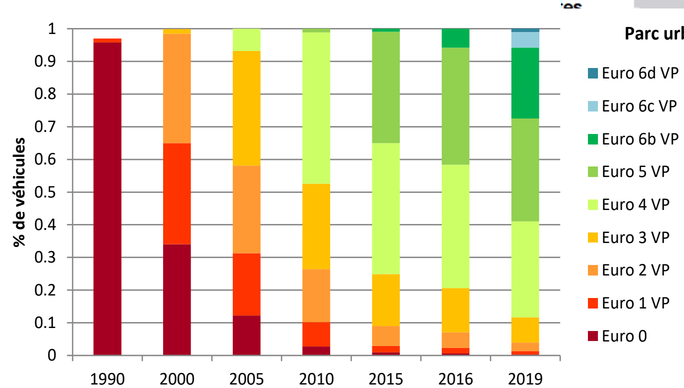
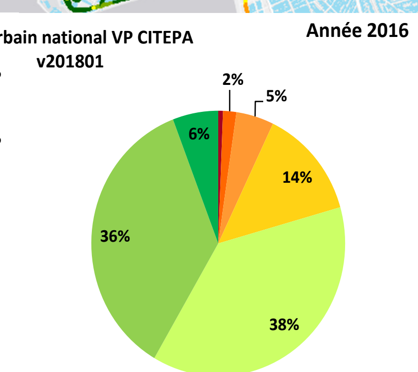
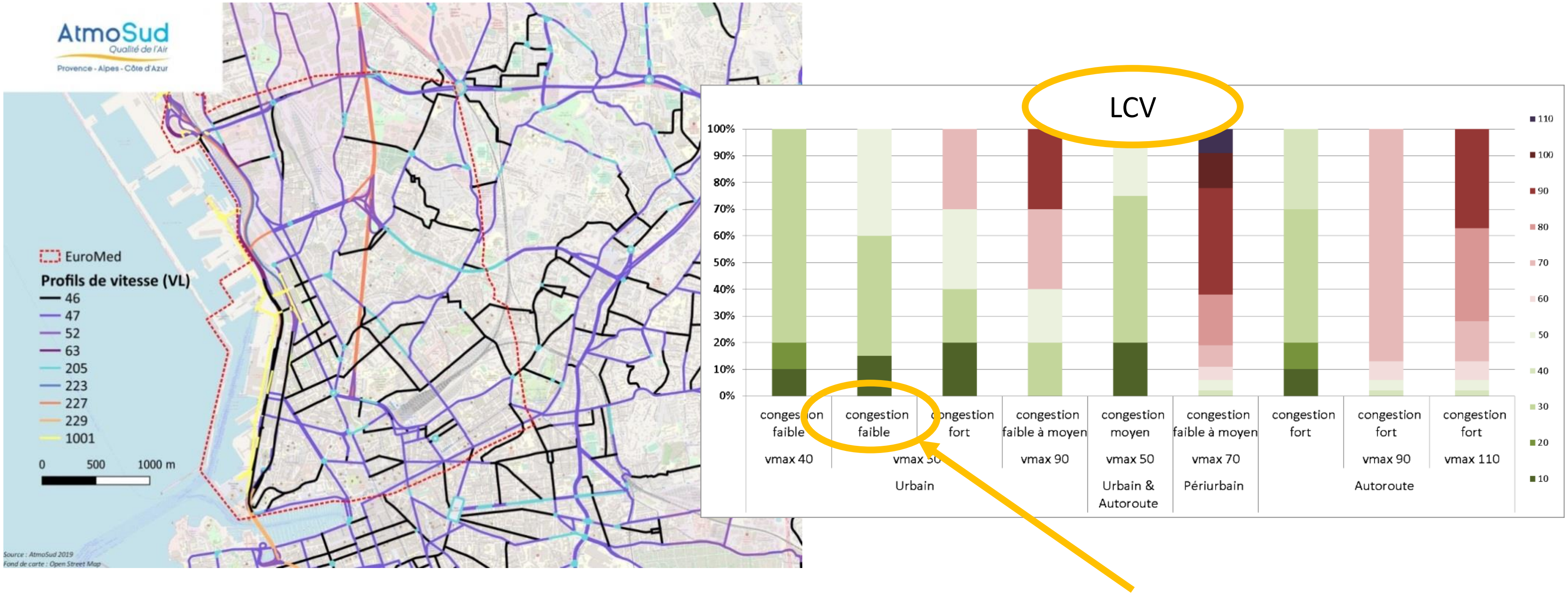






Speed profile: Macroscopic Methodology



- For each road segment, and for each type of vehicle, different speed profiles are established by AtmoSud according to the slope, sinuosity and level of congestion.

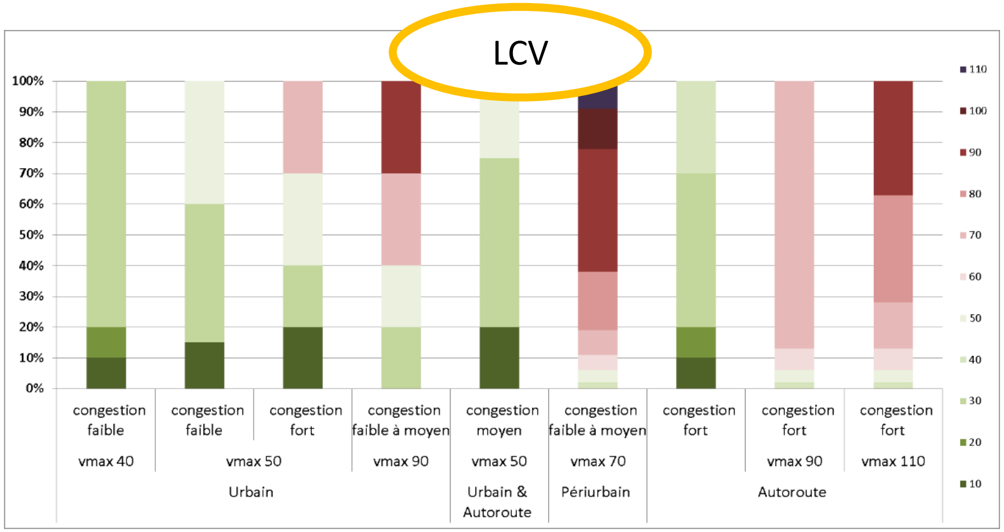
- For a low congestion level on a road limited to 50km/h, 15% of the vehicles drive at 10km/h, 45% at 30km/h and 40% at 50km/h.

Emission: Macroscopic COPERT Methodology

$$E(t, ca, e) = AADT(t, ca, e) \times EF(t, ca, e, V)$$

- E: Emission
- FE: Emission factor

- t : type of vehicle: PC, LCV, HGV, BUS and 2-W
- ca : type of engine (Gazoline, diesel)
- e : EURO Norme
- V: Speed profile



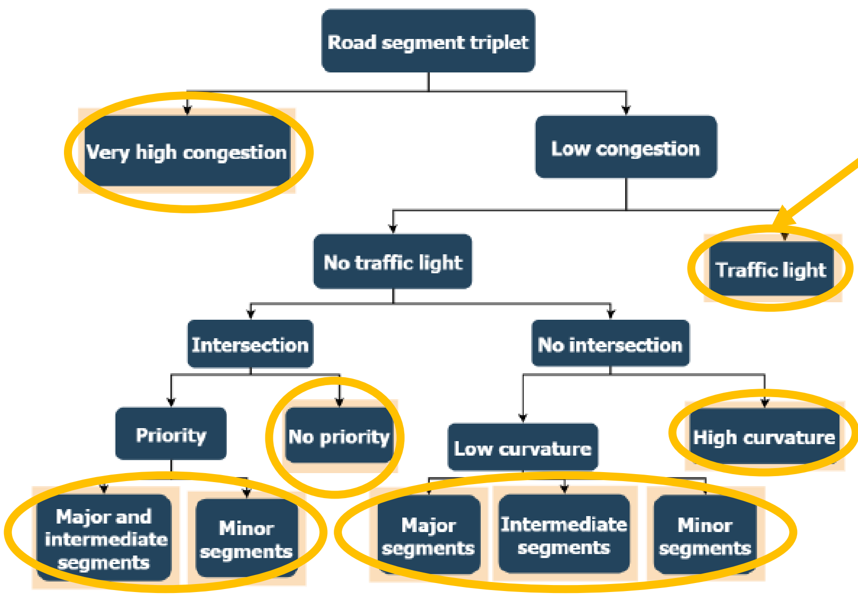
Limitations:

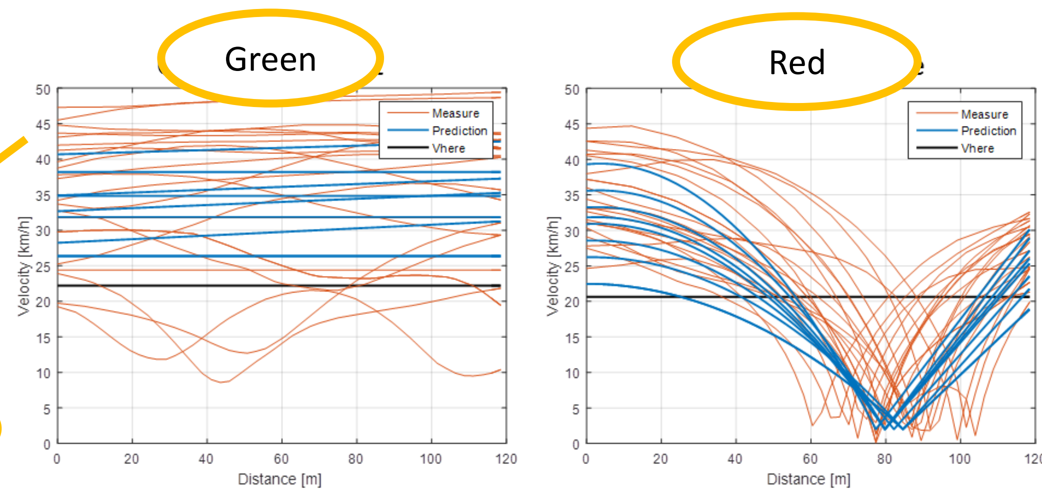
- The COPERT methodology assumes two-way streets.
  The over-emission during uphill driving is compensated by an equivalent under-emission during downhill driving.

- In the COPERT methodology, the slope, road signs and driving behaviors do not have a first-order impact on vehicle accelerations, and so on emission.

Speed profile: Microscopic AIRMES Methodology

- Each road segment is described by approximately 50 pts and is labelled with one of the following categories.
- Several sub-classes are defined for each category (example of the traffic light).





Speed profile: Microscopic AIRMES Methodology

- The *Geco air* smartphone application collected the GNSS signal at 1 Hz of the position, speed and acceleration of vehicles, with the license plate giving access to the vehicle characteristics. By June 2019, the database covers 59 10^6km in France.
- The speed profiles from the database are adjusted to Gaussian statistics for every subclass of each category, and for each vehicle type, and the probability of occurrence of each subclass is deduced. The Gaussian statistics allows an independent approach of the *Geco air* application.

Validation in the district of Marseilles:

- Gaussian statistics are used to randomly generate, 20 speed profiles per road segment, respecting the maximum speed of the road, a possible stopping point, and keeping the statistical weighting of each subclass of a given category.
- AIRMES learns from the 2 10^6 speed profiles of Lyon and Paris, and randomly generates profiles.
- Randomly generated profiles are compared to those measured in the district of Marseille.

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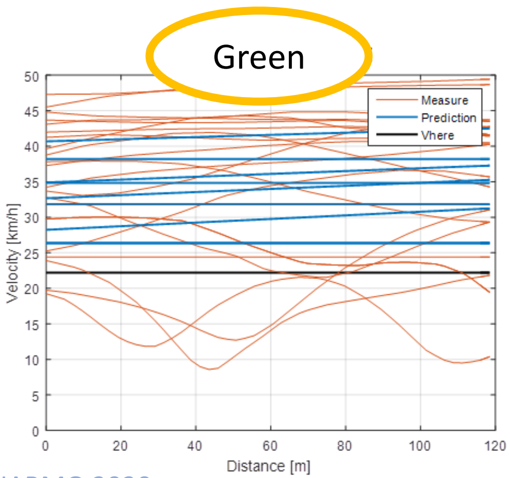
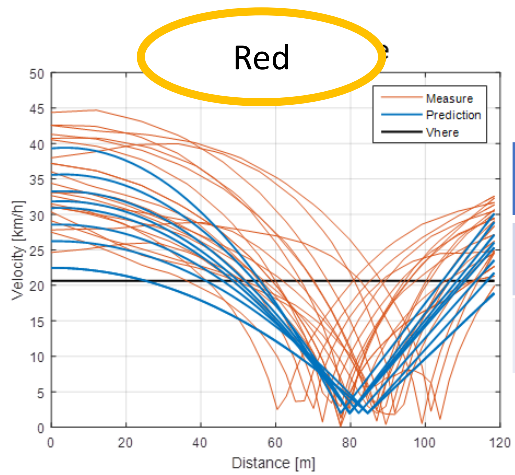
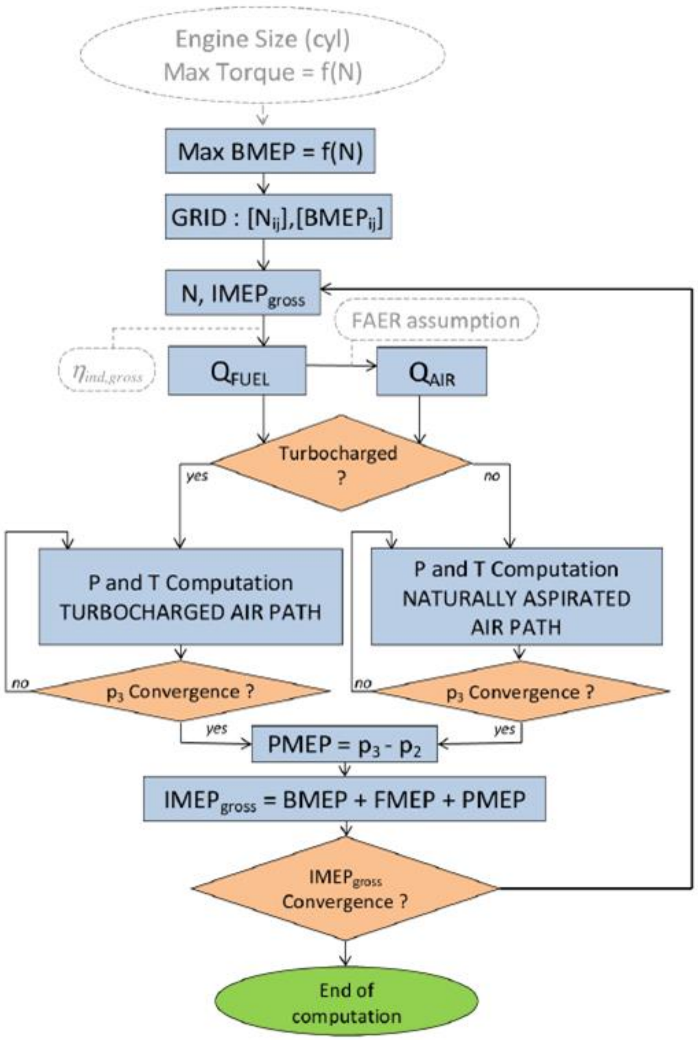




Error	Vi	Vm	Vf
Mean absolute error (km/h)	2.22	2.26	2.32
Relative error (%)	8	8.5	9

Emission: Microscopic AIRMES Methodology



- The entire engine is modeled by IFPEN for each type of vehicle (gasoline or diesel ; PC or LCV or HGV) and on every road segment.
- Emissions are scaled up to the district level in accordance with the traffic (AADT).

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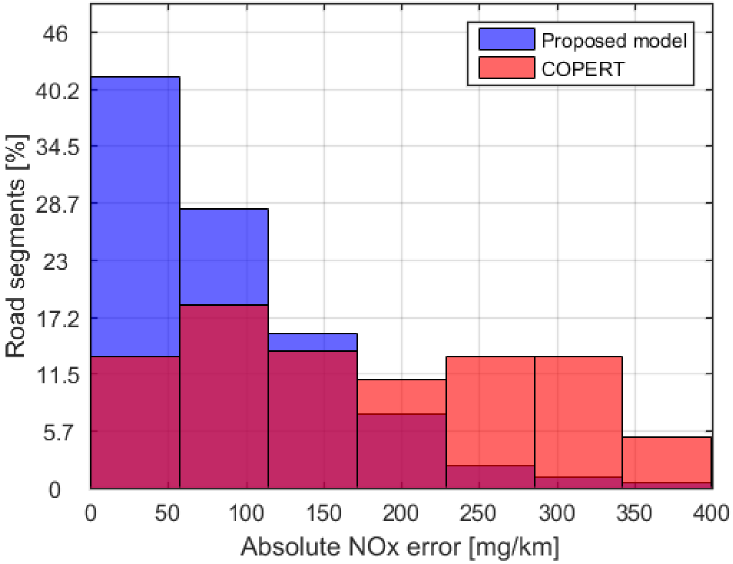

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- Emissions are scaled up to the district level in accordance with the traffic (AADT).

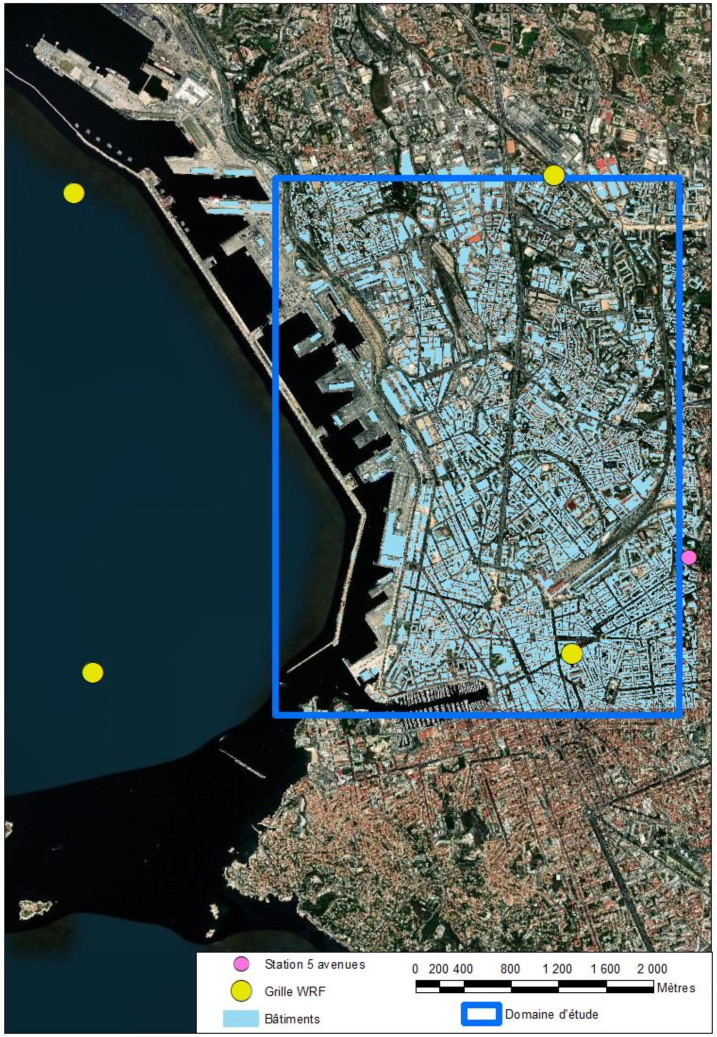
Verification in the district of Marseilles:

- The NOX emissions are computed from the measured speed profiles and compared to those computed from COPERT methodology and randomly generated profiles.

- 75% of the segments have less than 100 mg/km error with AIRMES, compared to 30% with COPERT.
- The mean absolute error is reduced by more than 55%.

Modeling the dispersion

- The impact of COPERT and AIRMES methodologies on the dispersion is computed.
- The large modelled domain covers an area of 3.4km wide by 4.5km high at 4m resolution and the small one 400m by 800m at 1m resolution.
- PMSS fed with meteorological data by the finer scale WRF simulation performed daily by AtmoSud for weather forecast.



- **The air quality is modeled for June 20, 2019**
  - Low level of background pollution in SO_2
  - Proximity of the 2019 annual mean for NO_2

PSWIFT: 3D micro-meteo model

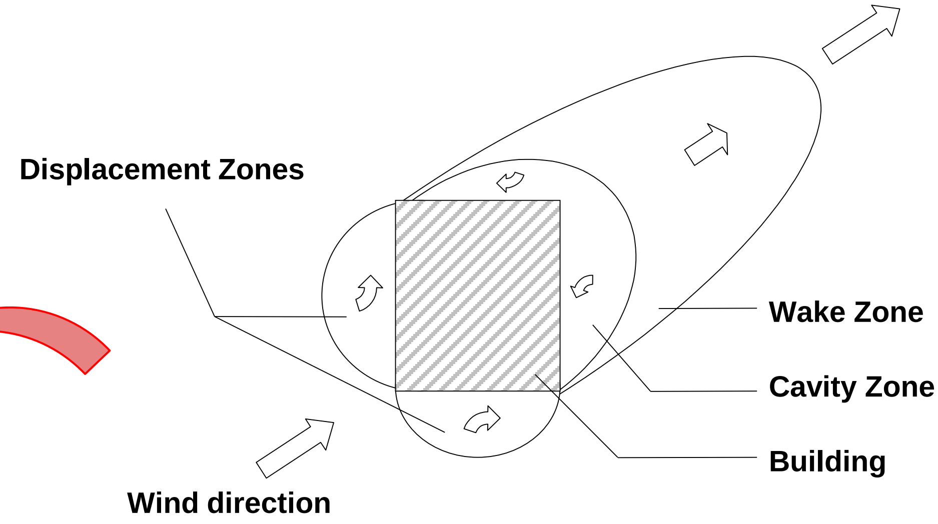
Meteorological Data

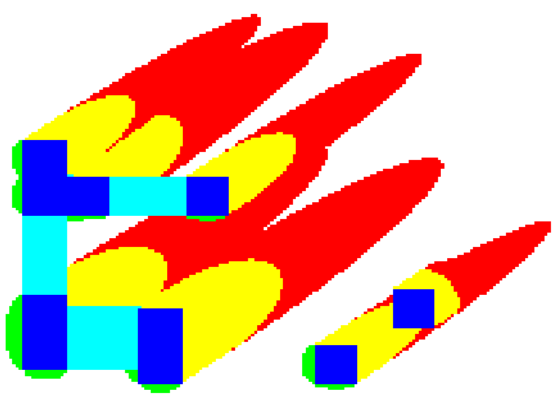
Spatial interpolation on the domain

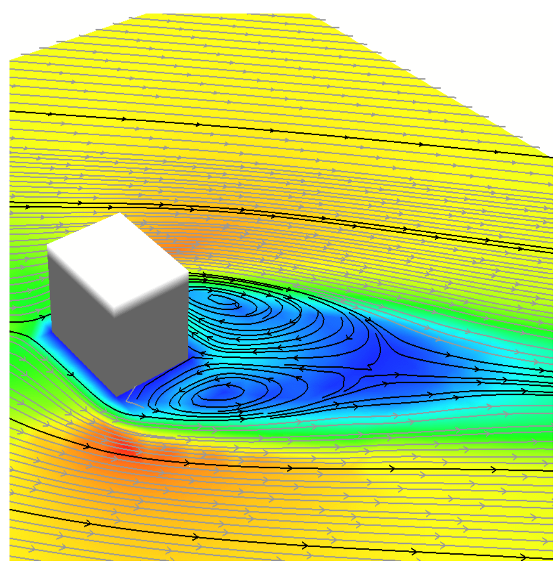
Construction of analytical areas around buildings

Adjustment by mass and *momentum* conservation

3D wind field







PSPRAY: 3D lagrangian dispersion model

Particles initial positions

3D wind field

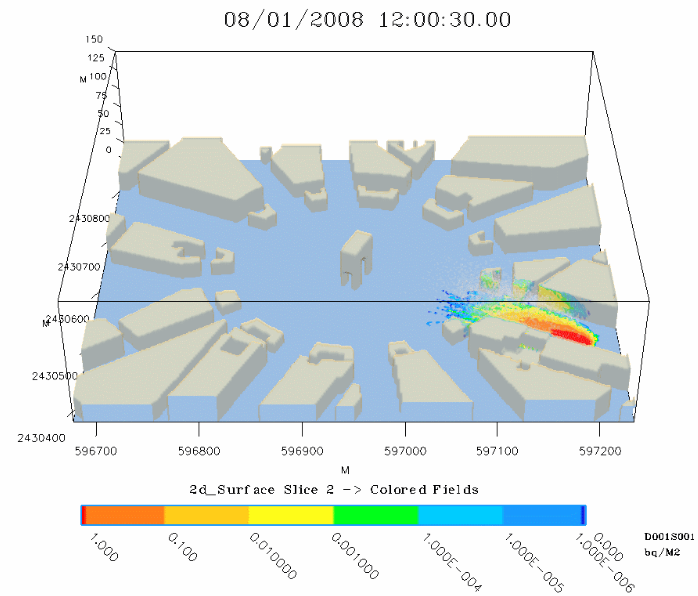
"stochastic" turbulent velocity

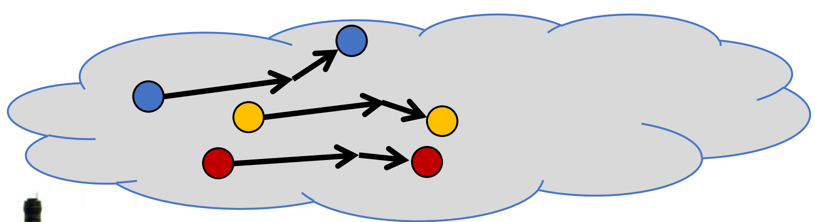
Buoyant velocity

$$\mathbf{X}_0(t) = \mathbf{X}_0 + \left(\bar{\mathbf{U}}(X_0,t) + \mathbf{U'}(X_0,t) + \mathbf{U_b}(X_0,t) \right) \Delta t$$

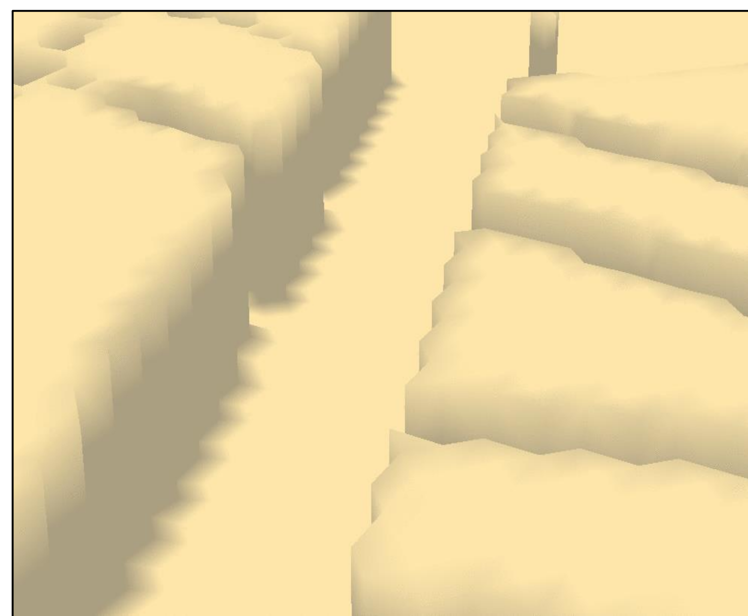
$$\mathbf{X}_1(t) = \mathbf{X}_1 + \left(\bar{\mathbf{U}}(X_1,t) + \mathbf{U'}(X_1,t) + \mathbf{U_b}(X_1,t) \right) \Delta t$$

$$\mathbf{X}_2(t) = \mathbf{X}_2 + \left(\bar{\mathbf{U}}(X_2,t) + \mathbf{U'}(X_2,t) + \mathbf{U_b}(X_2,t) \right) \Delta t$$



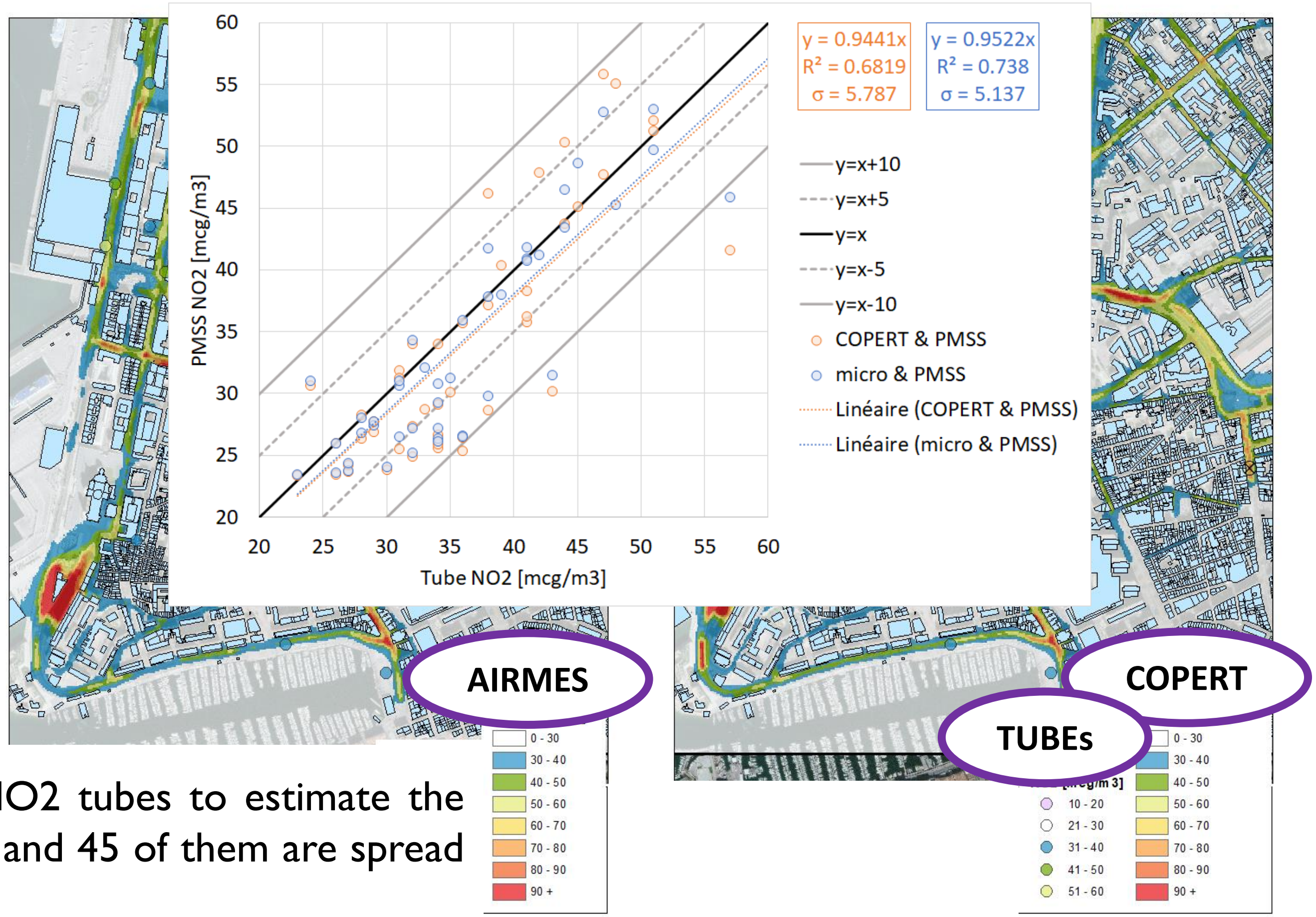


Discretization of the plume into virtual particles, each carrying a fraction of the emitted mass



Results on the large domain

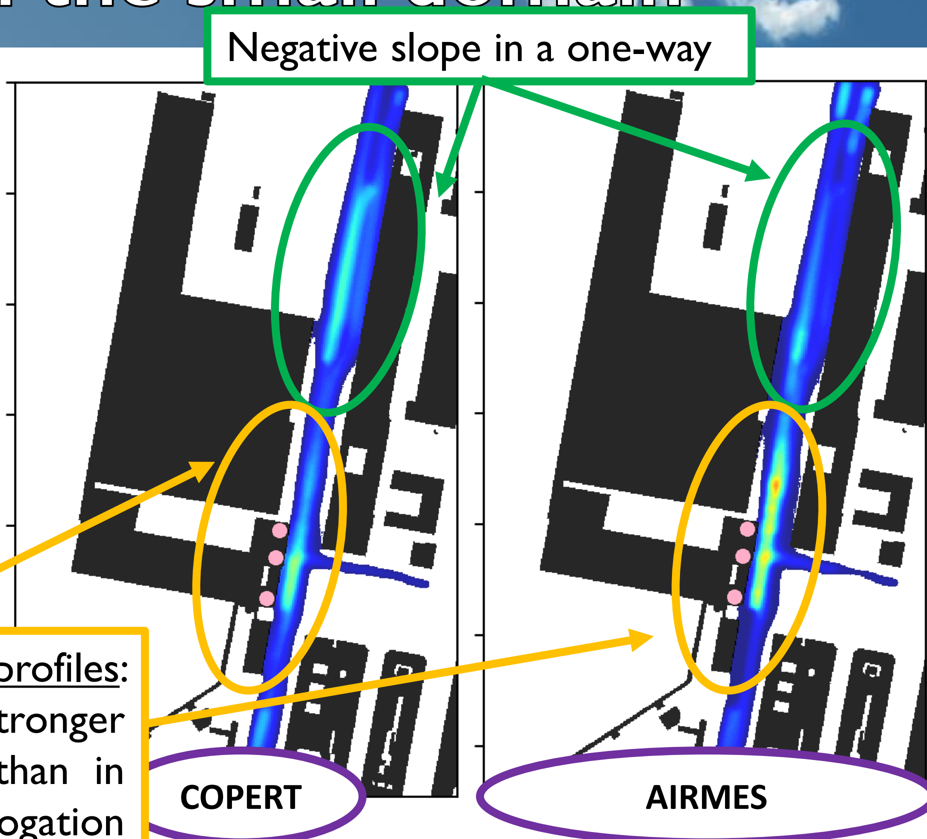
- The annual mean limit value for NO2 concentration is 40µg/m3. The AIRMES methodology indicates an increase in the NO2 exceedance area for the modelled day, with an area increasing from 0.864km2 to 0.890km2, i.e. 3% more.



- AtmoSud regularly deploys NO2 tubes to estimate the annual average concentration, and 45 of them are spread over the large domain.

- The proportion of modelled values at +/-5µg/m3 from the observations goes from 71.1% for the AIRMES methodology to 60% for the COPERT methodology.

Results on the small domain

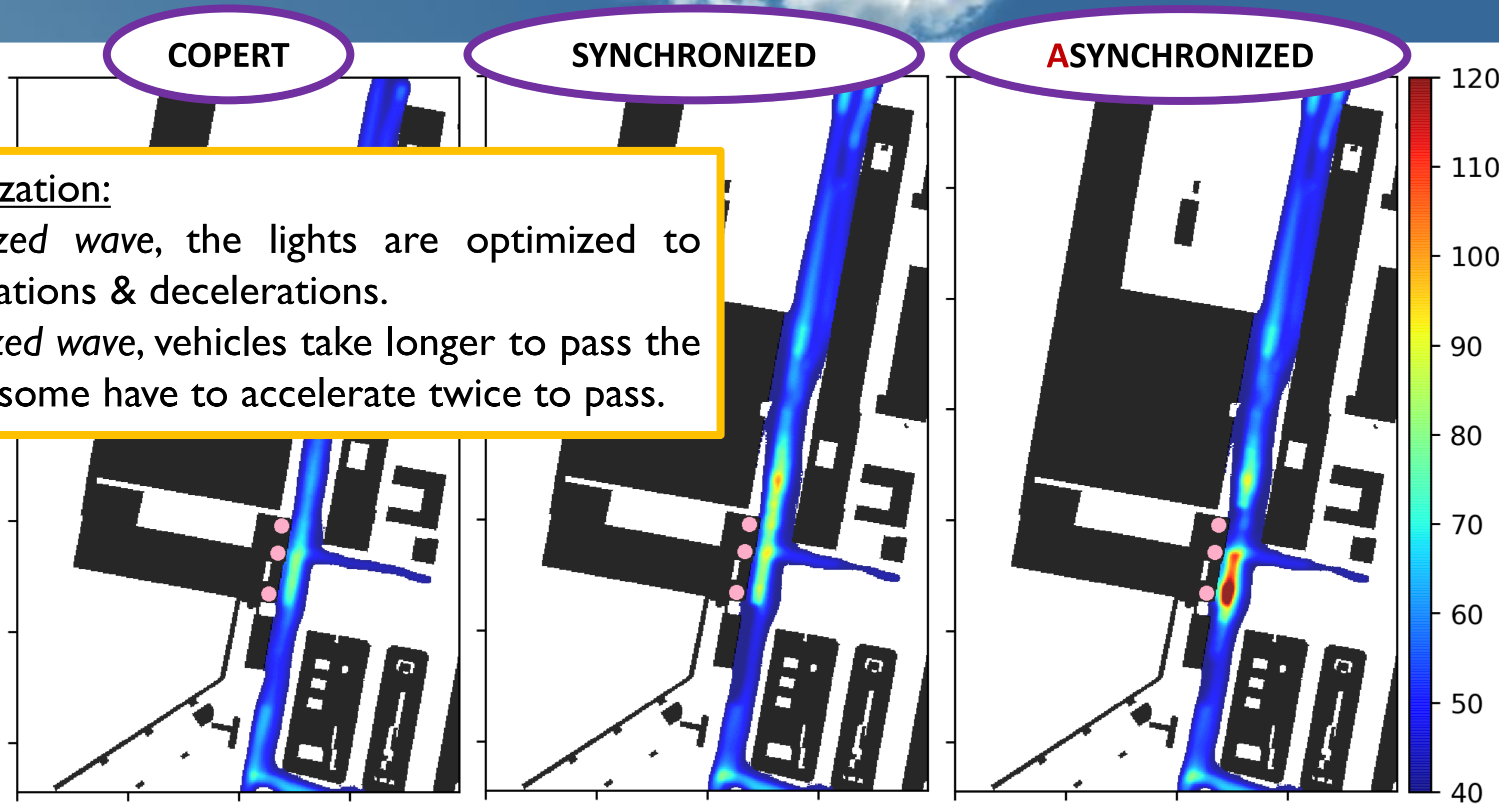


<u>Realistic speed profiles</u>: accelerations are stronger and more frequent than in the vehicles' homologation conditions

- A 300m lane has a succession of 3 traffic lights.
  An additional 5s modulation is added to the traffic density.

- The average density equals the AADT, but there are no vehicles downstream of red lights, and more upstream of red lights than green lights.

Results



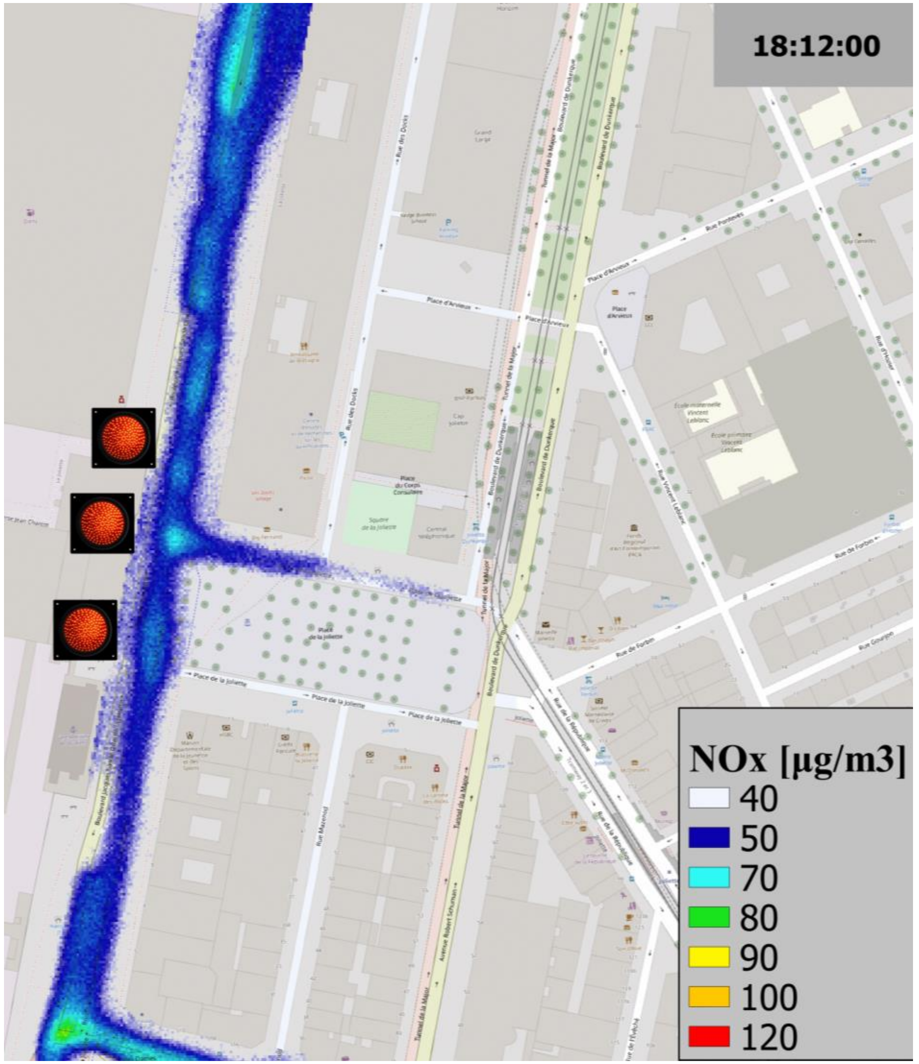
Traffic lights synchronization:

- For the *synchronized wave*, the lights are optimized to reduce the accelerations & decelerations.
- For the *Asynchronized wave*, vehicles take longer to pass the 3 traffic lights, and some have to accelerate twice to pass.

Time (s)	0		10		20		30		40		50		60		70	
Light 1																
Light 2																
Light 3																
	Synchronized wave															
	Acceleration				Green light				Deceleration				Red light			
	Asynchronized wave															
Light 1																
Light 2																
Light 3																

Thank you !

- The microscopic methodology AIRMES captures the high sensitivity of pollutant emissions to traffic conditions, slopes, road signs and driving style, and significantly reduces errors in estimating emissions compared to the COPERT methodology.
- Hot spots for air quality (asynchronized wave, significant contributions from LCVs or diesel engines) are explained by coupling the microscopic methodology to a high-resolution atmospheric dispersion model.
- This work can be quickly and inexpensively deployed in other areas, thus opening the prospect of a digital decision-support platform for urban air quality management.



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