An evaluation of the urban dispersion models SIRANE and ADMS Urban, using field data from Lyon

Soulhac, L.¹, Pradelle, F.² & Perkins, R.J.¹

¹ Ecole Centrale de Lyon, France
² Numtech, France
Outline of the presentation

• Objectives and motivations
• Description of the models: SIRANE and ADMS Urban
• LYON6: a field measurement campaign in a district of Lyon
• Comparison between models and data
• Analysis and conclusions
District scale pollution modelling

State of the knowledge
- District scale less studied than agglomeration and street scales
- Few models and datasets for this scale

Applications related with district scale
- Urban air quality: cartography of pollution, population exposure, …
- Accidental or terrorist release of hazardous materials
### District scale phenomenology

Plume size $\sigma_z / \text{Height of the buildings } H$

<table>
<thead>
<tr>
<th>$\sigma_z$</th>
<th>$\sigma_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;&lt; H$</td>
<td>$\sim H$</td>
</tr>
</tbody>
</table>

#### Main characteristics
- **$\sigma_z << H$**: The plume is transported by local flows around or between obstacles.
- **$\sigma_z \sim H$**: The plume is meandering between obstacles and mixed by the topology of the flow (exchange at the intersection).
- **$\sigma_z >> H$**: The plume is mainly transported over the canopy, in the RSL.

#### Processes to reproduce
- **Microscale flows** (recirculating zone, deviations)
- **Topology of the flow within the district**
- **Exchange between recirc. zones and external flow**
- **Flow and turbulence characteristics in RSL or special parameterisation of plume spread ($\sigma_y$ and $\sigma_z$)**
### District scale phenomenology

Plume size $\sigma_z / \text{Height of the buildings } H$

<table>
<thead>
<tr>
<th>$\sigma_z$</th>
<th>Main characteristics</th>
<th>Processes to reproduce</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ll H$</td>
<td>The plume is transported by local flows around or between obstacles</td>
<td>Microscale flows (recirculating zone, deviations)</td>
</tr>
<tr>
<td>$\approx H$</td>
<td>The plume is meandering between obstacles and mixed by the topology of the flow (exchange at the intersection)</td>
<td>Topology of the flow within the district. Exchange between recirc. zones and external flow</td>
</tr>
<tr>
<td>$\gg H$</td>
<td>The plume is mainly transported over the canopy, in the RSL</td>
<td>Flow and turbulence characteristics in RSL or special parameterisation of plume spread ($\sigma_y$ and $\sigma_z$)</td>
</tr>
</tbody>
</table>
**District scale phenomenology**

Plume size $\sigma_z$ / Height of the buildings $H$

<table>
<thead>
<tr>
<th>$\sigma_z &lt;&lt; H$</th>
<th>$\sigma_z \sim H$</th>
<th>$\sigma_z &gt;&gt; H$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main characteristics</strong></td>
<td>The plume is transported by local flows around or between obstacles</td>
<td>The plume is meandering between obstacles and mixed by the topology of the flow (exchange at the intersection)</td>
</tr>
<tr>
<td><strong>Processes to reproduce</strong></td>
<td>Microscale flows (recirculating zone, deviations)</td>
<td>Topology of the flow within the district</td>
</tr>
</tbody>
</table>
Difficulties in modelling district scale

- Many buildings to model:
  - Cannot be replaced by roughness nor modelled in detail
  - Which geometrical model or simplifications to use?
- Meteorological preprocessing:
  - What are the relevant meteorological parameters at district scale?
  - How to estimate them from measurements near the ground or outside the district?
  - Which modifications are needed from existing "rural" preprocessors?
- Validation datasets:
  - Few datasets available (field or wind tunnel experiments)
  - Need of a variety of experiments, from simple cases to real complex configurations
Methodology

- Use of two models designed for the district scale: SIRANE and ADMS Urban
- Coupling with traffic and emission modelling
- Application in a real case where detailed traffic, meteorological and concentration measurements were performed
- Comparisons and discussion
**SIRANE Model**  
*(Soulhac, 2000)*

**Street network model**

- Meteorological preprocessor, based on Monin-Obukhov theory
- Gaussian plume model with spread parameters derived from similarity theory
- Simple chemical scheme for NO-NO$_2$-O$_3$

**Pollutant budget in each street**

**Exchange at the intersections**

**Dispersion over the roof level**
**SIRANE Model: street modelling**

- Model for the flow along the street
- Pollutant budget in the street

\[
\underbrace{Q_S + Q_I + Q_{\text{part,H}}}_{\text{Ingoing flux}} = \underbrace{Q_{H,\text{turb}} + \text{HWU}_{\text{street}} C_{\text{street}}}_{\text{Outgoing flux}} + Q_{\text{part,g}} + Q_{\text{wet dep.}}
\]

- Turbulent exchange at the interface

\[
Q_{H,\text{turb}} = \frac{\sigma_w WL}{\sqrt{2\pi}} (C_{\text{street}} - C_{\text{ext}})
\]
SIRANE Model: intersection modelling

- Calculation of the exchange flux as a function of wind direction
  \[ Q_{i,j}(\theta) \]

- Averaging on wind direction distribution
  \[
  \overline{Q}_{i,j}(\theta_0) = \int P(\theta - \theta_0)Q_{i,j}(\theta)d\theta
  \]
ADMS Urban model
(McHugh et al, 1997)

- Modification of the ADMS3 model for urban areas
- Gaussian plume model with spread parameters derived from similarity theory
- Meteorological preprocessor based on Monin-Obukhov theory
- Street-canyon effects reproduced using the OSPM street canyon model (Berkowicz et al, 1997)
- Chemical reactions for NO-NO$_2$-O$_3$ modelled with Derwent-Middleton correlation or GRS scheme
Main differences between the models

SIRANE

• Box model for the concentration within the streets
• Modelling of the exchanges at the intersection between streets
• Simple chemical scheme based on photostationarity

ADMS Urban

• Description of the concentration field within the streets
• No exchanges at the intersections
• 2 chemical schemes (DM and GRS)
LYON6 field experiment
(in collaboration with COPARLY)

Objectives: Measurement of traffic, meteorology and NO$_x$ concentrations at the scale of a district, to validate air quality models
**LYON6 measurements**

- **Traffic:**
  - 10 counting stations in the district

- **Meteorology:**
  - Meteorological ground station
  - SODAR + sonic anemometer placed on a roof

- **Pollutant concentration:**
  - 60 NO\(_2\) passive samplers (concentration integrated over 2 weeks) at 33 different positions
  - 3 NO\(_X\) analysers within the district + 3 others around which provide the background concentration

All located outside the district
LYON6 field experiment

- 15 days of measurements during July 2001
- NO$_2$ passive samplers corrected by analysers measurements
- Dataset available for people how want to use it
Simulation with the models

- **Traffic**: coupling between counting and traffic simulations for rush hours
  - Smallest streets are not taken into account
  - Error of 15% due to the use of traffic simulation
- **Emissions calculation with COPERT III**
  - Large variability (factor of 2 or more) depending on the assumptions used (vehicle fleet composition, ...) but no adjustment
- **Topography of buildings**: development of a program to calculate automatically width and height of the streets from GIS buildings maps
Comparisons with passive samplers

Passive samplers NO₂ concentration (µg/m³)

- Relatively good agreement for SIRANE and ADMS DM
- Low variability for ADMS GRS:

Tests done by Numtech show that the adjustment of the NOₓ concentrations with the measurements improve the GRS chemical modelling of NO₂ which becomes better than DM
Comparisons hourly analysers measurements

<table>
<thead>
<tr>
<th>NOX</th>
<th>NO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIRANE</td>
<td>SIRANE</td>
</tr>
<tr>
<td>FB</td>
<td>-21%</td>
</tr>
<tr>
<td>√NMSE</td>
<td>57.9%</td>
</tr>
<tr>
<td>ER</td>
<td>53.4%</td>
</tr>
<tr>
<td>R</td>
<td>0.66</td>
</tr>
<tr>
<td>MG</td>
<td>0.90</td>
</tr>
<tr>
<td>VG</td>
<td>1.61</td>
</tr>
<tr>
<td>FAC2</td>
<td>67.8%</td>
</tr>
</tbody>
</table>

Analyser 1

<table>
<thead>
<tr>
<th>NOX</th>
<th>NO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIRANE</td>
<td>SIRANE</td>
</tr>
<tr>
<td>FB</td>
<td>-21%</td>
</tr>
<tr>
<td>√NMSE</td>
<td>57.9%</td>
</tr>
<tr>
<td>ER</td>
<td>53.4%</td>
</tr>
<tr>
<td>R</td>
<td>0.66</td>
</tr>
<tr>
<td>MG</td>
<td>0.90</td>
</tr>
<tr>
<td>VG</td>
<td>1.61</td>
</tr>
<tr>
<td>FAC2</td>
<td>67.8%</td>
</tr>
</tbody>
</table>

9th Harmonisation Conference
Garmisch-Partenkirchen
**Discussion**

- It is an evaluation of a chain of models and not only of the dispersion models.
- Good agreement for 2 weeks averaged concentrations in different locations for SIRANE and ADMS Urban DM.
- Comparison for hourly concentrations:
  - The order of magnitude is reproduced.
  - The time variability is generally realistic.
  - Hourly concentration are more difficult to reproduce, because of:
    - The stochastic nature of atmospheric dispersion.
    - The simplifications in the dispersion models.
    - Incertitude in the input data (modelled and measured).

*It will not change!*

*That is our work in the future*

*Traffic and emission models can improve but an important "random" variability will remain*
Conclusions and perspectives

Conclusions

• Realisation of a field measurement campaign for the evaluation of air quality models at the district scale
• Comparison between SIRANE, ADMS Urban and the measurements :
  – "Correct" agreement for the two models (order of magnitude and variability)
  – More difficulties to reproduce hourly concentrations
  – Differences between the models :
    • Differences observed between the chemical schemes
    • With such real case, it is more difficult to identify the differences between the dynamical formulations

Perspectives

• Need of wind tunnel experiments to improve our knowledge on dispersion processes at this scale and to provide simple cases for model evaluation ; some experiments are in preparation at the Ecole Centrale de Lyon
• Need of field tracer experiments in a dense network of streets (not a group of obstacles)