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DEVELOPMENT OF A GENERIC MODELLING CHAIN FOR WEATHER PREDICTION AND POTENTIAL ATMOSPHERIC DISPERSION FROM THE MESO-SCALE TO LOCAL SCALE

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Abstract: The test case presented in this paper details the calculations made for a crisis exercise on March 8, 2016, when a release of radioactive substance was considered from the Allianz Riviera stadium in Nice. It shows the state of the art of the simulations that can be carried out with the PMSS software when it is implemented with WRF in a chain covering all the scales, from the mesoscale to the local scale.

Key words: meso-scale, urban scale, WRF, PMSS, crisis exercise.

INTRODUCTION

It is more and more admitted that atmospheric dispersion modelling may be of great help for rescue teams and public authorities at least for preparedness before a crisis implying the release of hazardous materials, and also in the course of a real emergency. This is nevertheless a challenge for modelers because releases resulting from an industrial accident or a terrorist action are by essence poorly known (at least at the beginning of the crisis). Moreover, simulations on a large area around the release point may be needed in order to provide a relevant answer to the authorities, wanting to know where dangerous areas and also where safe areas are located. As urban districts and industrial facilities are complex environments which may be located in a complex geographic environment (coastal area, rugged terrain or both) modelling the flow and dispersion in these areas is most often complicated. Therefore, reliable impact assessment of hazardous releases more often requires an advanced 3D approach with high spatial resolution up to a few kilometers from the source.

To address this kind of issues, we have developed a generic and flexible modelling chain applicable from the meso-scale to the micro-scale for the flow computation and from the micro-scale to the regional scale for the atmospheric dispersion computation. It is based on the WRF weather reconstruction and forecast model and Parallel-Micro-SWIFT-SPRAY (PMSS) that combines a 3D flow diagnostic or momentum solving model (PNSWIFT) with a 3D Lagrangian Particle Dispersion Model (PSPRAY). PMSS is on common development of ARIA Technologies, ARIANET, Mokili and the CEA. The paper details the main principles of the downscaling modelling chain and illustrates its use through the simulation of a hypothetical synthetic accidental situation.

DESCRIPTION OF THE MODELLING CHAIN

These last years, successive evolutions of the PMSS suite made possible the construction of a complete computation chain for flows and atmospheric dispersion. The introduction of nesting in PNSWIFT allowed the calculation of atmospheric flows from the mesoscale to the local scale (Duchenne, 2010). The parallelization of PMSS (Oldrini, 2017) provided the opportunity to make simulations on huge calculation domains which can cover an entire city at a metric resolution (Oldrini, 2016). Recent modifications in the PSPRAY code now authorize to deal with atmospheric dispersion not only inside the inner domain but also for the other nests computed by PNSWIFT (up-scaling or down-scaling). The principle of nesting in PSPRAY is to consider the transfer of numerical particles from a domain to another with a different level of nest in the same way as the transfer of particles between two tiles of the same computational domain.

Using GFS global data as input data, the WRF part of the chain is two-way nesting and computes atmospheric flows to the finest resolution considered achievable with this kind of meso-scale weather reconstruction and forecast tool (1 km). Then, the PNSWIFT part of the chain is one-way nesting, introduces a finer topography and land-use at the regional scale and takes account of the vegetation. The consideration of vegetation is introduced by a canopy model similar to the canopy model for urban areas defined by Coceal (2004). In practice, vegetation is modeled by a mean height and a density, and a drag coefficient is applied in the fluid cells of the calculation grid where vegetation is present. The values of the drag coefficient depend on the canopy density. Building data are introduced at the local scale and flows around them are resolved either with diagnostic or momentum PNSWIFT version (Oldrini, 2014).

DESCRIPTION OF THE TEST CASE

We illustrate the use of the WRF-PMSS chain through a realistic test case that was implemented in the framework of a civilian security exercise. It considers the fictitious release, on March 8, 2016 at 8:30 am (UTC) and during two minutes, of a noxious release, emitted from a drone above a grandstand of the stadium Allianz Riviera near the city of Nice. This test case contains some tricky stuff to solve: a release inside a complex built structure, the proximity of a big city where we want to know if there will be consequences, and a location in a coastal area with a mountainous hinterland that makes weather conditions difficult to predict.

Figure 1 and

Table **1** show the footprints and the characteristics of the four WRF calculation domains and the three PNSWIFT calculation domains. PSPRAY calculation domains are identical to those used for PNSWIFT. WRF simulation is initiated and nudged every three hours with GFS global data at 0.5° resolution. The analysis at noon on March 7, 2016 is used; following timeframes are forecasts. To catch correctly meteorological phenomenon which may appear inside the valley of Var river where the stadium lies, we disabled smoothing for topography and used SRTM 3-second-arc topography for domain D04.

(a) 

(b) 

(c) 

Figure 1. WRF and PNSWIFT calculation domains and view of the Nice stadium (inner domain).

Table 1. Characteristics of the WRF and PNSWIFT domains.

Model	Domain	Resolution (m)	Number of nodes (horizontally)	Number of nodes (vertically)	Top of the calculation box (m)
WRF	D01	27000	121×121	45	19300
	D02	9000	127×127	45	19300
	D03	3000	127×145	45	19300
	D04	1000	133×121	45	19300
PNSWIFT	N01	75	401×401	31	3500
	N02	3	3001×2101	37	1500
	N03	1	401×401	55	1500

Topography for PNSWIFT domains comes from 75m-resolution BD ALTI and 5m-resolution RGE ALTI products from the French National Geographic Institute. Vegetation data for domain N01 is available at a 20m-resolution (http://www.statistiques.developpement-durable.gouv.fr/clc/fichiershr/) and is shown Figure 2 for the region of Nice (low percentages of woodlot coverage are light green and high percentages are dark green). Building data in domain N02 comes from BD TOPO product provided by French NGI. The resolution of this huge domain with the PNSWIFT diagnostic version requires to split it into 7×5 tiles. The PNSWIFT momentum version is used in domain N03 and the digital model of the stadium was built on the basis of plans and photos taken on the spot.

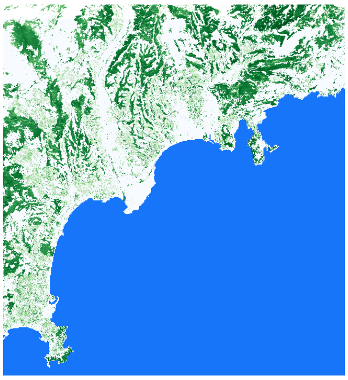


Figure 2. Woodlot coverage.

RESULTS OF THE TEST CASE

On the morning of March 8, 2016, air flow was relatively complex and variable in the Nice region as shown in the illustrations in Figure 3. At 8:30 am UTC (9:30 am local time), the flow in the Var valley, going alongside the Allianz Riviera stadium, was oriented from north to south and met the north-east flow from Liguria in the “baie des Anges”, off Nice. At 9:30 am UTC, the wind speed in the Var valley was weakening and the wind already changed direction at sea north of Antibes, with a flow directed from south to north. At 10:30 UTC the change of direction of the wind also affected the area around the Allianz Riviera stadium, with a southwest-to-northeast directional flow.

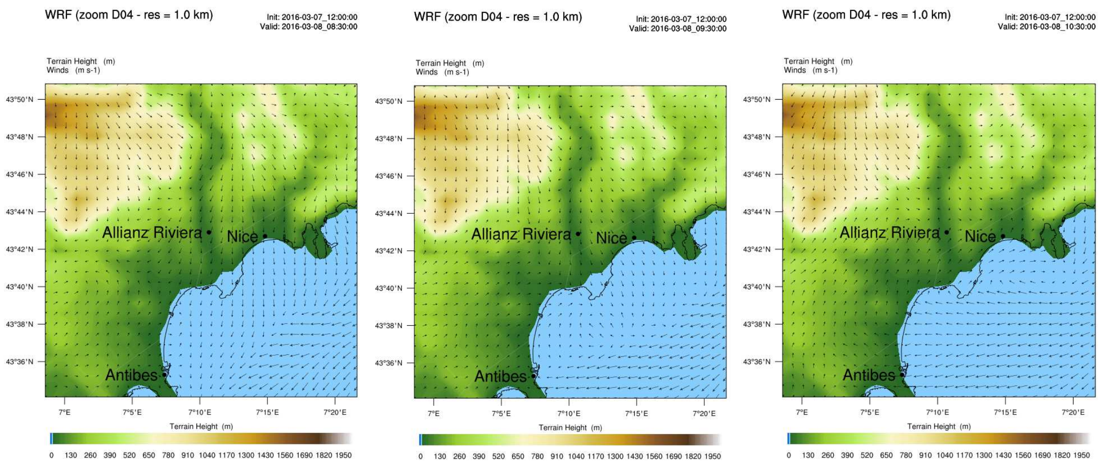


Figure 3. Topography and WRF wind field near the ground (h=15m) for domain D04 (zoom on the Nice area).

Figure 4 shows horizontal and vertical cuts of the wind field on domain N03 at 8:30 am UTC, performed by the PNSWIFT momentum version. The particular shape of the roof of the stadium, which extends behind the stands and envelops them, leads to fairly low wind speeds within its enclosure and to the creation of large vertical eddies above the lawn.

The illustrations in Figure 5 show, at different time frames, the pattern of the concentration field near the ground. These illustrations integrate the concentration fields calculated on the three nested domains of the PNSWIFT calculation. Because PSPRAY code is Lagrangian and volumes of the computation meshes between the three domains are very different, we observe discontinuities of the lowest concentrations, on the graphical representation of the plume at the domain interface between two different nests. The results of the PSPRAY calculation show that, 80 minutes after the release, particles are still present in the stadium enclosure and in its immediate vicinity. The architecture of the Allianz Riviera stadium makes it a rather closed place that does not facilitate the dispersal of pollutants, and a fraction of cloud remains stuck under the roof and in the space between the roof and the back of the stands. The part of the cloud that leaves the stadium is carried south-south-east and reaches the sea, west of Nice airport, about thirty minutes after the initial release. Then, the wind that occurs over the sea stretches it in two opposite directions. Thus, a small part of the cloud is directed towards the south-west, *i.e.* to the city of Antibes, while the rest of the cloud is driven towards the northeast and passes over Nice airport and further, towards the city of Nice, over the neighborhoods close to the sea.

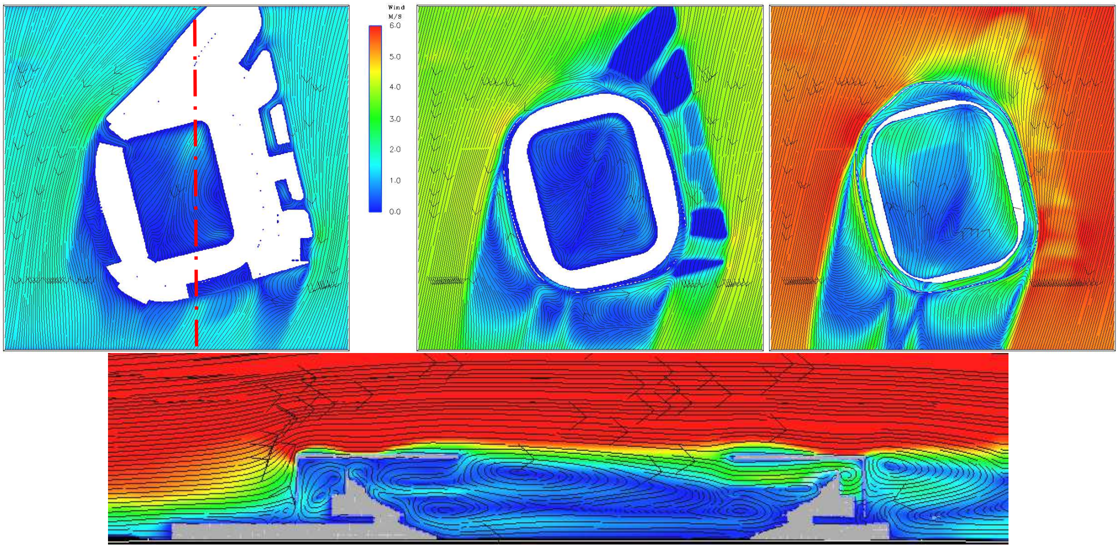


Figure 4. Horizontal and vertical cuts of the wind field on domain N03. The horizontal cuts are represented at a height of 4 m (middle of the lower rostrum), 13 m (middle of the intermediate stand) and 21 m (middle of the upper stand). The vertical section plane is indicated by the red line on the first illustration.

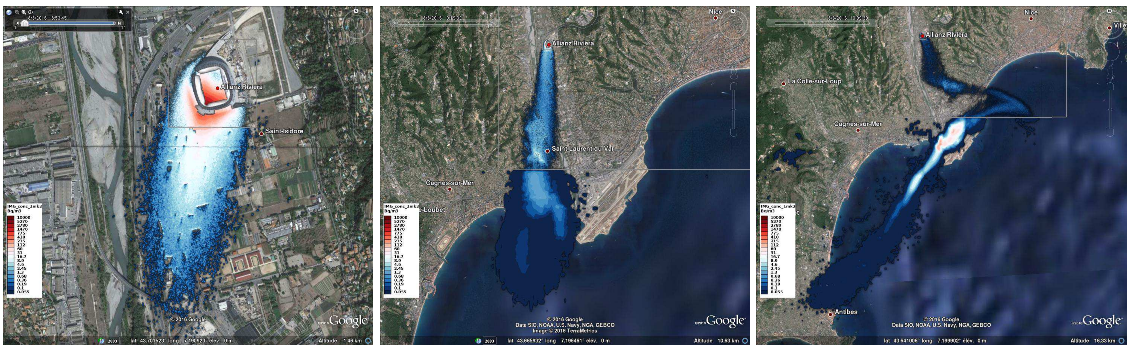


Figure 5. Concentration field after the release at different time frames
(4 minutes, 30 minutes and 80 minutes, respectively).

This test case illustrates the contribution of nesting in PSPRAY for long-distance tracking of the particles' emitted plume. Indeed, the simulated meteorological situation (wind direction change in the morning over the bay of Nice), quite frequent at this place, brings back to the N02 domain of metric resolution a large part of the cloud that came out of it. This behavior of the cloud would not have been observed if the simulation of atmospheric dispersion had been limited to the metric resolution domain and knowledge of the noxious distribution would have been degraded. An increase in the size of this domain could be envisaged instead, but on the one hand it would require more computing resources and, on the other hand, it would be somewhat inopportune because there is no physical phenomenon of small scale to simulate above the sea.

The health impact assessment was carried out for the discharge considered in this exercise (Figure 6a), but also for a rejection of a larger quantity (factor of 1000) of the noxious release (Figure 6b). For the weak release, considering two threshold values, the consequences remain limited to the stadium enclosure. For the strong release, these thresholds are exceeded even far from the stadium, close to Nice airport, where the plume stagnated during the turn of the wind direction.

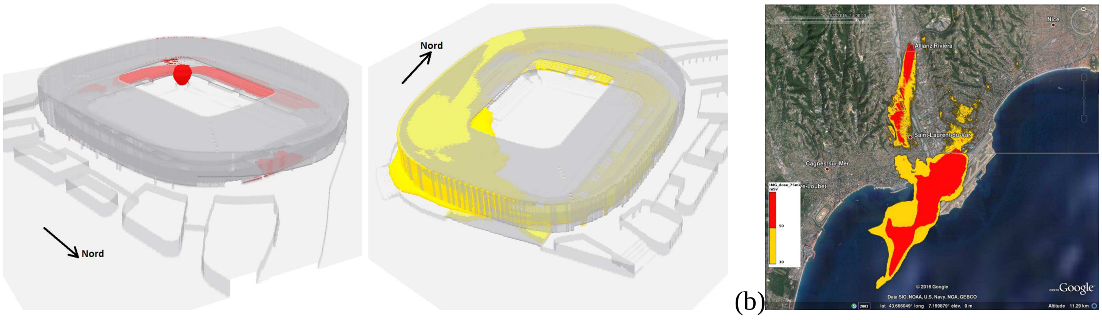
(a)  (b)

Figure 6. Consequences regarding threshold values (in red and yellow) for the two releases.
(a). Weak release. (b). Strong release

CONCLUSION AND PERSPECTIVES

The test case presented in this paper shows the state of the art of the simulations that can be carried out with the PMSS software when it is implemented with WRF in a chain covering all the scales, from the mesoscale to the local scale and even the inner part of infrastructures (here, a stadium). The combination of developments made in the past years in PMSS (nesting and parallelization in PNSWIFT and PSPRAY, development of a regional canopy model on a regional scale that we have adapted in this work to take account of vegetation, development of a momentum conservation solver in PNSWIFT, particle-splitting in PSPRAY) makes it possible to perform particularly realistic simulations of atmospheric dispersion. It is now possible to follow a plume of hazardous substance from the vicinity of its source with very high accuracy, to a distance of several kilometers, and then again with a very high (metric) accuracy on an area of interest far from source.

It is also worth noting that the momentum version of PNSWIFT was used to simulate atmospheric flows in the N03 domain (inside and outside the Allianz Riviera stadium) but the CFD model Code-SATURNE could have been used instead, because it accepts PNSWIFT results as input data and wind fields that it produces can be accepted as input data by PSPRAY. Finally, the fine 3D simulation of a toxic release distribution is mandatory to accurately evaluate the health consequences on the population and first responders in the event of an accident or a malicious activity.

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