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STUDY OF ATMOSPHERIC DISPERSION UNDER LOW WIND CONDITIONS IN AN URBAN ENVIRONMENT, FIRST RESULTS

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Abstract All atmospheric conditions must be considered in the impact calculation of industrial facilities. In low wind conditions (wind speed below 2m.s^{-1}), the meandering (low frequency horizontal wind oscillation) becomes one of the predominant physical processes which drive atmospheric dispersion of pollutants. Experimentally, it can be identified by analyzing the autocorrelation function of the horizontal wind speed components. However, modeling these situations is more complicated, and most models are unable to correctly reproduce the turbulent flow structure and the resulting plume dispersion. The CFD models could overcome these limits by adapting the existing modeling approaches to low wind speed situations. In this study, we present the first analyses of datasets from an experimental campaign that has been performed at SIRTA in the south of Paris in 2020 as well as first simulation results obtained with a CFD model using two different modelling approaches: stationary and pseudo stationary conditions. The analysis of wind data acquired during one selected time period of the campaign allowed to identify the presence of meandering and to estimate its period. Compared to concentration measurements, the first modelling approach seems to lower lateral dispersion while the second approach seems to give closer results.

Keywords *Low wind speed, built-environment, meandering, atmospheric dispersion, CFD*

INTRODUCTION

Atmospheric dispersion in low wind speed conditions (hereafter LWS) is a critical situation which is not well understood. There are several places in the world where the LWS situations are common, it can occur up to 70 % of the time in certain sites (Anfossi et al., 2005). Studies suggested that low wind is defined by its mean horizontal speed lower than 2 m.s^{-1}. In these conditions, dispersion mechanisms and turbulence properties are modified leading to the stagnation of pollutants around the source and high concentration in the atmosphere. So, it turns necessary to consider these situations when it comes to calculate the impact.

In LWS conditions, the dispersion is partially driven by the phenomenon called meandering. It is a low frequency horizontal wind oscillation. The standard deviation of wind direction increases when the wind speed decreases, therefore it becomes difficult to define a mean plume direction. The meandering disperses the plume over a rather wide angular range. Consequently, the modeling of dispersion in these situations is hampered. The existing dispersion models are unreliable in such conditions specially when the wind speed approaches zero.

Turbulence and dispersion measurements in LWS conditions are hardly available at international level, particularly in built environment. In this context, IRSN and EDF-R&D have launched a study in order to acquire experimental data and improve modeling. The objectives of this presentation are to present and analyze experimental data of dispersion of a tracer gas (Helium) under LWS conditions in urban area and to compare these results to the first simulations obtained from a CFD model.

SITE AND METHODOLOGY

Site

The experimental site is located at SIRTA (Site Instrumental de Recherche par Télédétection Atmosphérique) (Figure 1) near Paris in a peri-urban area. It includes areas of buildings and vegetation. The height of the buildings is in the range of 5 to 30 m. LWS frequency is 20 % over 20 months at a height of 30 m.

Experimental method

Two measurement campaigns have already been carried out in 2020 (in July and September). Each campaign includes 7 experiments, which means 14 experiments in total. The acquisition of data on the dispersion of a plume is based on the use of a gas tracer (Helium). Emission and measurement points locations were decided based on weather forecasts and wind measurements. Helium concentrations were measured, using mass spectrometers, with air samples as well as in real time, in the near field of the emission point (<300m). Wind and turbulence conditions are measured by ultrasonic anemometers positioned on a 30 m mast at three heights (5m, 10m, and 30 m) and at several locations inside the buildings canopy layer. The experiments allow to determine atmospheric transfer coefficients (hereafter ATC, in $s.m^{-3}$, equal to the ratio between the concentration of helium in the air and its emission rate) which quantify the dispersion of the plume between the point of release and measurement or sampling points.

The sonic anemometers datasets were divided into subsets of two hours since the meandering period can exceed 1h in some cases (Mortarini et al., 2013). The wind components were rotated in the mean wind coordinate system before proceeding with the analysis which aims at characterizing the physical processes occurring during LWS. The meandering is characterized by an oscillating behavior of the Eulerian autocorrelation function with a negative loop for the horizontal components U and V. Regarding the vertical component W, it exhibits a classical exponential behavior (Anfossi et al., 2005).

The Eulerian autocorrelation function R of horizontal velocity components can be fitted by equation (1) (Frenkiel, 1953):

$$R(\tau) = \exp(-p\tau)\cos(q\tau) \quad (1)$$

With:

- p is a parameter associated to the turbulence time scale (small scall motions)
- q is linked to the oscillation time scale (large scale motions)
- τ is the difference time between two instants
- The meandering period (Mortarini et al., 2016) is given by equation (2) :

$$T = \frac{2\pi}{q} \quad (2)$$

- The ratio between q and p (equation (3)) define the loop parameter m which is a decisive parameter to define the meandering:

$$m = \frac{q}{p} \quad (3)$$

Following (Mortarini et al., 2016), we have defined the situations with meandering using the condition: $m_{u,v} > 1$. When $m \geq 1$ for one of the horizontal wind components the corresponding time step is classified as “almost meandering”. When $m > 1$ for both components, it is classified as meandering.

Modelling method

The simulations rely on the CFD model Code_Saturne, an open-source code developed by EDF-R&D. The mesh used in this study includes 13 million cells for an area of dimensions 2400 m x 1600 m x 300 m. Inlet profiles of wind, temperature, and turbulence, are built according to the Monin-Obukhov theory. The roughness length is specified for each grid cell through a fine land use cover map. Two calculations have been performed for a chosen release of the measurement campaign. The first consists in a unique stationary simulation with constant boundary conditions. The second uses a combination of several stationary simulations performed with different inlet conditions representative of the temporal variation of the meteorological conditions during the release.

RESULTS

Experimental data analysis

We present here the data of the experiment 14 which took place on 11 September 2020 between 05:35 and 06:05 UTC. In this period, the mean wind speed is about 1.4 $m.s^{-1}$ at a height of 30 m. Figure 1 shows the Helium plume dispersion based on ATC distribution. Due to the predominant northern wind, ATC are higher south of the emission point.

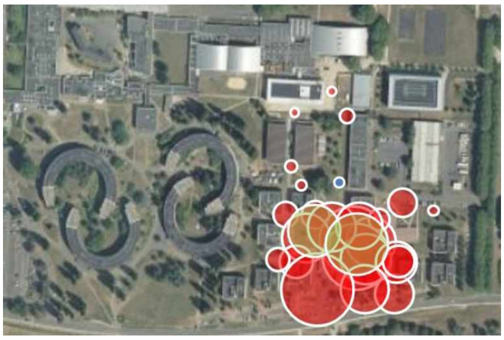

Figure 1. Helium measurements on 11 September 2020 between 5:35 and 06:05 UTC at SIRTA. Emission point in blue, ATC at sampling in red point, and ATC at real time spectrometer in green point. The bubbles size is proportional to the ATC.

The time series of wind speed components u and v and of the wind direction measured at 30 m over a selected period of 2 hours are shown in Figure 2. We can observe the meandering phenomenon, the wind direction oscillates clearly between 05:25 and 06:10. So, to verify and prove the existence this physical process, we also plotted the autocorrelation function of wind speed components in figure 3.

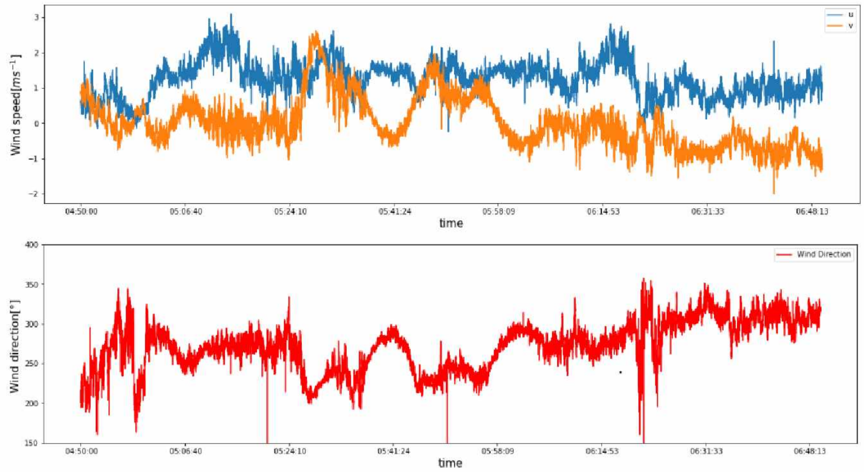

Figure 2. Horizontal wind-velocity components u and v *(top)*, Wind direction *(bottom)* on 11 September 2020.

The left of Figure 3 shows the autocorrelation function for the the horizontal wind velocity component u. the negative loop appears between 500 s and 1000 s. The meandering period is 33 minutes and it is not well as marked as for the component v on the right of Figure 3. This last has a period of 21 minutes and a higher value of the parameter m. Thus the meandering appears to be stronger on the v component than the u component in this case.

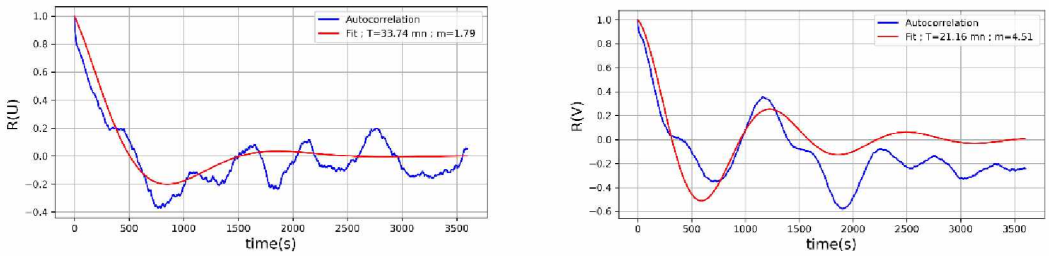

Figure 3. Autocorrelation function for the horizontal wind-velocity components u (on the left) and v (on the right) of data between 05:25 and 06:10 on 11 September 2020. Red line represents the theorical behavior proposed by (Frenkiel, 1953)

First modelling results

The results of the two calculations that have been performed for the last reject in 2020 are given in Figure 4. The first (on the left of Figure 4), that represents a unique stationary simulation underestimates the lateral dispersion. The second (on the right of Figure 4), that uses a combination of several stationary simulations better models the horizontal dispersion compared to the measurements.

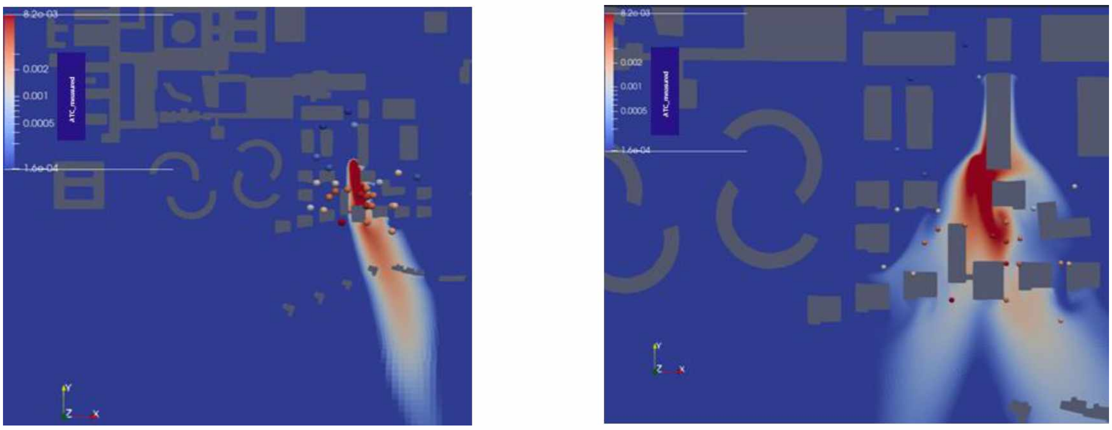

Figure 4. Two simulations of the plume dispersion for the release of 11 September 2020 Stationary case (on the left) and combination of several stationary simulations (on the right).

CONCLUSION AND OUTLOOK

To conclude, this study aims to characterize dispersion atmospheric in LWS conditions, where a specific physical process called meandering appears. The methodology used consists in experimental analyses and modelling.

The first part is based on the autocorrelation function to estimate the meandering period. We present results for a 2 hour period which includes one of the tracer releases that were performed during a measurements campaign in September 2020. By analyzing the autocorrelation functions, we show that meandering is visible on both horizontal wind components, but more in the transverse component than the longitudinal component in this case. The estimated period is around 20 minutes (for the transverse component) to 30 minutes (for the longitudinal component).

The second part is a test of two methods to model the plume dispersion of the gas tracer (Helium) used in our measurement campaigns. The model used is the CFD code code_saturne developed by EDF-R&D. The first method, which consists in a unique stationary simulation, lowers the lateral dispersion compared to the experimental results. In contrast, the model shows closer results in the case of combination of several stationary simulations, as it models more representatively this lateral dispersion.

In further studies, we will continue defining meandering for more cases of measurement campaign 2020 and studying the impact of different parameters on this process such as wind and direction speed, or the atmospheric stability. Besides, we will realize a third and a fourth experiment in 2022 to enrich and consolidate our database. A next challenge will also be to run more simulations to better model these situations notably by adapting the Monin-Obukhov theory to LWS.

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