DE LA RECHERCHE À L'INDUSTRIE

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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Introduction - Context of the project (1/2)

1) Accidental or malicious Chemical, Biological or Radiological-Nuclear (CBRN) releases in the air, possibly preceded by an Explosion, are a major threat for the Civilian Security

2) Moreover, in an urban district or on an industrial site, these releases are likely to be transferred inside buildings or other infrastructures and result in numerous fatalities

3) The only way to produce realistic and detailed enough space and time (4D) distribution of a noxious contaminant is to use CFD (or simplified CFD) models (other methods are pointless)

4) After several emergency exercises performed by the CEA with Paris and Marseille firefighters, these professionals now deem 4D modelling as a useful component for emergency handling

5) Constraints for the modelers are to give operational results in a limited amount of time ; therefore, for huge domains covering large cities at very high resolution (1 m), HPC is mandatory!

Introduction - Context of the project (2/2)

6) In 2014, EMERGENCIES was a capacity demonstrator of the feasibility to perform 4D simulations supporting decision-making in all Paris city, its huge urbanized vicinity and airports, a territory under the responsibility of Paris Fire Brigade (3D domain, 6.5 billion of cells, horiz. 40 km x 40 km)

7) In 2016, EMERGENCIES Mediterranean (sea) was the transposition of the previous demonstrator to a domain encompassing Provence, Alps & French Riviera region (part of the French Med. coast) at a 1-km resolution with zooms in on Marseille, Toulon and Nice cities at 3 m resolution

8) This successfully project was done by the French Atomic and alternative Energies Commission and AmpliSIM as a "Big Challenge" at the Research & Technology Computing Center of the CEA

9) 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 (27, 9, 3 and 1 km res.) and accounting for all buildings in the urban domains

10) N.B. PMSS is developed by ARIA Technologies and the CEA with MOKILI and ARIANET

Details about models and computations (1/2)

1) PMSS explicitly takes account of the buildings in PSWIFT flow and PSPRAY dispersion models ; PSWIFT has been parallelized in space and timeframe, PSPRAY in particles with load balancing

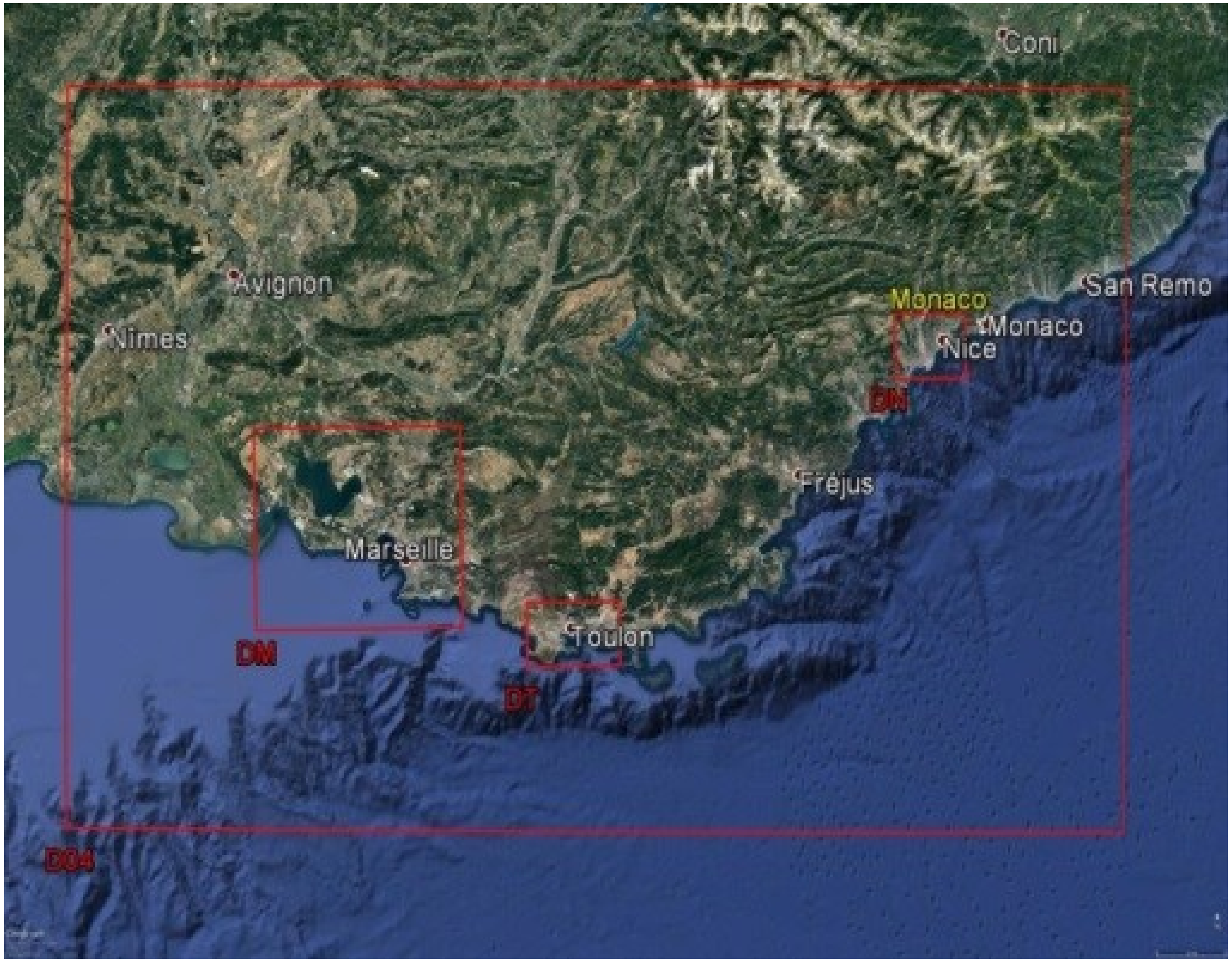
2) Simulations in the urban areas are at high resolution (3 m horiz. and 1 m in the first vertical levels) and done by dividing the domains in sub-domains (tiles) distributed to cores of a massive cluster

3) Hypothetical noxious releases are supposed to occur in the cities of Marseille, Toulon or Nice and the giant 3D results are post-processed and visualized with tools described in a companion paper

4) The domain over Marseille and surrounding is the intervention area of Marseille firefighters (!)
   a) Horizontal dimensions are 58 x 50 km^2 meshed with 19,333 x 16,666 grid nodes
   b) There are 39 vertical levels and the total number of cells is 12.5 billions
   c) The tiles have 401 x 401 x 39 nodes to keep a memory print consistent with the RAM of the cores
   d) Thus, the number of cores able to deal with the large urban simulations is 2,058 over Marseille area (N.B. The optimum number of sub-domains, thus of requested cores, may be decreased to 1,672)

Details about models and computations (2/2)

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



Static data provided by the French 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 resolution (3-m)

Buildings are processed from BD TOPO®

Local scale domains are not only urban but have a stiff landform with a drop of 1,000 m for Marseille and Nice

Rationale of the met' and dispersion simulations

1) On one hand, the real time sequence from the 13th to the 23rd of July 2016 was reconstructed with WRF (using GFS analyses at 0.5° as boundary conditions) and downscaled with PSWIFT to show the feasibility of met' predictions at meso- and local scale in the huge urban domains

2) On the other hand, typical met' profiles on the land and on the sea were used in PSWIFT domains to mimic the academic shift in the wind direction occurring when a sea breeze decreases to be replaced by the "Mistral" wind (as e.g. on the 10th of August 2016 between 19 and 23 local time)

3) Wind field produced every quarter of an hour with a linear interpolation for intermediate times

4) The meso- and local scale flows are very complex influenced by the regional "Mistral" wind blowing along the Rhône river valley and by sea breeze / land breeze effects with accelerations over and between the mountains and also the influence of the buildings with circulations around them

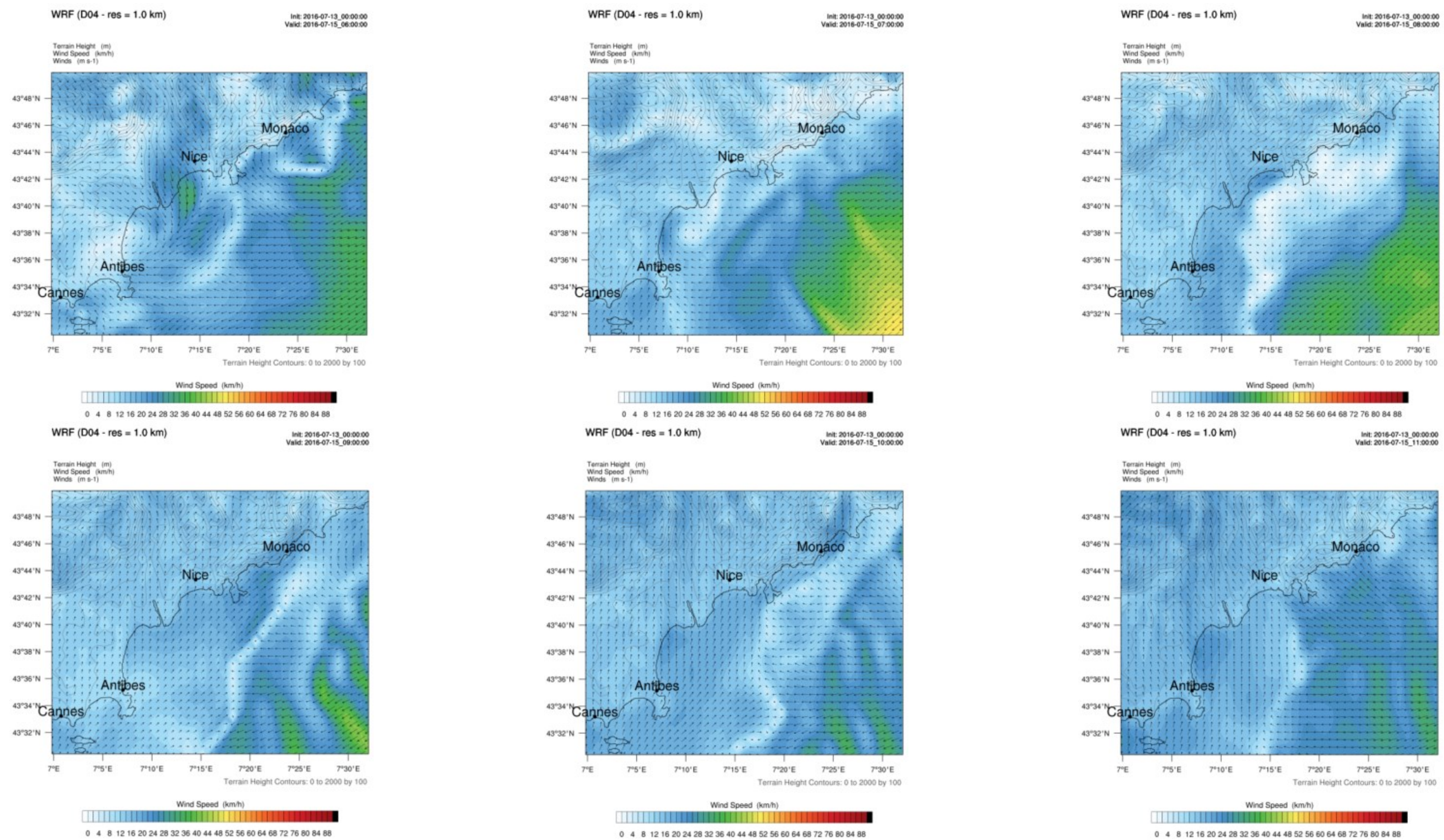
5) Dispersion simulations were done according to fictitious scenarios (without special justifications)
   a) A unit mass of a tracer was released from different locations in the cities for 20 minutes
   b) 400,000 numerical particles were emitted every 5 seconds and concentrations averaged over 5 minutes
   c) Plume transport and dispersion were computed for 5 to 6 hours
   d) The "particle-splitting" option in PSPRAY was activated to smooth the concentration field

Overview of the meteorological results (1/2)

Meso-scale WRF wind field over Nice region on the 15th of July 2016 between 6 and 11 am (local time)

(zoom-in in the D04 domain at 1-km horizontal resolution at 10-m AGL)

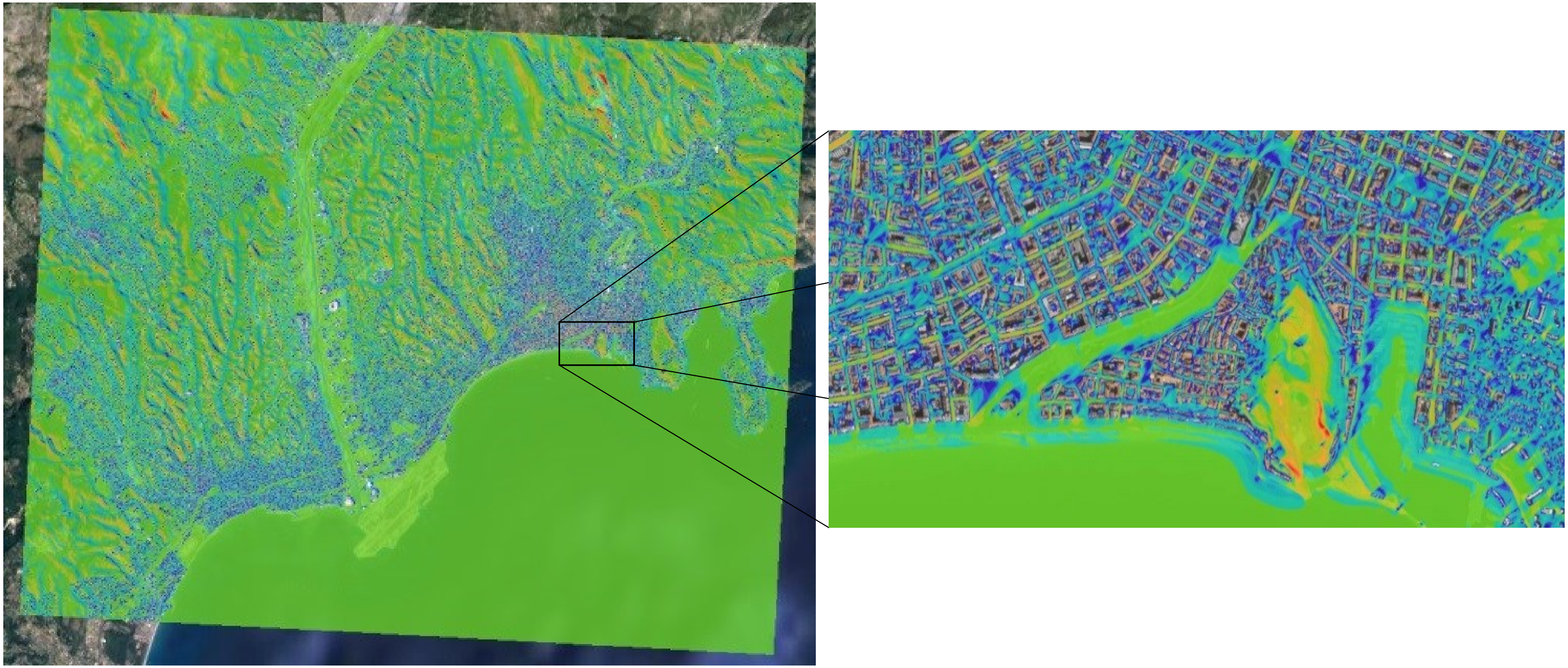
(the wind blows successively from the NW, SE, SW, and finally S; wind speed is weak between 10 and 20 km.h^{-1})



Overview of the meteorological results (2/2)

Local scale PSWIFT wind module at 11 pm (local time) over Nice domain (left) and city center (right)

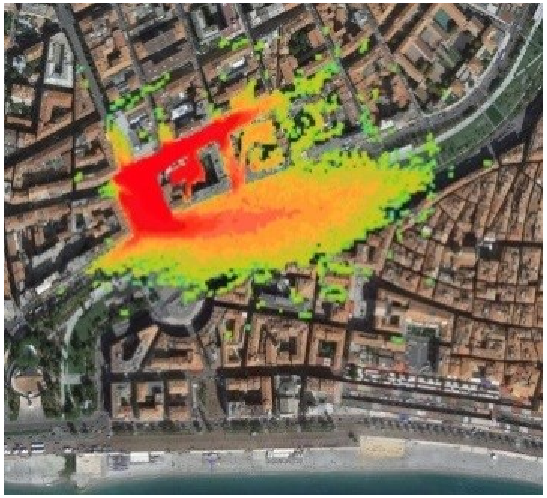
(full view and zoom-in in the DN domain at 1-m horizontal resolution at 1.5 m AGL)
(views are produced from the 3D PMSS results as juxtaposed and multiscale series of tiles)

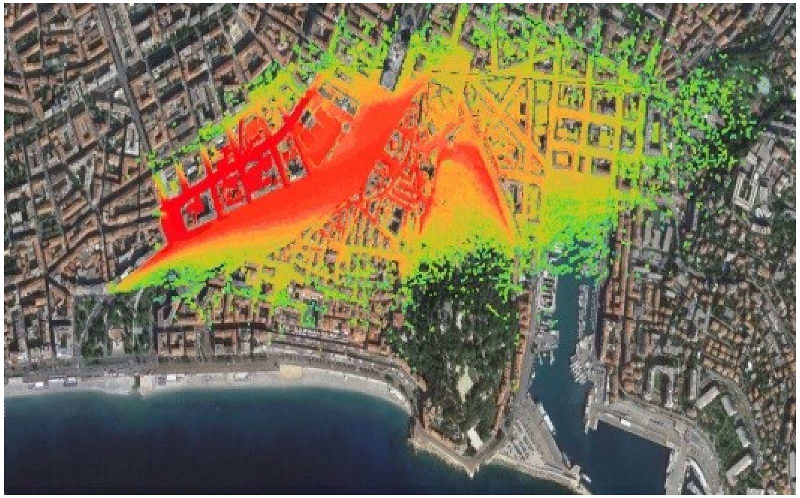


Overview of the dispersion results (1/2)

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 academic meteorological input – PSPRAY concentration field at 1.5 m AGL)
(the images are multiscale tiles generated with the same technologies as for the wind field)
(scales are arbitrary from cold to warm colors, from the weakest to the strongest values)

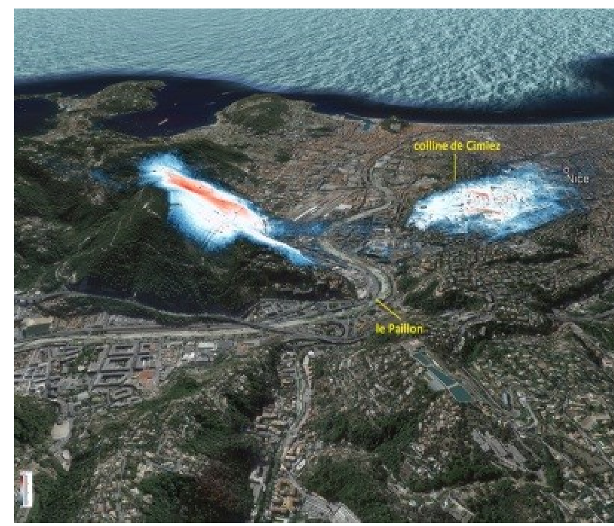




Overview of the dispersion results (2/2)

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)

(simulations using real meteorological input – PSPRAY concentration field at 1.5 m AGL with GE® underlying views)
(at the beginning of the release in Nice, the plume slowly moves to the South reaching the beach;
then, the wind shift makes the plume turning down to the North and the city center;
the wind direction keeps on evolving S to WSW with the plume hanging the hills in the center and East of Nice)
(scales are arbitrary from cold to warm colors, from the weakest to the strongest values)



Data about the computations

CPU print of PSWIFT and PSPRAY computation

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

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

Conclusions and perspectives

1) This paper summarizes the main features of EMERGENCIES Mediterranean "Big Challenge"
   a) Weather prediction at meso-scale over "PAFR" region downscaled to Marseille, Toulon and Nice cities
   b) Atmospheric transport and dispersion of hypothetical fictitious gaseous or particulate releases
   c) Efficient parallelization of PMSS to divide the huge (50-km edge) highly-resolved (3-m) domains in tiles
   d) Development of GIS and web technologies to visualize results on huge meshes (12.5 billion of nodes)

2) With 2,500 cores, met' forecast at urban metric resolution over Marseille can be provided each day for the next one and dispersions computed as necessary with a factor of five time acceleration and the 3D chain can be supplemented with CFD nested domains to evaluate indoor / outdoor transfers

3) Compared to EMERGENCIES "Big Challenge" over Paris and vicinity, the 3D modelling chain was one step closer to its operational generalization to entire vast regions (as e.g. "Auvergne-Rhône-Alps")

4) These multiscale computations are worldwide unique as they combine a huge geographical print with a metric resolution; they are not an exercise in style but mandatory to take account of intricate flow and dispersion patterns and provide detailed, reliable and realistic simulation results

5) Even if this project is 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

Questions?

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