Laboratoire de Mécanique et d'Énergétique d'Evry

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Two methods to estimate the standard deviation of lateral dispersion in low wind stable conditions

By

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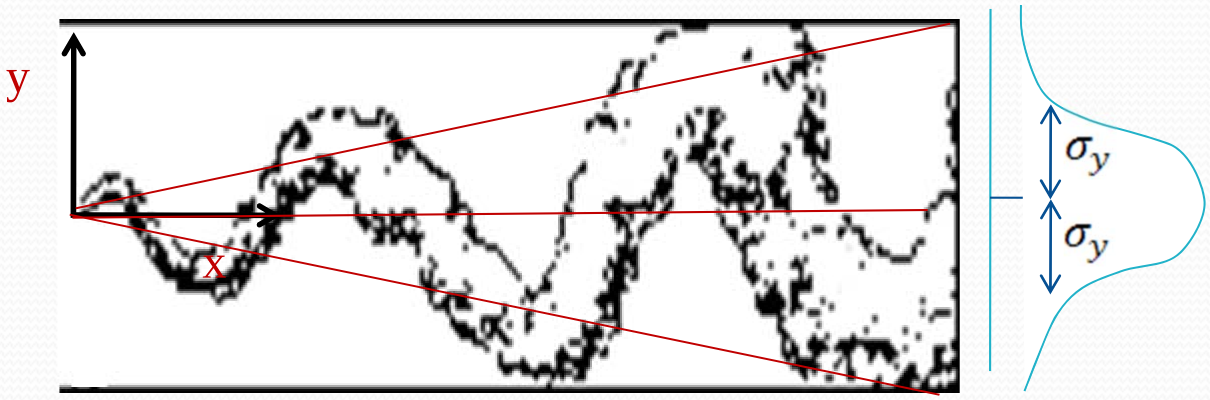
Plan

- **Problematic and objectives**
- **Experimental site and wind model**
- **Methods to estimate the standard deviation of lateral dispersion**
- **Results**

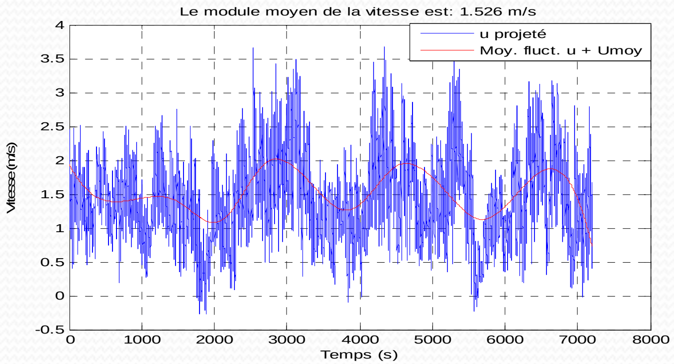
Problematic

- **In low wind speeds conditions :**
  - The natural low wind speed is typically non-stationary
  - Large horizontal wind speed oscillations, commonly known as meandering (*Anfossi et al.*, 2005), can be observed
  - Standard deviation, in the crosswind direction, may significantly differs from the expressions commonly found in the literature



Objectives

- **Two methods have been locally developed to obtain suitable dispersion coefficients, during low wind and stable conditions, by using :**
  - Wind velocities recorded with an **ultrasonic anemometer**
  - A **wind model** adapted to non-stationary conditions
  - **Analysis techniques**, such as wavelets or Empirical Mode Decomposition (EMD), extensively employed to analyze wind speed oscillations in strong wind conditions



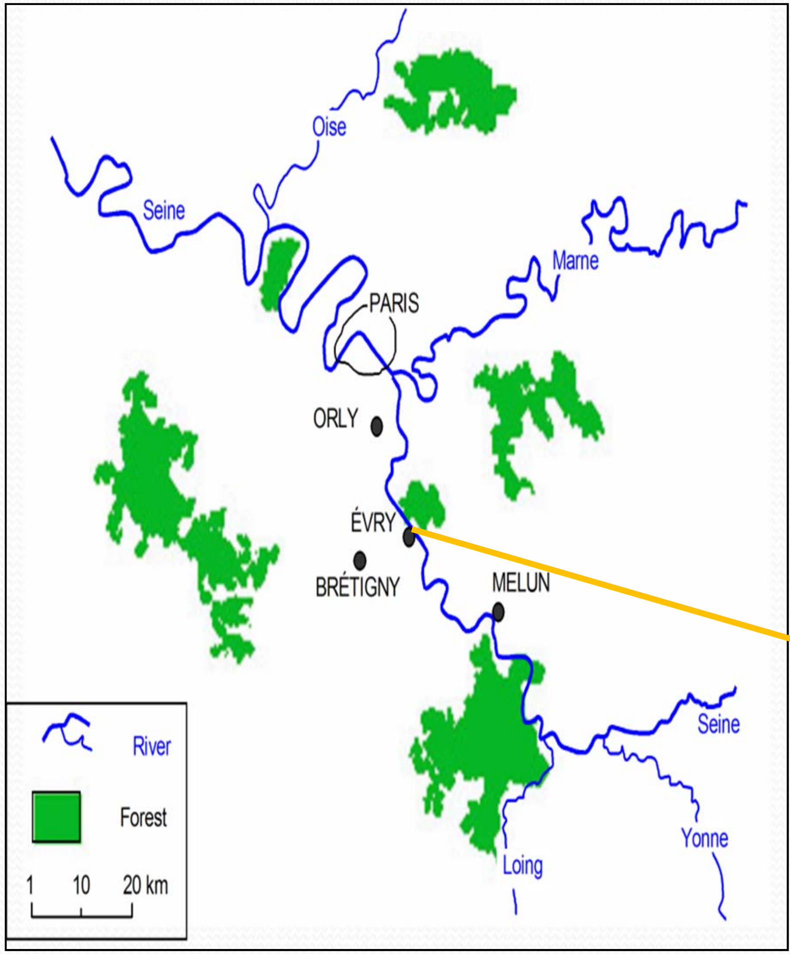
Plan

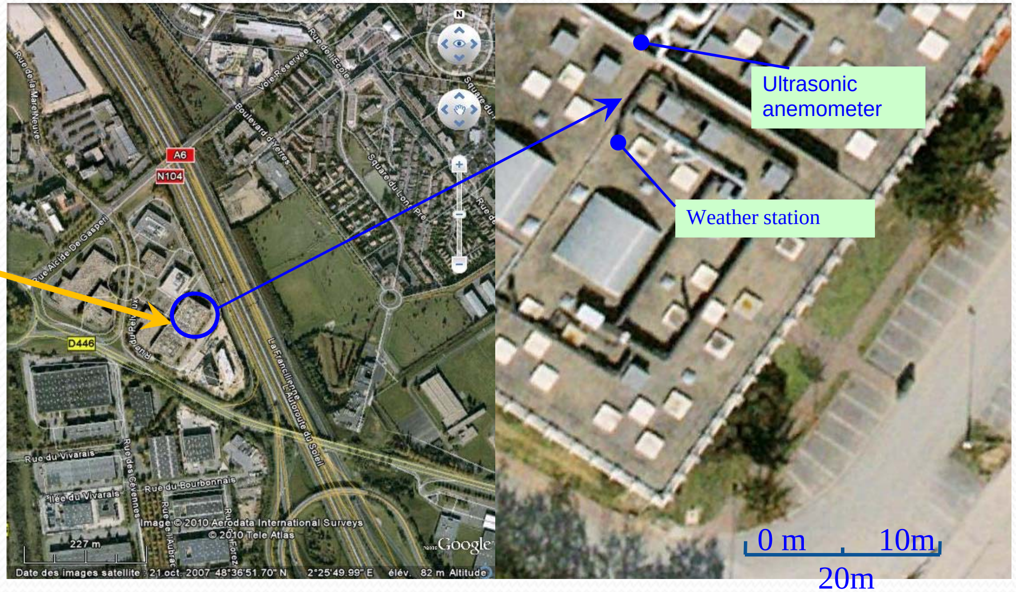
- Problematic and objectives
- **Experimental site and wind model**
- Methods to estimate the standard deviation of lateral dispersion
- Results and Conclusions

Experimental site and wind model

❑ Experimental site

- South of the Paris region (Evry, France)
- Typical sub-urban site
- Instruments located on the top of a low rise wide industrial building (11 meters high)



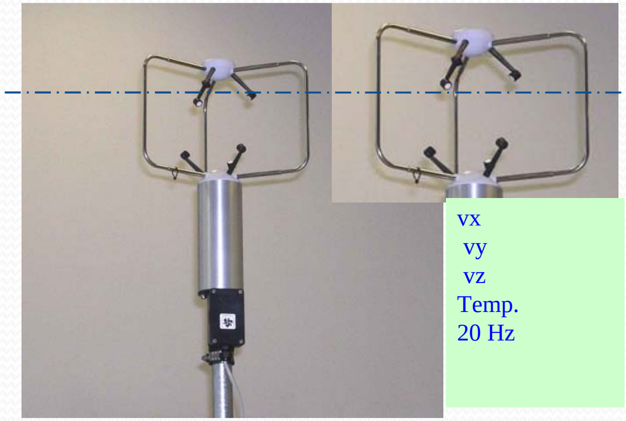


Experimental site and wind model

Instruments

➢The measurements were performed over 16 months, both with an ultrasonic anemometer, at 20 Hz, and a weather station, at 1 Hz

High : 3m above the roof



vx
vy
vz
Temp.
20 Hz

Ultrasonic anemometer YOUNG 81000V

Weather station Young

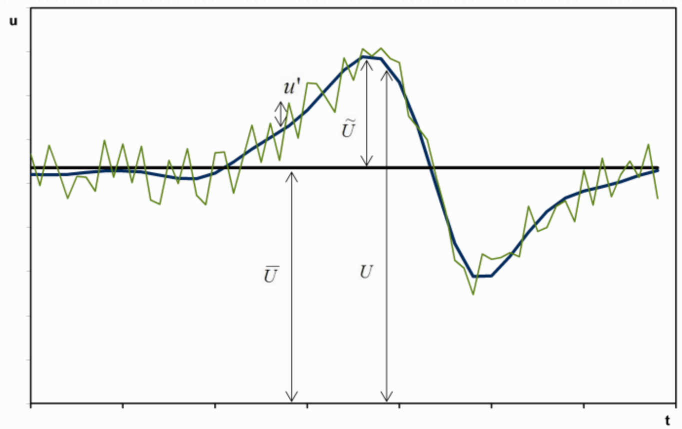
Experimental site and wind model

Wind Model

$\vec{u}(M,t) = \vec{U}(M,t) + \vec{u}'(M,t)$ With $\vec{U}(M,t) = \overline{\vec{U}}(M,t) + \tilde{\vec{U}}(M,t)$

$$\vec{u}(M,t) = \overline{\vec{U}}(M,t) + \tilde{\vec{U}}(M,t) + \vec{u}'(M,t)$$

Overall time-mean + Low frequency fluctuations + Turbulent fluctuations



- **Longitudinal component, in the mean wind direction:**

$$u(M,t) = \overline{u}(M) + \tilde{u}(M,t) + u'(M,t)$$

- **Lateral component, in the crosswind direction :**

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

➢ The main difficulty is to extract the slow time-varying component

Plan

- Problematic and objectives
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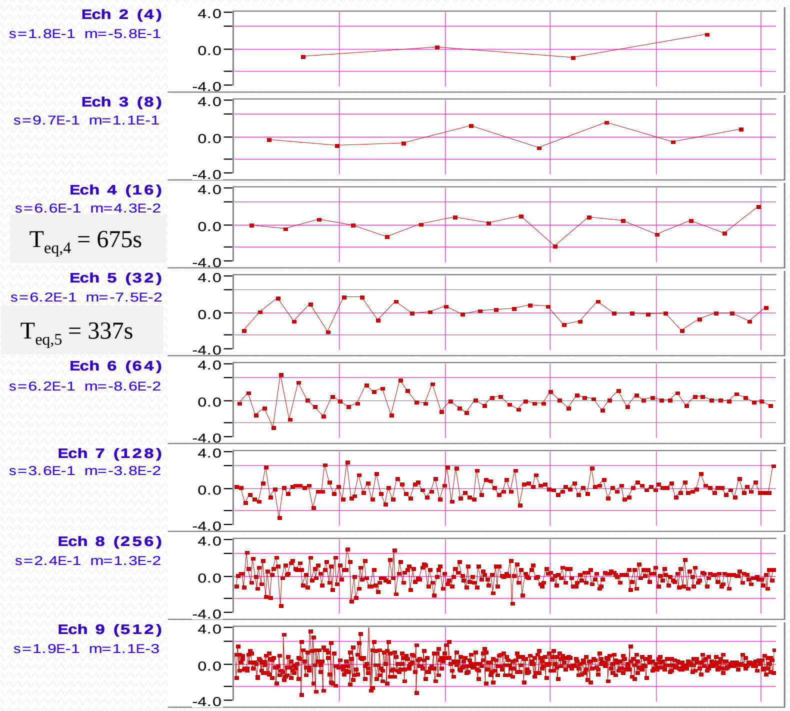
- **Methods to estimate the standard deviation of lateral dispersion**
  - Method based on the generation of random particle trajectories
  - Method based on the experimental analysis of velocity fluctuations
- Results

Methods to estimate the horizontal dispersion

❑ Method based on the Generation of Random Particle Trajectories (GRPT)

- Representative local low wind velocity records are wavelet transformed using Daubechies (DB4) wavelets
  - This results in sets of wavelet coefficients characteristic of the time-scale structure of the natural wind
- Random signals, statistically similar to the original ones (with the same energy), are obtained by inverse wavelet transform
  - The original wavelet coefficients are kept at each scales, however, their positions in time are randomly permuted before performing the inverse wavelet transform

Wavelet decomposition of a representative signal

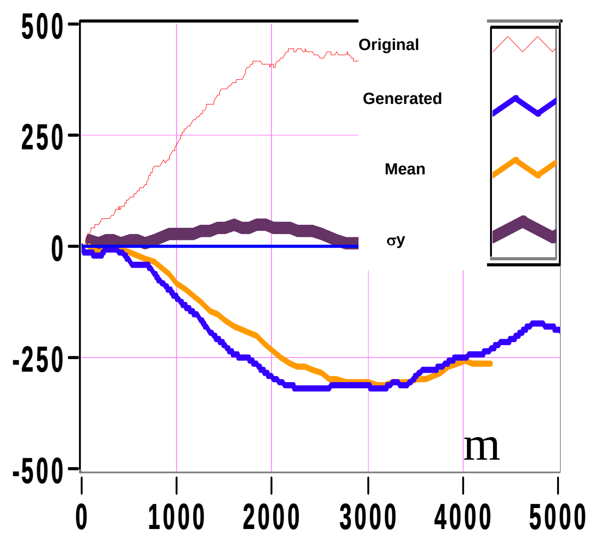


Methods to estimate the horizontal dispersion

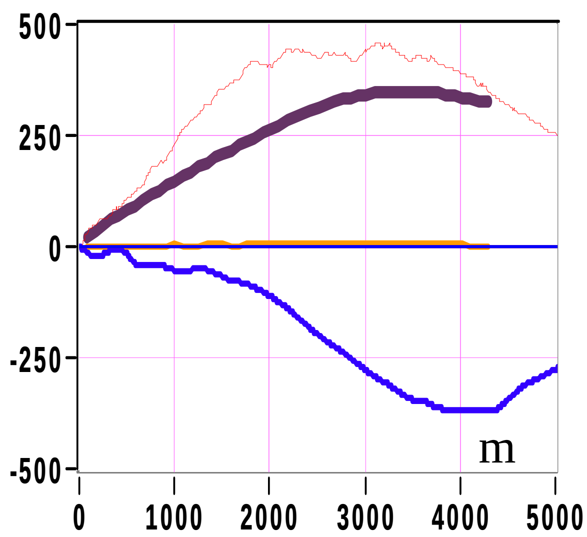
❑ Method based on the GRPT

- Time integrations of the generated velocities led to trajectories $y_k = \sum_{i=0}^{k} v_i \Delta t$

- $\sigma_y(x)$ *is* gradually constructed by computing j trajectories, until the mean trajectory is aligned in the x-axis (y=0)



a/ 10 trajectories



b/ after 700

Methods to estimate the horizontal dispersion

Method based on the Experimental Analysis of Velocity Fluctuations (EAVF)

- Empirical Mode Decomposition (EMD) is used to separate the organized and turbulent lateral fluctuations
- Variance of the organized fluctuations is evaluated over T_s *(the sampling time duration)*
- Variance of the turbulent fluctuations is evaluated over N designated time intervals of T seconds, $N=int(T_s/T)$
- Variance of the lateral wind speed component can be approximated by

$$\sigma^2_{v,T_s} = \frac{1}{N}\sum_{i=1}^{N} \sigma^2_{v'_i,T} + \sigma^2_{\tilde{v},T_s}$$

- Lateral standard deviation can be computed by using the Taylor's theorem

$$\sigma^2_y(T_s) = 2\sigma^2_{v,T_s} T_L T_s$$

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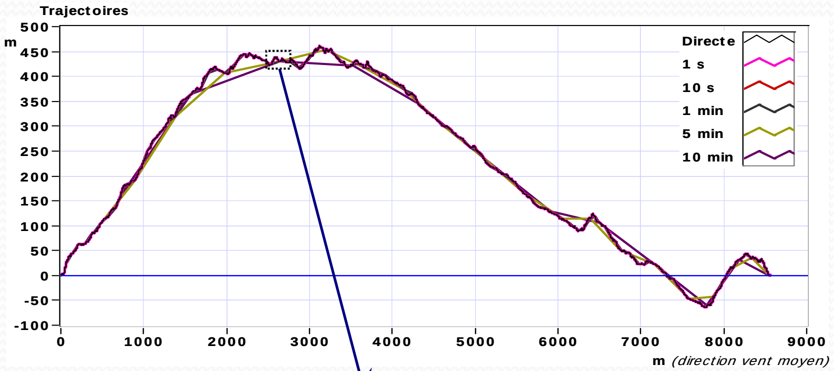
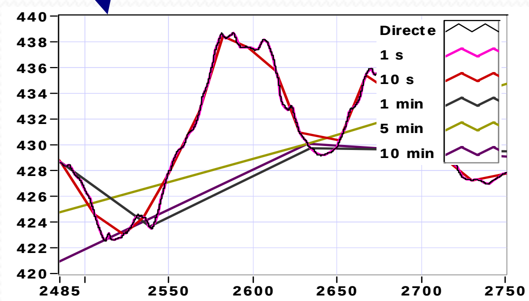
Results

- With the GRPT method, if the signals are generated by omitting the high frequency terms (*by setting the wavelet coefficients related to those particular fluctuations to zero*) :
  - the overall trajectories are very similar to that obtained without neglecting any coefficients



Averaging :

1s, 10s, 1min, 5min and 10 min



Trajectories of the particles by time scales

This result confirms that, in low wind speed conditions, the lateral dispersion parameter is mainly governed by « large scale » atmospheric motions

Results

- With the EAVF method, it has been observed that the turbulence intensity on the test site, over time intervals of T seconds

$$I_{v'} = E\left[\frac{\sigma_{v',T}}{\left|\overrightarrow{U}_i(t)\right|}\right]_T$$

With

$$\overrightarrow{U}(M,t) = \overline{\overrightarrow{U}}(M,t) + \tilde{\overrightarrow{U}}(M,t)$$

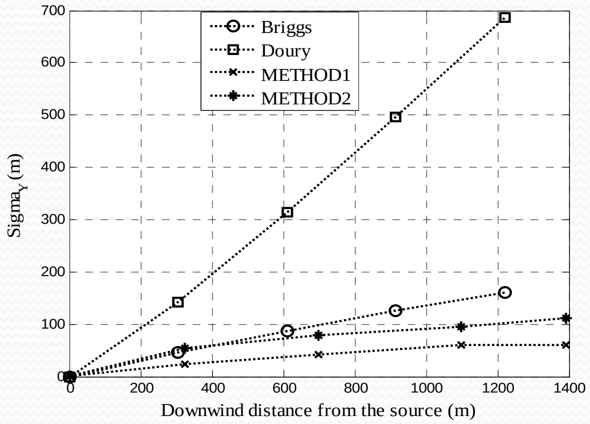
- is nearly constant, and equal to **0.28**, for **T=600s**
- thus, $\sigma_{v',T}$ can be considered as proportional to the slow time-varying wind speed

This results show that the lateral dispersion is mainly governed by the slow time varying wind speed, which can be predicted by using appropriate methods

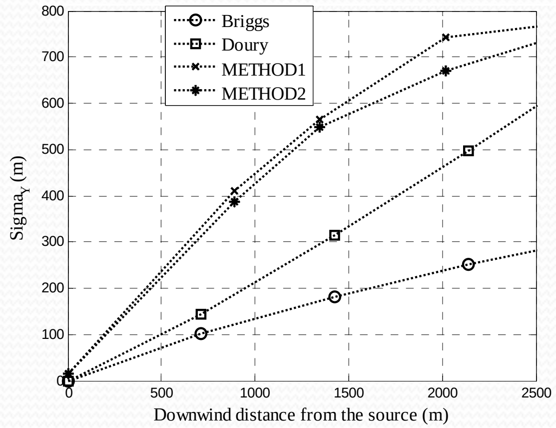
Results

Comparison of the results with Briggs's and Doury's parameterizations

- U = 0.51 m/s , $\sigma_\theta = 12°$



- U = 1.18 m/s , σ_θ=29°



- **Doury** gives very high values of σ_y for very low wind speeds, leading to an underestimation of the concentrations
- **Briggs** tends to underestimate σ_y when σ_θ is large, leading to overestimation of the concentrations
- **GRPT** (Method1) and **EAVF** (Method2) exhibit **similar results**, close to Briggs's parameterization for small $\boldsymbol{\sigma_\theta}$
- For **large $\boldsymbol{\sigma_\theta}$**, the two developed methods give **more consistent** results

Conclusions

- Our methods provide simple yet effective ways to obtain a quantitative estimate of the lateral dispersion coefficient in low wind speed conditions
- They give consistent results in the presence of large slow horizontal wind motions, notably for $1m/s < U < 2m/s$ and $\sigma_\theta > 25°$, when both Doury's and Briggs's parameterizations appear to be less efficient
- Our study confirms that the lateral dispersion in low wind speed conditions, is mainly governed by large scale atmospheric motions
- Thus suitable parameters can be computed by using advanced methods (ANN, ARIMA, …) to predict the slow time varying wind speed.

Thank you for your attention