21st International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
27-30 September 2022, Aveiro, Portugal

DISPERSION OF RADIONUCLIDES IN A URBAN ENVIRONMENT (DIFLU): COMPARISON OF NUMERICAL RESULTS WITH EXPERIMENTAL MEASUREMENTS

Liying Chen[1], Malo Le Guellec[1], Amita Tripathi[1], Sophie Vecchiola[2], Anne Mathieu[2], Philippe Laguionie[2], Olivier Connan[2], Denis Maro[2], Luc Solier[2], Irène Korsakissok[2]

[1]Fluidyn, 84 rue Charles Michels Bât.IRIS Hall B, 93200, Saint-Denis, France
[2]Department of healthcare and Environmental Science, French institute for radiation protection and nuclear safety, France

Abstract:

The DIFLU project (DIspersion of FLuor 18 in an Urban environment) has been initiated by IRSN alongside with FLUIDYN France and Ecole Centrale Lyon to assess the performance of numerical simulation in the evaluation of the impact of radionuclide dispersion in urban areas.
The project is specifically aimed at the release in atmosphere of fluorine 18 used in medical imaging by cyclotrons located in hospital premices, so near housing, offices and health care centers. Such impact assessments have been performed in the past with Gaussian or 2D modelling, which cannot take into account the specificities of the release environment, such as obstacles and buildings, which are expected to have a strong influence in the nearfield. Therefore, the DIFLU project aimed at comparing the results of experimental campaigns with results from 3D-CFD (Computational Fluid Dynamics) models, among them fluidyn-PANACHE.
In 2019, the cyclotron located in Beuvry (North of France) was used to carry out two atmospheric tracing experiments using helium as a tracer gas, emitted from a chimney above the cyclotron. The first campaign results have been presented before. The results of the comparisons between the experimental data and the numerical results for the second campaign are presented here. The comparison is carried out both for the flow behaviour (local wind velocities) and for the tracer behaviour (concentrations).
The statistical evaluation results show the CFD model Fluidyn-PANACHE is capable of simulating the Fluor 18 dispersion in urban environment.

Key words: *atmospheric pollution dispersion, CFD model evaluation, Fluidyn-PANACHE, radionuclide dispersion*

INTRODUCTION

Radionuclide impact assessment within urban environment in near-field (<3km) is more and more predicted with CFD dynamic codes. A CFD model solves the Navier–Stokes equations using a small grid size (of the order 1m or even less) (Hanna et al., 2004). Compared with simple Gaussian dispersion model or other analytical approximations, the CFD model efficiently predicts the obstacles influence on wind patterns and cloud shapes (Kumar& al., 2015).
Nevertheless, the CFD model evaluation against experimental datasets is one important point to estimate its capability to provide reliable and valuable information in emergency planning or chronic impact assessment (Hanna & al., 2004; Riddle & al., 2004).
To meet this objective, DIFLU (DIspersion of FLUorine) project has been initiated in order to provide a database of observations (concentrations, wind velocities) in the near field (<200m) of a release for model validation.

The current paper concerns the Fluidyn-PANACHE CFD model evaluation. PANACHE uses physical models and deterministic solutions that are adapted to any kind of release scenarios, complex environments and pollutant characteristics. To demonstrate the PANACHE model's capabilities with regard of dispersion in urban environment in the framework of DIFLU project, numerical results have been compared with experimental datasets.

DESCRIPTION OF THE DIFLU EXPERIMENTS

Datasets of measurements

DIFLU project aims to study near field dispersion of a gas emitted in an urban or industrial environment. Two campaigns were carried out in october and december 2019 at the Beuvry hospital site (northen France). For the December campaign, a total of 10 helium releases and 200 atmospheric concentration measurements were made at distances up to 560 m from the release point.

Helium releases were most of the time located in the hydraulic vein of the stack oriented with an angle of -45° to the horizontal on the roof of the cyclotron at 10 m high. The total flow rate was 7200 ± 100 m^3/h and the emission flow velocity were 6 m/s.

Weather database

For the December campaign, a wind LIDAR was deployed for wind speed and direction from 40 to 290 m height (Table 1), as well as four anemometers (between 3.6 and 11 m height) for the measurement of wind characteristics and turbulent parameters.

Table 1. Weather data recorded by the LIDAR at z=40 m

Experience	Wind speed		Wind direction	
	$\bar{u}$ (m/s)	σ_U (m/s)	$\overline{Th}$ (°)	σ_{Th} (°)
2-1	6.0	0.6	173.5	6.0
2-2	7.6	1.1	172.2	6.6
2-3	7.7	1.1	174.3	5.5
2-4	2.5	0.4	212.0	4.4
2-5	3.3	0.5	191.8	4.8
2-6	3.5	0.3	203.6	7.1
2-7	4.1	0.5	187.0	5.6
2-8	3.8	0.6	166.8	5.5
2-9	5.5	0.6	168.6	5.0
2-10	8.9	1.7	160.6	7.7

The wind direction ranges from 160 ° to 212° and the standard deviation goes from 4.8° to 7.7°. The wind speed ranges from 2.5 m/s to 8.9 m/s. Four experiences get a wind speed at 40 m lower than 4 m/s. The standard deviation of the wind speed represents from 9% to 19% of the average speed.

The weather data recorded by the LIDAR have been used to defined the boundary conditions of the computational domain. The windfield results have been compared at the four anemometers locations for 40 couples wind direction/wind speed extracted from the weather database.

DESCRIPTION OF THE CFD MODEL

Fluidyn-PANACHE is a 3D diagnostic model for atmospheric dispersion modelling over complex terrain with topography and obstacles.

Governing Equations

The Fluidyn-PANACHE model solves the Navier-Stokes equations along with the equations describing conservation of species concentration, mass, and energy for a mixture of ideal gases.

Fluidyn-PANACHE solves the Reynolds averaged forms of these equations for turbulent flow. The Reynolds stresses are modeled using the linear eddy viscosity model (LEVM) (Ferziger and Peric, 2002). Ideal gas law is used for the thermodynamic model of mixture of gases. Air is modeled as moist air with effective properties of the mixture of dry air and water vapor.

Turbulence Model

The Fluidyn-PANACHE model uses modified standard k-ε turbulence model to solve the turbulence structure within the domain. The implementation of this model is derived from the standard high-*Re* form with corrections for buoyancy and compressibility (Hanjalic, 2005). It solves the transport equations for turbulent kinetic energy, *k* and its dissipation rate, ε.

Boundary Conditions

Boundary conditions are required on the main domain boundary, the ground, and on obstacles. The top boundary is treated as an outflow boundary. The lateral boundaries of the domain are treated as inflow and outflow boundaries based on the direction of the wind with respect to the domain boundary.

Wind profile

A log-law profile based on Monin–Obukhov (M–O) similarity theory is used to parameterize the inflow boundary condition. The reference velocity and direction of the wind profile was mesured at 40 m during the campaign.

Turbulence profile

The turbulence profile selected for this study is a semi-empirical model based on similarity theory and measurements (Han & al., 2000).

STATISTICAL PERFORMANCE MEASURES (SPM)

The evaluation dataset contains pairs of Cp (predicted concentration) and Co (observed concentration), which represent averages over the same averaging time. In the frame of DIFLU, the sampling time ranges from 8 to 10 min beside the case.

Before calculating various statistical performance measures, it is also recommended that exploratory data analysis be performed by simply tracing scatter plot or quantile-quantile plot.

Then, quantitative evaluation of the performance of atmospheric dispersion models requires the definition of appropriate statistical performance measures (SPM) which compare model predictions with measurements. The decision criteria comprise a combination of elements drawn from scientific assessment, the verification process, and the extent to which quantitative values of the SPM output from the validation exercise are also met. Chang et Hanna (2004) propose the following modified quantitative assessment criteria to be met by a model:

- Fractional Bias (FB) with $-0.3<FB<0.3$;
- Normalized Mean Square Error (NMSE) with $NMSE<4$;
- Fraction of predictions within a factor 2 of observations (FAC2) with FAC2> 50%.

In addition to these standard criteria, the Fraction of predictions within a factor 5 of observations (FAC5) has been calculated.

It is important for environmental applications like radionuclide impact to evaluate model predictions at specific locations such as densely-populated neighborhoods. That is why, to meet the objective of DIFLU project and unlike the mostly comparisons made for Gaussian models, the performance of the CFD model is not conducted only for the maximum concentration on a sampling line but point to point. Pairing in space is clearly most stringent.

RESULTS AND DISCUSSIONS

Windfield model validation

The comparison of the simulation results (Wind speed, Wind direction and Turbulent Kinetic Energy (TKE)) with the experimental data at the 4 anemometers positions is presented on the figures below.

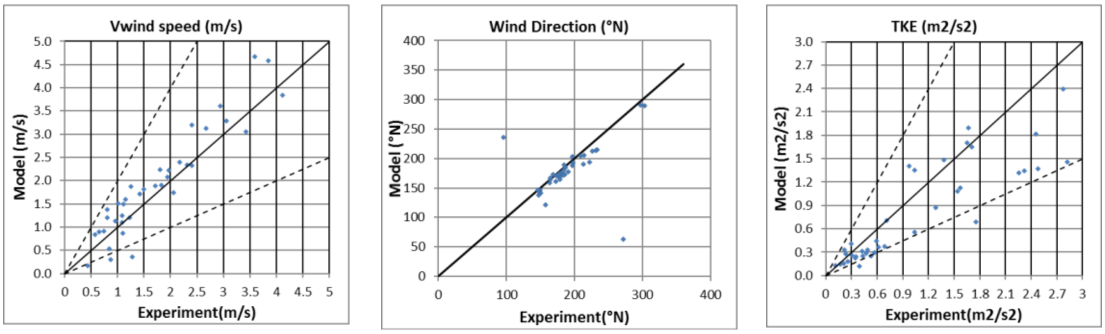

Figure 1: Scatter plots of the model/experiment comparison for wind speed, wind direction and TKE

The comparison shows a very good agreement with experimental results. The TKE is slightly under-predicted by the model.

The statistical performance measures for the wind speed are FB=0.04, NMSE=0.04, FAC2=94%

Dispersion model validation

For regulatory applications of IRSN, sites with routine emissions, the primary objective is how well a model simulates the long-term averaged concentration anywhere on the sampling network. That is why, the dispersion modelling considers averaged wind conditions (speed and direction) over each experiment even if weather measurements are available at higher frequency. No modification or tuning have been done to improve the modelling results because it is not the objective of DIFLU project. The CFD model has been used similarly as for an impact study.

The helium concentrations from the modelling tool are compared with experimental values for each point and the SPM criteria are then computed.

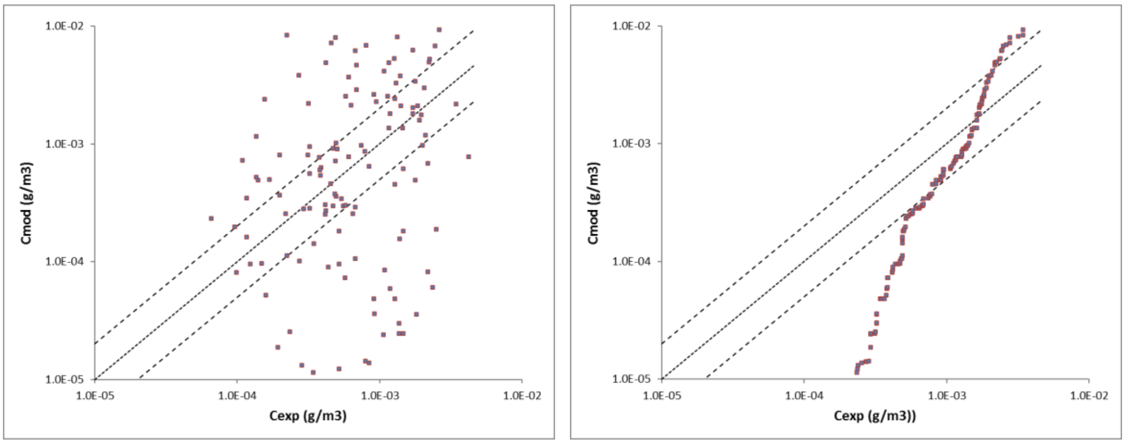

Figure 2: (a) Scatter plot and (b)Q-Q plot of predicted versus observed concentration

The scatter plot shows that 34% of the pairs are in the range of the FAC2. The Quantile Quantile-plot shows the tendency of the modelling tool to underestimate low concentration and overestimate high concentration. This could be explained by the averaged wind direction and the parameters of the turbulence model.

The results indicate inhomogeneity between the experiments. The case 2-02 and 2-03 give the best performance. The case 2-01 gives the worst comparison. It seems that the averaged wind direction for the modeling make the plume miss the sensors. The comparison could be improved by considering the wind direction fluctuations at the boundary conditions.

Table 2. SPM criteria the datasets[1]

	FB	NMSE	FAC2	FAC5
2-01	1.39	6.64	5%	5%
2-02	0.23	0.73	64%	86%
2-03	-0.09	0.76	37%	79%
2-04	-0.86	7.82	18%	29%
2-05	-0.55	3.10	24%	43%
2-06	-1.04	4.04	24%	79%
2-07	-0.31	5.89	16%	37%
2-08	0.46	4.96	29%	61%
2-10	1.00	1.87	29%	54%

The statistical performance measures for the overall experiments are FB=0.37, NMSE=3.81, FAC2=34%, FAC5=65%.

CONCLUSION

The present paper shows the performance of a 3D-CFD modelling tool (fluidyn-PANACHE) in the frame of DIFLU project dedicated to the evaluation of the impact of radionuclide dispersion in urban areas. The comparison consists in paired concentrations (observed vs modelled) in space and not maximum arc-wise concentrations.

For the second campaign, the CFD model used in a standard way has shown acceptable performance for the objectives of the DIFLU project. Some cases could be improved by considering wind direction fluctuations or tuning turbulence parameters.

REFERENCES

Ferziger, J.H. and M. Perić, 2002: Computational Methods for Fluid Dynamics, Springer.

Han, J., S.P. Arya, S. Shen and Y-L Lin, 2000: An Estimation of Turbulent Kinetic Energy and Energy Dissipation Rate Based on Atmospheric Boundary Layer Similarity Theory, NASA/CR-2000-210298.

Hanjalic, K., 2005: Turbulence And Transport Phenomena: Modelling and Simulation, Turbulence Modeling and Simulation (TMS) Workshop, Technische Universität Darmstadt.

Kumar, P.,Feiz, A-A, Ngae, P., Singh, S.K. and Issartel, J.P., 2015: CFD simulation of short-range plume dispersion from a point release in an urban like environment. *Atmospheric Environment*, 122, 645-656.

[1] The case 2-09 is not presented because measured concentrations show unphysical constant concentration at all the sensors.