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A COUPLING BETWEEN RANS CFD AND STOCHASTIC LAGRANGIAN MODELLING FOR LONG TERM IMPACT ASSESSMENT ON AN INDUSTRIAL SITE.

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Abstract: Industrial and consulting companies performed impact assessment studies of atmospheric pollutant dispersion to ensure that the concentrations around each industrial release are below the regulatory thresholds. Industrial sources are located inside a site of complex geometry with topography and various obstacles so that simple modelling approaches based on Gaussian models or using a flat rough terrain assumption are not relevant. Therefore, CFD approaches, with RANS or LES turbulence modelling, are now commonly used to simulate flow and dispersion in complex industrial or urban areas. However, for long term impact assessment, the direct application of the CFD approach is still computationally prohibitive using the typical IT resources of consulting offices or environment and safety departments.

In order to address this issue, a specific simulation approach has been developed, based on the coupling between a CFD pre-calculated wind field database and a stochastic Lagrangian dispersion model (SLAM – Safety Lagrangian Atmospheric Model). The wind field database is calculated for an ensemble of triplets of parameters representing the variety of meteorological conditions. Considering the probability of occurrence of each situation in the meteorological time series, it is possible to simulate the PDF of the concentration values and to calculate all the statistics (mean, percentiles, probability of exceedance) on a real complex site.

This modelling methodology has been applied to evaluate long term dispersion around nuclear power plants. To validate the approach, specific measurements on a realistic reduced scale model of a nuclear site have been performed in the atmospheric wind tunnel of the Ecole Centrale de Lyon. The comparison between the model and the experiment highlights the performance and capability of the model and the differences are discussed and analysed to suggest further developments and improvements of the approach..

Key words: *chronic pollution impact, CFD, Lagrangian dispersion.*

INTRODUCTION

In this short presentation we will give an overview of a methodology developped throught the last years and currently used by industrial company for long term impact assesment on their site. Until recently, impacts of chronical releases were eveluated by the mean of gaussian model. The short time response of such models allows users to compute the impact of each hour sample taken from long time sequence of hourly meteorology, which means more than 40000 simulations for a 5 years range, in less than a few hours. However, main weakness of gaussian approaches are their bad capacities to correctly take into account real complex obstacles and realistic topography. Nuclear power plants sites are caracterised by numerous obstacles and buildinds, and sometimes complex orography as well. It’s therefore quite logical to consider more pefected simulations tools, built on 3D detailed flow representation, to better represent dispersion phenomena. CFD approaches, with RANS or LES turbulence modelling, are now commonly used to simulate flow and dispersion over industrial aeras giving a response in a few hours for a particular wind condition. However, the compuation cost is still prohibitive for engineering purposes because long term impact requires hundreds of thousand CPU hours to be computed. The aim of our methodology is to drastically reduce compution time by the means of two innovations : on one side the storage of a CFD database to eveluate a full realistic 3D windfield used as an eulerian input in a lagrangian particles dispersion model and on the other side the reduction of the number of simulations by a meteorological classification approach. The next section globally describes these methodology called AST&Risk

(Atmospheric Simulation of Transport & Risk). Then we shortly introduce principles and validation of each part of the methodology before showing an exampe of application on a idealized nuclear site.

AST&RISK METHODOLOGY

The methodology has been implemented in the AST&Risk software platform presented in **Figure 1**. The main steps of the calculation methodology are the following:

- Meteorological preprocessing and classification: from a time series of sequential meteorological data, a meteorological preprocessing module is applied to determine the parameters. The classes are then formed and the frequencies of occurrence of the meteorological conditions of each class are determined.
- Performing SLAM simulations: based on the N meteorological classes and the release parameters, the platform controls the performance of N dispersion simulations with the SLAM software, by optimizing the use of the processors allocated to the calculation.
- Statistical post-processing of the results: using the frequencies of occurrence associated with each of the classes, the concentration fields are statistically aggregated in order to obtain the average and the concentration percentiles at each point of the domain.
- 3D visualization and export of results: the graphical user interface of the AST&Risk software allows a 3D representation of the results (iso-contours of concentration, isosurface) on a cartographic background (map, aerial photo).

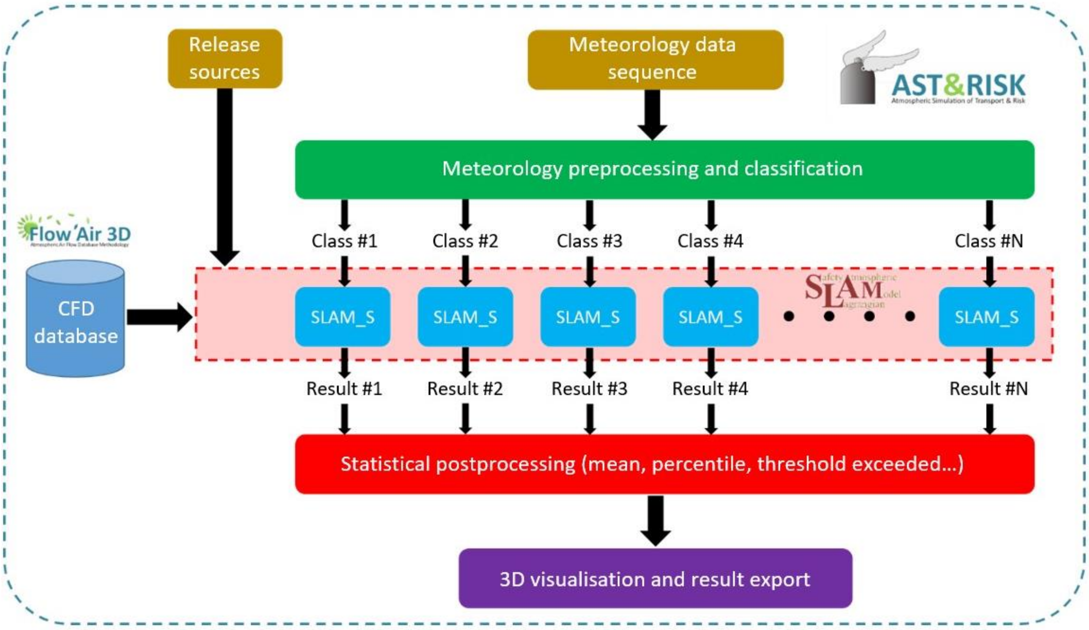


Figure 1. Overall diagram of AST&Risk methodology.

RANS CFD SIMULATIONS OF ABL AND LAGRANGIAN DISPERSION

The Safety Lagrangian Atmospheric Model (SLAM) is a stochastic particle dispersion model, based on the tracking of Lagrangian trajectories of individual particles. The temporal evolution of the Lagrangian velocity of each particle is given by two contributions :

$$U_i(t) = \overline{U_i}(t) + U_i'(t) \text{ with } U_i'(t+dt) = U_i'(t) + dU_i'$$

The first one, is the mean velocity of the flow obtained from the CFD velocity field. The evolution of second, the fluctuating velocity, is determined by the stochastic differential equation (Thomson, 1987):

$$dU_i' = a_i(X, U', t)dt + \sum_j b_j(X, U', t)d\xi_j$$

in which the terms a_i and b_j are expressed in terms of standard deviations of velocity fluctuations σ_{u_i} and of the Lagrangian times T_{L_i} calculated from the k-ε turbulence model:

$$\sigma_u = \sqrt{\frac{2}{3}k} \text{ and } T_L = \frac{2\sigma_u^2}{C_0\varepsilon}$$

SLAM model has been validated on several configurations (Vendel et al., 2011) and required reliable CFD fields that are obtained by the simulation of the surface boundary layer in neutral, stable or unstable stratification conditions (Vendel et al., 2010b).

DATABASE OF WIND FIELD

In a simulation of the flow and dispersion with a CFD model, an important part of the computing time is devoted to modelling the flow and turbulence field. The principle of our approach, illustrated on **Figure 2**, is to prepare in advance a database of wind fields on the considered industrial site. In this way, only the dispersion is modeled in operational situations and time savings are considerable. The parameters that constitute the database are the wind direction and the inverse of the Monin-Obukhov length. As it was shown by Vendel et al. (2010a), it is possible to overcome the wind speed by normalizing the velocity and turbulence fields by the friction velocity u_* (and the same kind of assumption is made for the temperature field normalized by using the potential temperature at ground level).

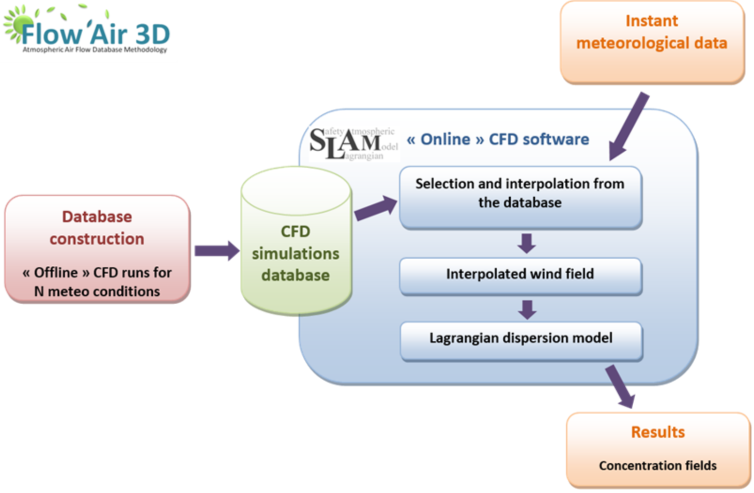


Figure 2. General desciption of Flow'Air 3D methodology.

Vendel et al. have also shown that a discretization of the database in 18 wind directions (step of 20°) and 7 values of $1/L_{MO}$ can limit the interpolation error in the database to a few percents (**Figure 3**). Once the database is ready, it is used as input for the Lagrangian model SLAM. In operational situations, a point meteorological data (measurement or forecast) is used in a meteorological preprocessor to estimate the wind direction, the inverse of the Monin-Obukhov length and the friction velocity u_*. These parameters are interpolated in the database to obtain wind, temperature and turbulence fields corresponding to the real atmospheric conditions. These fields are then used to model the dispersion with the SLAM Lagrangian model.

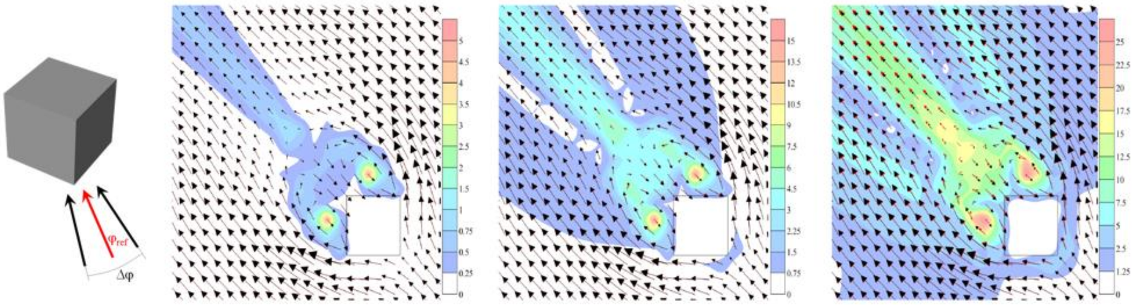


Figure 3. Validation of direction discretisation of the database approach. Comparison of velocity field between direct RANS calcultation and 3 interpolations with step angle of 5°, 10° and 20° from left to right. Colours show error levels.

METEOROLOGICAL CLASSIFICATION

In our methodology, building a CFD database of RANS simulations requires at the inlet boundary 1D horizontally homogeneous description of the ABL given by analytical profiles from Monin-Obukhov theory. We usually used profiles from Gryning et al (2007) and Truchot (2015) whose parameters are wind direction φ, friction velocity u_*, Monin-Obukhov L_{MO}, ground temperature T_0 and ABL height h_{ABL}. Those variables have to be deducted from measurements providing classically wind speed and direction, pressure, temperature and cloud cover. This is done by a meteorological preprocessing described by Soulhac et al (2011) and issuing from Fischer et al (1998). To reduce the number of parameters, choice is made to keep T_0 and h_{ABL}constant and equals to their average value on the long term sequence. A analysis of a few real meteorology data sequence in different places has given us a procedure to disctretize in class the parameters by comparison of pdf in a $(u_*, 1/L_{MO})$ coordinate system. We then validate this approach by comparison of average concentration from different sources at many distances obtain on one side by the classical sequential approach and on the other side by the classification method. Sensitivity studies have been done on the discretisation of each of the three parameters (φ,u_*, $1/L_{MO}$) and a example is given **Figure 4**.

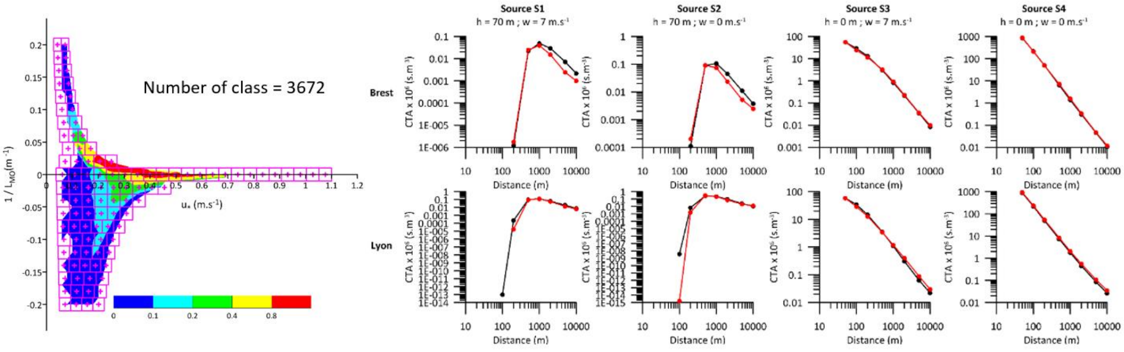
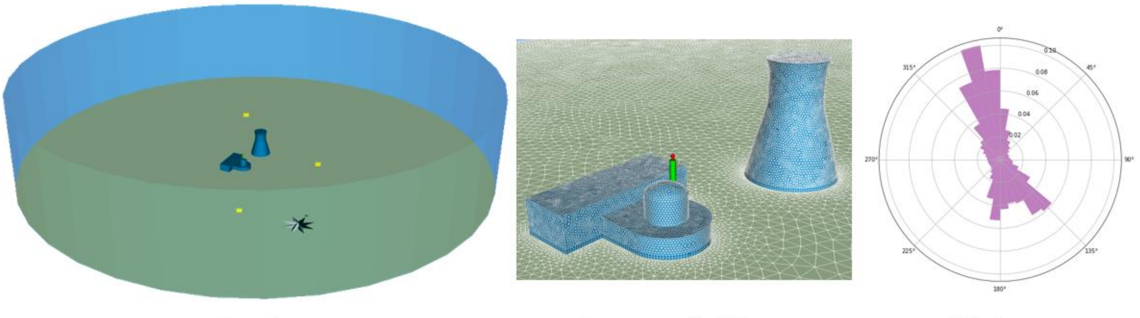


Figure 4. Validation of the classification approach. Left : illustration of class. Right : Comparison of concentration between sequential (black) and classification (red) for 4 differents sources in 2 different sets of 5 years meteorology.

APPLICATION

In order to illustrate the potentiality of the methodology without revealing confidential content a simplified domain containing typical power plant buildings is created and meshed before a CFD database of 126 wind conditions (18 wind direction times 7 Monin-Obukhov lenght) is computed and stored. **Figure 5** shows the cylinder shaped domain of diameter 2.5 km by 500 m height, and a zoom on buildings mapped with their surface mesh (1.1 millions cells in the volume). Then, in a second step, a fictive chimney source is placed closed to the reactor building (green cylinder with red arrow at top in center of **Figure 5**) with arbitrary emission of 10 g.s^{-1} of CO (carbon monoxyde) and a five years long hourly meteorological data sequence is given to the tool (see the windrose obtained by analysis of these data on the right of **Figure 5**).



Domain Source and buildings Windrose

Figure 5. Configuration of the application case. Left: view of the computation domain. Center: zoom on buildings and the source. Right: Wind direction frequency occurence.

Classification methodology reduces the description of the meteorology variability to only 1620 classes and the corresponding lagrangian simulations are runned on a laptop with a single Intel Core i9 processor and 64.0 GB of RAM. Frequency occurences of each class is then used to computed concentration mean and percentiles fields. The whole dispersion process is achieved in less than 2.5 hours and some results are illustrated on **Figure 6** which shows isocontours of percentile 95 on ground and buildings. At three locations points, percentile repartition between 0.8 and 1 is also shown.

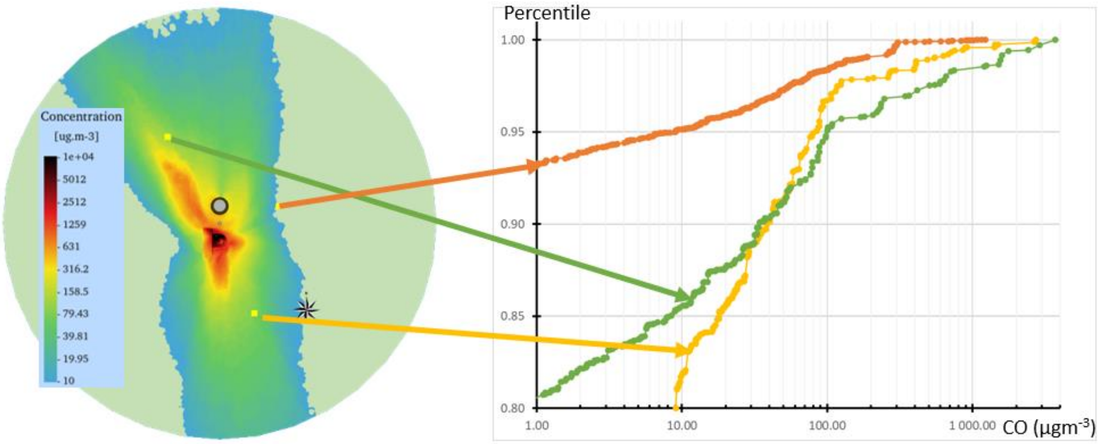


Figure 6. Cartography of percentile 95 and percentile repartition curve at three locations.

CONCLUSION

This presentation is a quick overview of a methodology developped during the last years by LMFA in collaoration with EDF-DIPDE. Improvements are regularly made on both software features and scientific content. Assumptions made by this method at each step (CFD computation, database interpolation, meteorological preprocessing and classification, Lagrangian simulations) leads to some limitations but remains also challenging as each step is perfectible to continue to improve the response quality without degrading the response time.

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