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TWO METHODS TO ESTIMATE HORIZONTAL STANDARD DEVIATIONS OF DISPERSION IN LOW WIND SPEEDS CONDITIONS

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Abstract: In this paper, two methods to obtain dispersion coefficient, during low wind speed and stable conditions, are presented. These methods have been developed by using wind velocities recorded with an ultrasonic anemometeron a typical suburban site.

Key words: *Low wind speed, Lateral dispersion coefficient, Sonic anemometer data, Random trajectories.*

INTRODUCTION

The lateral dispersion coefficient, $\sigma_y(t)$, forms an essential input to the dispersion models currently used to simulate atmospheric dispersion at micro-meteorological scales. In low wind speeds conditions, standard deviation in the crosswind direction may significantly differs from the expressions commonly found in the literature. In fact, it has been observed that the natural low wind speed is typically non-stationary, with large horizontal wind speed oscillations, commonly known as meandering (*Anfossi et al.*, 2005). However, in this context, little attempt has been made to apply analysis techniques, such as wavelets (e.g., *Gurley, K. and Kareem, A.*, 1999; *Kareem, A. and Kijewski, T.*, 2002), empirical mode decomposition (*Chen, J. and Xu, Y. L.*, 2004), extensively employed to analyse wind speed oscillations in strong wind conditions. In this work, by using wind velocities recorded with an ultrasonic anemometer, two methods have been developed to obtain suitable dispersion coefficient, during low wind and stable conditions, at a typical suburban site, located in the southern part of the Paris region (Evry, France). The first one, based on the generation of random particle trajectories, and the second one, based on the characterization of the standard deviations of organized and turbulent lateral wind velocity fluctuations, use advanced decomposition techniques.

SITE, METHODOLOGY AND WIND MODEL DESCRIPTION

Site and methodology

The observation area was a typical suburban site located in Evry (France) in the southern part of the Paris region.

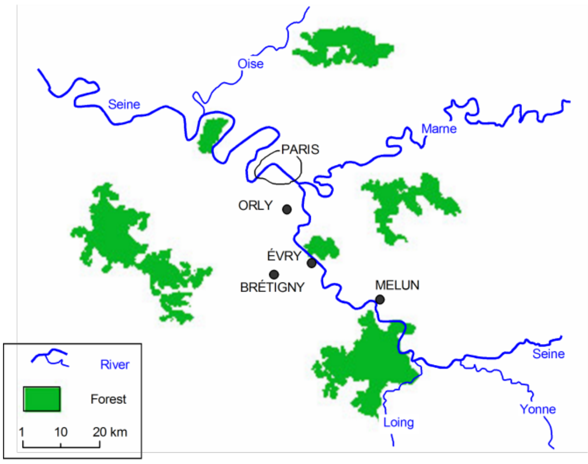

Figure 4: Geographical localisation of the test site.

Measurements of meteorological parameters have been performed from september 2008 to december 2009, both with an ultrasonic anemometer at 20 Hz and with a weather station at 1 Hz (these data were further averaged every 10 min). The anemometers were mounted on masts, at 3m above the roof of a low rise wide industrial building (9 meters high). The measurement site is not perfect. But, under light wind conditions, the separation at the upwind edge of the building was indiscernible, owing to immediate reattachment, and negligible effects due to the wakes induced by the surrounding obstacles were observed. For the present study we will exclusively focus on 20 wind speed time histories, of 2 hours duration, which correspond to typical low wind speeds ($\bar{u} < 2.0 ms^{-1}$) and stable conditions (stability was estimated by using the Monin-Obukhov stability parameter).

Wind model

During low wind conditions, and/or over large time period (i.e. over periods of hours and days), it has been observed that the natural low wind speed is typically non-stationary with large horizontal oscillations. Under theseconditions, as explained by *Turbelin, G., Ngae, P. and Grignon, M.*, 2009, the horizontal wind speed can be thought of as the summation of a slowly time-varying organized component, $\vec{U}(M,t)$, governed by large scale motions of the atmosphere, and a turbulent component, $\vec{u}'(M,t)$, with random high frequency fluctuations, mainly due to local topographic and terrain effects:

$$\vec{u}(M,t) = \vec{U}(M,t) + \vec{u}'(M,t) \quad (1)$$

The horizontal dispersion of a plume is simultaneously influenced by these two types of fluctuations: the turbulent one promotes mixing within the plume and the organized one is responsible for its horizontal spread. It should be noted that the slow time-varying component can be seen as an instantaneous mean, or as a time varying mean wind speed, which is the sum of the overall time-mean value $\bar{\vec{U}}(M)$ and low frequency fluctuations $\tilde{\vec{U}}(M,t)$:

$$\vec{U}(M,t) = \bar{\vec{U}}(M) + \tilde{\vec{U}}(M,t) \quad (2)$$

After rotating the coordinate system so that the lateral mean wind speed is equal to zero, the longitudinal component, in the mean wind speed direction, can be expressed as:

$$u(M,t) = \bar{u}(M) + \tilde{u}(M,t) + u'(M,t) \quad (3)$$

and the lateral component, in the crosswind direction, as:

$$v(M,t) = \tilde{v}(M,t) + v'(M,t) \quad (4)$$

By assuming this model, two methods have been developed to obtain suitable dispersion coefficients during low wind speeds and stable conditions.

METHODS TO ESTIMATE THE HORIZONTAL DISPERSION

Method based on the generation of random particle trajectories

The first method, based on the analysis of random particle trajectories, uses the wavelet decomposition technique. The aim of a wavelet analysis is to determine a time-scales representation of a series and to assess the temporal variation of the different scales involved. In this study, a representative local low wind velocity record has been wavelet transformed using Daubechies (*DB4*) wavelets. This has resulted in a set of wavelet coefficients characteristic of the time-scale structure of the natural wind. The generation of a random signal with the same energy content (statistically similar to the original one) was carried out by an inverse wavelet transform. The original wavelet coefficients were kept at each scales, however, their positions in time (their times of appearance) were randomly permuted before performing the inverse wavelet transform. Next, assuming the homogeneity of the wind in the area around the observation point,a simple time integration of the generated velocities has led to trajectories. The lateral standard deviation $\sigma_y(x)$ has been gradually obtained by computing *j* trajectories, see *Fig. 2*,until the mean trajectory has been aligned on the x-axis. The main drawback to this method is that, because of the zero lateral mean wind speed, each trajectory must have a y-value of zero at the maximum distance downstream from the source. Thus, only the first half part of each trajectory can be retained to evaluate $\sigma_y(x)$.

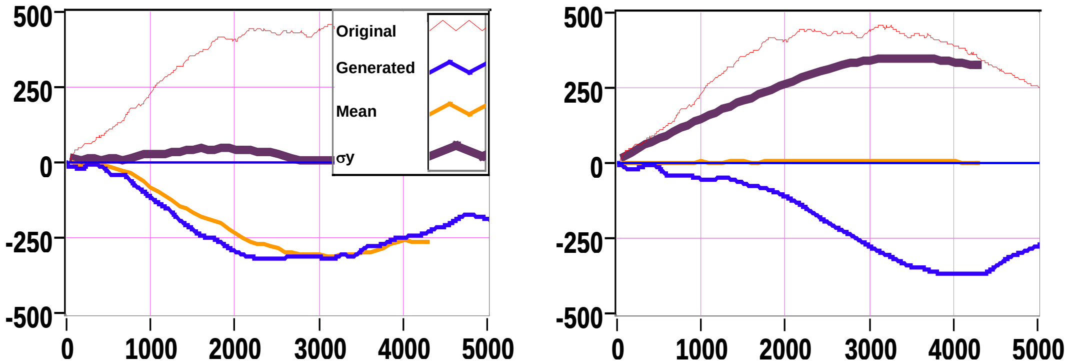

Figure 2: Evaluation of the standard deviation by random trajectories generation. j= 2 (left), j=700 (right).

Moreover, if the signals were generated by omitting the high frequency terms (by setting the wavelet coefficients related to those particular fluctuations to zero), it has been observed that the overall trajectories were very similar to that obtained without neglecting any coefficients. This result confirms that, in low wind speed conditions, the lateral dispersion parameter is mainly governed by large scale atmospheric motions.

Method based on the experimental analysis of velocity fluctuations

The wind model, described by equation (4), suggests that the low frequency wind fluctuations play an important role in lateral dispersion. Thus, the lateral wind velocity $v(t)$ can be separated into a slow time varying component $\tilde{v}(t)$ and a turbulent component $v'(t)$, considered as a random process, by using empirical mode decomposition (EMD), described by *Chen, J. and Xu, Y. L.*, 2004, or wavelet shrinkage, described by *Chen, L. and Letchford, CW.*, 2006. After $\tilde{v}(t)$ being subtracted from $v(t)$ (run test has been used for checking the randomness of $v'(t)$) the variance of the turbulent wind velocity fluctuations $\sigma^2_{v',T}$ can be evaluated over *N* designated time intervals of *T* seconds, *N=int(T_s/T)*, where T_s is the sampling time duration. Since the slow time-varying wind speed $\vec{U}(t)$, introduced in equation (1), changes at each time *t*, the turbulence intensity, over the *i*th time interval (*i=1,…,N*), is time-dependant with a mean value defined as:

$$I_{v_i'} = E\left[\frac{\sigma_{v_i',T}}{\left|\vec{U}_i(t)\right|}\right]_T \qquad (5)$$

where $E[\;]_T$ is the mean value over the time interval, $\vec{U}_i(t)$ and $\sigma_{v_i',T}$ are, respectively, the slowly time-varying wind speed component and the standard deviation of the turbulent wind speed component over the *i*th interval. The results obtained on the test site, with the classical 600 seconds value for *T*, indicate that $I_{v'}$ is nearly constant and equal to 0.28. Thus the variance of turbulent lateral wind speed (which is a stochastic property of the fluctuating speed at turbulent scales) can be considered as proportional to the slow time-varying wind speed (driven by large scale atmospheric motions). Moreover, by dividing the T_s-seconds long records into *NT*-seconds long subrecords, and, following *Moore, G. E. et al.*, 1985, the variance over the complete measurementperiod can be approximated by:

$$\sigma^2_{v,T_s} = \frac{1}{N}\sum_{i=1}^{N}\sigma^2_{v_i',T} + \sigma^2_{\tilde{v},T_s} \qquad (6)$$

Since $\sigma_{v',T}$ is proportional to $\vec{U}(t)$, σ^2_{v,T_s} can be derived only from the slow time-varying wind speed time history. Then, a rough estimate of $\sigma_y(T_s)$ can be computed by using the Taylor's theorem :

$$\sigma_y^2(T_s) = 2\sigma^2_{v,T_s} T_L T_s \qquad (7)$$

where T_L is a Lagrangian time scale. Even if the estimation of the ratio between Lagrangian and Eulerian time scales is still an open problem, T_L can be estimated from the Eulerian Autocorrelation Function (EAF) of *v(t)*, by using one of the expressions proposed by *Anfossi et al.*, 2006. More elaborate models for $\sigma_y(t)$, such as those defined by *Anfossi et al.*, 2005, can also be used. In these models, the fundamental parameters to reproduce low frequency oscillations transport effects (i.e. the quantities *m* and T_3 or T_m and T_n) can be derived respectively from the EAF of $\tilde{v}(t)$ and $v'(t)$.

RESULTS

These methods have been tested by using the wind speed time histories recorded during typical low wind episodes for stable conditions, as described in a previous section.The results (the evolution of the standard deviation as a function of the downstream distance from thesource) have been compared with the classical Briggs's and Doury's parameterizations for standard deviations. The third commonly used parameterization, the similarity theory, has not been tested since *Irwin, J.*, 1979 explain that the expression for $\sigma_y(t)$:

$$\sigma_y^2(t) = \sigma_v^2 t^2 \frac{1}{1 + 0.5\frac{t}{T_L}} \qquad (8)$$

was derived from Taylor's equation and thus is the same that equation (7) for $t >> T_L$. For each wind speed time history, the standard deviation of the horizontal wind direction, σ_θ, which is the single most parameter in determining the shape of a plume extending downwind from a continuous point source, has also been calculated. The results illustrate the large variability of this parameter at low wind speed, since it varies between 4° and 30°.

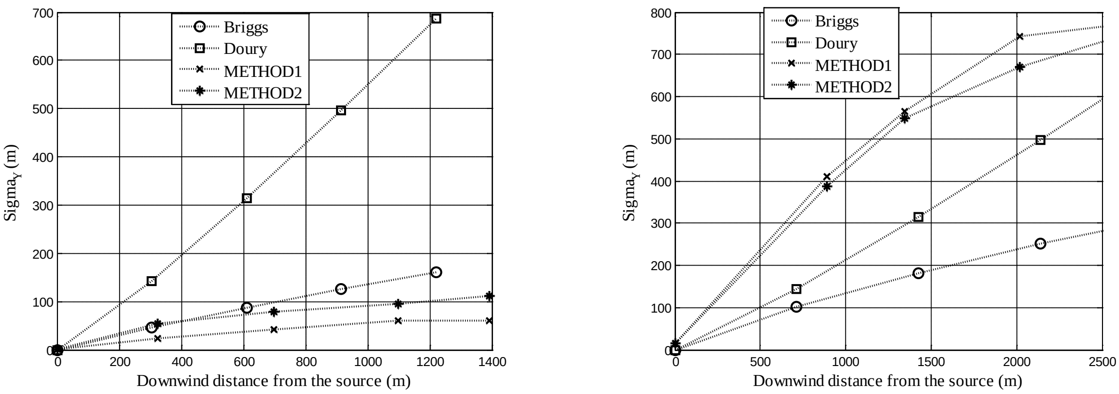

Figure 3: Evolution of σ_y, $\bar{u}$ =0.51ms^{-1}, σ_θ=12° (left) $\bar{u}$ =1.18ms^{-1}, σ_θ=29° (right).

The two methods exhibit similar results: σ_y evolves in the same way with values close to those given by Briggs's parameterization when $\sigma_\theta$is small, see *Fig. 3 (left)*. The latter parameterization is based on the Pasquill classification and supposes that σ_θ becomes small under light wind conditions. Thus for large σ_θ, see *Fig. 3 (right)*, i.e. in the presence of slow horizontal motions, it tends to underestimate σ_y. It should be noted, as explained by *Hanna, S. R.*, 1983, that the standard deviations calculated by using the standard Pasquill technique (such as the Briggs's parameterization) can be multiplied by a correction factor, "which can be as high as 6.0 for wind speed less than *2.0ms^{-1}*", to take into account the effects of lateral meander. In most of the cases, at a given distance, Doury's parameterization supposes that the standard deviation increases as speed decreases, and thus gives very high values of σ_y, especially at very low wind speeds ($\overline{u}$ <*1.0ms*$^{-1}$), see *Fig. 3 (left)*. Our methods take into account the meandering effects notably for *1.0ms*$^{-1}$< $\overline{u}$ <*2.0ms*$^{-1}$ and σ_θ>25°, see *Fig. 3 (right)*, i.e. when both Doury's and Briggs's parameterizations appear to be unsatisfactory and tend to underestimate the plume spread, leading to overestimation of the concentrations.

CONCLUSIONS

Two methods have been developed to obtain suitable dispersion coefficient, during low wind speed and stable conditions, on a site where meteorological data were available. The first one assumes that σ_y can be obtained by studying the statistics of random trajectories of particles (obtained from measured wind speed time histories) which move from the source for a given time. The second one assumes that the time-varying wind can be expressed by a superposition of high frequency oscillations around a much more slowly varying speed. The latter can be extracted from the measured wind speed time histories and used to estimate the variation of σ_y with time. Both give similar results since they take into account the presence of low frequency horizontal wind oscillations. Thus, these methods provide simple yet effective ways to obtain a quantitative estimate of the lateral dispersion coefficient in low wind speed conditions.

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