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# A NEW METHODOLOGY BASED ON 3D MULTI-SCALE MODELLING TO ASSESS THE IMPACT ON HEALTH AND THE ENVIRONMENT OF INDUSTRIAL FACILITIES

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**Abstract:** In real life, most of the industrial sites are located over rugged terrain and involve several buildings. As the assumptions underlying the Gaussian-type models are obviously not verified, these models should not be utilized to simulate the space and time distribution of pollutants released into the air from these sites and to evaluate their impact on the health and environment. Contrarily, impact assessement studies should leverage state-of-the-science 3D multi-scale flow and dispersion modelling systems. This paper presents the detailed meteorological characterization of the environment around a research center emitting atmospheric releases. The study is based on the meteorological meso-scale AROME model and micro-scale PNSWIFT model (inside the PMSS sytem). The hourly numerical results are compiled over the year 2018 to elaborate wind roses showing very large variations even at only some tens of meters from each other. This reveals the significant influence of the relief, land use and buildings on the regional and local flow, and subsequently on the atmospheric dispersion of the releases. While the impact assessment of the site will be presented in another paper, the interest of 3D multi-scale modelling is apparent from this study. Moreover, the method developed in the paper is of general application and a major breakthrough for the impact assessment.

***Key words:*** *3D multi-scale modelling, atmospheric flow and dispersion, impact assessment.*

## INTRODUCTION

Routine operations of industrial plants as hypothetical or actual accidents affecting them often result in respectively controlled or unwanted releases of gases or particles to the atmosphere. Thus, it is of utmost importance to evaluate the space and time distribution of the pollutants emitted by the industrial facilities in order to verify their compliance with the environmental regulation and their harmlessness to health in normal conditions or to estimate their health impact on the surrounding population in adverse conditions.

Still nowadays, Gaussian-type models are commonly used to evaluate the dispersion of pollutants. Yet, such simplistic models may be inappropriate to properly and rigorously assess the impact on health and the environment of industrial facilities as shown for instance in the framework of the COST Action ES 1006 (Armand et al., 2015; Baumann Stanzer et al., 2015). Contrarily, 3D models provide a better insight into the consequences of normal and accidental atmospheric releases (Armand et al., 2014, 2016, 2017, 2019). Thereupon, we have developed a generic and flexible high resolution modelling system cascading up and down from the meso-scale to the local scale and from outside to inside plants (or vice-versa).

This paper presents an original application of our 3D modelling system to check that the normal operating conditions of the facilities at a research center do not have any impact on health and the environment. This research center has a large number of buildings and it is located on a plateau surrounded by a rugged terrain. Such complex features are common in real environments and they substantially depart from the assumptions underlying the use of the Gaussian models. Thus, 3D modelling is anticipated to provide a more realistic and more reliable characterization of the flow and dispersion around the research center.

For the sake of brevity, the paper focuses on the meteorological study of the research center environment, hereafter called “the site”. Of course, this is only the preliminary step in the consequences evaluation of the site activities. But as such, it is valuable to underline the role of 3D modelling in the field of impact assessment. The subsequent sections of the paper give details about the multi-scale meteorological study.

## PRESENTATION OF THE STATIC DATA

3D modelling has the great advantage to account realistically for the environment. In this respect, it is necessary to generate a 3D digital mock-up gathering the main features of the site at the local scale.

The simulation domain has horizontal dimensions of 13 km x 14 km. The numerical model of the terrain is issued at a resolution of 5 m by the French National Geographical Institute (RGE ALTI®). The hilly landform is characterized by a central plateau at a maximum altitude of 500 m with quite deep valleys at a minimum altitude of 300 m (**Figure 1**). The vegetation data are available at a resolution of 20 m on the internet site of the French Ecology Ministry (**Figure 2**). The height of the trees is one of the parameters of the canopy model at the local scale. It is found in the ECOCLIMAP-SG data base of Météo France.

The buildings present on the site are distributed among two domains (high part and low part of the site). Buildings are also considered in four villages located between 3 and 7 km from the site. These villages are explicitly modelled as measurement stations used for the environment monitoring are set up there.

## PRESENTATION OF THE METEOROLOGICAL MEASUREMENTS

The site is equipped with a meteorological mast measuring every minute the wind speed and direction at 10 m and the air temperature at 2 m above the ground. **Figure 3** shows the wind rose by sectors of 10° elaborated with the data of the year 2018 (the availability rate is 96%). Over all velocities, the 250° sector has the larger occurrence (more than 5%) followed by the 0° sector (about 5%). Over all directions, winds less than 1 m/s have an occurrence of 14%, winds between 1 and 3 m/s of 55%, winds between 3 and 8 m/s of 23%, winds between 5 and 8 m/s of 7% and winds more than 8 m/s of 1%.

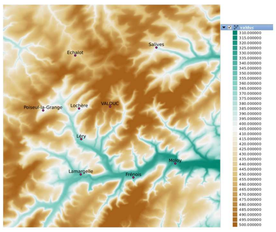

**Figure 1.** Site topography.

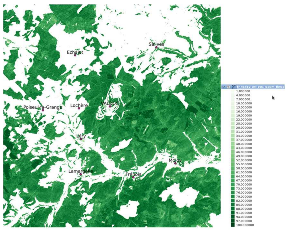

**Figure 2.** Site tree crown cover.

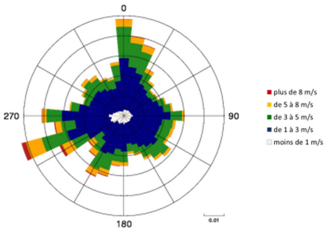


**Figure 3.** Site wind rose 2018.

## MESO-SCALE METEOROLOGICAL STUDY

AROME is a Météo France high resolution atmospheric model providing weather forecast with a lead-time of 36 hours refreshed five times per day. AROME hourly data projected on a regular mesh with a resolution of 0.025° are available on internet and archived for the site considered in this study. At the latitude of the site, the resolution is about 2.7 km and 1.9 km in the respectively SN and WE directions. **Figure 4** shows the locations of the 9 x 5 = 45 points of the AROME grid over the domain of 13 km x 14 km centered on the site. AROME data are computed at 25 levels between the ground and 3,000 m.

Wind speed and direction have been compiled along the year 2018 to establish wind roses in 5 velocity classes and 36 direction classes (like for the wind rose of the mast) at each point of the AROME grid. On **Figure 5** and **Figure 6**, the roses are drawn at heights of respectively 1,000 m and 10 m. At 1,000 m, the roses are identical showing winds blowing from the SW and the NE. This is clearly not the case at 10 m where the topography has a local and regional influence on the wind regimes. First, the velocity at 10 m is weaker on average than at 1,000 m. Then, none of the 45 roses at 10 m has a form similar to the roses at 1,000 m. The wind velocity is weaker on average at the S and E forested areas compared to the N and E more open areas of the domain. Furthermore, the main wind directions may significantly vary even inside the simulation domain, which extends only some tens of $km^2$ around the site.

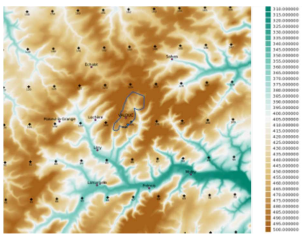

**Figure 4.** AROME grid points.

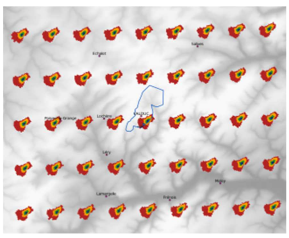

**Figure 5.** Wind roses at 1,000 m elaborated with AROME data.

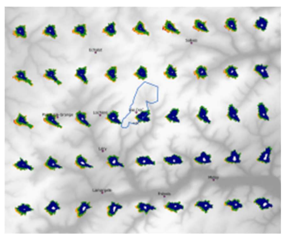

**Figure 6.** Wind roses at 10 m elaborated with AROME data.

As some valleys around the site have a width of 1 km of less, it is not obvious that they are correctly resolved at 0.025°. Thus, supplementary simulations have been carried out using WRF meteorological model. Yet, it has been observed that WRF had a systematic bias of wind velocity overprediction while AROME results were more consistent with the measurements at the mast (see in the paper below). Accordingly, it was decided to use AROME meso-scale numerical data in the following of the study.

## MICRO-SCALE METEOROLOGICAL STUDY

The horizontal resolution of the meso-scale flow computations is around 1 km. Indeed, it is not enough to assess the dispersion and impact of pollutants around and in-between buildings. Thus, the AROME hourly results (wind, temperature, humidity…) have been downscaled for the whole year 2018 using the PMSS modelling system which combines PNSWIFT and PSPRAY (Tinarelli et al., 2013). PNSWIFT is a 3D diagnostic flow model interpolating between meso-scale numerical data, measurements and analytical solutions of the flow where it is influenced by buildings. PSPRAY is a 3D Lagrangian Particle Dispersion Model. PMSS benefits from an efficient parallelization (Oldrini et al., 2017; 2019) and it was thoroughly validated against wind-tunnel and in-field trials (Trini Castelli et al., 2018; Oldrini and Armand, 2019).

**Figure 7** illustrates the PNSWIFT 13 km x 14 km domain centered on the site with a resolution of 20 m, and six nested domains at a resolution of 2 m, where the buildings are explicitly accounted for. Two built domains encompass the high part and low part of the site and four domains correspond to villages around the site, where devices are set up for environmental monitoring. Micro-scale computations in the villages aim at identifying a potential influence of the buildings on the measurements performed at these places.

**Figure 8** shows the wind roses 10 m above the ground at the closest to the location of the meteorological mast PNSWIFT grid points. The wind roses are elaborated using all hourly PNSIWFT results of the year 2018 in the domain at a resolution of 20 m. The influence of the vegetation can be seen in the forested areas where the proportions of weak winds are higher compared to open terrains. The roses differ in shape even at distances of only tens or hundreds meters from the mast. While the three main wind originating directions (W, NE and SE) of the AROME data are retrieved near the mast, they are replaced by SW and NE directions at 200 m E of the mast or by W and E directions at 250 m NE of the mast.

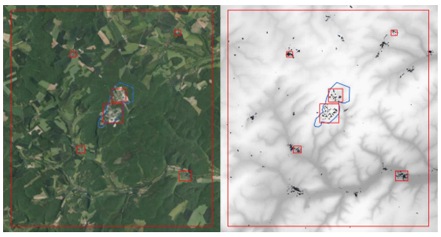

**Figure 7.** PNSWIFT simulation domains.

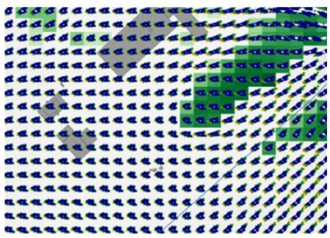

**Figure 8.** PNSWIFT wind roses at 10 m for 2018.

**Figure 9** shows the 10 m height wind field in the 20 m resolution domain at two timeframes chosen as examples of contrasted meteorological situations. **Figure 10** and **Figure 11** show the 2 m height wind field at the same timeframes in the 2 m resolution domains covering respectively the high part of the site and the village around the site. The influence of the buildings on the wind speed and direction is obvious. On the site, the buildings are at distances from each other large enough that their wakes do not interact. Contrarily, the old buildings in the village are close to each other inducing a more complex wind flow.

## COMPARISON OF THE AROME RESULTS WITH MEASUREMENTS

AROME data at the closet to the meteorological mast grid point have been systematically compared with the observations on the mast at 10 m above the ground. **Figure 12** attests the consistency between the wind speed and direction computed by AROME and the measurements for one three day period chosen at random. Yet, the comparison is between the hourly outputs of the model and high frequency observations. To get more comparable data, “minute” measurements on the mast have been averaged over one hour.

**Figure 13** shows the distribution of the gap between the AROME wind direction results near the mast and the one hour averaged wind direction measurements on the mast for all data along the year 2018. Across all wind velocity classes, the average gap is +6.9° not depending on the wind velocity but depending on the wind direction, perhaps due to the influence of neighboring obstacles.

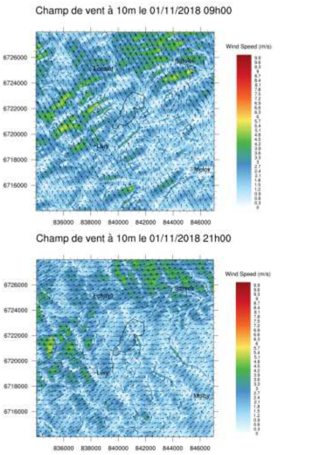


**Figure 9.** PNSWIFT wind field at 20 m resolution on 1 Nov. 2018 at 9 and 21 LT.

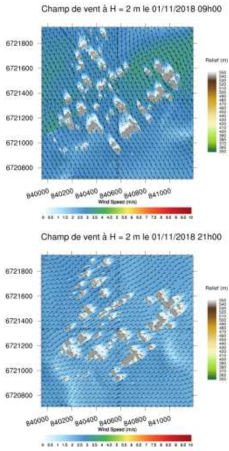


**Figure 10.** PNSWIFT wind field at 2 m resolution on 1 Nov. 2018 at 9 and 21 LT (high part of the site).

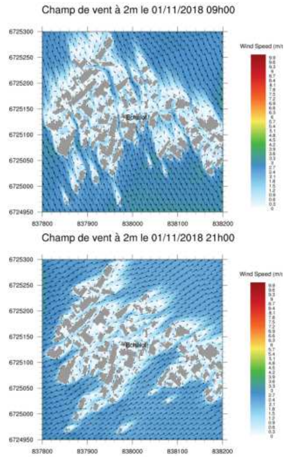


**Figure 11.** PNSWIFT wind field at 2 m resolution on 1 Nov. 2018 at 9 and 21 LT (village with a monitoring station).

**Figure 14** shows the distribution of the gap between the AROME wind velocity results near the mast and the one hour averaged wind velocity measurements on the mast for all data along the year 2018. Across all wind velocity classes, the average gap is only +0.02 m/s, what proves the agreement of the AROME computations and the observations. However, it is worth noticing that weak (high) wind velocity results are overestimated (underestimated) by AROME. This could be explained by respectively the insufficient horizontal resolution of the model which can only partly reproduce the local features of the flow and the hourly temporal resolution of the model which tends to average the highest wind velocities.

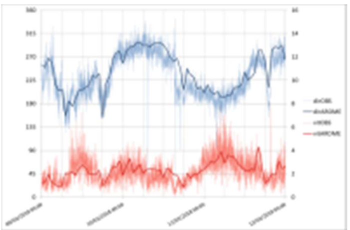

**Figure 12.** Wind speed and direction computed by AROME and measured on the mast.

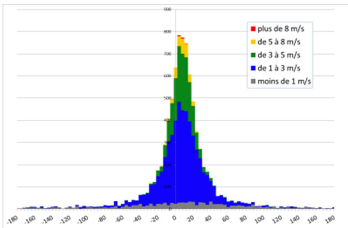


**Figure 13.** Gap between wind directions: AROME results versus one hour averaged measurements on the mast.

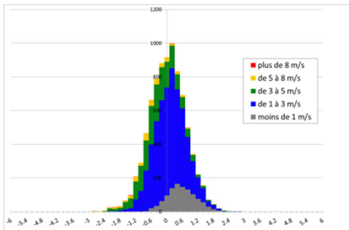


**Figure 14.** Gap between wind speed: AROME results versus one hour averaged measurements on the mast.

## COMPARISON OF THE PNSWIFT RESULTS WITH MEASUREMENTS

PNSWIFT data at the closet to the meteorological mast grid point have been systematically compared with the observations on the mast at 10 m above the ground. **Figure 15** illustrates the evolution of the wind speed and direction computed by PNSWIFT and of the measurements for the same three day period chosen in Figure 12. The wind direction in particular as the wind speed match the observations very well.

**Figure 16** shows the distribution of the gap between the PNSWIFT wind direction results near the mast and the one hour averaged wind direction measurements for all data along the year 2018. Across all wind velocity classes, the average gap is +7.8°. In comparison with AROME results, the PNSWIFT simulations at the resolution of 20 m improve the wind direction prediction versus the observations for winds stronger than 3 m/s ; yet, the prediction is not improved for winds less than 1 m/s.

**Figure 17** shows the distribution of the gap between the PNSWIFT wind velocity results near the mast and the one hour averaged wind velocity measurements for all data along the year 2018. Across all wind velocity classes, the average gap is slightly negative -0.72 m/s, what demonstrates the agreement of the PNSWIFT computations with the observations. In comparison with AROME results, the weak winds are better predicted by PNSWIFT, but it is not the case for the strong winds. Over the whole simulation domain, PNSWIFT spatial refinement allows better accounting of the topography, what leads notably to local reductions of the wind velocity. Yet, as PNSWIFT exploits the larger scale AROME data, the same effect of hourly average seems to slow down the strongest winds.

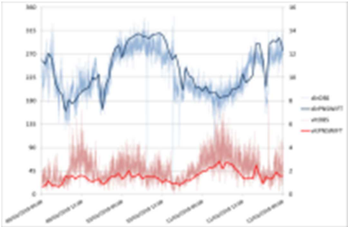

**Figure 15.** Wind speed and direction computed by PNSWIFT and measured on the mast.

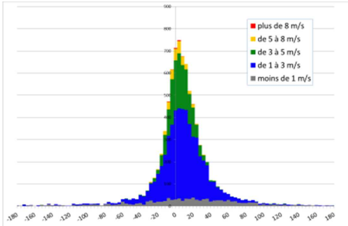


**Figure 16.** Gap between wind directions: PNSWIFT results versus one hour averaged measurements on the mast.

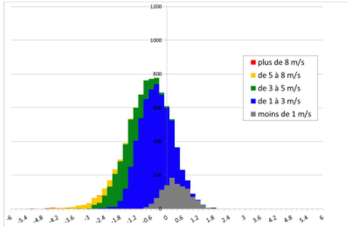


**Figure 17.** Gap between wind speed: PNSWIFT results versus one hour averaged measurements on the mast.

## CONCLUSIONS

Studies for regulatory purposes must be carried out to evaluate the impact of atmospheric releases on the environment and human health. Most of these studies still rely on Gaussian-type dispersion models. Yet, most of the facilities emitting gases or particles into the air in normal operation or in case of an accident are characterized by complex environments inducing local or regional effects which cannot be accounted for by Gaussian models and request a 3D modelling approach. This is precisely the case of the research center considered in this study as an example. The 3D digital mock-up of the site has been developed using high resolution static data (relief, land use, buildings…). All buildings in the research center have been integrated as the buildings in the villages around where devices monitor the environment.

The paper sums up the detailed regional and local meteorological study of the site as it is the crucial step preceding dispersion simulations and impact assessment of the atmospheric releases. The meteorological conditions are reconstructed for a full year at hourly resolution with the WRF and AROME meso-scale models and downscaled with the PNSWIFT flow model inside PMSS modelling system. At micro-scale, the flow in the atmosphere is resolved at 20 m in the 13 km x 14 km domain and at 2 m in the nested built up domains. Annual wind roses are drawn at each model grid points enlightening large discrepancies even for neighboring points due to the presence of narrow valleys, wood areas adjacent to open terrains, and dense or sparse built areas. Finally, it has been checked that AROME and PNSWIFT results satisfactorily compare with the measurements averaged over one hour at the meteorological mast set up on the site.

This study confirms the interest to leverage weather models to correctly account for site effects emerging at meso-scale and, even more, at micro-scale. 3D flow simulations are essential to predict the space and time distribution of pollutants and assess their harmlessness as will be shown in an upcoming paper.

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