H15-129: Large-eddy simulation of flow and dispersion in an heterogeneous urban area: Comparison with field data

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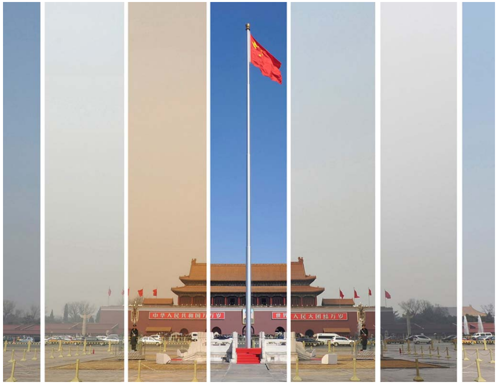
Motivation

- Urban areas:
  - 50% world population
  - 75% european population
- Air pollution issues in urban areas
- Pollutant dispersion process:
  - Experimental campaigns (in situ)
  - Wind tunnel experiments
  - Numerical modelling
    - ∗ mesoscale models
    - ∗ high-resolution atmospheric boundary layer models
      - · Exchanges between surfaces, urban canopy and atmosphere
    - ∗ obstacles resolving models

Source: JN Jornal de Notícias, Tuesday 12 April 2012



Source: guardian.co.uk, Tuesday 19 March 2013

ANR Villes durables 2009

Research Project

VegDUD

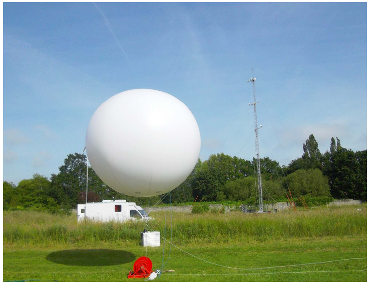
Role of vegetation in Sustainable Urban Development

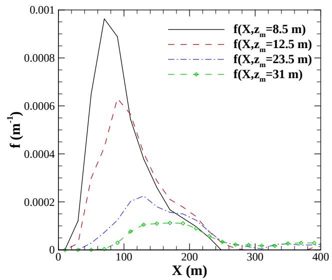
An approach related to climatology, hydrology, energy management and ambiences

www.IRSTV.fr

FluxSAP data: urban dispersion experiments

- Maro et al. 2011; Francis et al. 2012:
  - Comparison between FluxSAP experimental data and the results of the Briggs' urban Gaussian model
- Maché et al. 2012:
  - Analysis of the influence of the neighbourhood morphological heterogeneity
- Borrego et al. 2012:
  - Application of the ARPS results in order to define the inflow conditions of the micro-scale model VADIS for dispersion purposes
- Rodrigues et al. 2012:
  - Footprint function computation for homogeneous urban canopies using the scalar flux field simulated by the ARPS model





Methodology

- Dispersion and scalar flux modeling:
- Large-eddy simulation atmospheric model ARPS
  - Drag-force approach: Influence of urban canopy on the flow and turbulence dynamics, without resolution of buildings

$$F_{Di} = 0.5C_d(z)\rho u^2(z)a_f(z) \tag{1}$$

    - $C_d(z)$: sectional drag coefficient, function of built density (λ_p)
    - $af(z)$: frontal area density
    - mean and maximum buildings height
    - extracted with OrbisGIS (OpenSource Software developed by the IRSTV of Nantes) from the French urban database BDTopo®
  - The scalar diffusion-transport equation:

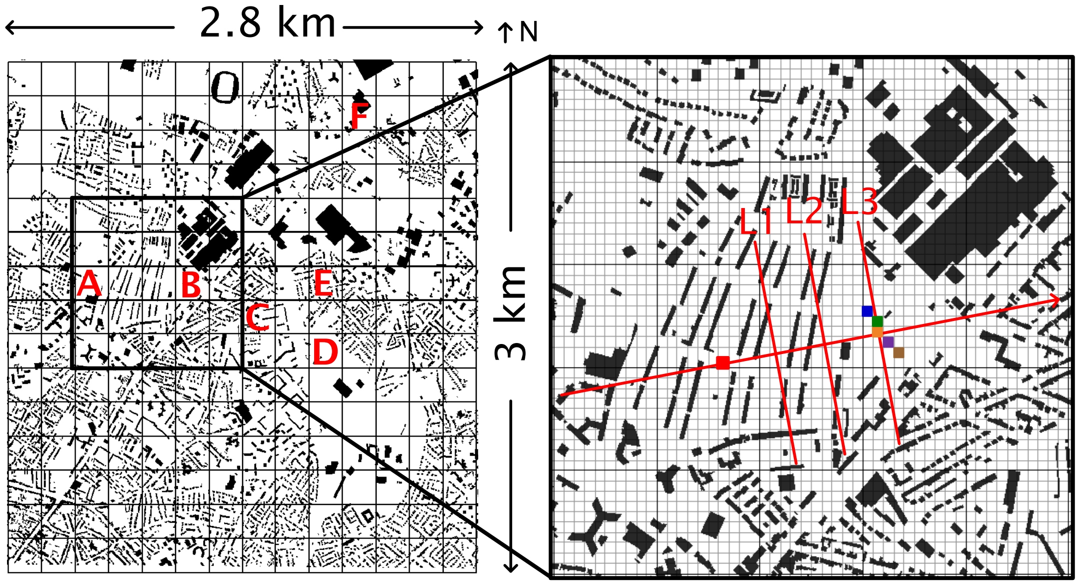
$$\frac{\partial \overline{C}}{\partial t} + \frac{\mathbf{1}}{\mathbf{G}}\frac{\partial \mathbf{G}\overline{u_j}\overline{C}}{\partial x_j} = \frac{\mathbf{1}}{\mathbf{G}}\frac{\partial \mathbf{G}q_j^{SGS}}{\partial x_j} + \frac{\mathbf{1}}{\mathbf{G}}S_C \tag{2}$$

    - G: Ratio between the air volume and the total grid volume

Simulation Details

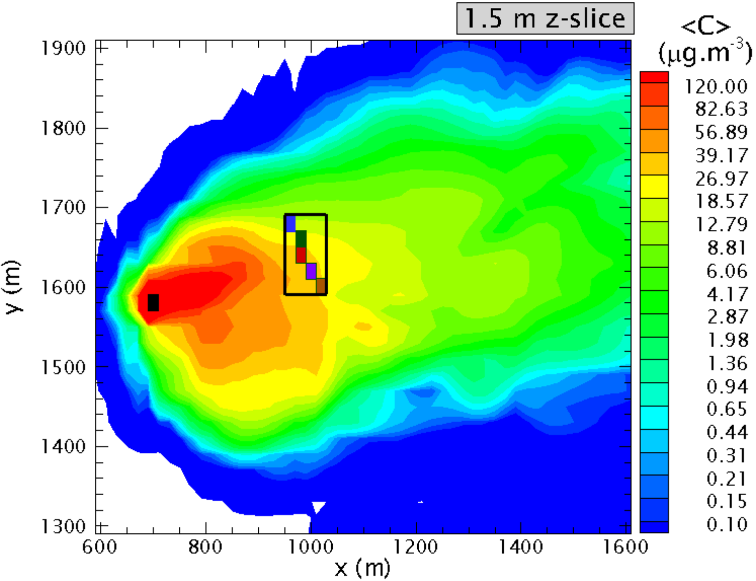
- FluxSAP 2010 and 2012:
  - Suburban district of Nantes (France)
  - Several measurements of meteorological variables
  - SF_6 gas tracer experiment

- Main characteristics of data in analysis:
  - Emission grid: 20 m x 20 m x 1 m
  - Emission period: 09:47 am – 09:57 am
  - Emission rate: $5.3 g.s^{-1}$
  - Measurement period: 09:47 am – 10:11 am



Dispersion analysis: Mean concentration

- Mean concentration isocontours for one z-slice:



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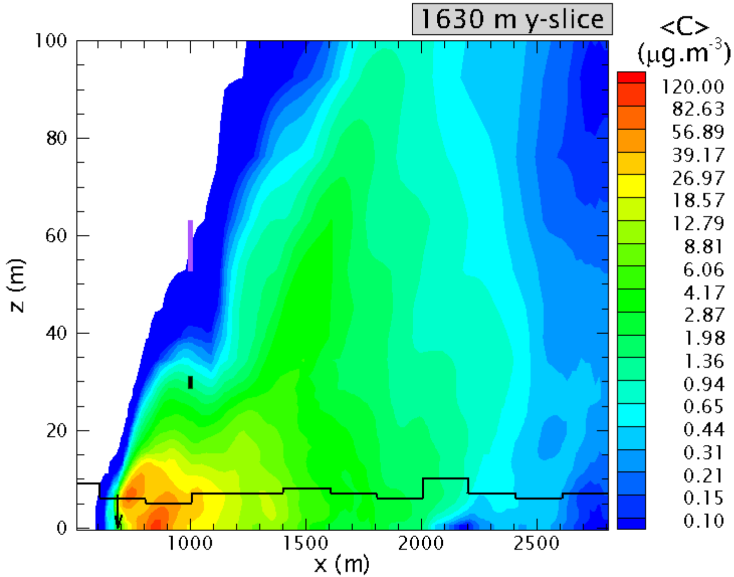
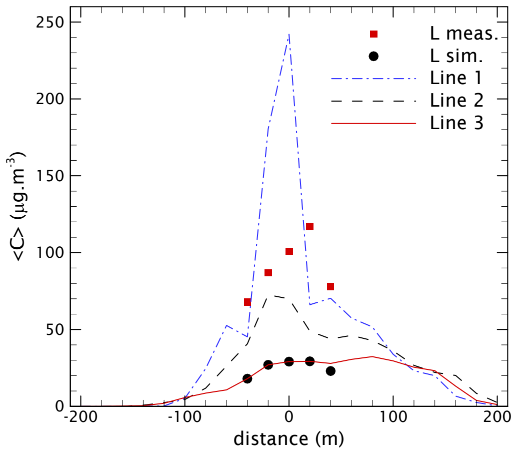
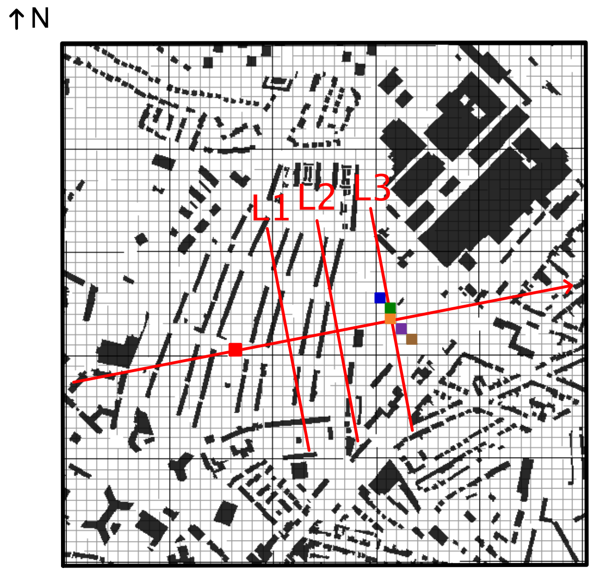


- SF_6 concentration measured: $68 - 117\ \mu$g.m^{-3}
- Comparison between experimental and simulation results: Slight underestimation

Horizontal plume profiles

- Intersection plume profiles:

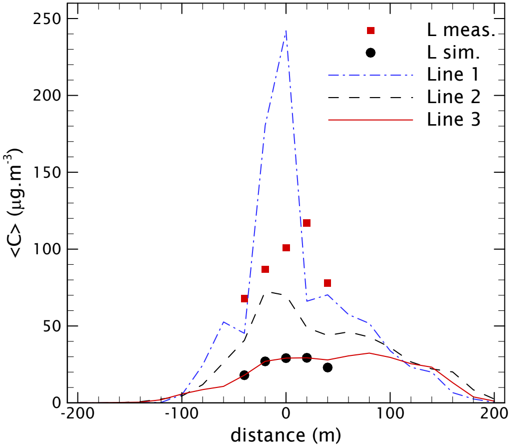




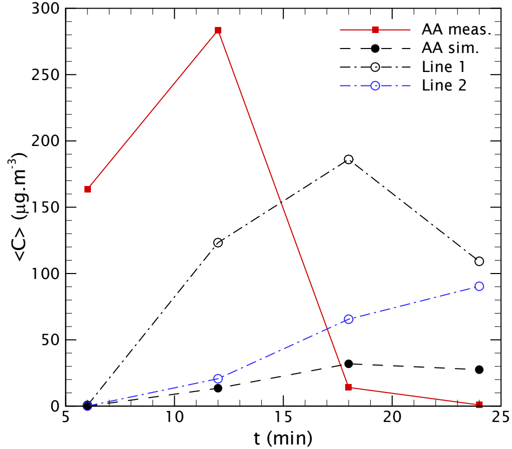
- Point-to-point comparison shows that the simulated concentration values are underestimated
- Mean concentration values matching with experimental data are simulated closer to the emission source
- Tracer accumulation in the vicinity of the emission source
- Space- and time-shift of the simulated plume compared with the experimental plume

Horizontal plume profiles

- Intersection plume profiles:



- Transit time of the experimental and simulated plumes:



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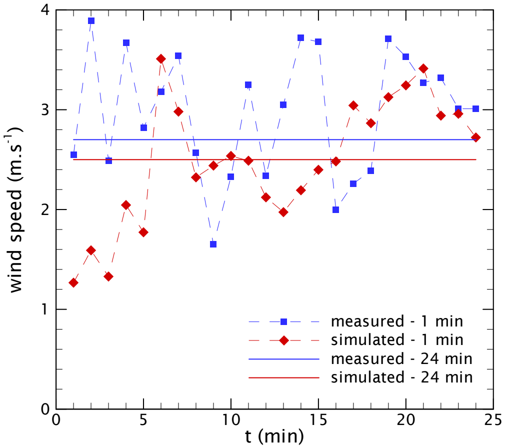
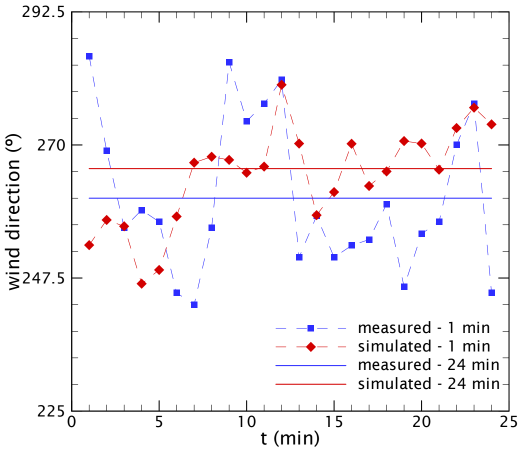
Wind speed and direction

- Time evolution of wind speed, at Goss 21 m:



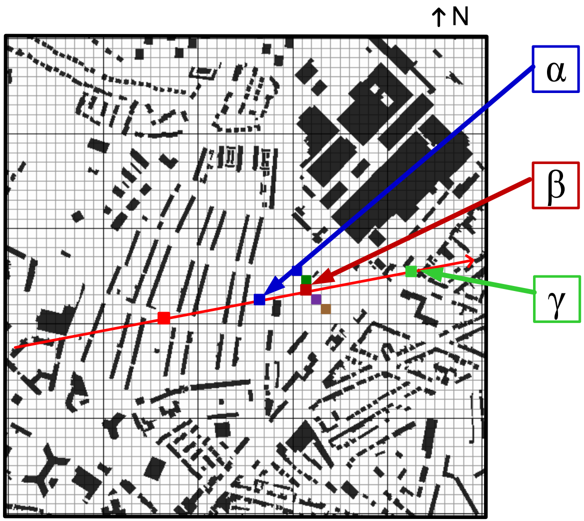
- Time evolution of wind direction, at Goss 21 m:



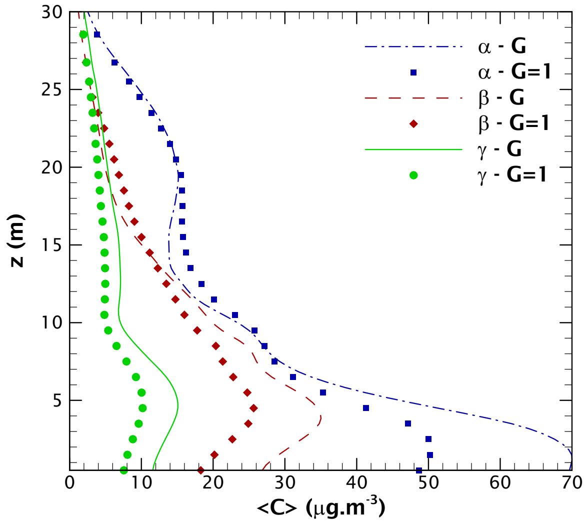
- Highlight the wind variability in both simulation and experiment
- The MBE is equal to $-0.5\ m.s^{-1}$ and the RMSE is about $0.93\ m.s^{-1}$
- The flow unsteadiness is difficult to reproduce in the simulation
- Wind speed discrepancies at the beginning of the release explain the space and time-shifting of the simulated plume

Air volume in a computational grid

- Grids with different buildings densities



- Influence of the buildings volume in the grid



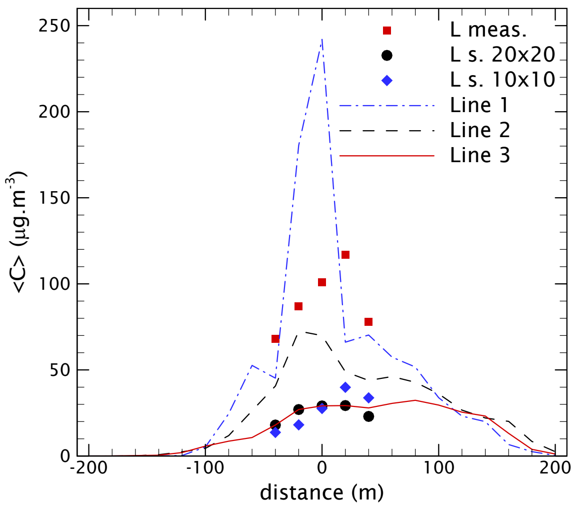
- The scalar diffusion-transport equation:

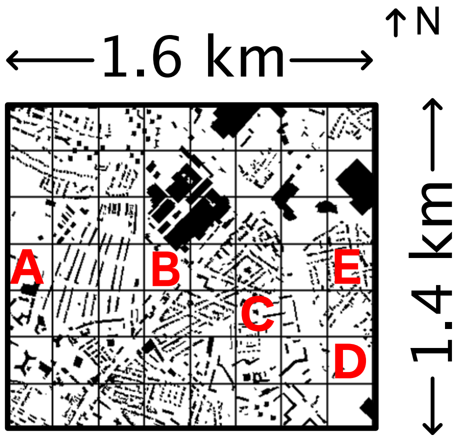
$$\frac{\partial \overline{C}}{\partial t} + \frac{\mathbf{1}}{\mathbf{G}} \frac{\partial \mathbf{G} \overline{u_j} \overline{C}}{\partial x_j} = \frac{\mathbf{1}}{\mathbf{G}} \frac{\partial \mathbf{G} q_j^{SGS}}{\partial x_j} + \frac{\mathbf{1}}{\mathbf{G}} S_C \quad (3)$$

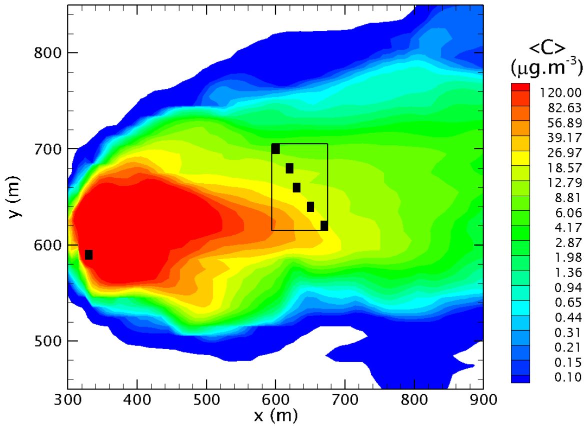
- Taken into account the volume of buildings in a grid causes higher concentrations

Grid resolution refinement

- Influence of the horizontal mesh:
  - Results still show an underestimation of the simulated concentration







- Detailed information about the fraction of buildings in a computational grid

Conclusions and perspectives

- **Real urban canopy simulations:**
  - Systematic underestimation of the simulated concentration
  - Space and time-shift of the simulated plume
  - Mean wind speed and direction, 24 min averaged, are in good agreement with measurements
  - Wind unsteadiness is difficult to reproduce
  - ARPS model is suitable for the dispersion study in a real urban canopy under neutral atmospheric stability conditions
- **Validation of the simulation results:**
  - Grid resolution refinement
  - Comparison with other models
  - Further simulations of different experimental datasets from FluxSAP 2010 and 2012 campaigns
- **Application of the presented methodology to determine the footprint function to real urban canopy**

Thank you!

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