H13-20

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.

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Abstract: Some recent developments in Micro-SWIFT, the diagnostic meteorological model of the Micro-SWIFT-SPRAY (MSS) modelling system, now allow nesting to compute meteorological flow at various scales. The new entity, called NSWIFT, is able to use 3D wind fields issued by mesoscale models and then, work out meteorological flow at local scale by downnesting. Dispersion calculation with Micro-SPRAY code and impact assessment with post-processing tools may follow on. The main interest in the MM5-NSWIFT-Micro-SPRAY suite is the possibility to work as a meteorological forecasting system, where wind fields are continuously produced. Predictive Micro-SPRAY calculations are then able to be completed very quickly in case of a toxic release into a built environment, and a really relevant health impact solution is able to be proposed, so that the MM5-NSWIFT-Micro-SPRAY suite could be worked within a crisis center.

Key words: *meteorological flow, MM5, NSWIFT, downnesting, mesoscale, urban scale, dispersion, Micro-SPRAY, impact.*

INTRODUCTION

The LIRC (French acronym for Radiological and Chemical Impact Laboratory) of the French Atomic Energy Commission (CEA) carries out physical modelling and detailed numerical 3D simulation in urban environments. The Micro-SWIFT-SPRAY (MSS) software is among the modelling tools used for such studies. It is developed and maintained by ARIA Technologies and ARIANET companies. The system is composed of Micro-SWIFT and Micro-SPRAY, which are upgrades of SWIFT and SPRAY, adapted to the local scale, that is to say taking into account buildings. Some recent developments to Micro-SWIFT allow nesting in a new entity called NSWIFT. More than using surface stations and profiles as meteorological inputs, NSWIFT is also able to use 3D wind fields issued by mesoscale models and then, work out meteorological flow at local scale by downnesting. The purpose of this work was to elaborate an operational suite from the global scale to the local urban scale by linking MM5 and NSWIFT, and then, calculate dispersion and health impact at local scale with Micro-SPRAY. Centered on Madison Square Garden, in New York City, a simulation is proposed, to show, in practical terms, how the suite is implemented.

THE MSS NESTED VERSION

The Micro-SWIFT-SPRAY modelling system [Tinarelli, 2007] is designed to represent atmospheric dispersion inside dense urban environment in a reduced computing time compared with those of Computational Fluid Dynamics softwares (CFD). MSS includes two modules, Micro-SWIFT and Micro-SPRAY, for meteorological flow and dispersion computations, and four pre-processors in charge of creating input files. RELIEF, SHAFT, LANDUSE and MM52ARIA convert respectively topography files, "shapefiles", which describe 3D buildings, land use data and MM5 3D output fields into ASCII files usable by Micro-SWIFT. When release is due to an explosion, an additional module, TESATEX [Armand, 2008], can be inserted in the MSS suite.

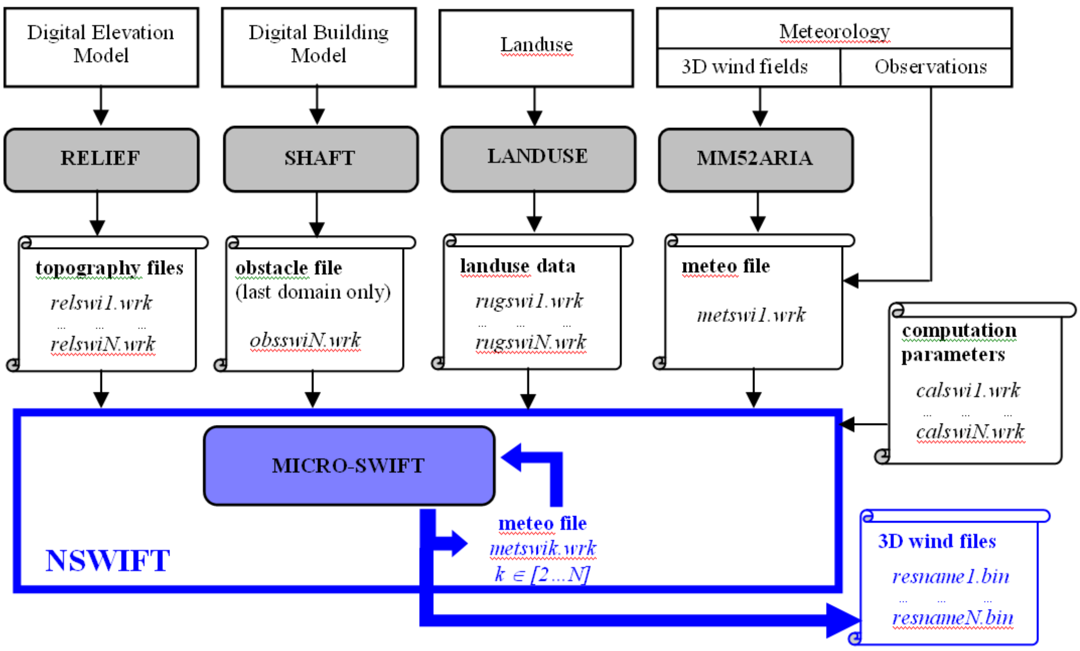


Figure 1 Schematic diagram of the NSWIFT entity.

Same modules and pre-processors are used in the MSS nested version. The NSWIFT entity only manages calls to the Micro-SWIFT module for each nest (*cf.* Figure), *via* a configuration file. It contains the number of nests, links each computation domain to its father domain and lists input files needed for each meteorological flow calculation. For each nest, NSWIFT produces 3D output fields and a meteo file, as input data for the next nest.
At this time, only *one-way nesting* is implemented in NSWIFT, that is to say 3D wind fields are computed first for the father domain and then for its subdomain, without feedback of the sub-domain to the father domain. Moreover, nesting is submitted to some rules concerning subdomains: no overlapping between two subdomains, mesh of the father domain has to be a multiple (horizontally and vertically) of those of subdomains, and corners of a subdomain have to correspond to nodes in the father domain.

METEOROLOGICAL FLOW MODELLING: DOWNSCALING TO NEW YORK CITY
Observations from local weather stations or assumed academic data are usually used for meteorological flow simulations at local urban scale. Through the MM52ARIA pre-processor, NSWIFT is able to treat MM5 results, which can be forecasts or analyses. Mesoscale 3D fields may be enhanced by local observations such as ground meteorological values and vertical profiles. A suite from the global scale to the local urban scale was elaborate by linking MM5 and NSWIFT. Centered on the Madison Square Garden in New York City, a meteorological flow calculation was performed to show how the suite works. Starting from operational global analysis and most of North America, 3D wind fields are computed in five nested domains with MM5, and then, to the local urban scale in four nested domains with NSWIFT (Figure).

Figure 2. Coverage of the considered MM5 and NSWIFT domains.

The five MM5 grids (D01 to D05) are in a scale factor equal to three with downscaling, starting from an 81 km resolution for the first domain to a 1 km resolution for the last domain. The four NSWIFT grids (N01 to N04) have respectively a 300-meter, 100-meter, 20-meter and 4-meter resolution. Topography and land use data are refined at each level. As these data are available at various resolutions for the entire world and in a compatible format with MM5, data at a smaller scale come from various providers and usually need to be converted to the NSWIFT input data format. In this case, a 3 arc second digital elevation model, produced by USGS, a digital elevation model with a 10-meter resolution and land use data in a shape file format, both provided by New York State (Department of Environmental Conservation), were used to describe topography and land use on NSWIFT domains. On the last domain (N04), 3D building model is introduced instead of taking into account buildings through a land use class.
In meteorological models, land use types interfere with flow and turbulence calculation. In MM5, at each land use class is associated a value for physical parameters such as roughness length, albedo, moisture available, emissivity and thermal inertia. In NSWIFT, tabulated values for roughness length, albedo and Bowen ratio have to be created for each land use class. Except Central Park, Manhattan is a dense, built-up area, so that it corresponds to a single class of land use and a single value of roughness. Using such values does not allow to discern areas with very high buildings, like in south of Manhattan or south of Central Park, from the rest of urban canopy. Morphometric methods exist to determine roughness on built areas (Grimmond, 1999). An empirical relation is considered here:

$$z_0 = f_0 \cdot \bar{z}_H \qquad (1)$$

where z_0 is roughness length, $\bar{z}_H$ is buildings' mean height on a mesh and f_0 is a coefficient taken equal to 0,1 (Hanna, 1992).

Buildings data are not available on the whole domain N02. For all that, $\bar{z}_H$ is estimated as the difference between the digital elevation model (DEM) used to describe topography and a digital surface model (DSM) at the same resolution, the one produced by NASA referring to the Shuttle Radar Topographic Mission (SRTM). 2D field of roughness length is produced considering the maximum between the tabulated and the calculated value on dense built area, and tabulated values everywhere else. Results for domain N02 are shown on Figure .

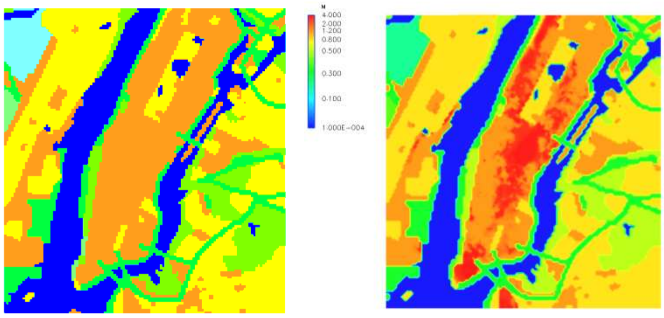


Figure 3. Roughness length on domain N02 for tabulated values (on the left) and calculated with empirical relation for urban areas (on the right).

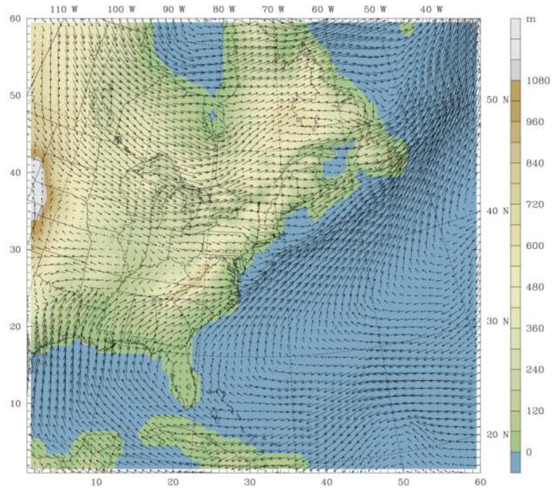
At a very local scale (domain N04), when 3D buildings data are present, roughness length does not represent the type of land use any more, but rather street furniture and type of ground.

RESULTS AND DISCUSSION

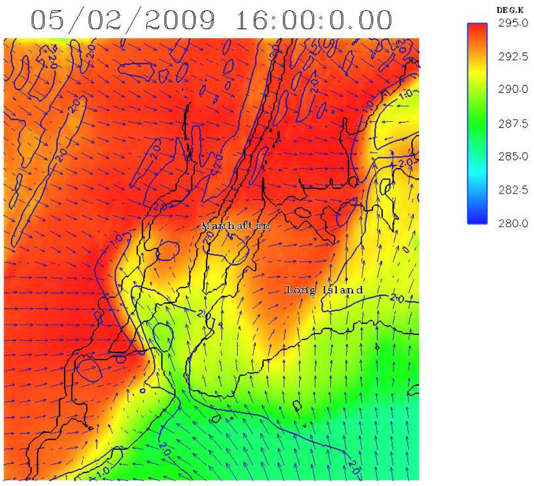
The MM5-NSWIFT suite computes meteorological flow and gives 2D and 3D fields as results for each of the nine levels. Simulated time period covers some days before May 2009, the 2nd and one day after, with hourly results for MM5 and every fifteen minutes but on a shorter period for NSWIFT. Looking at wind field near the ground, we can observe benefits brought up by downscaling to the quality of results. As only synoptic effects are observed on the two largest grids (D01 and D02), more local phenomena appear at a finer resolution. In the example we treat in this paper, a west or north-west wind flux is observed in the New York City area with the large scale simulation (Figure a). On D03 to D05 grids, physical phenomena like convection are not estimated through parameterizations but are explicitly solved. It allows to represent effects like sea-breeze we can observe on Figure b. In such a case with slight wind speed, the temperature field, hotter above land than above sea, creates, at the end of the afternoon, a southeast wind flux in the first hundred meters above sea-level, which is the opposite of the northwest synoptic flux observed higher.

Better description of topography, land use and land mask improve results too, basically near the ground. Scarcely no terrain effect on wind field is observed on N01 to N03 grids because of seemingly flat terrain in the New York City area. Only finer land mask has an effect on meteorological flow near the ground with a better description of wind canalization along Hudson River. Moreover, big differences of roughness between seaborne and built areas lead to higher wind speeds above water bodies (Upper New York Bay, Hudson River, East River).

Presence of obstacles at the finest resolution (N04 grid) has a huge effect on wind flow inside the urban canopy (Figure c), with wind direction depending on streets arrangement. Mean wind speed does not change but there are streets, parallel with mean flow, where wind speed increases because of a canyon effect, and streets, perpendicular to mean flow, where wind speed is very slight.



a)



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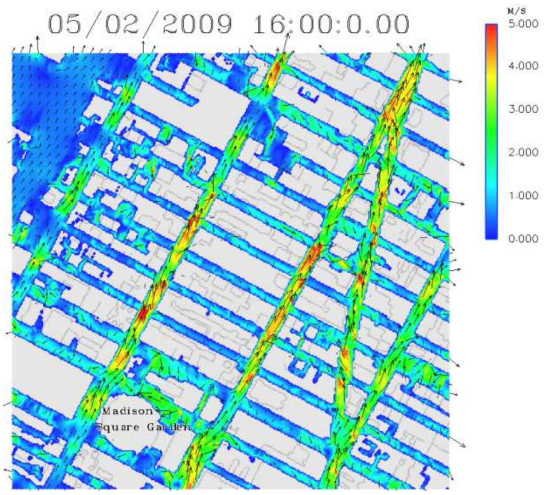

c)

Figure 4. Wind field near the ground on D01 (a), N01 (b) and N04 (c) grids at the same time (May 2nd 2009, 4:00PM).

Comparisons with observations are made to characterize relevance of MM5 wind fields. 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).

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

where C_{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. Four wind speed classes and eighteen wind direction classes are considered here. Average of criteria for the 25 stations of the METAR network included inside domain D05 is given in Table 1. Average criterion increases with downscaling, so as pertinence of 3D wind fields, due to a complete calculation of physical phenomena like convection.

Table 1. Average of criteria calculated with relation (2) at each level of the nesting

	D01	D02	D03	D04	D05
Average on the 25 METAR stations included inside D05 (%)	43.7	49.9	53.0	53.9	53.5

DISPERSION MODELLING AND RESULTS

A hypothetical toxic release, which could be due to a terrorist attack, is assumed to take place in front of one of Madison Square Garden gates. 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 and to happen at 4:00PM 2nd May 2009. The Micro-SPRAY simulation is performed for a period of two hours, with a concentration field computed every minute. A total amount of $2{,}4.10^6$ numerical particles has been emitted to represent dispersion of the cloud.

As the cloud's stem remains a long time near the place of the explosion before being dispersed, because of low winds at this downwind place, the top of the cloud moves faster and, less than five minutes after the attack, is already 1 km away (Figure). As soon as part of the cloud reaches a street with a canyon effect, dispersion is very fast, so that release has an impact on a large area.

Figure 5. View of the cloud, respectively 1 min, 2 min, 3 min and 4 min after explosion.

IMPACT ASSESSMENT

The Micro-SPRAY simulation gives 3D concentration and deposition fields every minute. Recorded concentration is an average of instantaneous concentration during this minute. 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. Calculations are made for non moving receptors.

A rigorous dose assessment would imply waiting until all particles leave the computation domain in order to evaluate the integral of radionuclide concentration. We consider that we are in this case, as only few particles remain inside the grid at the end of simulation.

In each point (I,J) of the grid, inhalation dose for a non moving person verifies :

$$H_{inh}(I,J)=\left(\sum_{t_i=t_1}^{t_i=t_N} C(I,J,K=1,t_i)\cdot\Delta t\right)\cdot\frac{\tau_{resp}}{3600}\cdot f_{inh}\cdot 1000 \qquad (3)$$

where $C(I,J,K=1,t_i)$ is airborne concentration on the first K-level (Bq/m^3), τ_{resp} is breathing rate for an adult (m^3/h) and f_{inh} is effective inhalation dose coefficient (Sv/Bq). Breathing rate for an adult with normal activity is considered equal to 1,2 m^3/h. Effective inhalation dose coefficient is given by ICRP 71 and is $3{,}1.10^{-8}$ Sv/Bq for ^{60}Co (for an aerosol with a 1 µm aerodynamic diameter under the S physical-chemical form and for an adult to the age of seventy).

With a release of one terabequerel of Cobalt-60, the 10 mSv level is reached only in a very small area in front of Madison Square Garden's gate (Figure). Dose level decreases quickly with distance to the 0,1 mSv level, but this value is nevertheless observed far away from the place of the explosion. Dilution inside streets is not a simple function of distance and reconcentration may be observed inside farther streets.

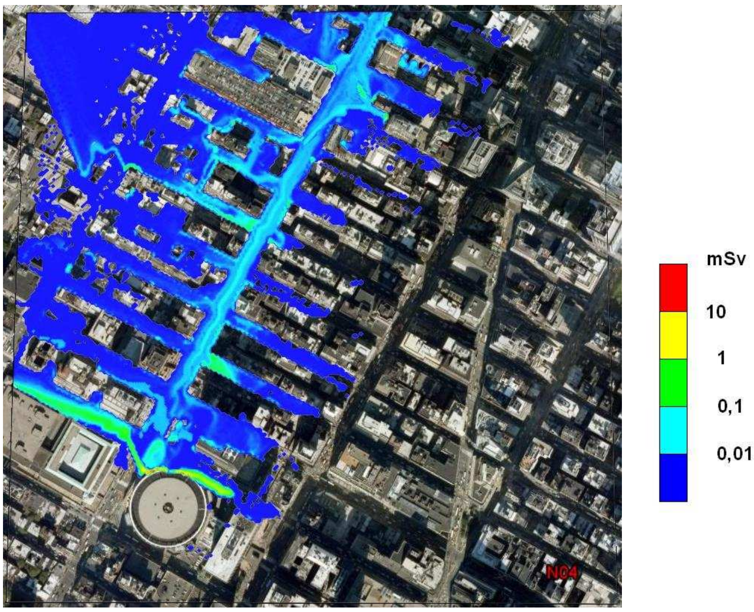

Figure 6. Inhalation dose computed near the ground.

Radiation exposure is quite a lot more difficult to perform because it has an effect from a distance. Then, a person staying in a zone without radioactive particles may receive a non zero dose. A tool like CLOUDSHINE (Armand, 2005) performs dose field due to gamma radiations emitted by a cloud. The algorithm sums the contribution to radiation exposure of each gamma ray of each numerical particle of the Micro-SPRAY output particle file and takes into account shading of obstacles. Some inadequacies in the algorithm with shading of obstacles in case of complex urban environment and the need to consider the contribution of deposition on floor and walls to the radiation exposure require additional developments to have a more complete version of CLOUDSHINE.

CONCLUSION AND PERSPECTIVES

New developments to the Micro-SWIFT-SPRAY modelling system now allow downscaling for meteorological flow calculation. MSS is now linked to MM5 and the MM5-NSWIFT-Micro-SPRAY 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.

Centered on Madison Square Garden, in New York City, a flow calculation is proposed to show how the suite is implemented. Starting from operational global analysis and most of North America, 3D wind fields are computed in five nested domains with MM5, and then, to the local urban scale in four nested domains with NSWIFT. Input data like topography and, land use or 3D building models, are refined at each level. More and more local effects appear with downscaling (sea-breeze effect with a few-kilometers resolution, land use effects with a hundred-meter resolution, buildings effects with a few-meters resolution), so that 3D output fields are very relevant. Comparisons with METAR observations prove that.

A 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 gates. Dispersion, computed using Micro-SPRAY Lagrangian model, shows the rapid expansion of the cloud and the contamination of the whole quarter near Madison Square Garden. Health impact was here assessed considering a radioactive release but doses due to a chemical release could have been performed too.

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 species inside urban environment. With a rigorous downscaling, calculated meteorological flows are very realistic. The introduction of obstacles on the grid with the finest resolution could be improved because buildings description turns from a parameterization through roughness to an explicit description. A future development will consist to consider buildings as porous meshes in an intermediate step.

Linking NSWIFT with a mesoscale code (MM5 today, WRF in the future) gives the opportunity to use the suite as a meteorological forecasting system, where wind fields are continuously produced. Such a system already exists at the LIRC, and displays forecasts for France at mesoscale (Achim, 2010). Extension to the local scale with the MM5-NSWIFT suite will allow to dispose of 3D local wind fields for cities or industrial sites under survey. Predictive Micro-SPRAY calculations are then able to be completed very quickly in case of a toxic release, and a really relevant health impact solution is able to be proposed, so that the MM5-NSWIFT-Micro-SPRAY suite could be worked within a crisis centre.

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