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EMERGENCIES MEDITERRANEAN – A PROSPECTIVE HIGH-RESOLUTION MODELLING AND DECISION-SUPPORT SYSTEM IN CASE OF ADVERSE ATMOSPHERIC RELEASES APPLIED TO THE FRENCH MEDITERRANEAN COAST

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Abstract: CBR accidental or malevolent gaseous or particulate releases into the atmosphere are a threat to human life and at stakes for Civilian Security. Advanced physical modelling has been proven to be informative about space and time distribution of noxious species, thus their sanitary impact. Yet, computations over large urban areas with high metric resolution to solve the flow and dispersion details call for HPC. In 2014, CEA and AmpliSIM developed the "EMERGENCIES" modelling system based on Parallel-Micro-SWIFT-SPRAY (PMSS) covering Paris and vicinity, a 40 x 40 km^2 territory under Paris Fire Brigade responsibility. In 2016, a new computational challenge was launched with "EMERGENCIES Mediterranean" extending the system to the weather forecast in "Provence, Alps & French Riviera" region downscaled to urban domains encompassing Marseille, Toulon and Nice cities at 3-m resolution taking account of their stiff relief and whole buildings. These domains were so vast that they had to be divided in tiles distributed to the cores of a supercomputer. Then, dispersion simulations of fictive releases were performed still using the efficient parallelization of PMSS and new technologies adapted to the visualization of the plumes in domains with billions of cells via GIS and / or a web service. The paper describes how this project pushes the limits of the decision-support systems with state-of-the-art CFD models in the framework of emergency preparedness and management.

Key words: EMERGENCIES Mediterranean, WRF-PMSS multiscale modelling system, high resolution, HPC.

INTRODUCTION

Accidental or malicious releases of gases or particles into the atmosphere, potentially preceded by an explosion, are considered as a major threat by the Civilian Security. In an urban district or on an industrial site, these possibly Chemical, Biological or Radiological (CBR) releases are likely to be transferred inside buildings or other infrastructures and result in numerous fatalities. To tackle this issue, advanced physical models giving the detailed space and time distribution of a noxious contaminant are deemed by many professionals as firefighters as a useful component for emergency handling. Constraints for the modelers are therefore to give realistic operational results in a limited amount of time. For huge domains covering large cities at very high resolution (1 to 3-m), High Performance Computing (HPC) is thus mandatory.

The "EMERGENCIES" project was launched in 2014 as a capacity demonstration of the feasibility and interest to perform 4D numerical simulations aimed at supporting decision-making in an emergency involving noxious atmospheric releases (Oldrini *et al.*, 2016). This forward-looking concept was applied to Paris city, its urbanized vicinity and airports, a territory under the responsibility of Paris Fire Brigade. This 3D simulation domain had horizontal dimensions of 40 x 40 km^2 and 6.5 billion of cells.

"EMERGENCIES Mediterranean (sea)" was a new project performed with success in 2016 by the French Atomic and alternative Energies Commission (CEA) and AmpliSIM. The project was acknowledged as a "Big Challenge" by the Research & Technology Computing Center of the CEA. It was the transposition of "EMERGENCIES" to a domain encompassing "Provence, Alps & French Riviera" region (a large part of the French Mediterranean coast) at a 1-km resolution with zooms in on the largest cities of this region (Marseille, Toulon and Nice) at 3-m resolution. Meteorological forecast from the meso-scale to the local scale and dispersion simulations of fictive releases were performed using Parallel-Micro-SWIFT-SPRAY (PMSS) modelling system nested within WRF and accounting for all buildings in the urban domains. PMSS is developed by ARIA Technologies, ARIANET, MOKILI and the CEA (Tinarelli *et al.*, 2013).

The paper gives some details about "EMERGENCIES Mediterranean" computational characteristics and examples of results with future prospects and possible applications of the modelling system.

N.B. "EMERGENCIES" stands for "high rEsolution eMERGEncy simulatioN for CitIES".

PHYSICAL MODELS, SIMULATION DOMAINS AND COMPUTATIONAL FEATURES

Downscaling flow and dispersion simulations were performed with WRF (in nested domains at 27, 9, 3 and 1-km resolutions) and Parallel-Micro-SWIFT-SPRAY (PMSS) in the three urban domains. PMSS modelling system explicitly takes account of the buildings and it is efficiently parallelized as described in Oldrini *et al.* (2017a). Simulations were done by dividing the large PMSS domain in sub-domains or tiles distributed to the cores of a massive cluster (e.g. Marseille domain was divided into 2,058 tiles). PMSS is state-of-the-art and it comprises the PSWIFT and PSPRAY models dedicated to respectively the flow and dispersion computations. PSWIFT is parallelized in space (tiles) and timeframe, PSPRAY in numerical particles distributed to the tiles with load balancing. Finally, the gigantic volume of “big data” 3D results is post-processed and visualized with tools described in a companion paper (Oldrini *et al.*, 2017b).

Figure 1 shows the horizontal extent of the highest resolution (1-km) meso-scale domain and of the three urban local scale domains. The meso-scale domain encompasses the “Provence, Alps and French Riviera” region in the South-East of France. Hypothetical noxious releases are supposed to occur in the cities of Marseille, Toulon or Nice. Simulations in the urban areas are at high resolution: 3 m in the horizontal dimension and 1 m in the first vertical levels. The computational domains are huge: e.g., the domain over Marseille and the surrounding has horizontal dimensions of 58 x 50 km^2 meshed with 19,333 x 16,666 grid nodes and 39 vertical levels (total number of cells is 12.5 billions). The sub-domains or tiles have 401 x 401 x 39 nodes in order to keep a memory print consistent with the RAM of the cores. Thus, the number of cores able to deal with the large urban simulations is e.g. 2,058 over Marseille area.

Figure 1. Horizontal extent of the high resolution meso-scale domain (D04 / 1-km) and local scale domains (DM, DT and DN / 1-m).

N.B. The very large domain over Marseille corresponds to the intervention area of Marseille firefighters.

Static data were provided by the French Forest and Geography Information Institute (IGN). Topography data are those of the RGE ALTI® product for Nice and Marseille (5-m resolution) and of the BD ALTI® product for Toulon (25-m resolution) interpolated at PMSS horizontal resolution (3-m). Buildings data correspond to the BD TOPO® product and they are processed to generate “obstacles” files. Local scale domains are not only urban but have a stiff landform with a drop of 1,000 m for Marseille and Nice. The flows there are very complex as they are influenced by the regional Mistral wind blowing from North to South along the Rhône river valley and by sea breeze / land breeze effects with accelerations over and between the mountains and hiding effects of the buildings or recirculations around them.

Two kinds of meteorological simulations were carried out: the first ones with academic conditions at local scale by imposing “typical” wind and temperature profiles, the second ones with real conditions issued by WRF to PSWIFT downscaling (and an adapted division into tiles of the urban simulation domains):

- The academic typical simulation mimicked a sea breeze progressively decreasing to be replaced by the regional “Mistral” wind (as e.g. on the 10th August 2016 between 19 and 23 local time); wind profiles were set up on the land and on the sea with the wind directions varying with time;
- The actual time sequence from the 13th to the 23rd of July 2016 was reconstructed with WRF (using GFS global analyses at 0.5° as initial and boundary conditions); from these computations, days with a shift between land breeze and sea breeze were selected for the local simulations.

The wind field was produced every quarter of an hour with a linear interpolation for intermediate times. Simulations in real meteorological conditions were done with an optimized division into sub-domains in order to minimize the number of requested cores decreased to e.g. 1,672 for the domain over Marseille.

Dispersion simulations were done according to fictitious scenarios (without specific justifications). A unit mass of a gaseous or particulate tracer was released from different locations in the cities for 20 minutes. 400,000 numerical particles were emitted every 5 seconds and concentrations averaged over 5 minutes. Plume transport and dispersion was computed for 5 to 6 hours. The “particle-splitting” option in PSPRAY was activated to regularly double the number of numerical particles and smooth the concentration field.

OVERVIEW OF THE METEOROLOGICAL RESULTS

On one hand, WRF reconstruction of a real time sequence was downscaled with PMSS to demonstrate the feasibility of meteorological predictions at meso- and local scale in the huge urban domains. On the other hand, "typical" meteorological conditions were used in PMSS domains to study an academic shift in the wind direction. Examples of these results for the domains over Nice city are shown hereafter.

Meso-scale weather forecast

Figure 2 illustrates WRF wind field in the D04 domain (1-km horizontal resolution) at 10 m AGL in Nice region on July 15, 2016 between 6 and 11 am (in local time). During this time sequence, the wind blows successively from the NW, SE, SW, and finally S. Wind speed is weak, between 10 and 20 km.h^{-1}.

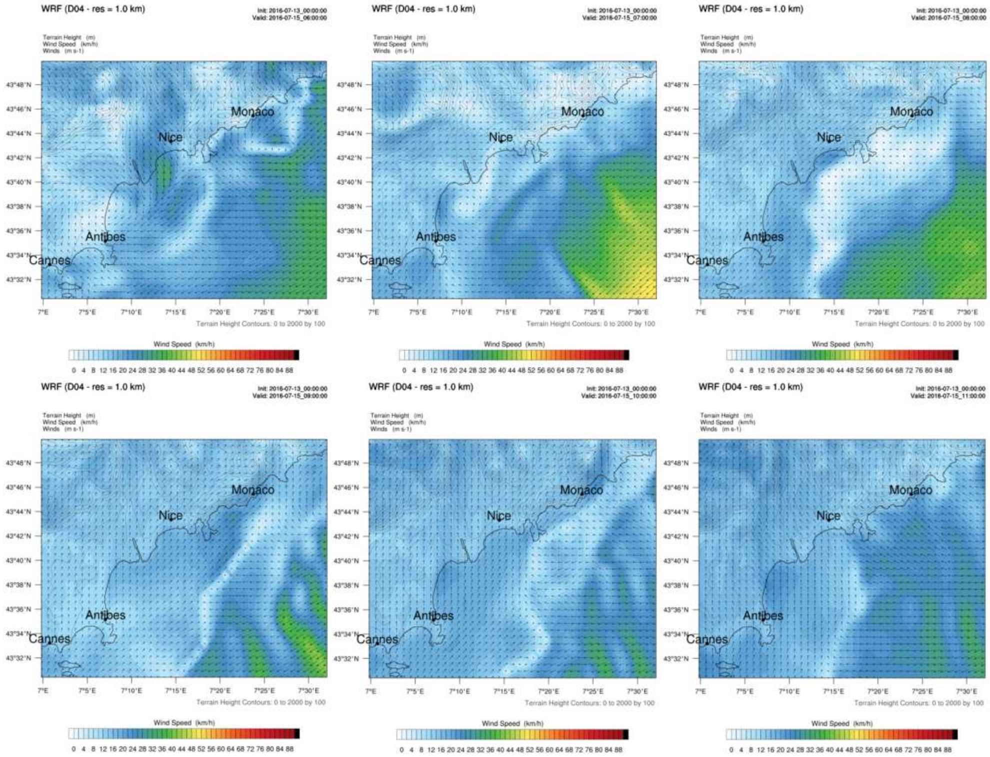

Figure 2. Meso-scale wind field over Nice region on July 15, 2016 between 6 and 11 am (local time).

Micro-scale academic simulations

Figure 3 illustrates PSWIFT "academic" wind field at 1.5 m AGL (first level above the ground) at 1-m horizontal resolution over Nice entire domain (left) and the city center (right). The views were produced from the 3D PMSS results as juxtaposed and multiscale series of tiles, also exportable to Geographical Information Systems (GIS). The same kind of results was obtained downscaling WRF results with PMSS.

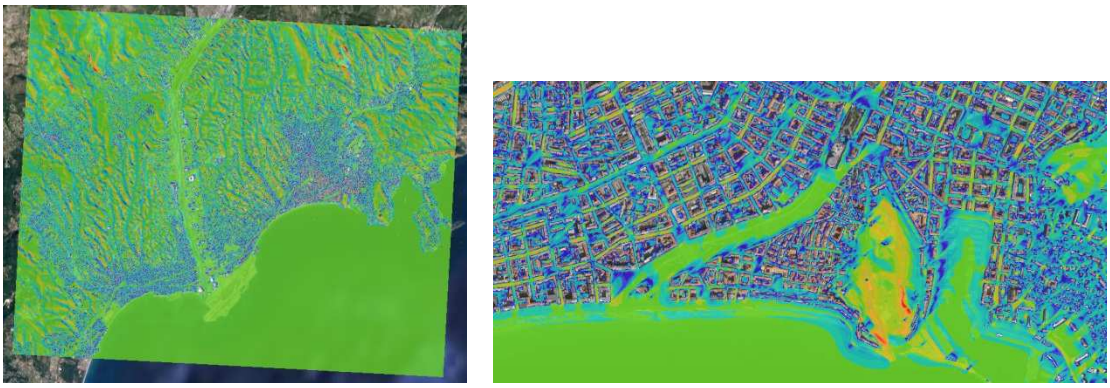

Figure 3. General view of the wind module at 11 pm (local time) over Nice domain (left) and Nice city center (Massena square and the Hill of the Castle) (right).

OVERVIEW OF THE DISPERSION RESULTS

Thereafter, dispersion results were produced on the basis of both “academic” and “real” wind conditions. While results are shown only for Nice city and region, there are also available for Toulon and Marseille.

Simulations using academic meteorological input

Figure 4 illustrates PSPRAY concentration field at 1.5 m AGL. The images are multiscale tiles generated with the same technologies as for the wind field. The dispersion pattern is presented at different (spatial) scales and times of the fictitious release scenario to point out the complex local and global distribution of the pollutant influenced by the varying meteorological conditions and the land / sea, land-use and relief configuration. The colored scale is arbitrary from blue to red (weakest to strongest values).

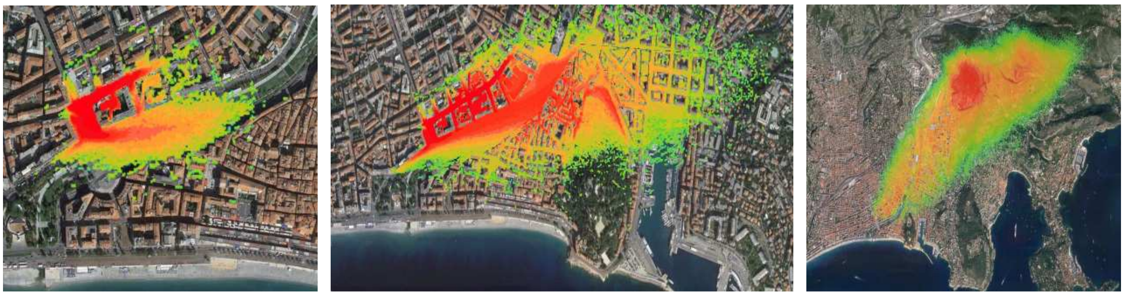

Figure 4. View of the plume on Massena square (left), over Nice city center (middle) and over the relief East of Nice (right) respectively 2, 15, and 55 minutes after the beginning of the (false) release.

Simulations using real meteorological input

Figure 5 illustrates PSPRAY concentration field at 1.5 m AGL with Google Earth® underlying views. At the beginning of the (fictitious) release in Nice domain, the plume slowly moves to the South reaching the beach (left). Then, a wind shift makes the plume turning down to the North and the city center (middle). The wind direction keeps on evolving from the South to the WSW with the plume hanging on the 100-m high Cimiez hill, passing over the Paillon river valley and being held on mountains East of Nice (right).

Figure 5. View of the plume near the ground level at 6:38 (left), 6:54 (middle) and 7:10 (right) (beginning of the false release at 6:30 am local time).

DATA ABOUT THE COMPUTATIONS

Here are some details about the characteristics of the local scale computations (academic configurations). **Table 1** shows the CPU print of the PMSS calculations and **Table 2** the input / output memory print. As can be observed, the volume of the data produced by PMSS (flow field and concentration field) is tens of teraflops implying adapted technologies to post-process and visualize the big data (Oldrini *et al*., 2017b).

Table 1. CPU print of PSWIFT and PSPRAY computations.

PSWIFT (for one time frame) (total computations = 17 time frames every quarter of an hour)					
Marseille domain		Toulon domain		Nice domain	
2,059 cores	1 hr 08 min	309 cores	39 min	239 cores	44 min
PSPRAY (400,000 numerical particles per second) (concentration output every one minute)					
Marseille (4 hr sim. x 4 releases)		Toulon (2 hr sim. x 1 release)		Nice (3 hr sim. x 1 release)	
1,500 cores	17 hr 36 min	200 cores	7 hr 50 min	200 cores	10 hr 42 min

Table 2. Input / output memory print.

Input data					
Buildings			Topography		
Marseille	Toulon	Nice	Marseille	Toulon	Nice
400 Mo	120 Mo	90 Mo	6,5 Go	900 Mo	700 Mo
Output data					
PSWIFT (total = 15 To) (3 dom. x 17 time frames tf)			PSPRAY (total = 1,6 To) (3 domains)		
Marseille	Toulon	Nice	Marseille	Toulon	Nice
668 Go / tf	96 Go / tf	74 Go / tf	830 Go	274 Go	501 Go
Visualization (images for a GIS or web service)					
Wind (17 time frames) (1 or 2 vert. levels)			Concentration (1 image per min) (2 vert. levels)		
Marseille	Toulon	Nice	Marseille	Toulon	Nice
1,6 Go	897 Mo	887 Mo	3,2 Go	613 Mo	1,2 Go

CONCLUSION AND PERSPECTIVES

This paper summarizes the principles and results of the computations carried out during summer 2016 in the frame of "EMERGENCIES Mediterranean Big Challenge" at the Research & Technology Computing Center of the CEA. Weather was predicted at meso-scale over "Provence, Alps & French Riviera" region and downscaled to domains covering Marseille, Toulon and Nice cities accounting for the local stiff relief and all the buildings. The 3D wind and turbulence fields were used to transport and disperse hypothetical fictitious releases. As the domains were huge (up to 50 km horizontal edge) and meshed at high resolution (3-m horizontally x 1.5-m vertically near the ground), it was necessary to divide them in tiles distributed to computational cores and to resort to the efficient parallelization of PMSS (Oldrini *et al.*, 2017a).

This project was the ambitious follow-up of EMERGENCIES "Big Challenge" over Paris and vicinity as the "Provence, Alps & French Riviera" topography was much more complex, the domain over Marseille was twice compared to Paris and several urban domains were considered. Thus, the modelling chain was one step closer to its operational generalization to entire vast regions (as e.g. "Auvergne-Rhône-Alps").

To our knowledge, these multiscale highly resolved computations are worldwide unique as they combine a huge geographical print with a metric resolution. This is not an exercise in style but mandatory to take account of intricate flows around obstacles and provide reliable, realistic and detailed simulation results.

Visualizing results on meshes with up to 12.5 billion of nodes was a full part of the project implying the development of technologies adapted to GIS and web services as explained in Oldrini *et al.* (2017b).

All in all, EMERGENCIES Mediterranean used 500,000 hours x cores for computations development and achievement. The project has shown that with around 2,500 cores, meteorological forecast at urban scale 3-m resolution can be provided each day for the next one and dispersions computed as necessary with a factor of five time acceleration. Moreover, the 3D modelling chain can be supplemented with CFD nested domains in and around the buildings in order to evaluate indoor / outdoor transfers.

Even if today, this project is still prospective, it is likely that supercomputing will become more and more usual and benefit to first-responders and their authorities for emergency preparedness and management.

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