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PRESENTATION OF SIRANERISK-2.0 – A DECISION-SUPPORT ORIENTED COMPUTATIONAL TOOL ADAPTED TO THE DISPERSION OF DELETERIOUS RBC AGENT IN THE URBAN ATMOSPHERIC ENVIRONNEMENT – EXAMPLES OF APPLICATION

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Abstract: Atmospheric dispersion modeling is a crucial issue in the case of deleterious release of RBC agent in urban environment, in order to produce detailed cartographies of pollutant concentrations that can help authorities during a scenario planning or a crisis management. One of the main difficulties in the modeling of urban atmospheric dispersion is to take into account a large number of complex buildings and obstacles, in a very small computational time, compatible with operational applications.

During the last five years, we therefore developed an operational urban dispersion model, SIRANERISK (Cierco et al., 2010), based on a representation of a city as a network of interconnected streets. Specific parameterizations are used to model flow and dispersion within each street, exchange at each intersection, and a Gaussian puff model is used to deal with dispersion over the roof level.

In this paper, we present in a first time the main features of the version 2.0 of SIRANERISK, including the new physical models (meteorological pre-processing, puff deformation due to the wind shear) and the numerical implementations used to get fast computational time. Then, we present some practical examples of application in the cities of Lyon and Paris, in order to illustrate the applicability of the model and the use of the results for decision support.

Key words: *Operational dispersion model, Application case, RBC agent, urban canopy, Gaussian puff model.*

INTRODUCTION

Depending on material toxicity, human health consequences of noxious accidental or deliberate releases is a topic of main interest for authorities. Considering the number of potential victims, urban areas get greater exposure to hazardous events because of high population density. During a crisis management, the decision-making process must be based on easy to use, fast responding and reliable tools. During scenario planning, these tools have to be able to produce complementary data to enhance both authorities and experts knowledge of such problematic. From toxic release instant to authorities' reaction, many different scientific skills have to be deployed. Atmospheric dispersion modelling is a crucial issue in this context. The SIRANERISK-2.0 model developed during the last five years is an operational urban dispersion model dedicated to numerical simulation of short unsteady releases of RBC agent in urban atmospheric environment. The model is partly presented in this paper with focus on new features whereas its validation is treated in another communication (Lamaison *et al.*, 2011). Examples of application in two different urban contexts are then described, showing what kind of useful data the model can provide.

THE SIRANERISK-2.0 MODEL

Overview of the model

The SIRANERISK model (Cierco *et al.*, 2010 and Lamaison *et al.*, 2011) is an operational dispersion model dedicated to the numerical simulation of accidental or deliberate release of pollutant in urban areas. It is based on the coupling between a canopy model developed by Soulhac (2000) in urban air quality context and a Gaussian puff dispersion model. The canopy model consists in the resolution of a mass budget equation for each street of an interconnected network of street canyons. Under mean and fluctuating wind action, streets are exchanging air fluxes and thus pollutant. Above the canopy, pollutant transport is ensured by puff advection and dispersion under local meteorological effects. The two parts of the model also exchange pollutant under vertical turbulent fluctuation: streets can emit parallelepipedic puffs in the atmosphere whereas puffs can give a part of its transported pollutant to the streets. Within the canopy, concentration is known in each street thanks to mass budget equation. Above the roofs, concentration has to be computed from the summation of the contribution of all the puffs in the domain. To improve the response time, OpenMP parallel algorithms have been implemented at key points of the numerical code. Due to lack of space in this short communication, only two specific aspects of the SIRANERISK model are developed: meteorological pre-processing and shear effects on puff.

Meteorological pre-processor

Atmospheric parameters influence the transport of pollutant within the canopy and above the roofs and also the exchange between the two parts of SIRANERISK. The model can either work with 1D calculated profiles from user given parameters or with full 3D meteorological field coming from an external model. In the first case, pre-processing is performed following the works of Holtslag and Van Ulden (1983) and Fisher *et al.* (1998). From few measured parameters like wind direction and velocity and fixed site parameters like roughness length or emissivity, reference meteorological data like boundary layer height or sensible heat flux are computed. Thanks to a fixed point method, parameters of Monin-Obukhov similitude theory are calculated. After few complementary parameters computation, vertical profiles of mean velocity, turbulent fluctuation, temperature, pressure and density are then found. These profiles will be then used in the current time step to transport puffs in the atmosphere and also to compute air fluxes within the canopy and pollutant exchange at the interface between the two parts of the SIRANERISK model. Because our model is dedicated to unsteady release dispersion, time steps are low and history of parameters has to be conserved: during a meteorological computation, the previous time step state is used to ensure the temporal coherence.

Puff deformation due to wind shear

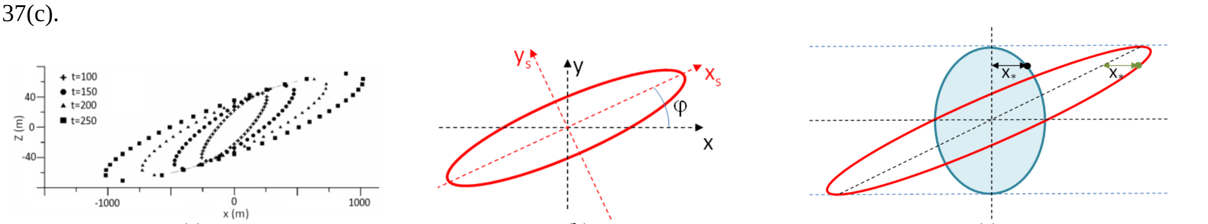
Shear effects on puff implies that variance-covariance matrix Σ that governs puff spatial distribution is not diagonal anymore. Concentration at point $\mathbf{x}$ due to a point source of mass M located at point $\boldsymbol{\mu}$ can then be written thanks to generalized Gaussian distribution :

$$C = \frac{M}{(2\pi)^{3/2}\sqrt{\det(\Sigma)}} \exp\left(-\frac{1}{2}(\mathbf{x}-\boldsymbol{\mu})^T.\Sigma^{-1}.(\mathbf{x}-\boldsymbol{\mu})\right) \qquad (1)$$

Following Sykes and Henn (1995), time evolution due to shear of the components σ_{ij} of Σ is written:

$$\left.\frac{d\sigma_{ij}}{dt}\right|_{shear} = \sigma_{ik}\frac{dU_j}{dx_k} + \sigma_{jk}\frac{dU_i}{dx_k} \qquad (2)$$

This formulation is consistent with Tennekes and Lumley (1973) theory for pure constant shear which effect on a puff can be seen on Figure 37(a). Difficulties occur if the source is not initially punctual but parallelepipedic because analytic integration of equation (1) is not possible when principal axis of the puff are not aligned with principal axis of the parallelepiped. To avoid this difficulty we propose an original approach consisting in first calculating Σ in the shear coordinates defined on Figure 37(b). Then, a transformation is applied to the puff giving it a horizontally isotropic ellipsoid form like on Figure 37(c).



(a) (b) (c)

Figure 37: Shear effects on puffs. Puff evolution in pure shear (a). Absolute and shear coordinates definition (b). Coordinate transformation taking shear into account (c).

Finally, it can be shown than concentration due to puff can be written:

$$C = \frac{\sigma_y}{\sigma_{x*}}\frac{M}{(2\pi)^{3/2}\sigma_y\sigma_y\sigma_z}\exp\left(-\frac{1}{2}\left(\frac{x^{**2}+y^2}{\sigma_y^{\,2}}+\frac{z^2}{\sigma_z^{\,2}}\right)\right) \qquad (3)$$

where $x^{**} = x^*\frac{\sigma_y}{\sigma_{x*}}$, $x^* = x - zR_{xz}\frac{\sigma_x}{\sigma_z}$, $\sigma_{x*} = \sigma_x\sqrt{1-R_{xz}^{\,2}}$ and $R_{xz} = \frac{\sigma_{xz}}{\sigma_x\sigma_z}$. Equation (3) can now be integrated thanks to erf functions.

EXAMPLE OF APPLICATION: STATIC RELEASE IN LYON, FRANCE

The first application presented in this paper is the instantaneous release of phosphine gas in front of the railway station of La Part-Dieu in Lyon, France. Up to 480000 inhabitants live in the city of Lyon which forms, together with its suburbs and satellite towns, the second-largest metropolitan area in France after Paris. Population of its metropolitan area is estimated to be up 1.75 million inhabitants. Figure 38 shows the part of the city where the source is located. Close to the railway station which daily passenger traffic is about 140000, the business district of La Part-Dieu forms the second-largest business district of France after La Défense in Paris, and the commercial mall is visited by 100000 customers per day.

(a) 3D view (b) Top view

Figure 38 : Overview of the application case of SIRANERISK model on a toxic release in the business district of Lyon. Yellow and red star shows source location and blue arrow shows wind direction.

The part of the town seen on Figure 38(b) is entirely modelled by an interconnected streets network. Its finally consists in 3200 streets connected by 1900 intersections. The Figure 38(b) also shows wind direction. Wind velocity at 10m height is constant at 3ms^{-1} and wind direction is mainly south-east oscillating from 120° to 150° during the calculation. The toxic release is instantaneous and 10 kg of phosphine gas are freed in atmosphere at the first calculation time step. Time step remains constant and equals 5s during the 50 minutes of the physical simulated time (600 time steps). Figure 39 shows time evolution of cartographies of concentration at street level. The source is located on a little square which is not a street canyon. Primary puff is therefore directly emitted in the atmosphere. After being released, pollutant begins to reach neighbour streets thanks to turbulent vertical fluctuations which perform the coupling between atmosphere and urban canopy in the SIRANERISK model. Then, each of street canyons containing pollutant is exchanging with its connected streets but can also emit puffs to atmosphere thanks to vertical fluctuations. These puffs are then advected and dispersed above the roofs and can fill downstream streets with pollutant. Puffs are thus generated during the whole calculation and their number reaches the maximum of 2500.

There are two cohabitating mechanisms responsible of advection: the wind flow in atmosphere surface layer and the more complex model of fluxes exchange within the canopy. The first mechanism is responsible of the fastest transport pollution because velocity magnitude is growing respect to altitude. The second mechanism is responsible of a slower transport of pollutant because velocity is lower in the streets than above the roof and also because of channelling effect due to streets network that deviate pollutant from the main flow direction. Far downstream from the source, presence of noxious material in the street is first due to pollutant that comes from above the roof and then the maximum of concentration occurs when pollutant comes from upstream streets. Mechanisms responsible of the dilution are also different for both parts of the model: in the atmosphere dilution is due to turbulent diffusion and shear effects and within the canopy dilution is due to turbulent mixing in a bounded domain, the street canyon. This latter mechanism is less efficient to lower concentration. Differences of advection and diffusion between the two parts of the SIRANERISK model explain why on the last snapshot after 35 minutes of physical time, pollutant still remains in the streets not so far from the source whereas the main cloud above the roof has left the domain and is no more visible.

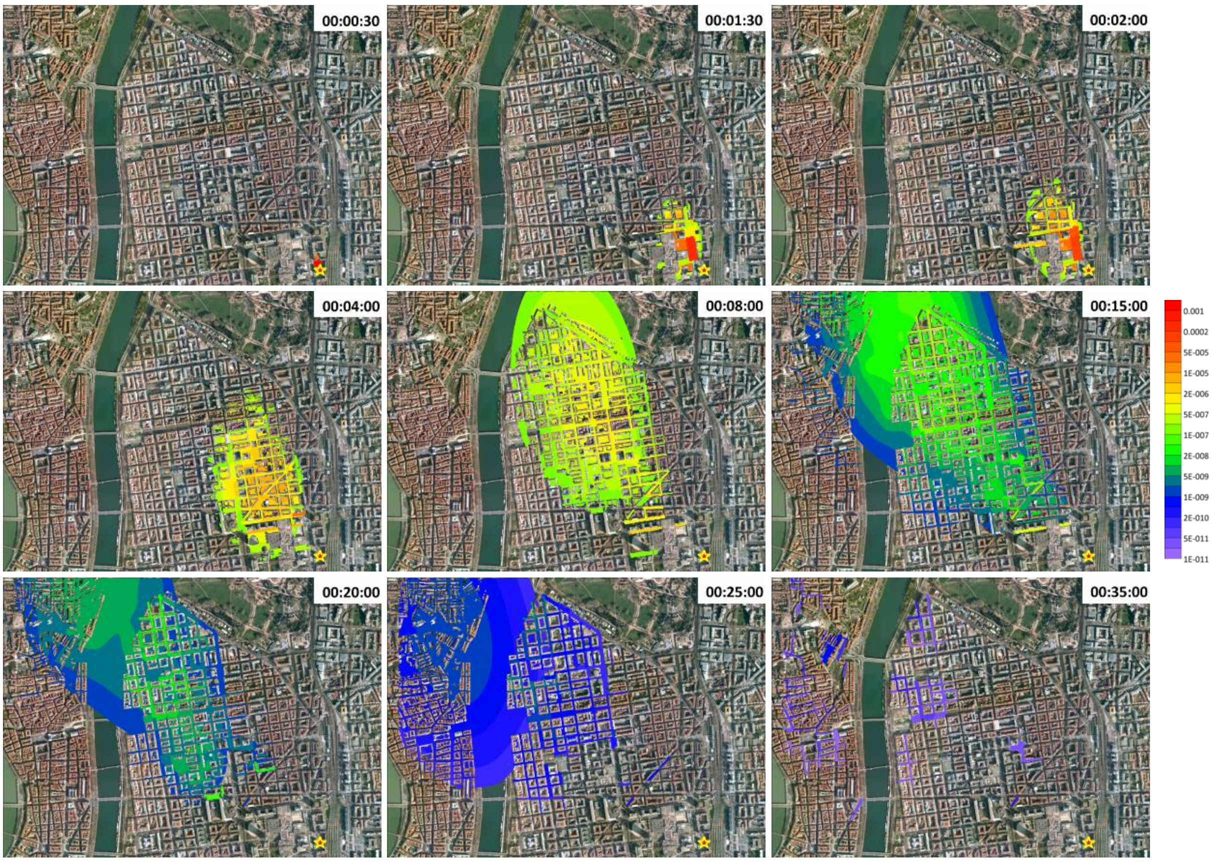
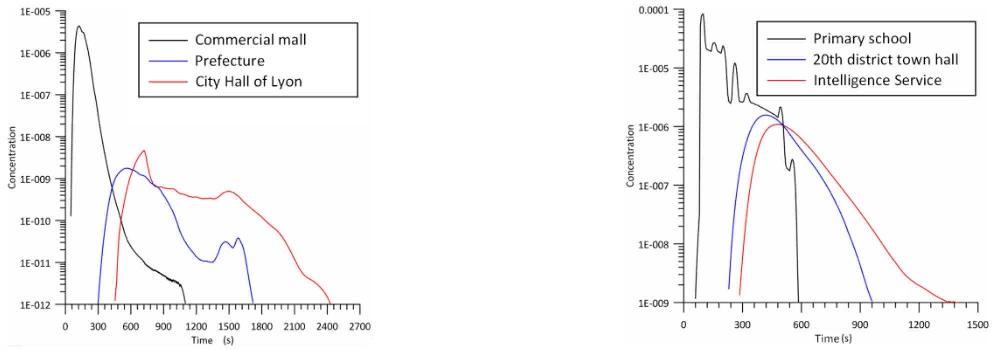


Figure 39 : Time evolution of cartographies of toxic gas concentration at street level in a district of Lyon.

Figure 40(a) shows time evolution of concentration at three locations: the highly frequented commercial mall and two strategic administrative buildings. Positions of these buildings are shown on Figure 38(b). Not surprisingly, the closest sensor to the source location records the highest level of concentration and the shortest time of cloud transit. On the two others signals, effects of dilution by urban canopy and atmosphere can be seen: whereas the release is instantaneous, the concentration of toxic gas is non-zero during almost 40 minutes at the city hall of Lyon, at 2.1km from the source. Computation time to simulate 50 minutes of physical time is about 2 minutes in this case, on a standard desktop computer device.

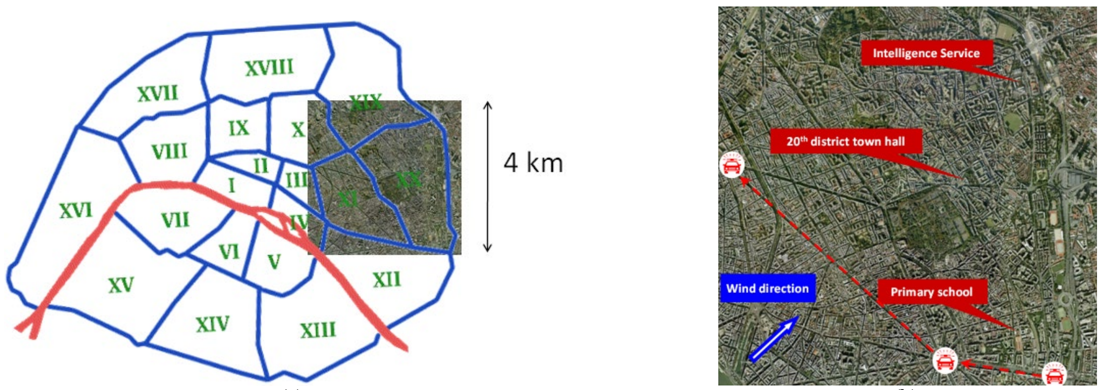
EXAMPLE OF APPLICATION: MOVING RELEASE IN THE EAST OF PARIS, FRANCE

The second application case presented is this paper is the numerical simulation of a moving noxious atmospheric release in East Paris. Location of the studied district in Paris is shown on Figure 41(a). Domain considered here is 4km x 4km square. Figure 41(b) shows a satellite top-view of the district which population is about 320000 inhabitants. Urban density is high and 3000 buildings have to be considered. Three potential critical impact points are also shown on this figure. Contrary to the previous application case, the source emission is not instantaneous and is also not static. A moving vehicle releases pollutant during its 5 minutes ride from Porte de Vincennes to Place de la République *via* Place de la Nation. Wind direction remains constant and equals 200° whereas wind velocity is 8ms^{-1} at 30m.



(a) Lyon application case. (b) Paris application case.

Figure 40: Time evolution of concentration at three locations after the static release of a toxic gas in Lyon (a) and a moving release of noxious material in East Paris (b).



(a) (b)

Figure 41 : Overview of the application case of SIRANERISK model on a toxic release from a moving vehicle in East Paris. (a): district situation. (b): Top view: Red arrows show source trajectory and blue arrow shows wind direction.

The SIRANERISK network model of the district consists of 2100 streets connected by 1300 nodes of intersection. Time step remains constant and equals 5s during the 50 minutes of the physical simulated time (600 time steps). The number of simultaneously present puffs in the calculation domain reaches the maximum of 23700 which is ten times bigger than in previous application case. Figure 42 shows 9 cartographies of concentration of toxic pollutant at the street level and Figure 40(b) shows the temporally evolution of concentration at three different locations. During the first five minutes, the source is emitting and moving so the pollutant is rapidly filling the whole downstream domain. During the five minutes following, whereas source emission has been stopped, the concentration decreases and the streets are emptying very slowly. It finally takes 20 minutes since the stop of emission to empty the first half of downstream streets as it can be seen on the last snapshot of Figure 42. These cartographies of concentration explain the high number of puffs during the calculation. Because the source is moving, more than thousand streets are rapidly containing pollutant. At each time step of the calculation, each of these streets can potentially emit a puff. Computation cost is directly impacted by the increasing number of puffs. Computation time to simulate 50 minutes of physical time is about 6 minutes in this case. To reduce the time of calculation, it is possible to increase the time step by finding a compromise between the loss of accuracy and the gain of time. In this application case, doubling the time step reduces by a factor of 3 the calculation time and limits the maximum number of puffs to 14500.

CONCLUSION

In this paper, new features of the SIRANERISK-2.0 operational model have been presented. Implementation of shear effects has been briefly described. In particular, use of the generalized Gaussian formulation has shown to be not straight forward when analytic integration is needed because of not initially punctual source. An original approach has been proposed with coordinates change and geometric transformation allowing thus the analytic integration. Second and third parts of the paper were dedicated to examples of application of SIRANERISK model. In the first example, an instantaneous release of toxic gas was simulated over a district of Lyon. In the second example, a moving source was releasing noxious material in the East Paris. Both examples showed coherent results of the model, particularly for reproducing retention effects due to urban canopy. Attention has been drawn to time computation to ensure compatibility of our model with operational applications.

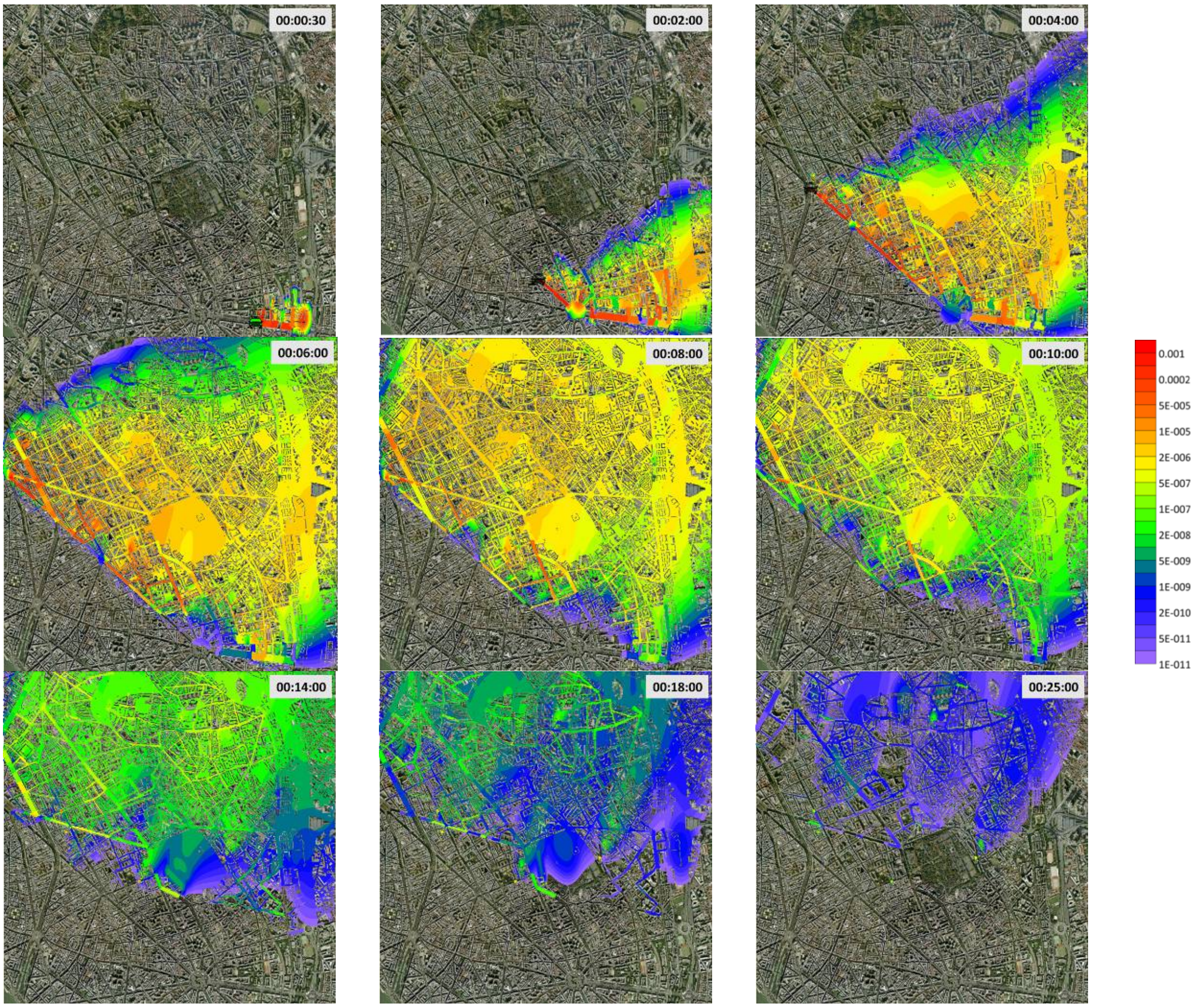


Figure 42: Time evolution of cartographies of toxic gas concentration at street level in East Paris.

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