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EVALUATION OF A LAGRANGIAN DISPERSION MODEL COUPLED WITH A CFD WIND FIELD DATABASE AGAINST A NEW FULL SCALE ATMOSPHERIC TRACER EXPERIMENT

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Abstract: Improving and evaluating atmospheric dispersion models in the vicinity of obstacles and buildings are important challenges for application in the context of impact assessment of pollutants emissions in urban areas (traffic, heating, etc.) and for risk prevention and emergency response in case of industrial accidents or deliberate releases. More specifically, some radiological materials (e.g. fluorine-18 used for medical imaging) are produced and partially emitted in the atmosphere by cyclotrons located very close to urban hospitals. In order to characterize the dispersion in this context, the French institute for radiation protection and nuclear safety (IRSN) has performed a full scale atmospheric tracer experiment, using helium tracer, in the first 200 meters around a cyclotron (DIFLU experiment, 2019). The measured concentrations, for a variety of atmospheric stability conditions, constitute a new original dataset for the validation of atmospheric dispersion models at very short distance of a building.

In this paper, we compare the results obtained with the SLAM (Safety Lagrangian Atmospheric Model) model against the DIFLU experiment dataset. SLAM is a Lagrangian stochastic particles dispersion model (Vendel et al., 2011, Marro et al., 2014), coupled with a wind and turbulence fields database. This database, composed of 126 wind fields, is built from RANS (Reynolds Averaged Navier Stokes) simulations performed with ANSYS Fluent, a CFD (Computational Fluid Dynamics) code.

This study shows a good correlation between measurements and SLAM estimates and indicates that the use of such model may be relevant in near-field impact assessments in urban area.

Key words: *Atmospheric dispersion modelling, Lagrangian model-CFD coupling, Full scale atmospheric tracer experiment, DIFLU project.*

INTRODUCTION

Cyclotrons are particle accelerators used for the production of ^{18}F (fluorine-18) for medical applications. The number of clinical applications with this radionuclide increases since the 2000s. ^{18}F mainly decays by β^+ and has a half-life of about 110 minutes. During the production of ^{18}F by cyclotrons, a fraction of the quantity produced is released into the atmosphere (in a controlled way) when the installation is not equipped with a temporary gas retention device. Most medical cyclotrons are located in urban or peri-urban areas. Generally, near cyclotrons (< 200 m), radiological impact assessments consider a Gaussian dispersion of the plume in the atmosphere. Despite their limitations, Gaussian models are used because they require few input data and computer resources to be implemented.

In order to improve methodologies for impact assessments, the French institute for radiation protection and nuclear safety (IRSN) has performed a full scale atmospheric tracer experiment in the first 200 meters around a cyclotron (DIFLU experiment, 2019). The DIFLU project ”Dispersion du Fluor 18 en Milieu Urbain”- aims to study the near field dispersion of a gas emitted in an urban or industrial environment. The measured concentrations, for a variety of atmospheric stability conditions, constitute a new original dataset for the validation of atmospheric dispersion models at very short distance of a building. This dataset has been used to evaluate the SLAM (Safety Lagrangian Atmospheric Model) model, developed by LMFA (Laboratoire de Mécanique des Fluides et d'Acoustique). SLAM is a Lagrangian stochastic particles dispersion model (Vendel et al., 2011, Marro et al., 2014), coupled with a wind and turbulence fields database.

The first section introduces the modelling approach used with the SLAM model. The second section describes the measurement campaign. Then the third section presents the comparison of the numerical results against experimental dataset.

LAGRANGIAN MODEL-CFD COUPLING

Flow'Air 3D Methodology

Modelling atmospheric dispersion with a CFD model is computationally expensive. An important part of the computing time is devoted to modelling the flow and turbulence field. The principle of the Flow'Air 3D approach is to build in advance a database of wind fields for the considered site. Therefore, in operational situations, only the dispersion is modelled and time savings is considerable. The parameters that constitute the database are the wind direction and the inverse of the Monin-Obukhov length (L_{MO}^{-1}). Vendel et al. (2010) show that it is possible to overcome the wind speed by normalizing the velocity and turbulence fields by the friction velocity u^{*}. Vendel et al. (2010) also indicate that a discretization of the database in 18 wind directions (step of 20°) and 7 values of L_{MO}^{-1} can limit the interpolation error in the database to few percents. Once the database is built, 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^{*}. From these parameters, an interpolation is carried out based on the database to obtain a wind and turbulence field corresponding to the real atmospheric conditions. This field is then used to model the dispersion with the SLAM Lagrangian model.

SLAM

SLAM (Safety Lagrangian Atmospheric Model) 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 estimated with the equation:

$$U_i(t) = \overline{U_i}(t) + U_i'(t) \text{ with } U_i'(t+dt) = U_i'(t) + dU_i' \qquad (1)$$

where $\overline{U_i}$ is the mean velocity of the flow. The evolution of the fluctuating velocity U_i' is determined by the stochastic differential equation (Thomson, 1987):

$$dU_i' = a_i(\boldsymbol{X}, \boldsymbol{U}', t)dt + \sum_j b_j(\boldsymbol{X}, \boldsymbol{U}', t)d\xi_j \qquad (2)$$

where a_i and b_j are expressed in terms of standard deviations of the velocity fluctuations σ_{u_i} and of the Lagrangian times $T_{L,i}$. Once the cloud of particles has been transported using the previous equations, the concentrations/volume activity are calculated by dividing the sum of the mass/activity of all the particles present in a grid cell, by the volume of this grid cell. SLAM has been validated against wind tunnels experiments (Vendel et al., 2011) and has been used in several studies (Foucher et al., 2018, Armand et al., 2014, Marro et al., 2014, Dubourg et al., 2013, Sadek et al., 2011, Vendel et al., 2010).

In this study, the stationary version of SLAM, called SLAM_S, has been used. This version considers that the emissions (source positions, release rates, etc ...) and the meteorological conditions are stationary. **Figure 1** show an example of a simulation performed by SLAM_S for the DIFLU project.

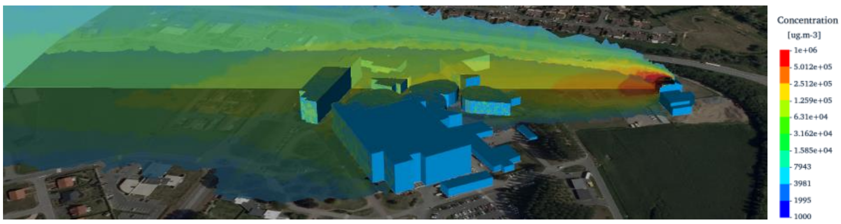

Figure 1. Concentration field on the ground simulate by SLAM_S.

DESCRIPTION OF THE MEASUREMENT CAMPAIGNS

In the framework of this project, IRSN has carried out two 3-days measurement campaigns. During these campaigns, helium tracer was emitted from the cyclotron of the Beuvry hospital center (France) (**Figure 2**). The cyclotron is an 8.5 m high building with a discharge stack of 10.2 m. The chimney from which the tracer was emitted has a complex geometry and is shown in the **Figure 2**. The topography of the site is flat. The site is surrounded by a mixture of rural and urban environments with also residential areas.

Figure 2. Location of the site studied and focus on geometry of the source.

The dispersion has been studied in the near field (< 500 m) of the cyclotron. The two campaigns were carried in October 2019 and December 2019. A total of 19 helium releases (10 minutes per release) and 395 atmospheric concentration measurements were made from air samples, at distances up to 560 m from the release point. The mean wind speed at the release point ranges from 0.9 to 4.4 m.s^{-1}. Helium atmospheric concentrations were documented along with meteorological and micrometeorological measurements. A wind LIDAR was deployed to measure wind speed and direction from 40 to 290 m height. Likewise, five ultrasonic anemometers, located from 3.6 and 11.6 m height, were used to measure turbulent parameters (**Figure 3**).

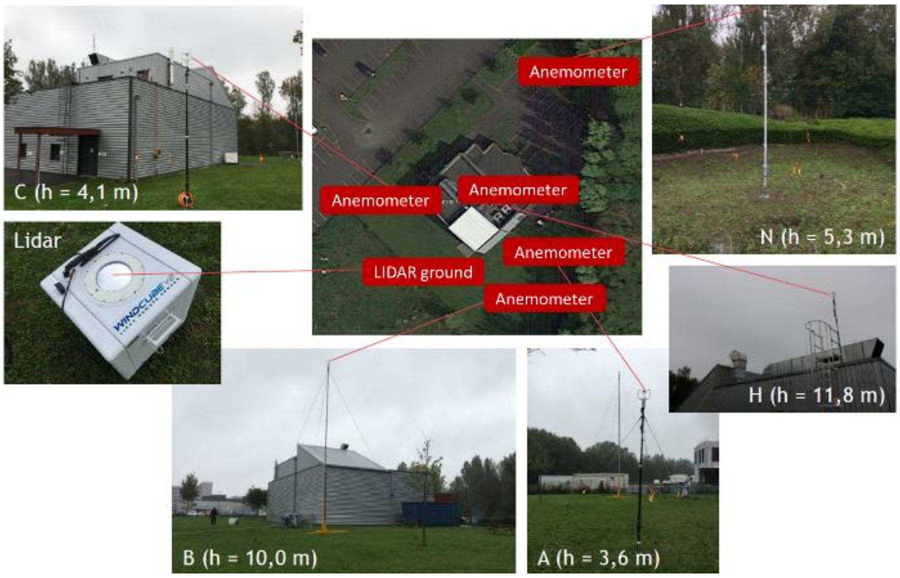

Figure 3. Location of wind LIDAR and ultrasonic anemometers deployed by IRSN for the two campaigns.

COMPARISONS BETWEEN IN-SITU MEASUREMENTS AND NUMERICAL RESULTS

For each release, simulations have been carried out with SLAM_S considering meteorological and emissions data collected during the measurements campaigns. In the following, the modelled concentrations are obtained using meteorological data provided by the anemometer H and the wind LIDAR (**Figure 3**).

Figure 4 and **Figure 5** compare the concentrations measured and modelled using meteorological data from the anemometer H and the wind LIDAR, respectively. The results show a good correlation between SLAM_S estimates and measurements. Note that the results are generally better for the campaign 2. Likewise, the results are globally more satisfactory using meteorological data from the wind LIDAR. This highlights the sensibility of the modelled concentrations to meteorological input. Further analysis will be carried out to explain the results discrepancies between the different campaigns and the different releases.

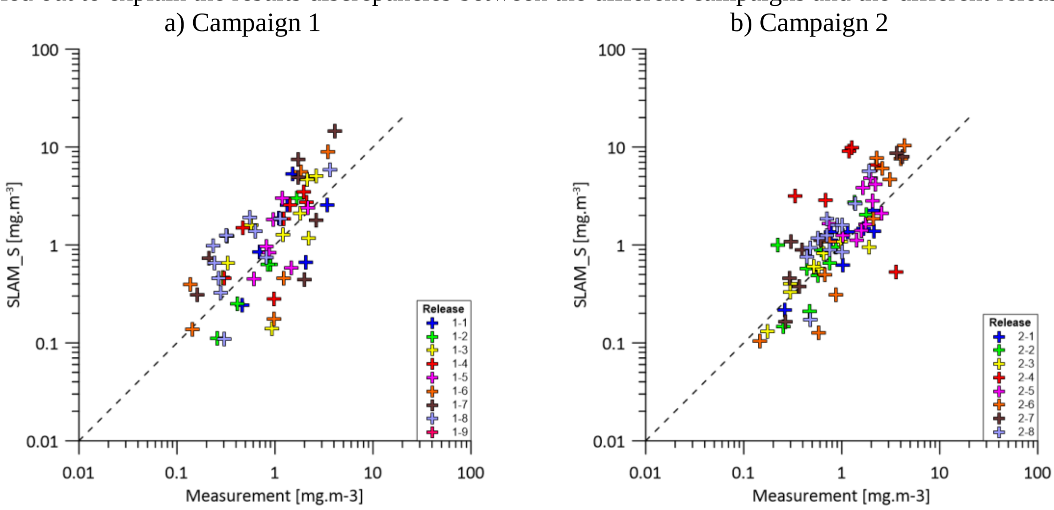

Figure 4. Comparison of concentrations measured and modelled with SLAM_S, using meteorological data provided by the anemometer H, for campaign 1 (a) and campaign 2 (b).

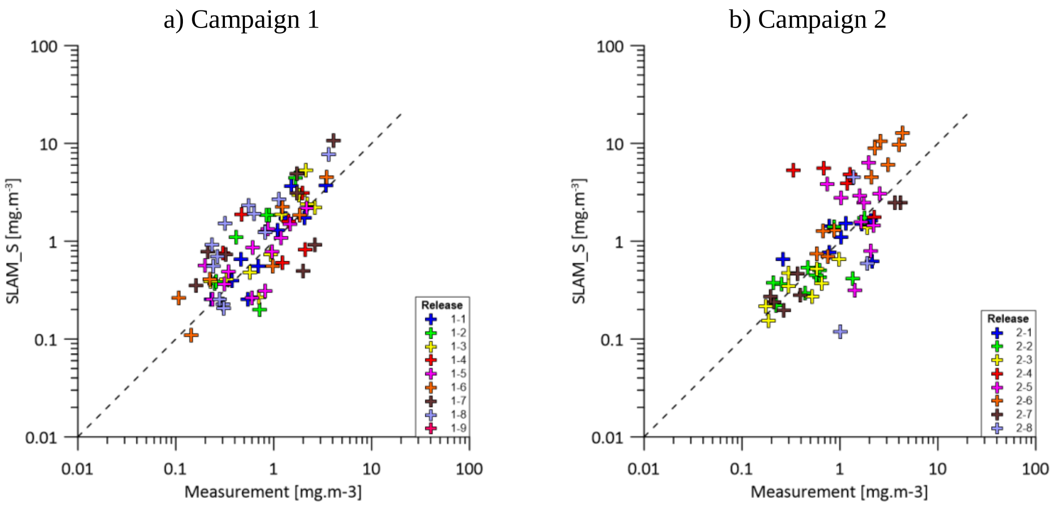

Figure 5. Comparison of concentrations measured and modelled with SLAM_S, using meteorological data provided by the wind LIDAR, for campaign 1 (a) and campaign 2 (b).

CONCLUSIONS

The DIFLU project aims to study the near field dispersion (< 200 m) of a gas emitted in an urban or industrial environment. In the framework of this project, IRSN has carried out two measurement campaigns nearby the cyclotron of the Beuvry hospital center. This study has assessed the ability of SLAM_S to model the atmospheric dispersion in this context. The results show a good correlation between SLAM_S estimates and measurements and suggest that the use of such model may be relevant for near-field impact assessments in urban area. Nevertheless, further analysis must be carried out to explain the discrepancies between modelled and measured concentrations and to improve SLAM_S simulations.

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