Development of a 3D modelling suite from the global scale to the urban scale using MM5 and Micro-SWIFT-SPRAY. Application to the dispersion of a toxic release in New York City

Christophe Duchenne and Patrick Armand
Radiological and Chemical Impact Laboratory
French Atomic Agency, Bruyères-le-Châtel, France

Harry Dupont
Alten Technologies, Boulogne-Billancourt, France
Downscaling

Global analysis (GFS) → MM5 → NSwift

3D meteorological flow at urban scale

Dispersion with Micro-SPRAY → Impact assessment

Grid resolution

1° (≈ 100 km) → 5 nested domains

about one kilometer → 4 nested domains

few meters
A few words about models …

- **MM5**
  - A parallelized, limited area, nonhydrostatic, terrain following and sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation (Dudhia, J. *et al.*, 2005)
  - works in two-way nesting.
  - some phenomena like convection are explicitly solved.

- **NSwift**
  - Diagnostic meteorological model, developed and maintained by ARIA Technologies and ARIANET, based on mathematical interpolation (for wind, temperature and humidity). Then, adjustment to produce a mass consistency wind field (no conservation of energy and momentum).
  - works in one-way nesting at this time.
  - a better description of topography and landuse allows to refine mesoscale 3D fields.
  - Choice of simulation parameters may lead to lose informations about turbulence.
NSWIFT only manages successive calls to SWIFT or Micro-SWIFT via a xml command file

- Digital Elevation Model
  - RELIEF
    - topography files
      - relswi1.wrk
    - obstacl file
      - obsswiN.wrk

- Digital Building Model
  - SHAFT
    - obstruction file
      - obsswiN.wrk

- Landuse
  - LANDUSE
    - landuse data
      - rugswi1.wrk
    - meteo file
      - metswi1.wrk

- Meteorology
  - MM52ARIA

SWIFT or Micro-SWIFT

3D wind files
- resname1.bin
- calswi1.wrk
- obsswiN.wrk
- relswi1.wrk
Domains characteristics

**MM5**

- **D01** 60×60 nodes
  - mesh = 81 km
- **D02** 100×100 nodes
  - mesh = 27 km
- **D03** 142×142 nodes
  - mesh = 9 km
- **D04** 184×184 nodes
  - mesh = 3 km
Domains characteristics

**MM5**
- **D01**: 60x60 nodes
  - mesh = 81 km
- **D02**: 100x100 nodes
  - mesh = 27 km
- **D03**: 142x142 nodes
  - mesh = 9 km
- **D04**: 184x184 nodes
  - mesh = 3 km
- **D05**: 202x202 nodes
  - mesh = 1 km

**NSwift**
- **N01**: 161x171 nodes
  - mesh = 300 m
Domains characteristics

**MM5**

- D01: 60x60 nodes, mesh = 81 km
- D02: 100x100 nodes, mesh = 27 km
- D03: 142x142 nodes, mesh = 9 km
- D04: 184x184 nodes, mesh = 3 km
- D05: 202x202 nodes, mesh = 1 km

**NSwift**

- N01: 161x171 nodes, mesh = 300 m
- N02: 121x131 nodes, mesh = 100 m
- N03: 161x156 nodes, mesh = 20 m
Domains characteristics

**MM5**
- D01: 60×60 nodes, mesh = 81 km
- D02: 100×100 nodes, mesh = 27 km
- D03: 142×142 nodes, mesh = 9 km
- D04: 184×184 nodes, mesh = 3 km
- D05: 202×202 nodes, mesh = 1 km

**NSwift**
- N01: 161×171 nodes, mesh = 300 m
- N02: 121×131 nodes, mesh = 100 m
- N03: 161×156 nodes, mesh = 20 m
- N04: 251×251 nodes, mesh = 4 m
### Spatial resolution and source of topography and *landuse* data

<table>
<thead>
<tr>
<th>Domain</th>
<th>Mesh size</th>
<th>Data resolution</th>
<th>Topography</th>
<th>Landuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>D01</td>
<td>81 km</td>
<td>30 min. (~55 km)</td>
<td>DEM_30M_GLOBAL</td>
<td>VEG-USGS.30</td>
</tr>
<tr>
<td>D02</td>
<td>27 km</td>
<td>10 min. (~18.5 km)</td>
<td>DEM_10M_GLOBAL</td>
<td>VEG-USGS.10</td>
</tr>
<tr>
<td>D03</td>
<td>9 km</td>
<td>2 min. (~3.7 km)</td>
<td>DEM_02M_GLOBAL</td>
<td>VEG-USGS.02</td>
</tr>
<tr>
<td>D04</td>
<td>3 km</td>
<td>30 sec. (~0.925 km)</td>
<td>GTOPO30</td>
<td>VEG-USGS.30s</td>
</tr>
<tr>
<td>D05</td>
<td>1 km</td>
<td>30 sec. (~0.925 km)</td>
<td>GTOPO30</td>
<td>VEG-USGS.30s</td>
</tr>
<tr>
<td>N01</td>
<td>300 m</td>
<td>3 sec. (~90 m)</td>
<td>USGS 1:250000 Scale DEM</td>
<td>USGS (US EPA .shp format) + projection on target grid</td>
</tr>
<tr>
<td>N02</td>
<td>100 m</td>
<td>100 m</td>
<td>NYS DEC 1:24000 DEM</td>
<td>Uniform</td>
</tr>
<tr>
<td>N03</td>
<td>20 m</td>
<td>10 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N04</td>
<td>4 m</td>
<td>10 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3D building model is introduced instead of taking into account buildings through a landuse class.
Refining roughness 3D field

**Domain N01**: land use classes are associated to tabulated data to attribute a value to roughness length, albedo and Bowen ratio

**Domain N02**: on Manhattan island, a single land use class (except Central Park)

→ use of morphometric methods (Grimmond, 1999) to determine roughness

\[
z_0 = f_0 \cdot z_H
\]

where \(z_H\) is the height difference between a DEM and a DSM

\[
z_0 = \max \left( f_{0 tabsulated} ; f_0 \cdot z_H \right)
\]
Meteorological flow results

**MM5 results**
Simulation on 5 days (from April 29, 2009 to May, 2\textsuperscript{nd} 2009) with every-15-minutes records → 480 3D fields

D01

D03
Comparison with observations

MM5 wind fields are compared with observations of the METAR network.

An objective criterion is performed for each surface station of the METAR network inside domain D05, which compares observed wind roses to calculated wind roses for these locations (Soulan, 2004):

\[
C_{\text{global}} = 100 - \frac{1}{2} \left( \sum_{i=1,18\times4} \left| g_i^{\text{METAR}} - g_i^{\text{MM5}} \right| \right)
\]

where \( C_{\text{global}} \) is the value for the criterion in percentage and \( g_i \) the occurrence for class i of simulated (MM5) or observed (METAR) wind rose.

<table>
<thead>
<tr>
<th>D01</th>
<th>D02</th>
<th>D03</th>
<th>D04</th>
<th>D05</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.7</td>
<td>49.9</td>
<td>53.0</td>
<td>53.9</td>
<td>53.5</td>
</tr>
</tbody>
</table>

Average on the 25 METAR stations included inside D05 (%)
Meteorological flow results

**NSWIFT results**
Simulation on 2 hours (between 16:00 and 18:00 on May, 2\textsuperscript{nd} 2009) with every-15-minutes records → 9 3D fields

- **N01**
- **Sea-breeze effect**

- **N04**

June 4th, 2010
Meteorological flow results

**NSWIFT results**
Simulation on 2 hours (between 16:00 and 18:00 on May, 2\textsuperscript{nd} 2009) with every-15-minutes records $\rightarrow$ 9 3D fields

**Increase of wind speed inside street canyon**

![Wind speed map](image)
Comparison with observations

Few METAR stations inside NSWIFT domains


But many of them are not representative of local meteorology or don’t provide data for the simulated period.
Dispersion with Micro-SPRAY

An hypothetical toxic release, which could be due to a terrorist attack, is assumed to take place in front of one of Madison Square Garden's gate.

Dispersion is computed on the finest grid (N04) using Micro-SPRAY.

Release, due to an explosion, is assumed to be a small cloud with a stem and a cap.

The Micro-SPRAY simulation is performed for a period of two hours, with a concentration field computed every minute.

A total amount of $2.4 \times 10^6$ numerical particles has been emitted to represent dispersion of the cloud.
Dispersion with Micro-SPRAY

T0+2min

T0+4min

T0+7min

T0+12min
Dispersion with Micro-SPRAY

T0+2min

T0+4min

T0+7min

T0+12min
Impact assessment

From dispersion results, post-processing allows to compute chemical doses or radiological exposures, depending on the nature of emitted species.

If we assume that release is radioactive Cobalt-60, we are able to compute short-term radiological impact, like inhalation dose or radiation exposure.

In each point (I,J) of the grid, inhalation dose for a not moving person verifies:

\[
H_{\text{inh}}(I,J) = \left( \sum_{t_i=t}^{t_N} C(J,K=1,t_i) \Delta t \right) \cdot \frac{\tau_{\text{resp}}}{3600} \cdot f_{\text{inh}} \cdot 1000
\]

Radiation exposure is quite more difficult to perform because it has an effect from a distance.

A tool like CLOUDSHINE (Armand, 2005) performs dose field due to gamma radiations emitted by a cloud.

At this time, no tool to perform radiation exposure due to ground deposition.
Conclusion and perspectives

- The MM5-NSWIFT-Micro-SPRAY suite is able to compute meteorological flows from global scale to the urban local scale in one run, and then calculate dispersion and health impact.
- Local observations are not necessary any more to perform wind fields at the local scale, but are still able to be added to 3D input meteorological fields.
- The main interest in the MM5-NSWIFT-Micro-SPRAY suite is to offer a complete and very relevant answer in case of dispersion of a dangerous specie inside urban environment.
- Introducing obstacles at local scale could be improved because buildings description turns from a parameterization through roughness to an explicit description. A development, who consider buildings as porous meshes in an intermediate step, is under progress.
- The suite could work as a forecasting system. A system called MEDICIS (Achim, 2010) already exists at the lab and displays mesoscale forecasts for France.
- Then, the MM5-NSWIFT-Micro-SPRAY suite could be worked within a crisis center.

Thank you for your attention
## Computation times

<table>
<thead>
<tr>
<th>Domain</th>
<th>Software</th>
<th>Computation time</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>D01 to D05</td>
<td>MM5</td>
<td>6 hours / simulated day</td>
<td>Cluster 16 core</td>
</tr>
<tr>
<td>N01</td>
<td>NSwift</td>
<td>3 min</td>
<td>Pentium IV</td>
</tr>
<tr>
<td>N02</td>
<td>NSwift</td>
<td>2 min</td>
<td>2,8GHz</td>
</tr>
<tr>
<td>N03</td>
<td>NSwift</td>
<td>3 min</td>
<td>2,0 Go RAM</td>
</tr>
<tr>
<td>N04</td>
<td>NSwift</td>
<td>30 min</td>
<td></td>
</tr>
</tbody>
</table>

Dispersion | Micro-SPRAY | 4 hours | Pentium IV |

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HARMO 13

June 4th, 2010