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REAL-TIME MONITORING OF AIR POLLUTION IN URBAN AREAS USING A 3D CFD SIMULATION TOOL

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Abstract: As in other major metropolitan areas, the air pollution is particularly acute in the Paris region, where more than 2.3 million people are exposed to pollution levels that do not comply with regulations, specifically people living near high traffic roads. The area around the Stade de France in the Paris suburbs is the most urbanized part of the department of Seine-Saint-Denis, as the stadium is surrounded by two highways. In this area, concentrations of air pollutants remain well above the thresholds set by the regulations, up to twice the limit values.
Urban air quality monitoring has gone beyond merely observation of concentration values through measurement networks. The objective is to set up a platform to monitor air quality through 3D modelling. This platform uses a real time function to produce uninterrupted and up-to-date pollutant maps on the surroundings.
This type of platform is based on CFD modelling in order to monitoring of local air quality with complex topography and land occupancy area (buildings, road network, bridges, crossing…). Simulations are made by coupling the CFD models for local wind flows simulation with Lagrangian models for dispersion modelling.
The scales cover areas of the order of four square kilometers and meshes at the scale of the street (ten meters). The platform targets primary pollutants for which simulation of micro-scale transport and diffusion is relevant, particularly small particles, PM10 and PM2.5.
The modelling platform is also provided with an inversion module which makes it possible, thanks to a sensor network to be deployed, to establish a link between the measurement and the emission source in a complex urban environment.

Key words: *Environmental impact assessment: Air pollution management and decision support systems.*

INTRODUCTION

Air quality concerns the well-being and everyday life of citizens, but it is above all a major health issue. According to the World Health Organization and the Ministry of Sustainable Development, air pollution annually causes the premature death of 7 million people worldwide.
In Paris region, on average, the concentrations of atmospheric pollutants stay widely beyond thresholds fixed by the regulations, being until twice superior for the limit values along certain main highways. According to an IFOP investigation, commanded by Airparif (the regional agency of surveillance of air quality) 29 % of Francilians (inhabitant of the Paris region) say they consulted a doctor, for them or for close friends, following an air pollution. Today, more than 2,3 million Francilians are still exposed to non-compliant levels of pollution, especially those who live near main highways with high traffic as is it in particular the highway A1, in the most urbanized part of the department of Seine-Saint-Denis.

Nowadays, urban air quality monitoring must go beyond merely observing concentration values through measurement networks but should provide interactive visualization of atmospheric pollution through modeling. The objective of this project is to set up a platform to monitor air quality at local level (neighborhood, built-up areas, proximity to road network / traffic) through 3D modelling. This platform is being deployed on the north sector of the Stade de France in the Paris suburbs. This sector was chosen because of several criteria, the proximity with two major highways (A1 and A86), very frequently used and thus an important source of pollution, and sensitive urban areas close to the major emitters of pollution.

DISPERSION MODELING

The methods used to describe the dispersion dynamics can be divided into two major approaches: the Eulerian approach and the Lagrangian approach. The first one is used to compute wind field mean while the second deals with the pollutant dispersion.

Wind field computation

A survey of the wind directions and intensities has been made to establish the frequencies of occurrence of wind characteristics. An eulerian methods is then used to solve the 3D Navier-Stokes equation to get the wind field pattern of the 108 different weather conditions representing the previous wind characteristics. The weather database is discriminated according to :

- Wind direction
- Magnitude (from 3 to 6.5 $m.s^{-1}$)
- Pasquill class (from B to F stability class)

The results of the wind field are obtained on a mesh covering a four square kilometers area and with a grid size around 10m. They compose a database of wind field generated before the deployment of the platform.

In order to predict the most realistic evolution of the dispersion, a numerical representation of the area and its surroundings is realized. The influence of surface roughness on flow pattern is treated through a roughness coefficient. This one comes from topographic maps and complementary data collected on the entire area. All natural elements and all types of facilities that could interact with air displacement were identified from GIS data (see Fig 1).

Figure 1: Numerical representation of the surface monitored by the platform

Pollutant dispersion

The Langevin equation, modeling the motion of pollutant particles, is solved within a Lagrangian approach. In Lagrangian particle method, the dispersion is evaluated by the tracking of several thousands of discrete particles emitted from the same source. The concentrations are then given by summation of the number of particles present in a given volume. This method makes it possible to represent accurately the physical phenomena. However, it requires an expensive computing time since it is necessary to simulate a great number of particles to correctly represent the turbulent dispersion of the particles.

In the Lagrangian Gaussian puff technique, the process of pollutant emission is discretized by a succession of puffs (Hernandez et al, 1997; Reynolds, 1999; De Haan and Rotach, 1998; Liu and Du, 2003). This method tracks the center of the puff and model the diffusion around it with a Gaussian evolution. Each puff can replace hundreds of Lagrangian particles and so reduce CPU needs. The performances of the method of dispersion by Lagrangian puffs are in particular exposed by Cheng et al (2008). Considering the real-time aspect of this platform, the Lagrangian puffs method has been chosen for this work.

REAL TIME MONITORING

The objective of the platform is to provide the concentration map of pollutant in real time. Even if the numerical methods chosen allow predicting the pollutant dispersion faster than real-time, some in-situ data are needed:

- Weather condition
- Roads pollutant emission

Weather condition

The weather condition is obtained using NCEP prevision service. This service provides the forecast of wind speed, wind magnitude and cloud coverage at a certain scale. For a particular weather condition, the real time wind field pattern can be interpolated from the wind field database. The database of wind field condition can be easily increased even after the start of the platform.

Road emission and sensor network

On the covered area, 30 road sections have been identified as the main pollutant sources of PM10 and PM2.5. These roads correspond to the sources used for the dispersion model. For each of them, the averaged emissions of PM10 and PM2.5 have been estimated but the real time emission, depending mainly on the road traffic, is unknown.

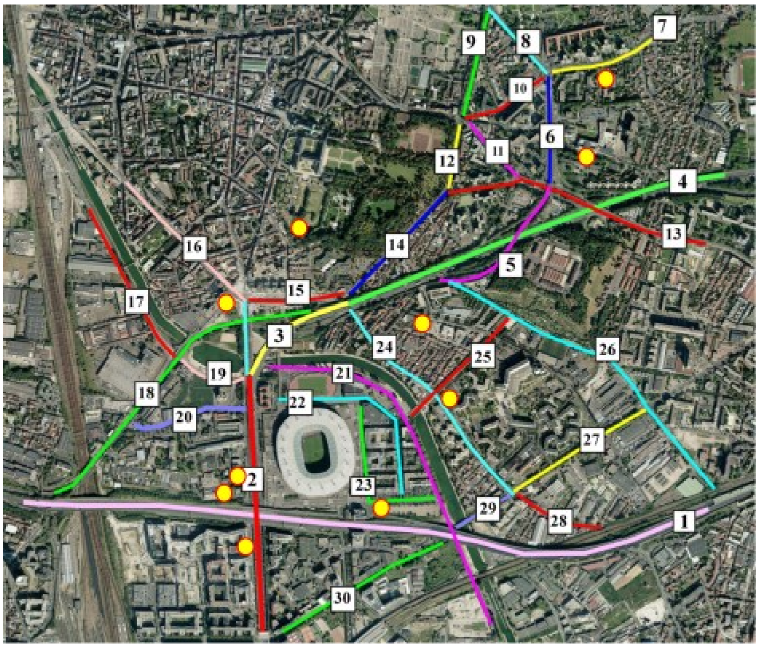

Figure 2: Position of road sections considered and sensor network localization

To improve the map concentration estimation, a sensor network has been deployed on the area. Each sensor saves the concentration of PM10 and PM2.5 with a frequency of 10 minutes. To save energy, the sensor working on solar panel, data are sent only every 30 minutes. These data allows rescaling the emission source used in the last thirty minutes for the 9 more polluting roads section, corresponding mainly to highway sections, and the background concentration. The 21 others road sections use the estimated averaged emission source.

CONCLUSION

The test of this platform will start in a few weeks. If results are satisfying, this platform could be implanted at other locations. The complete platforms includes following modules:

- An interface to set up and run simulations ;
- An interface for results visualization:
    - Intranet consulting service aimed at technical teams;
    - Internet consulting service aimed at populations living nearby

The combining of the Eulerian method, Gaussian Puff dispersion method and sensor network monitoring allow this platform to get a forecast of the pollutant concentration map caused by road traffic on the covered surface.

It can be used as a tool to visualize the pollution peaks with, as an alternative, corrective action on the emissaries of pollution (eg information, changes in traffic conditions, reduction in traffic speeds, reflection on signage, etc.) and constitutes an interactive communication tool with the population.

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