DE LA RECHERCHE À L'INDUSTRIE

DEVELOPMENT OF A NEW OPERATIONAL URBAN LAGRANGIAN DISPERSION MODEL FOR EMERGENCY RESPONSE

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Bruges

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1.Introduction

1.1 Context

Type of context

- Release of CBRN agents in the atmosphere
- Industrial accidents, malicious or terrorist activities
- Help public authorities and industrialists

Figure: Exemple of release in case of an accident

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The answer

- Need software tools gathering the following features
  - Easy use
  - Fast answer
  - Reliable estimate
  - Realistic simulation

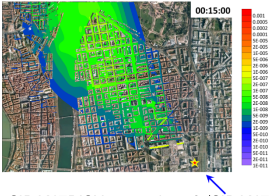

Figure: SIRANERISK, air.ec-lyon.fr/SIRANERISK/

1.2 State of the art

- Gaussian model

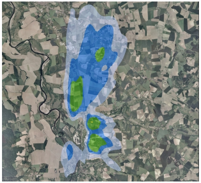

Figure: Illustrative simulation exercise with ARIA IMPACT, http://www.aria.fr/aria_impact.php

- [+] Very fast answer
- [-]Doesn't take obstacles info account

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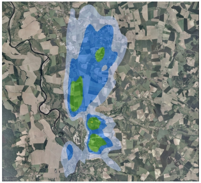

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- CFD model

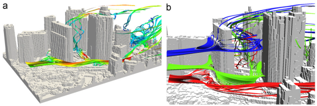

Figure: Time averaged 3D streamlines for tall buildings by LES. (Nozu et al.,2012)

- [+]Very reliable estimate
- [-]Very long computational time

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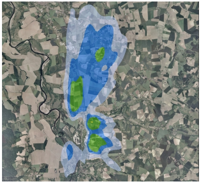

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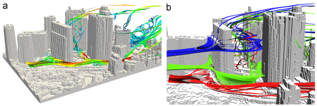

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- Street network model

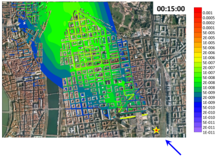


Figure: SIRANERISK,air.ec-lyon.fr/Introduction/SIRANERISK/

- [+]Operational model
- [+]Used by public authorities
- [-]Show some limitations

1.2 State of the art

- The limitation of existing approaches lead to the development of a new operational modelling software: BUILD

Building, Urban and Industrial
BUILD
Lagrangian Dispersion model

- In this presentation, we will present:
  - The main features of the BUILD model
  - The first results of the validation work

2.BUILD model overview

2.1 Presentation of BUILD

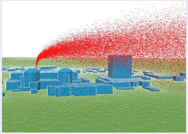
BUILD

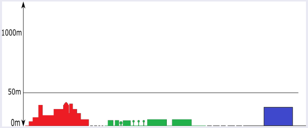
Lagrangian approach

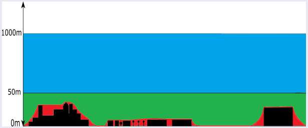
From urban area to isolated buildings

Use an analitycal model for the flow

Take account of the roughness sublayer







2.2.1 Street network model

How is a street network model built ?

- Simplified description of the geometry
- Streets = segments, intersections = nodes
- Streets represented by a boxes

Real geometry

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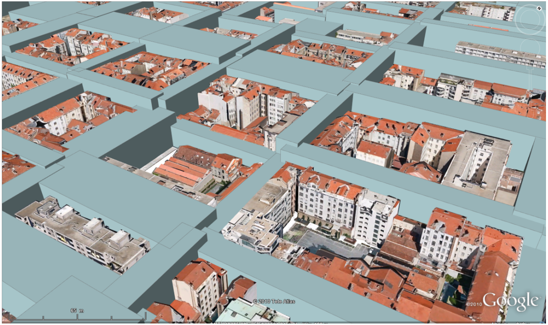
Real geometry → Street volumes



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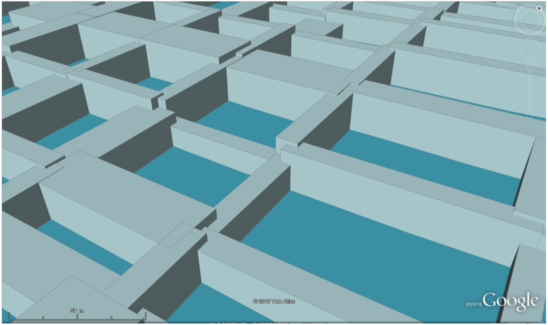
Real geometry → Street volumes → Street-canyons



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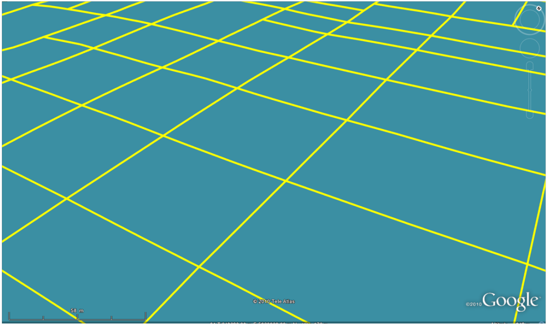
Real geometry → Street volumes → Street-canyons → Network of streets



2.2.2 Lagrangian stochastic model

- This approach allows to improve some limitations of the SIRANERISK approach
- Based on the Lagrangian tracking of individual particles trajectories
- The temporal evolution of the Lagrangian position of each particle is described by:

$$dX_i = \left(\bar{u}_i + U_i'\right) dt$$

Langevin stochastic equation

$$dU_i' = a_i dt + b_{ij} d\xi_j \quad \text{with} \quad \begin{cases} a_i &= -\frac{U_i'}{T_{Li}} + \frac{1}{2}\frac{\partial \sigma_{ui}^2}{\partial x_i} + \frac{U_i'}{2\sigma_{ui}^2}\left(U_j \frac{\partial \sigma_{ui}^2}{\partial x_j}\right) \\ b_{ij} &= \delta_{ij}\sqrt{C_0 \varepsilon} \\ T_{Li} &= \frac{2\sigma_{ui}^2}{C_0 \varepsilon} \end{cases}$$

Where :

$d\xi_j$ is Wiener incremental process whose mean is zero and variance is dt
a_i is the deterministic acceleration term (Thomson,1987)
b_{ij} is the stochastic diffusion term (Pope,1987)

T_{Li} is the Lagrangian time scale (Tennekes,1982)

2.2.3 Flow around isolated obstacle

Flow characteristic

- Complex flow
- Can't model everything
- Recirculation zones

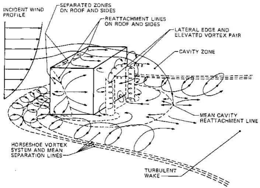


Figure: Flow patterns over a 3-d cube in a turbulent boundary layer based on wind-tunnel experiments, (Hosker,1984)

Determination of recirculation zone lenght

- Two equations from advection-diffusion equation :

$$\frac{\Delta U}{U_0}\Big|_{critical} = erf\left(\frac{W/H}{2\sqrt{20.253 x_r/H}}\right) erf\left(\frac{1}{\sqrt{20.173 x_r/H}}\right)$$

$$x_r/H = 0.15 + \frac{7-0.15}{2}\left(1 + erf\left[\ln\left(W/H\right) - 0.6\right]\right)$$

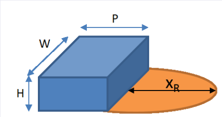


Figure: Characteristic dimension and recirculation zone length

2.2.3 Flow around isolated obstacle

Image processing approach

- Comparing to analytical equation
- Validation process

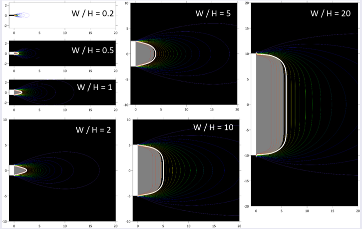


Figure: In white : boundary of the theoretical speed deficit. In grey : speed recirculation zone obtain with the algorithm based on an image processing approach

Application in BUILD model

- Compute for any wind direction
- Images saved to be used in BUILD

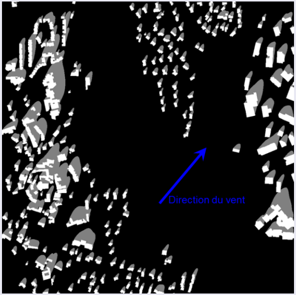


Figure: Recirculation zone of buildings for a real neighbourhood

2.2.4 Wind velocity within the streets

Longitudinal component

- Longitudinal velocity in each street is modelled analytically

  Balance between :

  - Entrainment by the external flow
  - The friction on the street walls

Longitudinal component equation

$$\overline{u_{street}} = U_H cos\left(\varphi\right) \frac{\delta_i^2}{HW} \left[\frac{2\sqrt{2}}{C} \left(1-\beta\right) \left(1 - \frac{C^2}{3} + \frac{C^4}{45}\right) + \beta \frac{2\alpha - 3}{\alpha} + \left(\frac{W}{\delta_i} - 2\right) \frac{\alpha - 1}{\alpha} \right]$$ (Soulhac et al.,2008)

$$\alpha = \ln\left(\frac{\delta_i}{z_{0,build}}\right)$$

$$\beta = \exp\left[\frac{C}{\sqrt{2}}\left(1 - \frac{H}{\delta_i}\right)\right]$$

$$U_H = u_* \sqrt{\frac{\pi}{\sqrt{2}\kappa^2 C}\left[Y_0\left(C\right) - \frac{J_0(C)Y_1(C)}{J_1(C)}\right]}$$

C solution of $\frac{z_{0,build}}{\delta_i} = \frac{2}{C} \exp\left[\frac{\pi Y_1(C)}{2J_1(C)} - \gamma\right]$

$$\delta_i = min\left(H; W/2\right)$$

2.2.4 Wind velocity within the streets

Cross-sectional components

- The street cross-sectional components of the velocity are modelled
- Assuming a separation of variables:

$$\bar{v}\left(y,z\right) = V_{street} f\left(\eta\right) g\left(\varsigma\right) \qquad \bar{w}\left(y,z\right) = W_{street} g\left(\eta\right) f\left(\varsigma\right)$$

with η and ς are dimensionless coordinates : $\eta = y/W$ and $\varsigma = z/H - 1/2$

- The linear model is defined by:

$$\begin{aligned} f\left(x\right) &= 1 - 4x^2 \\ g\left(x\right) &= 2x \end{aligned}$$

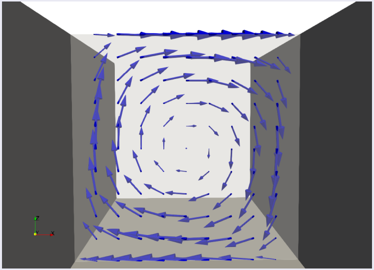


Figure: Example of a cross-sectional velocity field

2.2.5 Wind velocity in the intersections

Air flow field

- The air flow in each street i is given by: $P_{street,i} = \xi HWU_{street,i}$
- The vertical air flow is deduced applying the continuity equation $\Rightarrow P_{vert} = \Sigma_{i \in intersection} P_{street,i}$
- Assuming that the upwind streets flows behave in such a way they are bidimensional $\Rightarrow$ So they are not crossing each other

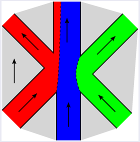


Figure: Air flow horizontal movement in an intersection, (Soulhac,2009)

Velocity distribution

- To compute the velocity distribution we use a potential model: Panel method

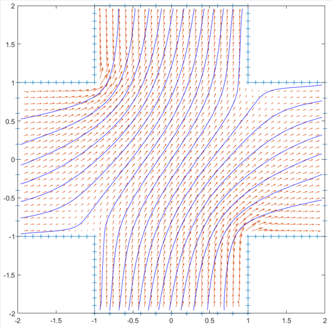


Figure: Velocity field in an intersection by panel method

2.2.6 Wind velocity above the roof level

- Modelled using the Monin-Obukhov similarity theory (described by Soulhac,2011)
- Coupling these different models we obtain the following profil

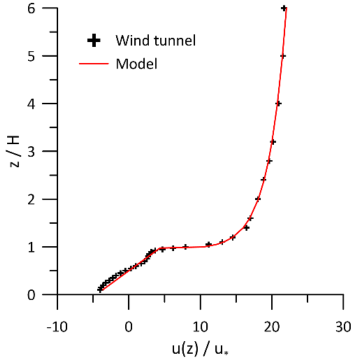


Figure: Vertical profile of the horizontal transverse component of the velocity inside and above a square street-canyon. Comparison between the analytical model and a wind tunnel experiment (Soulhac,2000)

2.3 Validation process

Complete and progressive approach

- Our approach covers a wide range of validation configurations
  - From isolated built to neighborhood
  - From wind tunnel tests to real dimension
  - From idealized configurations to real configuration
  - First with extended releases then releases in the form of puff
- Intercomparisons between CFD models, experimental measurements and BUILD model

Some examples

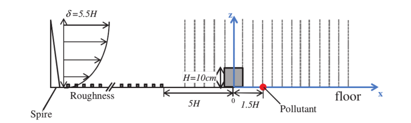


Figure: Example of isolated obstacle from Hervé GAMEL Thesis in wind tunnel

Figure: Example of idealized neighborhood in wind tunnel from (Garbero et al.,2010)

Figure: Example of idealized neighborhood from MOCK URBAN SETTING TEST in real situation

3.Preliminary results

3.1 Test configuration

Test configuration

- Idealized neighborhood
- Identical block
- Width = 250mm, Lenght = 250mm, Height = 50mm
- Spaced between buildings S = 50mm
- Several wind directions
- Source at H/2 in an intersection

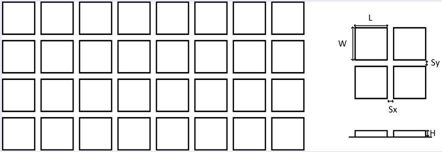
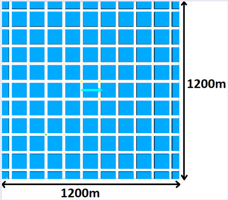


Figure: Geometrical layout of the obstacle array, W = L = 5H et S = Sx = Sy = H

Geometry and mesh on BUILD



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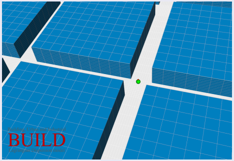

Figure: Mesh of the study case

3.2 Exemples of results

Result

- Preliminary result of the dispersion
- Wind direction = 30°
- CPU time on a laptop = 30s
- The behaviour of the plume is qualitatively realistic

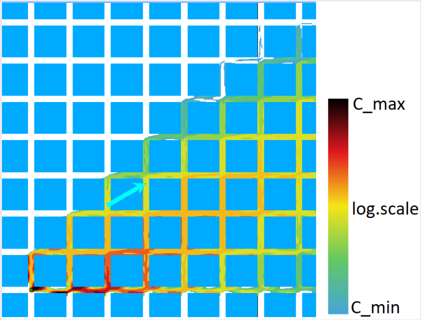

Figure: Tracer behaviour in an idealized neighborhood with BUILD (Wind direction : 30°, source : H/2)

3.3 Comparisons

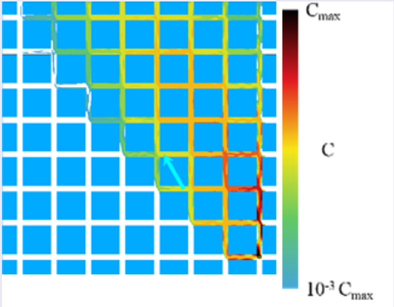

Figure: Numerical simulation with the BUILD model

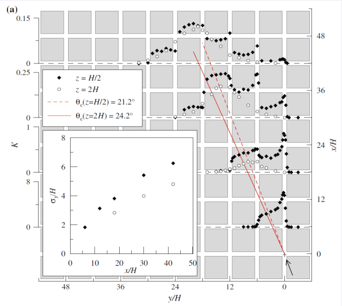

Figure: Wind tunnel measurements from (Garbero et al.,2010). Concentration field in a network of streets for a wind direction = 27.5°

Comparisons results

- Provide very encouraging results
- CPU time on a laptop = 30s

4. Conclusion and perspectives

Conclusion

Summary

- Presentation of the BUILD model with its main features
- The first version has been developed
- Some preliminary results have been given

Perspectives

- To continue the validation process
- To improve the BUILD model with more physical parametrization