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ASSESSMENT OF URBAN AIR QUALITY USING THE SIRANE DISPERSION MODEL AND A NEW METHOD FOR ESTIMATING TRAFFIC EMISSIONS

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Abstract: Nowadays, air pollution is one of the major risk to human health and environment. Exposure to air pollution can lead several diseases as pulmonary disease or lung cancers (EEA, 2020). The World Health Organization (WHO) indicates that the outdoor air pollution has caused 4.2 million premature deaths worldwide in 2019 (WHO, 2022). To evaluate air quality, population exposure, to locate concentration thresholds exceedances or to quantify the impact of urban and traffic planning, air quality agencies use monitoring stations and atmospheric dispersion modelling as SIRANE.

SIRANE is an operational model which represents the pollutants dispersion at the urban scale (Soulhac et al., 2017, 2012, 2011). This model is based on the street network concept introduced by Soulhac (2000) and takes into account the main flow phenomena in the urban area: advection along the street axis induced by the parallel component of the wind; turbulent diffusion across the interface between the street and the external atmosphere; exchanges at the street intersections. In addition, SIRANE also models the chemical reactions relative to the NO-NO2-O3 cycle (Soulhac et al. 2023). The inputs of the SIRANE model are the urban geometry, the meteorological data, the background concentration and the emissions, in particular those associated to the road traffic.

IFP Energies Nouvelles (IFPEN) has developed a new model-based methodology for estimating road traffic emissions and vehicle flow for each branch in a study area, based solely on static information (number of lanes, road slope, road signs, etc.) and dynamic information (average speed) provided by geographic information system (GIS). This work compares the NO2 concentrations modelled by SIRANE on the Lyon city for some weeks of 2023, using traffic emissions estimated with the new model-based methodology proposed by IFPEN, to measurements provided by monitoring stations to evaluate the modelling chain.

Key words: *Atmospheric dispersion modelling, Urban scale, Road traffic emissions.*

INTRODUCTION

Nowadays, air pollution is one of the major risk to human health and environment. Exposure to air pollution can lead several diseases as pulmonary disease or lung cancers (EEA, 2020). The World Health Organization (WHO) indicates that the outdoor air pollution has caused 4.2 million premature deaths worldwide in 2019 (WHO, 2022). To evaluate air quality, population exposure, to locate concentration thresholds exceedances or to quantify the impact of urban and traffic planning, air quality agencies use monitoring stations and atmospheric dispersion modelling as SIRANE.

SIRANE is an atmospheric dispersion model for urban air quality. The input data of the SIRANE model mainly concern the street network, the meteorological data, the background concentration and the emissions. At urban scale, the road traffic emissions play a major role and strongly influence pollution levels. IFP Energies Nouvelles (IFPEN) has developed a new model-based methodology for estimating road traffic emissions and vehicle flow for each branch in a study area, based solely on static information (number of lanes, road slope, road signs, etc.) and dynamic information (average speed) provided by geographic information system (GIS).

This work aims to assess the estimates provided by SIRANE, using traffic emissions estimated with the new model-based methodology proposed by IFPEN, on a case study which consists on evaluating the NO_2 concentrations on the Lyon city for three weeks of 2023.

ATMOSPHERIC DISPERSION MODELLING

For this study, the atmospheric dispersion is modelled with SIRANE. SIRANE is an operational model which represents the pollutants dispersion at the urban scale (Soulhac et al., 2017, 2012, 2011). This model is based on the street network concept introduced by Soulhac (2000) and takes into account the main flow phenomena in the urban area: advection along the street axis induced by the parallel component of the wind; turbulent diffusion across the interface between the street and the external atmosphere; exchanges at the street intersections. The roughness sub-layer just above the urban canopy is neglected and the flow in the external atmosphere is modelled as a boundary layer flow on a rough surface. This external flow is supposed to be horizontally uniform. In addition, SIRANE also models the chemical reactions relative to the NO-NO_2-O_3 cycle (Soulhac et al. 2023). The input of the SIRANE model are the street network, the meteorological data, the background concentration and the emissions, in particular those associated to the road traffic.

For the case study, the SIRANE simulations are carried out using a street network built based on the buildings data provided by the IGN, the french institut for geographic and forestry information. The meteorological data used come from the open source weather API *Open-Meteo*. The hourly concentrations of NO_2, NO and O_3 measured by the background station *Lyon Saint-Exupéry*, located about 20 km from the centre of Lyon, are used as background concentrations for the simulations.

The road traffic emissions are evaluated with the model-based methodology from IFPEN. The new model is composed of four main blocks, enhancing current macroscopic models by incorporating additional input parameters beyond average speed to better characterize traffic-related pollutant emissions at the road segment level. The model introduces parameters like congestion, topography, and road signage to better explain the impact of road infrastructure on emissions, making it more precise and also accessible even for non-experts.

1- Traffic flow estimation: This first block utilizes techniques such as neural networks and relies on counting station measurements in various cities to estimate traffic flow. The model can also leverage various data sources like loop-detector measurements and HERE API for input, enabling it to estimate daily traffic flow on road links.
2- Emissions estimation: This central block employs neural networks learned using actual 1Hz real-world recorded trips to estimate emissions accurately. Calibration is done using emission estimates derived with a microscopic emission model applied on the Geco Air database, which spans 100 million kilometers, obtained through a smartphone application capturing anonymized GPS signals. The model provides emission estimates for different driving styles and leverages Geco Air trajectories to improve emission estimates across the driving conditions. The model identifies emission values, for each type of emission (NO_x, CO_2, HC, CO, exhaust and non-exhaust PM, and noise).
3- Vehicle fleet estimation: This block uses national and local statistics to estimate the vehicle fleet composition, accounting for factors like vehicle type, powertrain, and Euro norm version. This ensures accurate emissions estimation by considering the appropriate mix of vehicles in a given territory.
4- Aggregation stage: This final block performs data fusion between vehicle fleet, unitary emissions per vehicles, traffic flows, and road infrastructure. It considers key inputs like infrastructure type, slope level, average speed, and speed limit, with each parameter impacting emission levels differently.

Validation of the mesoscopic emissions model was performed previously (fell out of the scope of this paper), involved comparisons with microscopic models estimations and experimental measurements, ensuring its accuracy across various scenarios. Model validation demonstrated its effectiveness in estimating emissions for different vehicle types and Euro norms, with comparisons against the state-of-the-art model known as COPERT, the European standard for vehicle emissions calculation.
Scenarios analyzing various road infrastructure configurations showed the model's ability to predict emissions accurately under different conditions. One of the main capabilities of the model is to allow for prospective studies of upcoming public policies impact on emissions (i.e. low emission zones, City 30 km/h, natural vehicle fleet evolution, modal shift, etc.).
The model's applicability extends to any territory using data provided by the GIS, covering diverse regions of interest, making it a highly replicable solution.

STUDY CASE

Description of the study case

The study case consists on evaluating hourly NO_2 concentrations in Lyon for three different periods (of seven days): 30th January 2023 – 5th February 2023 (winter), 21th May 2023 – 27th May 2023 (spring), and 19th June 2023 – 25th June 2023 (summer).

To evaluate the quality of the estimates, the modelled concentrations are compared to measured concentrations, provided by three traffic stations (A7 Sud Lyonnais, Trafic Jaurès, and Lyon Périphérique), by means of seven statistical indices: fractional bias (FB), relative error (ER), normal mean square error (NMSE), correlation coefficient (R), geometrical mean bias (MG), geometrical mean squared variance (VG), and fraction in a factor of 2 (FAC2). These indices and the associated quality criteria are defined in **Table 1**.

Table 1. Statistical indices and criteria to assess the quality of the estimates (C_m: measured concentration, C_p: modelled concentration)

	Expression	Optimal value	Criteria
FB	$\frac{\overline{C_p} - \overline{C_m}}{0.5(\overline{C_p} + \overline{C_m})}$	0	$-0.3 \leq \mathrm{FB} \leq 0.3$
ER	$\overline{\left(\frac{\lvert C_p - C_m\rvert}{0.5(\overline{C_p} + \overline{C_m})}\right)}$	0	
NMSE	$\frac{\overline{(C_p - C_m)^2}}{\overline{C_p}\,\overline{C_m}}$	0	$\sqrt{\mathrm{NMSE}} \leq 2$
R	$\frac{\overline{(C_p - \overline{C_p})(C_m - \overline{C_m})}}{\sqrt{\overline{(C_p - \overline{C_p})^2}\ \overline{(C_m - \overline{C_m})^2}}}$	1	
MG	$\exp\left(\overline{\ln(C_m)} - \overline{\ln(C_p)}\right)$	1	$0.7 \leq \mathrm{MG} \leq 1.3$
VG	$\exp\left(\overline{\left(\ln(C_m) - \ln(C_p)\right)^2}\right)$	1	$\mathrm{VG} \leq 1.6$
FAC2	Proportion of estimates that check $0.5 < \mathrm{C_p}/\mathrm{C_m} < 2$	1	$\mathrm{FAC2} \geq 0.5$

Results

The **Figure 1** to **Figure 3** show the hourly NO_2 concentrations modelled and measured at the three traffic stations for the period 21th May 2023 – 27th May 2023 (spring). These results indicate that the modelled concentrations reproduce the temporal variability of the measurements relatively well. However, they also show that the simulations tend to overestimate peak concentrations.

The **Table 2** to **Table 4** show the statistical indices values for the three traffic stations and the three period studied. Globally, these results indicate that the best scores are obtained for the period 30th January 2023 – 5th February 2023 (winter) and that the worst scores are associated with the period from 19th June 2023 – 25th June 2023 (summer). For the summer period in particular, the correlation coefficients are mostly below

0.5, indicating a poor representation of the temporal variability of the concentrations measured. Similarly, the results are generally better for the station Trafic Jaurès. It should be noted that the other two stations, A7 Sud Lyonnais and Lyon Périphérique, are located very close to major roads and therefore in areas with a strong concentration gradient. As a result, the concentrations modelled for these stations are (more) strongly influenced by the representativeness/quality of the input data (emissions, meteorology, street network, etc.). This may partly explain the poorer results for these stations.

For the three periods studied, the scores generally meet the quality criteria for the three stations (only the scores for VG sometimes fail to meet the quality criteria). The estimates provided by the modelling chain can therefore be considered satisfactory.

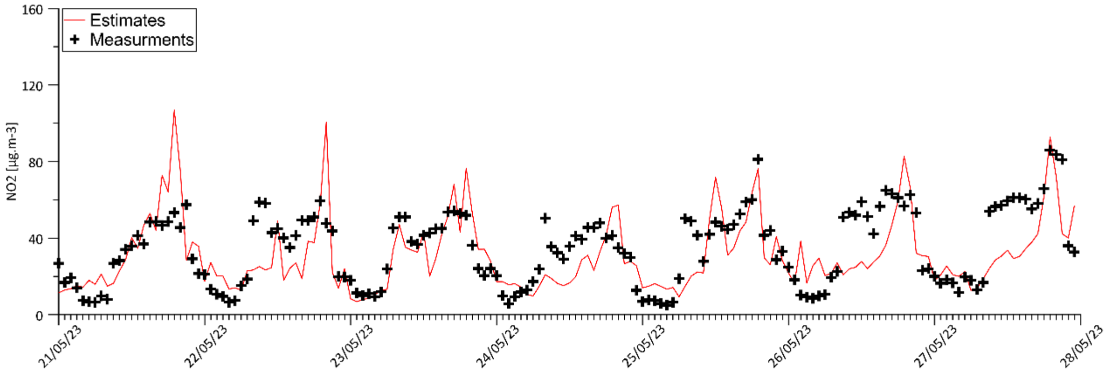

Figure 1. Modelled (red line) and measured (black cross) hourly NO_2 concentrations at the traffic station *A7 Sud Lyonnais* for the period 21th May 2023 – 27th May 2023 (spring).

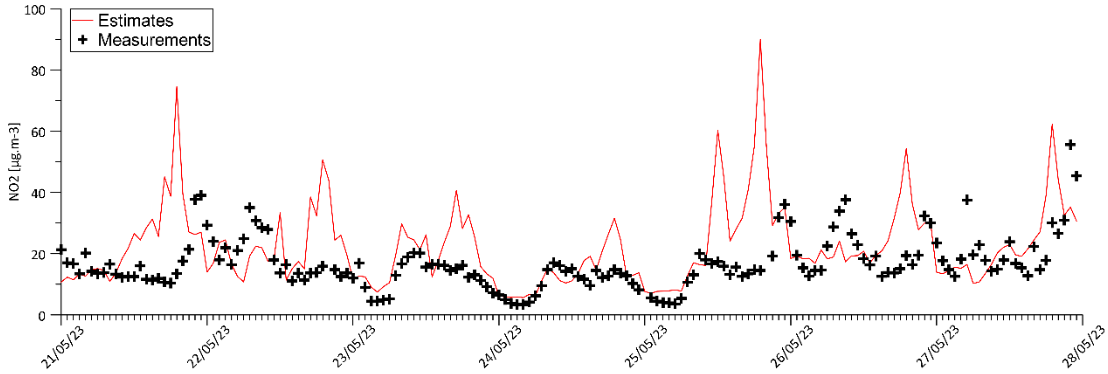

Figure 2. Modelled (red line) and measured (black cross) hourly NO_2 concentrations at the traffic station *Traffic Jaurès* for the period 21th May 2023 – 27th May 2023 (spring).

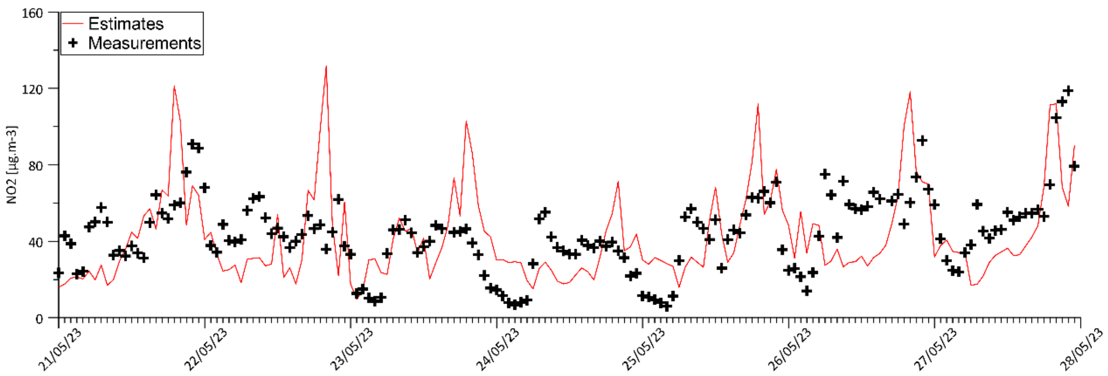

Figure 3. Modelled (red line) and measured (black cross) hourly NO_2 concentrations at the traffic station *Lyon Périphérique* for the period 21th May 2023 – 27th May 2023 (spring).

Table 2. Statistics for the period 30th January 2023 – 5th February 2023 (winter). Red values do not meet quality criteria.

Station	FB	ER	NMSE	R	MG	VG	FAC2
A7 Sud Lyonnais	-0.059	0.352	0.280	0.670	0.978	1.227	0.881
Trafic Jaurès	-0.047	0.320	0.192	0.737	1.050	1.196	0.886
Lyon Périphérique	0.048	0.339	0.174	0.749	1.131	1.191	0.910

Table 3. Statistics for the period 21th May 2023 – 27th May 2023 (spring). Red values do not meet quality criteria.

Station	FB	ER	NMSE	R	MG	VG	FAC2
A7 Sud Lyonnais	0.109	0.430	0.253	0.637	1.063	1.329	0.756
Trafic Jaurès	-0.273	0.438	0.563	0.260	0.774	1.394	0.764
Lyon Périphérique	0.036	0.488	0.311	0.417	1.036	1.456	0.711

Table 4. Statistics for the period 19th June 2023 – 25th June 2023 (summer). Red values do not meet quality criteria.

Station	FB	ER	NMSE	R	MG	VG	FAC2
A7 Sud Lyonnais	0.092	0.553	0.560	0.222	1.080	1.688	0.673
Trafic Jaurès	-0.222	0.427	0.357	0.384	0.789	1.376	0.765
Lyon Périphérique	0.008	0.577	0.497	0.393	0.968	1.855	0.648

CONCLUSION

This study aims to assess the concentrations modelled by SIRANE using traffic emissions estimated with the new model-based methodology proposed by IFPEN. This assessment is carried out on a case study which consists on evaluating the NO_2 concentrations on the Lyon city for three weeks of 2023.

The comparison of the modelled and measured concentrations indicates that the simulations reproduce the temporal variability of the measurements relatively well. However, they also show that the simulations tend to overestimate peak concentrations. In addition, the results indicate that the best scores are obtained for the period 30th January 2023 – 5th February 2023 (winter) and that the worst scores are associated with the period from 19th June 2023 – 25th June 2023 (summer). Similarly, the results are generally worst for the station located very close to major roads and therefore in areas with a strong concentration gradient. As a result, the concentrations modelled for these stations are (more) strongly influenced by the representativeness/quality of the input data (emissions, meteorology, street network, etc.).

Nevertheless, for the all the periods studied, the statistical indices values generally meet the quality criteria for the three stations. This indicates that the estimates provided by the simulations can therefore be considered satisfactory for this study case.

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