A MULTI-SCALE MODELLING SYSTEM OPERABLE IN AN EMERGENCY

APPLICATION TO A FICTITIOUS ATTACK AGAINST A CRITICAL INFRASTRUCTURE

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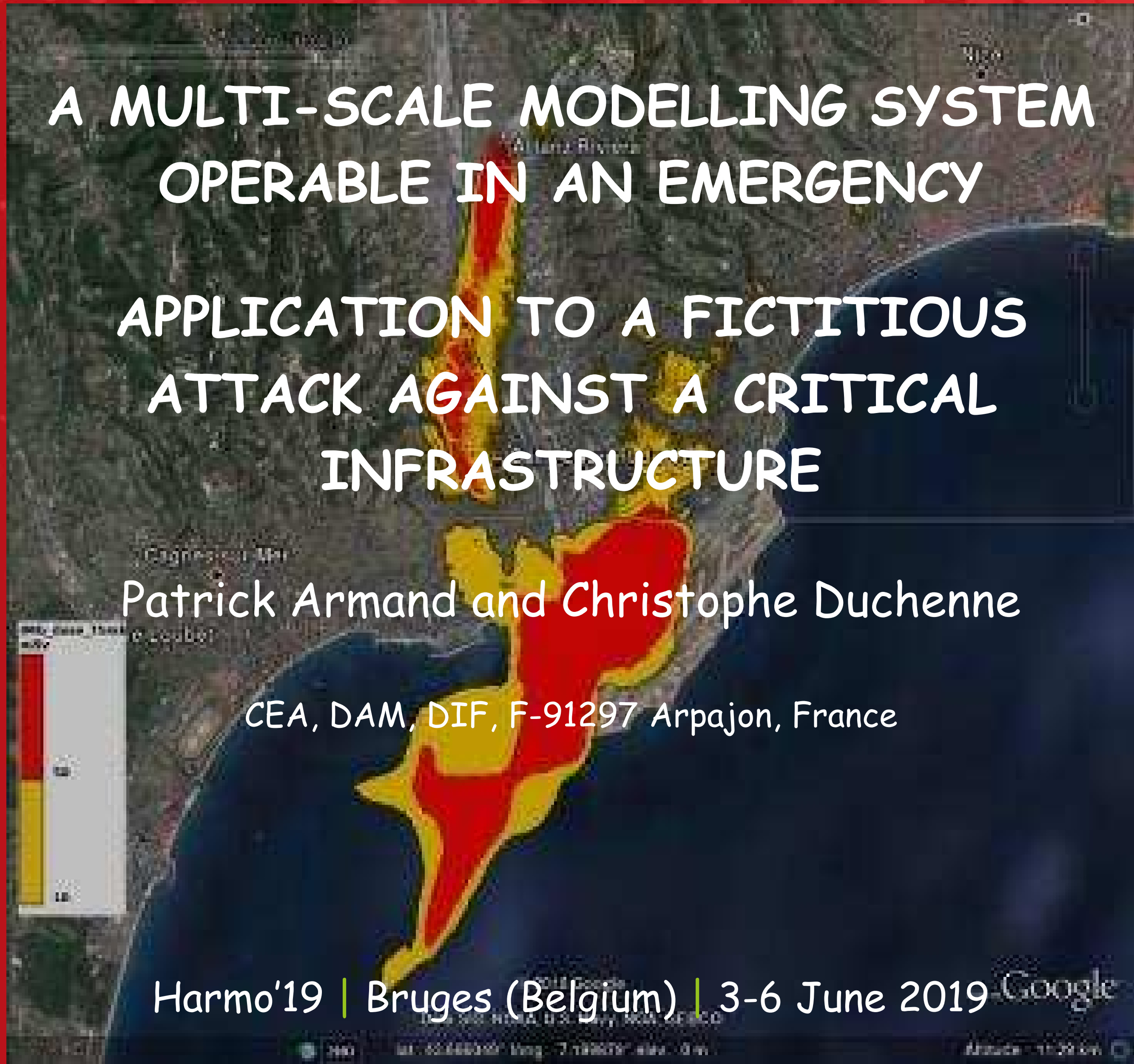

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INTRODUCTION – CONTEXT AND RATIONALE

- Accidents or malicious activities (terrorist attacks) may imply the release of hazardous materials into the air (threatening people health and the environment) and are more likely to occur in industrial or urban environments
- In the same time, modelling the flow and dispersion in built-up places is complex due to the influence of both the geography and the buildings geometry (in evolving meteorological conditions) and deserves a special attention
- Moreover, releases resulting from an industrial accident or a terrorist action are by essence poorly known and (several) simulations may be necessary from near the release point to the largest extent of the affected area
- These events are a major matter of concern for the rescue teams who need (as quick as possible) realistic and accurate (thus reliable) impact assessment of toxic releases to identify dangerous areas (and also safe areas)
- To address all these points, CEA has developed a multi-scale modelling chain with high space and time resolution for the flow and dispersion in view of producing results in a moderate time (given ad hoc computational resources)
- Outline – The presentation describes:
  1) The models embedded in the modelling system
  2) The simulations run and provided to the firefighters in the frame of a major emergency exercise
  3) The main lessons learnt from the exercise

WRF-PMSS-CS MULTI-SCALE MODELLING SYSTEM

- For the last ten years, we have developed and run a suite of models whose successive evolutions enabled the construction of a comprehensive multi-scale computational chain for atmospheric flow and dispersion

- This modelling system is based on WRF weather forecast model possibly using various global input data (NCEP, ECMWF, Météo-France…) and providing the wind flow to the highest resolution of 1 km and on Parallel-Micro-SWIFT-SPRAY (PMSS) introducing the topography and land-use at a finer resolution

- Micro-SWIFT-SPRAY has been developed to provide a simplified, but rigorous CFD solution of the flow and dispersion explicitly accounting for buildings presence in a moderate amount of time (Tinarelli et al. 2013)
  - ✓ SWIFT is a 3D mass-consistent diagnostic model providing the 3D fields of wind, turbulence, and temperature
  - ✓ SPRAY is a 3D Lagrangian Particle Dispersion Model also able to evaluate the deposition on accessible surfaces

- Brief history of (P)MSS evolution
  - ✓ Nesting capability of SWIFT and SPRAY to make downscaling and upscaling computations (Duchenne and Armand, 2010)
  - ✓ Efficient parallelization of SWIFT and SPRAY to deal with huge domains and reduce the CPU time (Oldrini et al., 2017)
  - ✓ Implementation of a momentum solver in PSWIFT to improve the 3D velocity and pressure fields (Oldrini et al., 2016)
  - ✓ Implementation of a canopy model and drag coefficient in PSWIFT to take account of the vegetation areas, etc.

- PSWIFT has been coupled with Code_SATURNE in order to simulate the flow both outside and inside buildings handled by PSPRAY to evaluate possible indoor/outdoor (and vice versa) transfers of harmful materials

- PMSS has been validated in particular in the frame of the COST ES1006 Action (Trini Castelli et al., 2018)

- The modelling system is generic and flexible as the calculation domains can be moved to any place in the world!

PRESENTATION OF THE EXERCISE SCENARIO

- Our modelling system was implemented as part of a civilian security exercise which took place on 8 March 2016 and consisted in the fictitious dispersion of a hazardous material in and out of a semi-open public infrastructure (weak explosion at 8:30 am UTC over a grandstand of the Allianz Riviera stadium located near the city of Nice)
- This situation has many tricky stuffs: release inside a complex built-up structure, the proximity of a crowded urban area in a coastal area with a mountainous hinterland making the weather situation difficult to predict

View of the Nice stadium (inner domain) and accesses to the stadium (supposed to be open during the event)

Woodlot coverage over Nice region (low percentages of woodlot coverage are light green and high percentages are dark green)

PRESENTATION OF THE SIMULATIONS

Footprints and characteristics of WRF and PSWIFT calculation domains (N02 is split in 7 x 5 tiles)

Local scale domains are not only urban but have a stiff landform with a drop of 1,000 m!

- Topography PSWIFT – BD ALTI at 75 m and RGE ALTI at 5 m resolution (National Geographic Institute – IGN)
- Vegetation data in N01 at 20 m res. (French Ministry of Ecology)
- Building data in N02 – BD TOPO (IGN) & Digital model of the stadium

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Model	Domain	Resolution (m)	Nr of hor. nodes	Nr of vert. nodes	Top of 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
PSWIFT	N01	75	401×401	31	3500
	N02	3	3001×2101	37	1500
	N03	1	401×401	55	1500

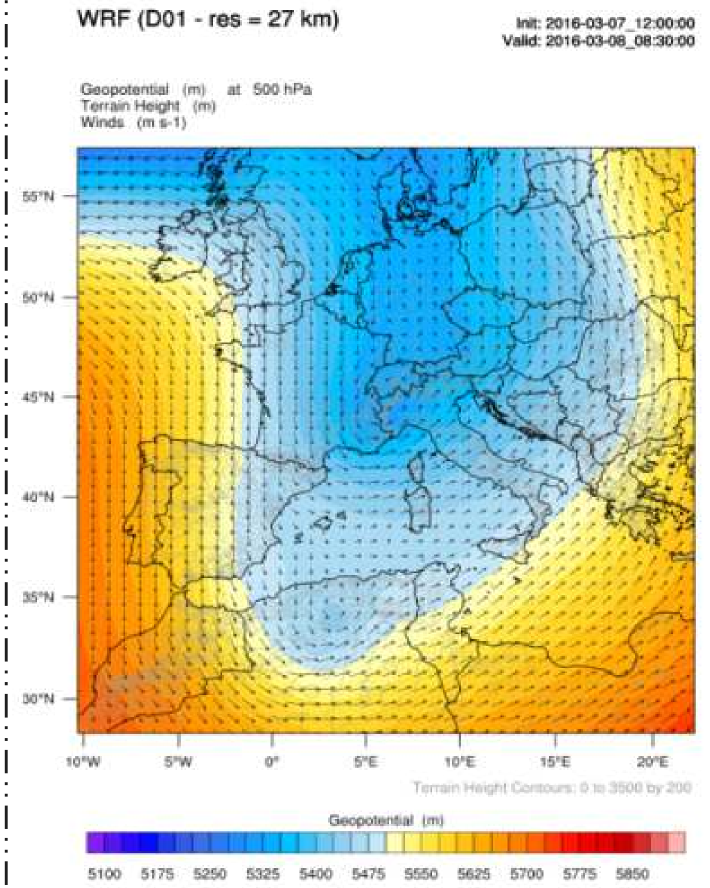
Synoptic weather report over France on 8 March 2016 (0830 to 1130 UTC)

An Atlantic ridge (highs off Spain and lows on Central Europe) generates a flux from the North to the South of France.

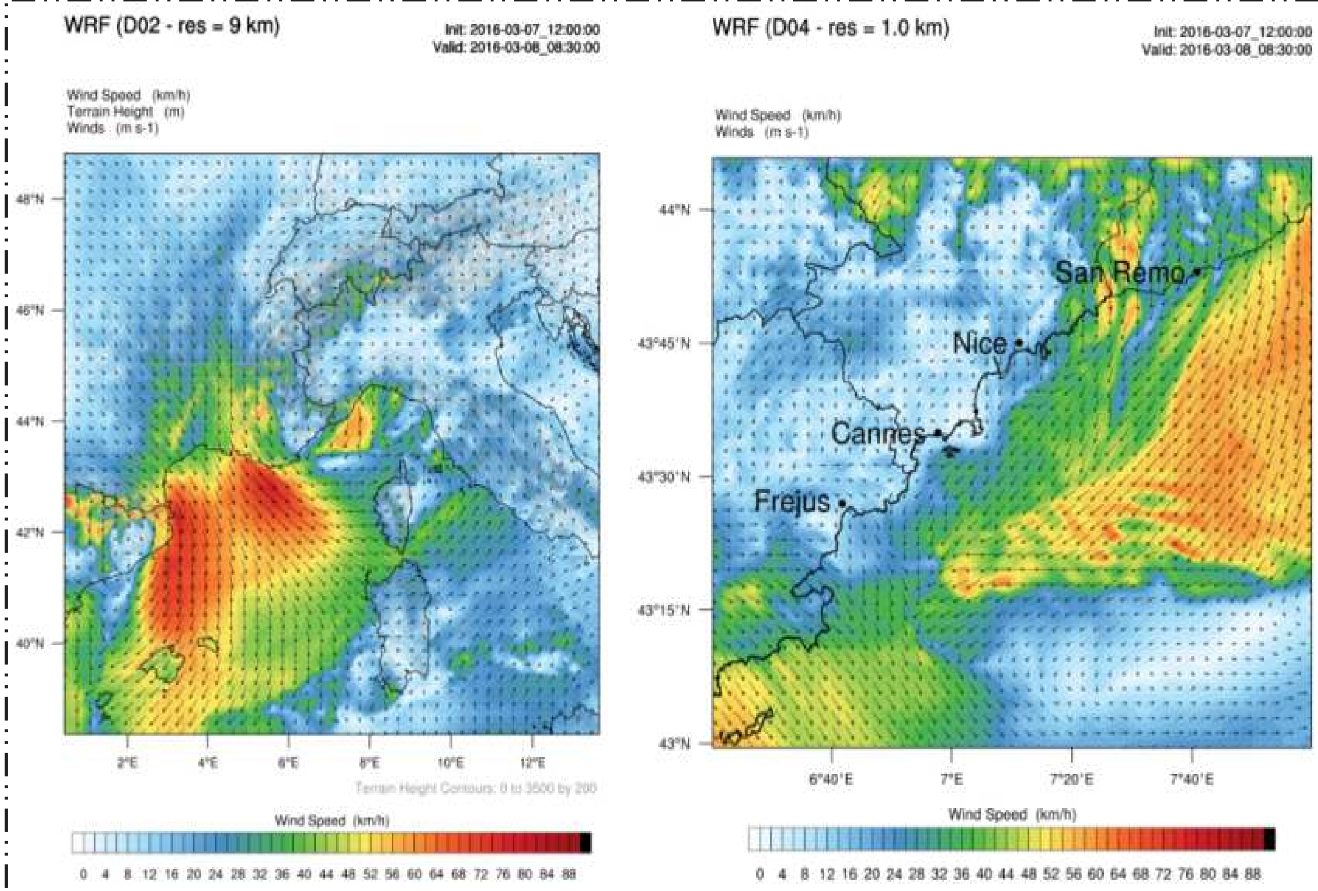
In the Southeast of France, the flux is channeled between the reliefs resulting in Mistral wind along the Rhône valley.

The wind strengthening over the Mediteranean sea and the presence of the Alps arc create a low over the Genoa gulf.

Warm air flowing to the Southwest off the Riviera meets the colder air flowing to the Southeast West of Nice city.



Wind field at 5,000 m and geopotential at 500 hPa in WRF domain **D01** at 0830 Z

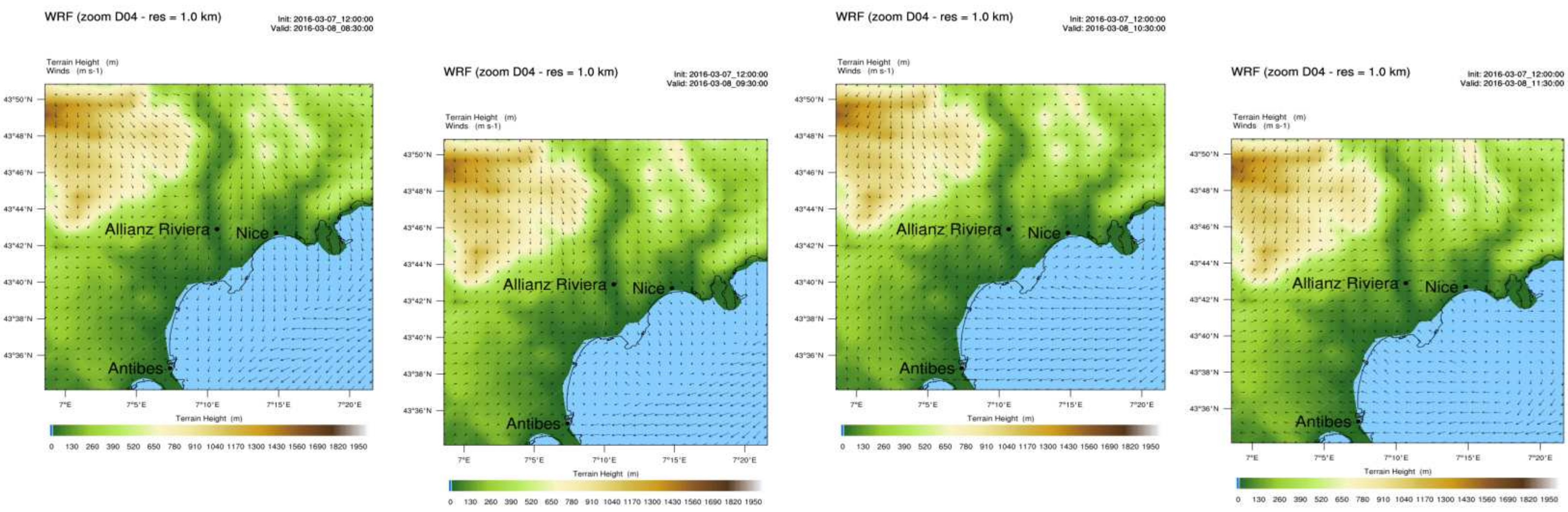


Wind field near the ground in WRF domains **D02** (left) and **D04** (right) at 0830 Z

… MULTI-SCALE WEATHER FORECAST (CONT'D)…

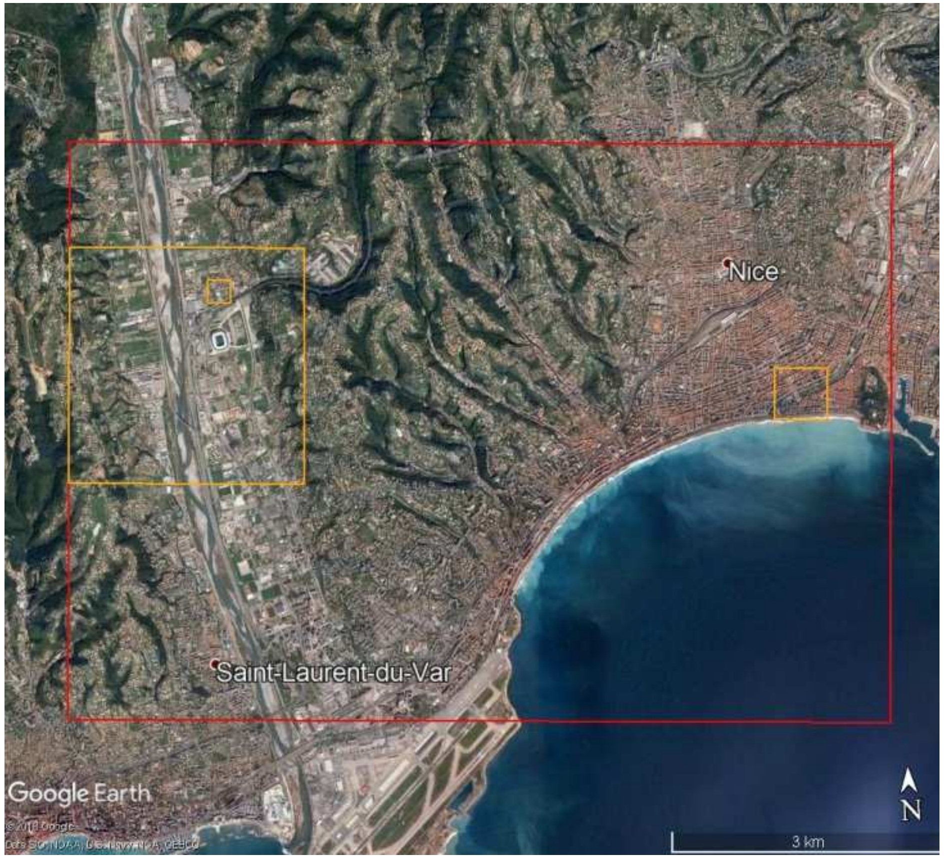
Weather report over Nice region on 8 March 2016 (0830 to 1130 UTC)

At 0830 UTC, the flow in the valley of the Var river, going alongside the Allianz Riviera stadium, is oriented from North to South and meets the Northeast flow from Liguria in the "bay of Angels", off Nice. At 0930 UTC, the wind speed in the Var valley weakens and the wind changes direction at sea North of Antibes city, with a flow directed from South to North (sea breeze). At 1030 UTC, the change in the wind direction also affects the area around the Allianz Riviera stadium, with a Southwest to Northeast directional flow orientating from the West to the East at 1130 UTC.

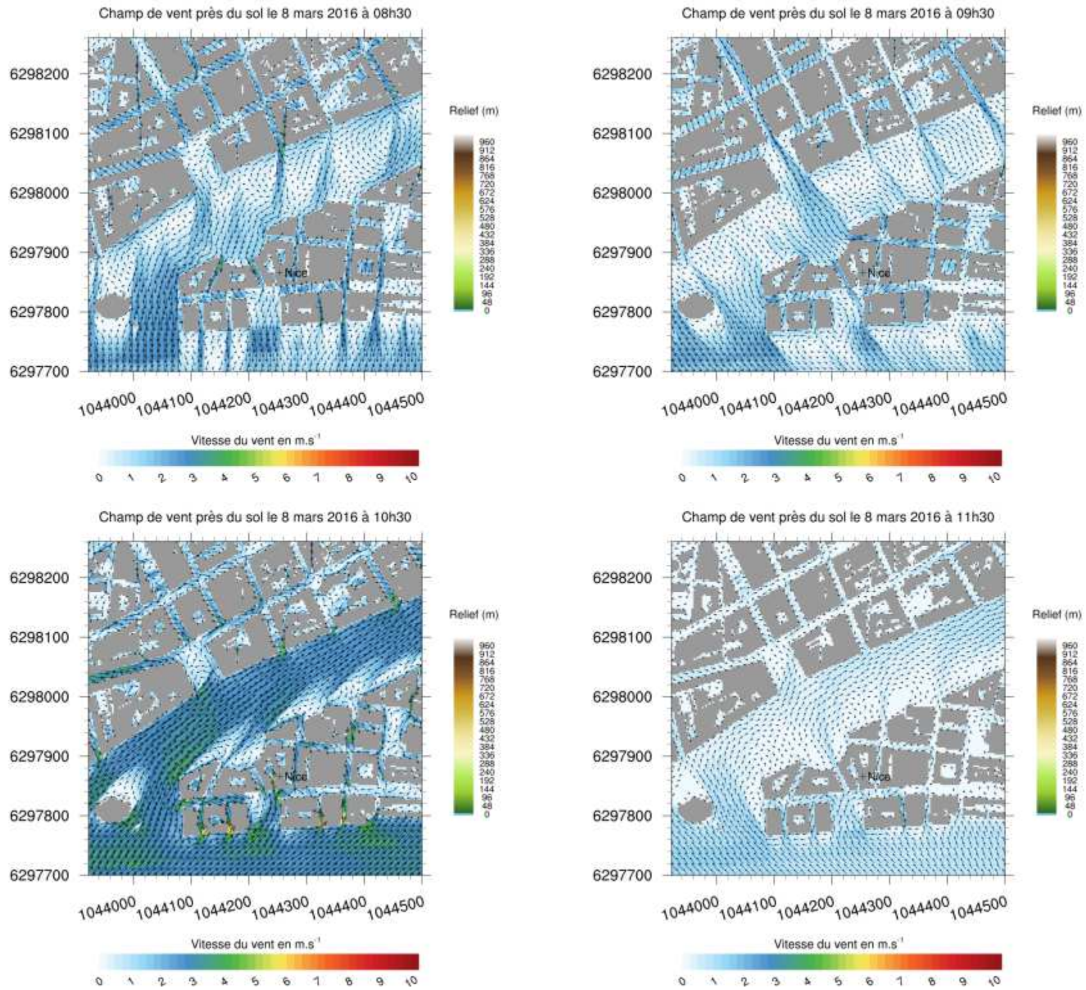


Topography and wind field near the ground (h = 15 m) in WRF domain **D04** (zoom on the Nice area) at 0830, 0930, 1030 and 1130 Z (from left to right)

The wind flow is computed at 3 m resolution in the streets of a large part of Nice city and suburbs combining the influence of the varying meteorological conditions and of all the buildings.



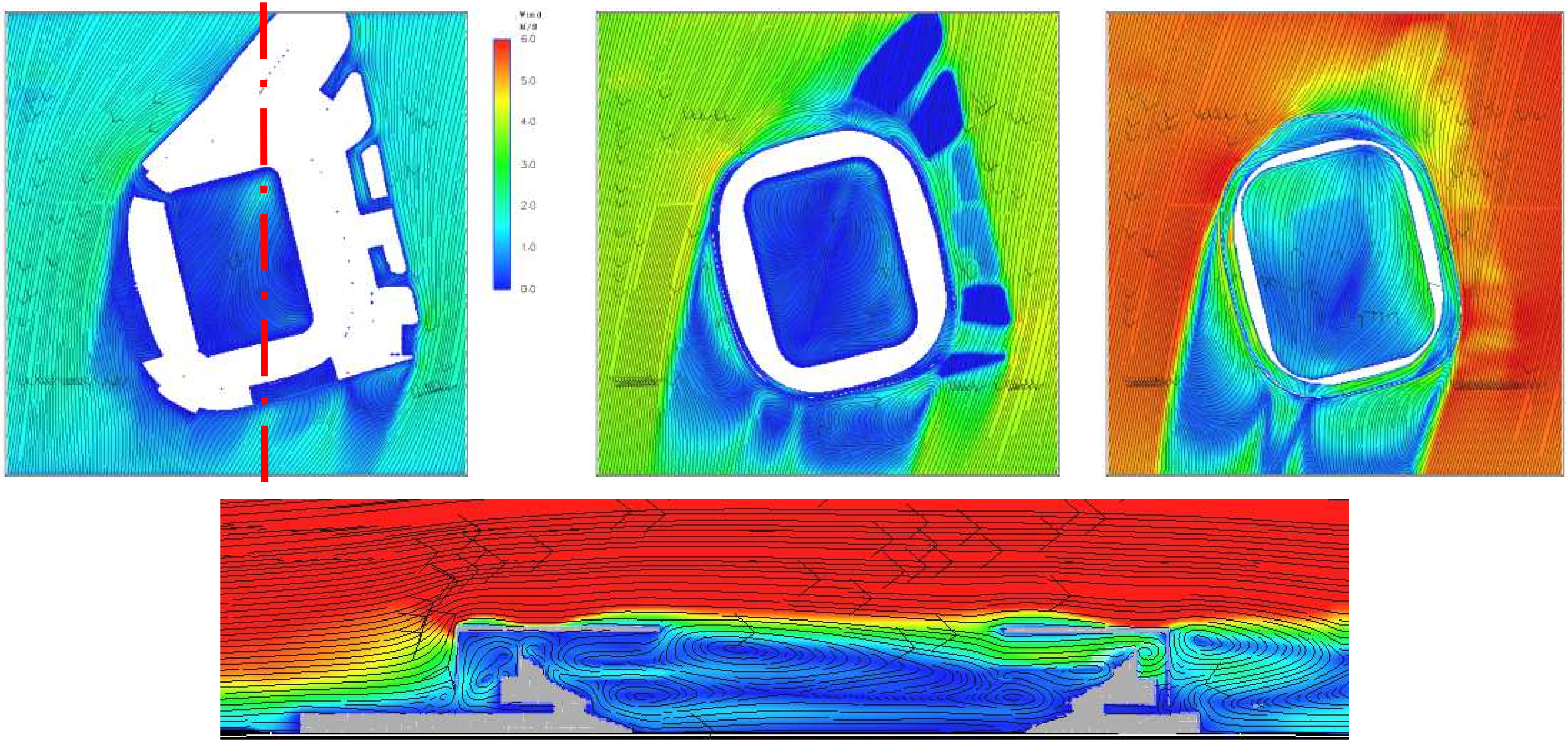
View of the PMSS domain **N02** (red rectangle) and zooms in around the Allianz Riviera stadium and Nice city center (Paillon promenade) (orange rectangles)



Wind field at high resolution in Nice city hypercentre at 0830, 0930, 1030 and 1130 Z

The flow computation inside and around the stadium is coupled with the local scale meteorological conditions

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 the creation of large vertical eddies above the lawn.



Horizontal and vertical cuts of the flow field in PMSS domain **N03** at 0830 Z. The horizontal cuts are presented at 4 m (middle of the lower rostrum), 13 m (middle of the intermediate stands) and 21 m (middle of the upper stands). The vertical section plane is indicated by the red line on the first illustration.

Concentration field near the ground in the three PMSS domains at successive time frames after the release (4 min, 12 min, 20 min, 40 min, 80 min and 120 min, top to bottom left to right)

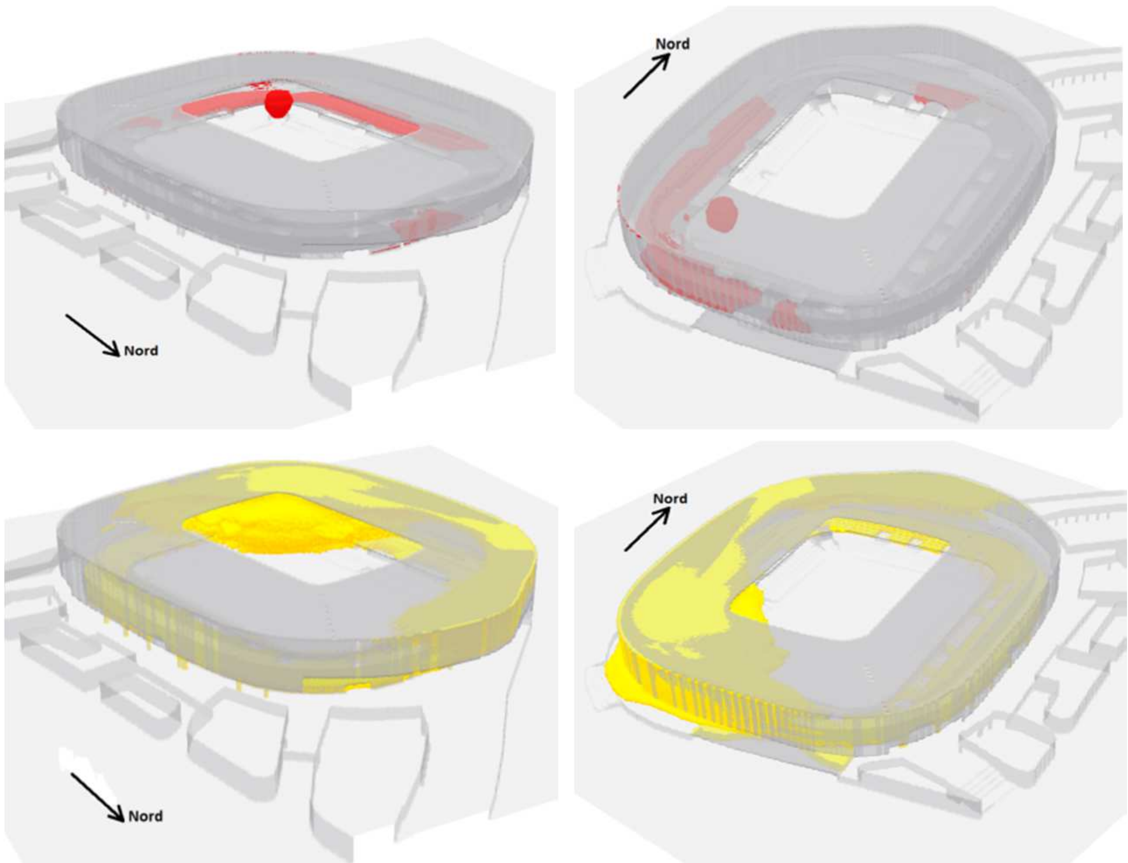
The release is still present in the stadium enclosure and in its immediate vicinity 80 minutes after the release!

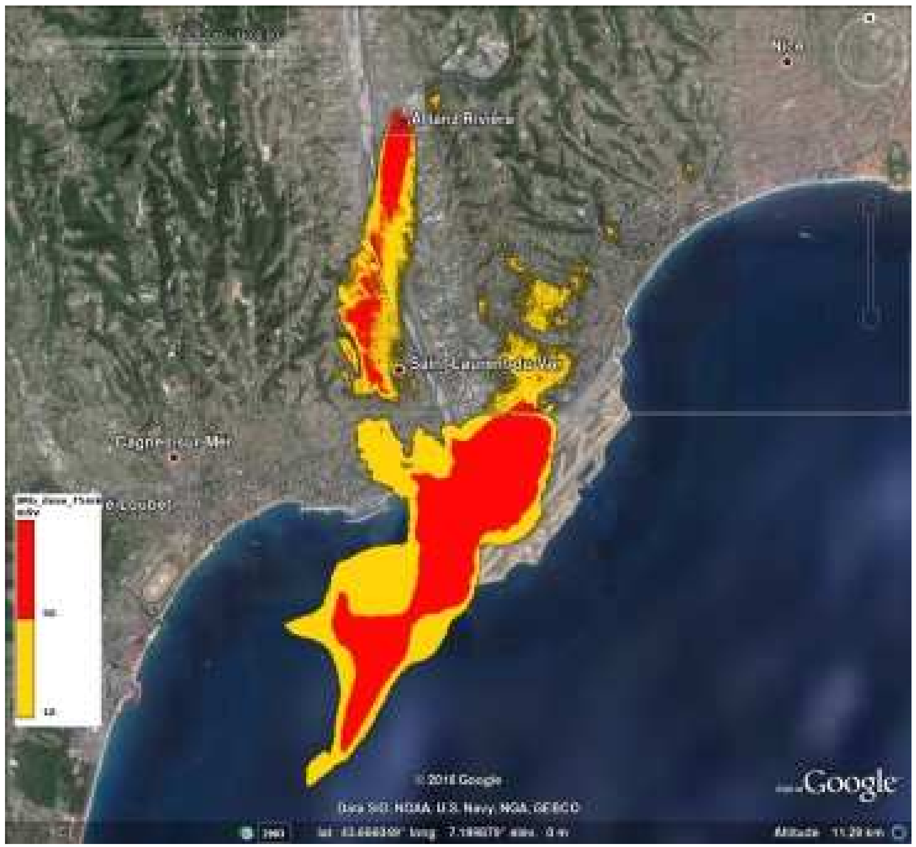
The part of the cloud that leaves the stadium is carried South-southwest and reaches the sea, West of Nice airport, around 30 minutes after the beginning of the release. Then, the wind over the sea stretches the plume in two opposite directions. A small part of the plume heads towards the Southwest (Antibes city) while the rest of the plume is driven towards the Northeast and passes over Nice airport, and further the neighborhoods of Nice close to the sea.

MULTI-SCALE HEALTH IMPACT ASSESSMENT

The impact assessment was performed for the release R of the exercise and for a larger release (R x 1,000).

For the release R, considering two typical threshold values, the consequences keep limited to the stadium enclosure.
In contrast, for the release R x 1,000, these thresholds are exceeded for kilometres far South from the stadium, close to Nice airport, where the plume stagnates during the turn of the wind direction.





View from the Northeast   View from the Southwest

Consequences regarding threshold values for health effects (in red and yellow) for two releases
Release R (left) and release R x 1,000 (right)

CONCLUSIONS AND PERSPECTIVES

- The test-case presented here achieves the twofold interest of demonstrating the state-of-the-art of a modelling system and applying it in real time for the purpose of a real civilian security exercise
- These multi-scale fine resolution computations are worldwide unique and not an exercise in style, but necessary to reliably estimate the health consequences on the population and the first responders in complex environments
- The nesting and parallelization of PMSS enable simulations on extremely large domains covering a whole city at metric resolution as in EMERGENCIES (Paris and Mediterranean) projects (Armand et al., 2017); moreover, coupled PSWIFT and Code_SATURNE allow to carry out precise simulations in and around buildings
- Thus, the plume may be simulated from the immediate vicinity of the source to a distance of several kilometers and visualized through a web service as presented in a companion poster (Oldrini et al., 2019)
- The results produced during the exercise were transmitted to the firefighters and the local state authorities and used by them in real time to identify the dispersion processes, communicate, share a collective view during the situation updates, adapt the first actions of the rescue teams and anticipate the event follow-up
- In the past years, our R&D effort in the field of atmospheric dispersion has not only focused on modelling, but also encompassed the transfer to operational applications and the adequacy of decision-support systems
- This approach has proven to be effective to promote the use of state-of-the-art 3D models by practionners, and increase the trust of the emergency players in modelling to diagnose and anticipate critical situations
- Even if today this activity 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 response!

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Thank you for your attention.

Questions ?

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