Determination of concentration fluctuations within an instantaneous puff

Wind tunnel experiments

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Introduction

- The question of short or instantaneous releases is of special interest for :
  - Accidental or deliberate release in industrial or urban areas
  - Transport of hazardous materials

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Introduction

- Short release dispersion requires specific attention :
  - The concentration distribution is the result of a single realization (not an ensemble average)
  - Necessity to estimate the 1st, 2nd, 3rd… moments of the concentration distribution
- With the followings restrictions :
  - Operational purposes require short computation times
  - Few available data to feed the models

- Design wind tunnel experiments so as to :
  - Characterize concentrations statistics for short releases
  - Develop a theoretical framework for an operational dispersion model : SIRANERISK, Soulhac et al., 2007 in Cambridge

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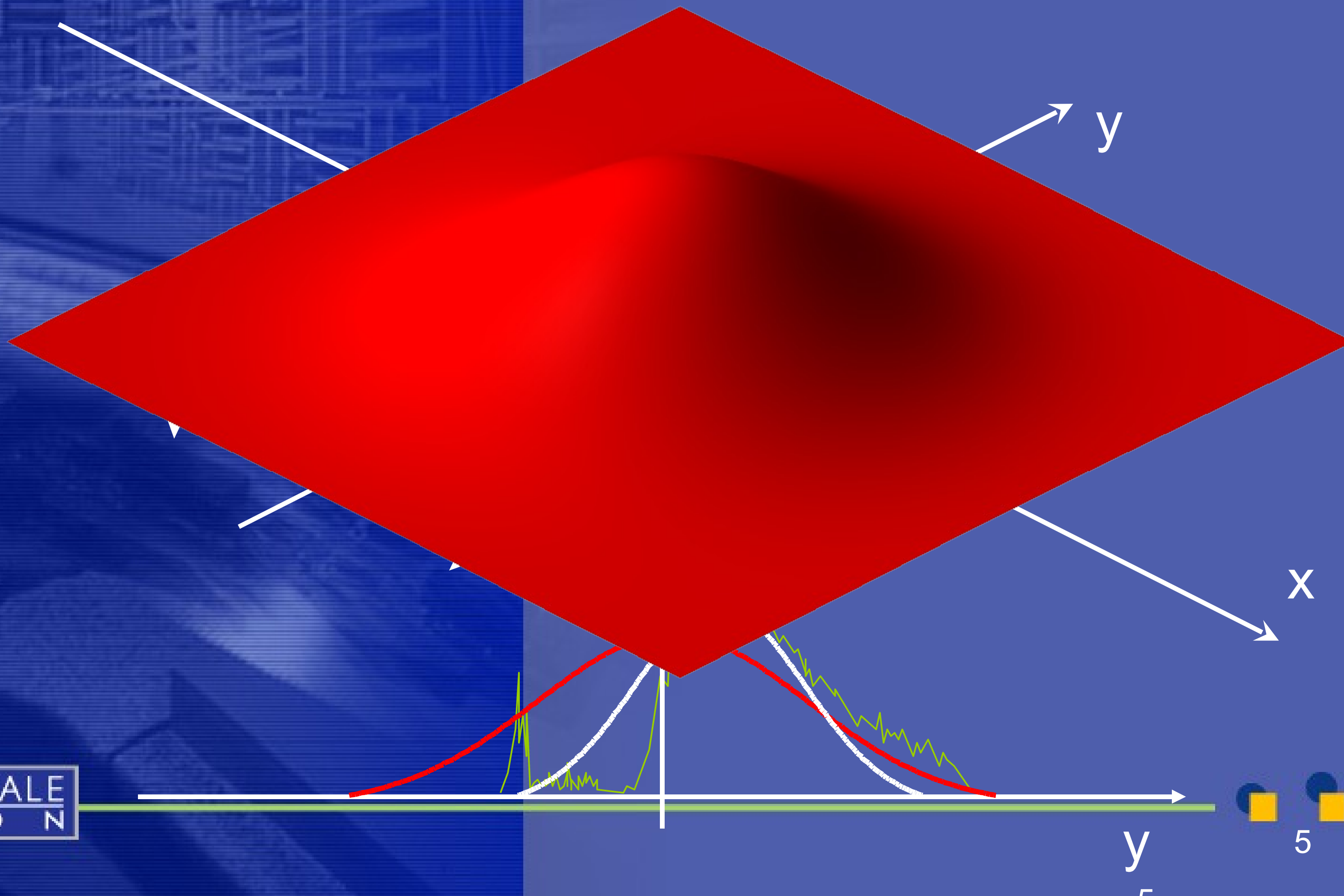
Description of a short term release

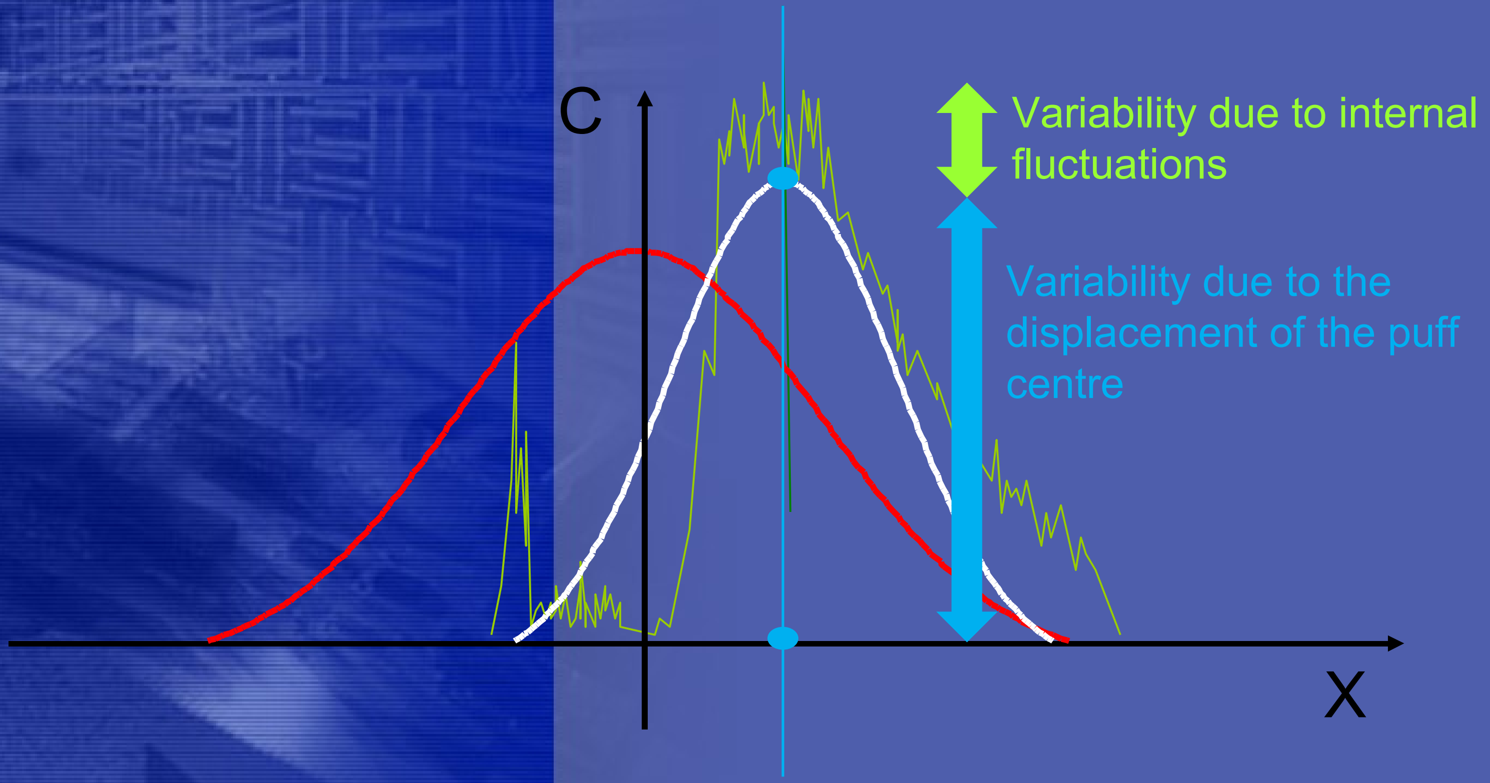
- The turbulent nature of the flow induces a particular behavior for each release
- Operational dispersion models are limited to statistic approaches

Instantaneous and mean puff

At a given time t



Concentration variability

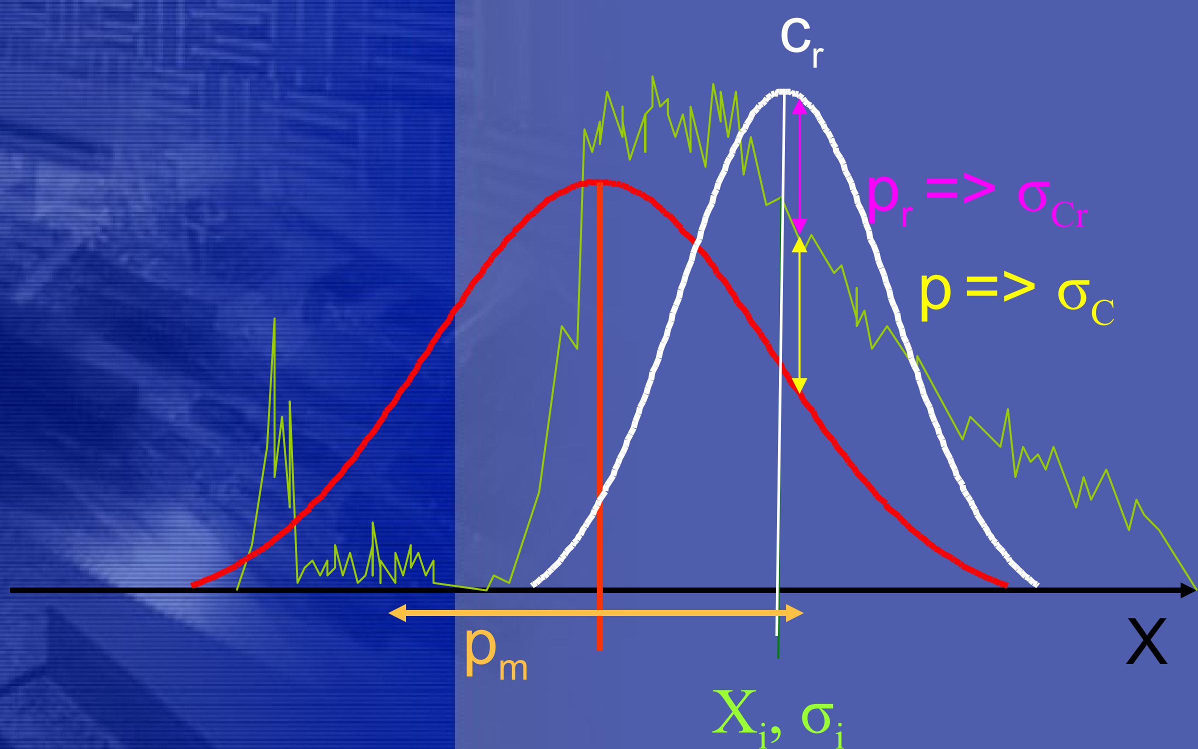


Instantaneous puff descriptors

$$p(C;x,y,z,t)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p_r\left(C;x-x_c,y-y_c,z-z_c\right)\,p_m\left(x_c,y_c,z_c\right)\,dx_c\,dy_c\,dz_c$$

$$p_r(C;x,y,z,t)=\frac{k}{c_r\Gamma(k)}\left(\frac{kC}{c_r}\right)^{k-1}\exp\left(-\frac{kC}{c_r}\right)$$

$$p_{m\_3D}(x_c,y_c,z_c)=\frac{1}{(2\pi)^{3/2}\sigma_{x,m}\sigma_{y,m}\sigma_{z,m}}\exp\left(-\frac{x_c^2}{2\sigma_{x,m}^2}\right)\exp\left(-\frac{y_c^2}{2\sigma_{y,m}^2}\right)\exp\left(-\frac{z_c^2}{2\sigma_{z,m}^2}\right)$$



Derivation of equations

- $c_r(x,y,z,t)$

$$\overline{c_r}(x,y,z,t) = \frac{M(x_0,y_0,z_0,t_0)}{(2\pi)^{3/2}\sigma_{x,r}\sigma_{y,r}\sigma_{z,r}} e^{-\frac{1}{2}\left[\frac{(x-x_c)^2}{\sigma_{x,r}^2}\right]} e^{-\frac{1}{2}\left[\frac{(y-y_c)^2}{\sigma_{y,r}^2}\right]} e^{-\frac{1}{2}\left[\frac{(z-z_c)^2}{\sigma_{z,r}^2}\right]} = c_{r,0} e^{-\frac{1}{2}\left[\frac{(x-x_c)^2}{\sigma_{x,r}^2}+\frac{(y-y_c)^2}{\sigma_{y,r}^2}+\frac{(z-z_c)^2}{\sigma_{z,r}^2}\right]}$$

- Yee and Wilson (2000) :

$$\frac{\overline{C^n}(x,y,z,t)}{c_{r,0}^n} = \frac{\left[\frac{1}{k^n}\frac{\Gamma(n+k)}{\Gamma(k)}\right]}{(1+nM_x)(1+nM_y)(1+nM_z)} e^{-\frac{1}{2}\left[\frac{x^2}{(1+nM_x)\sigma_{x,r}^2/n}\right]} e^{-\frac{1}{2}\left[\frac{y^2}{(1+nM_y)\sigma_{y,r}^2/n}\right]} e^{-\frac{1}{2}\left[\frac{z^2}{(1+nM_z)\sigma_{z,r}^2/n}\right]}$$

- 2 physical parameters :

$$M_i = \frac{\sigma_{m,i}^2}{\sigma_{r,i}^2} \quad k = \frac{1}{i_r^2} = \frac{\overline{c_r}^2}{\sigma_{Cr}^2} \quad \frac{\sigma_{tot,i}^2[n]}{\sigma_{tot,i}^2} = \frac{(1+nM_i)}{n(1+M_i)} \leq 1$$

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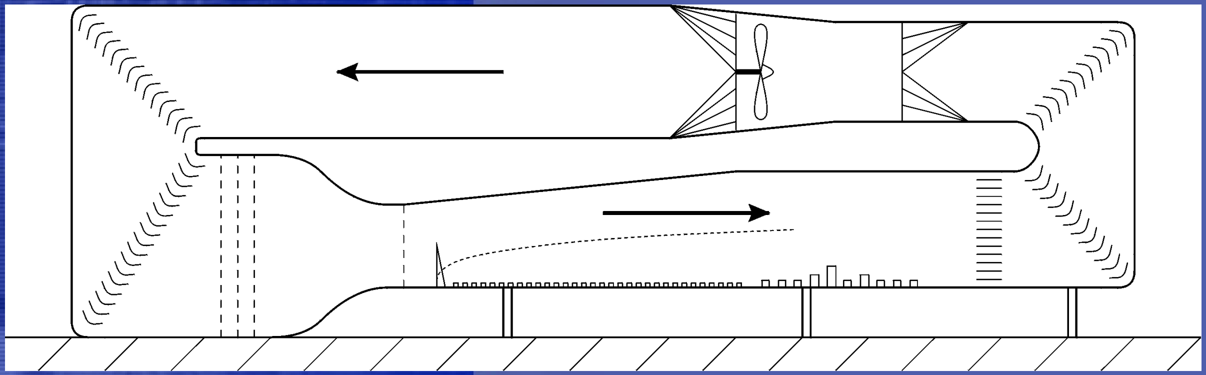
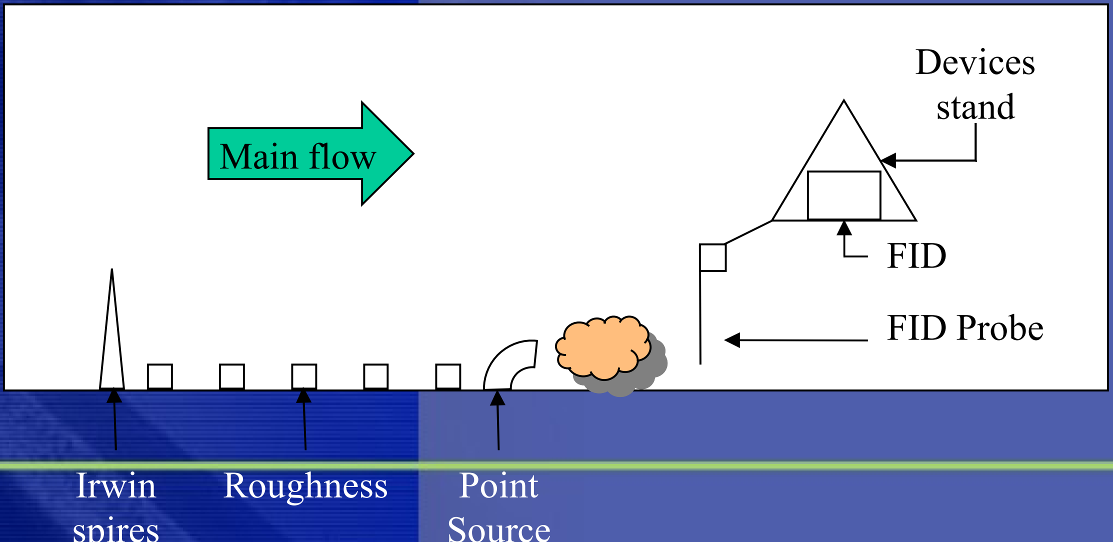
Experiment design

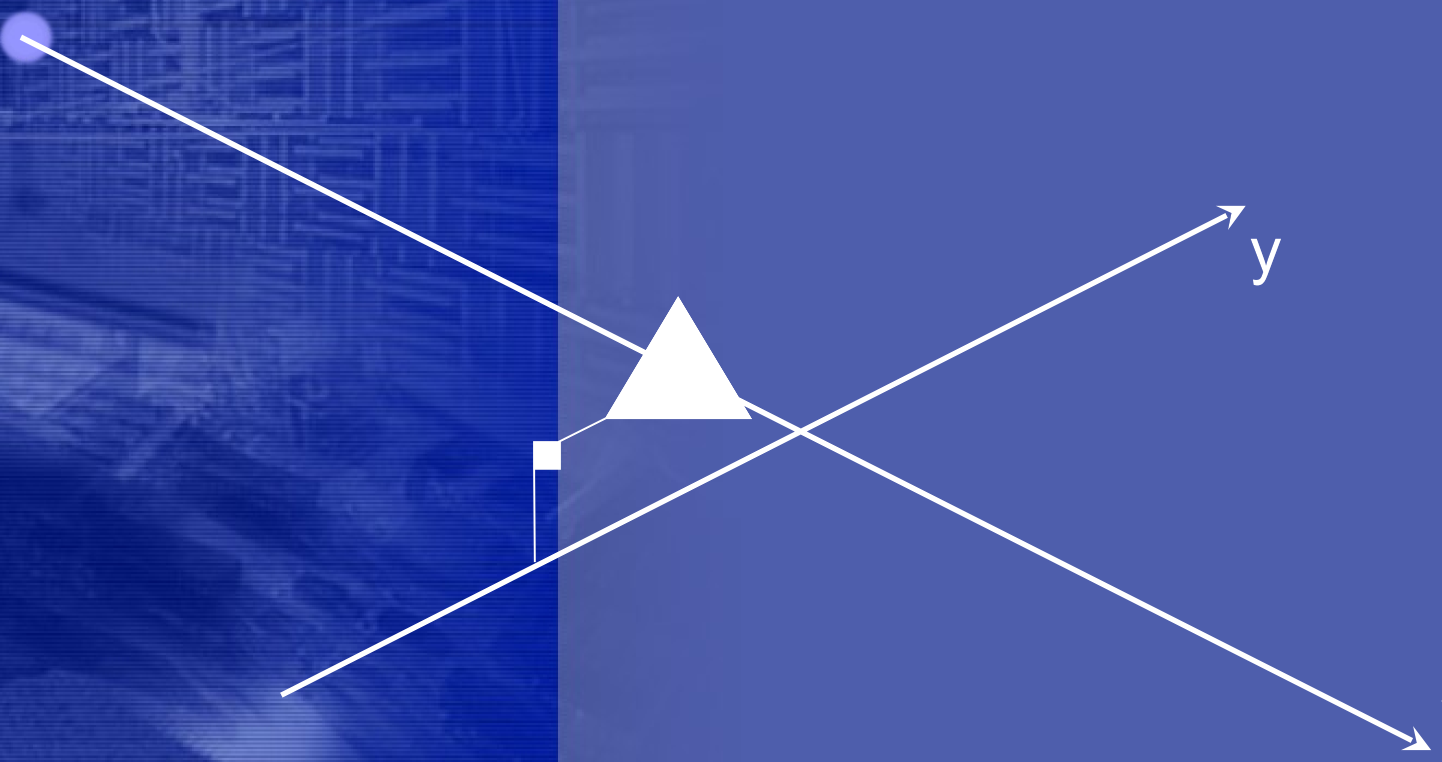
- Atmospheric wind-tunnel (Ecole Centrale de Lyon)



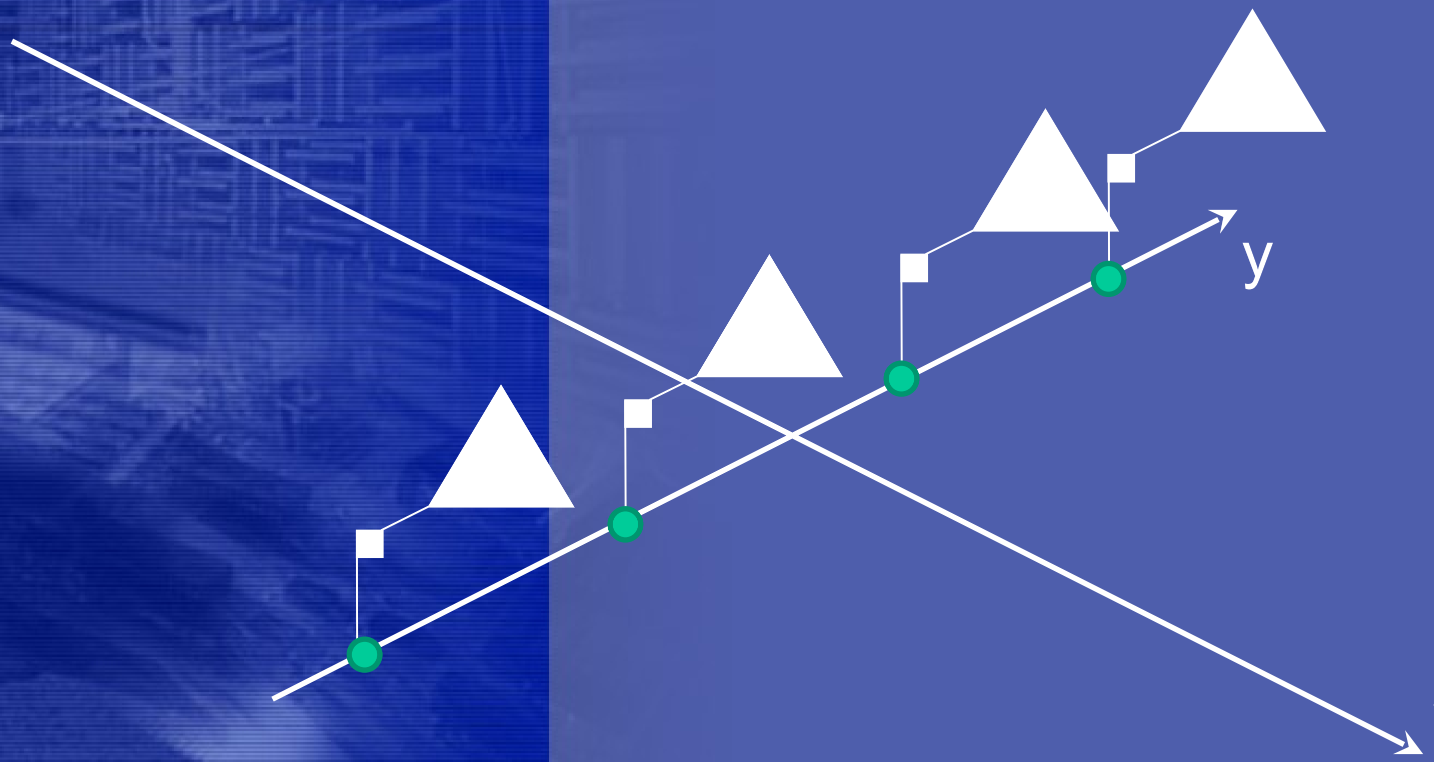
- Experimental setup



Instantaneous and mean puff



Instantaneous and mean puff



Experimental campaigns

- 2 stationary releases campaigns with Hs = 20 mm
- 1 instantaneous releases campaign with Hs = 20 mm

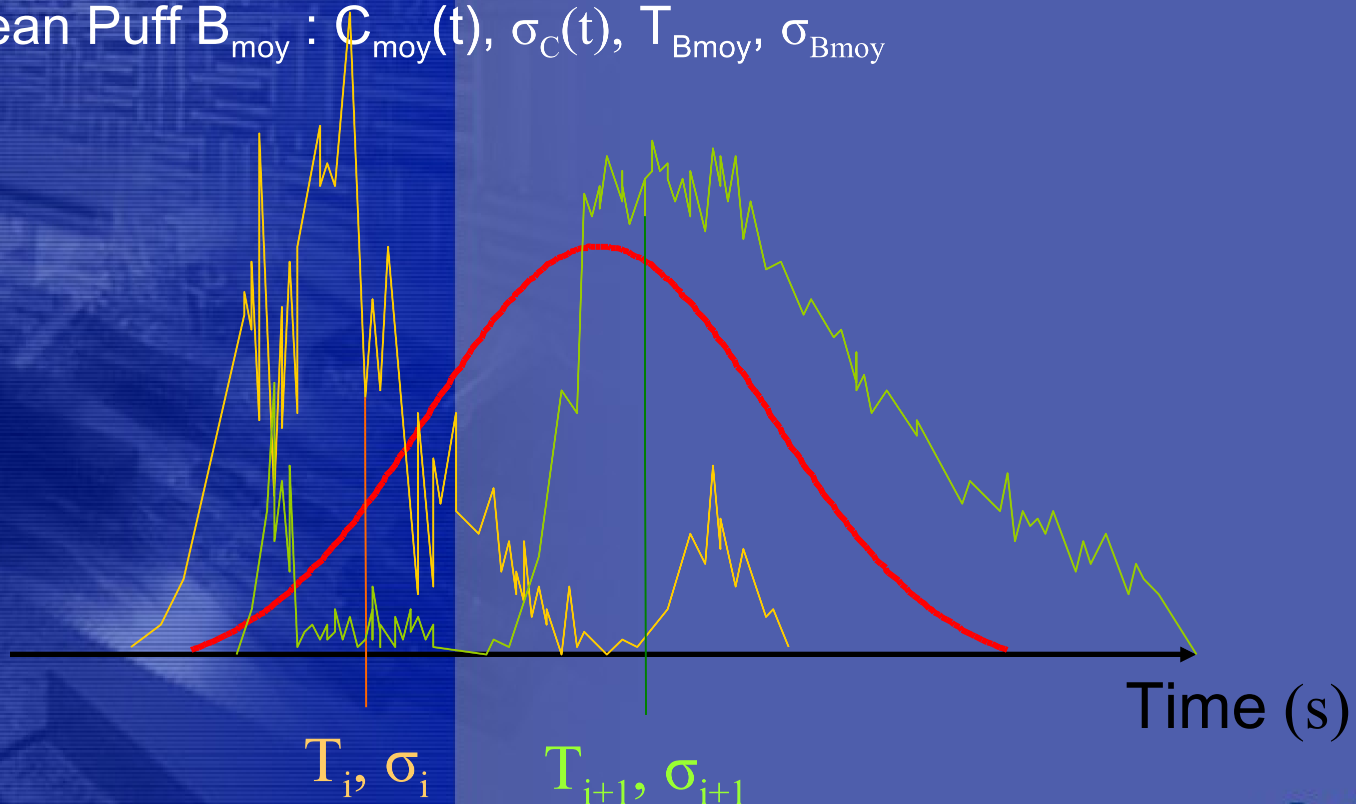
} R20

- 1 stationary release campaign with Hs = 50 mm
- 1 instantaneous releases campaign with Hs = 50 mm

} R50

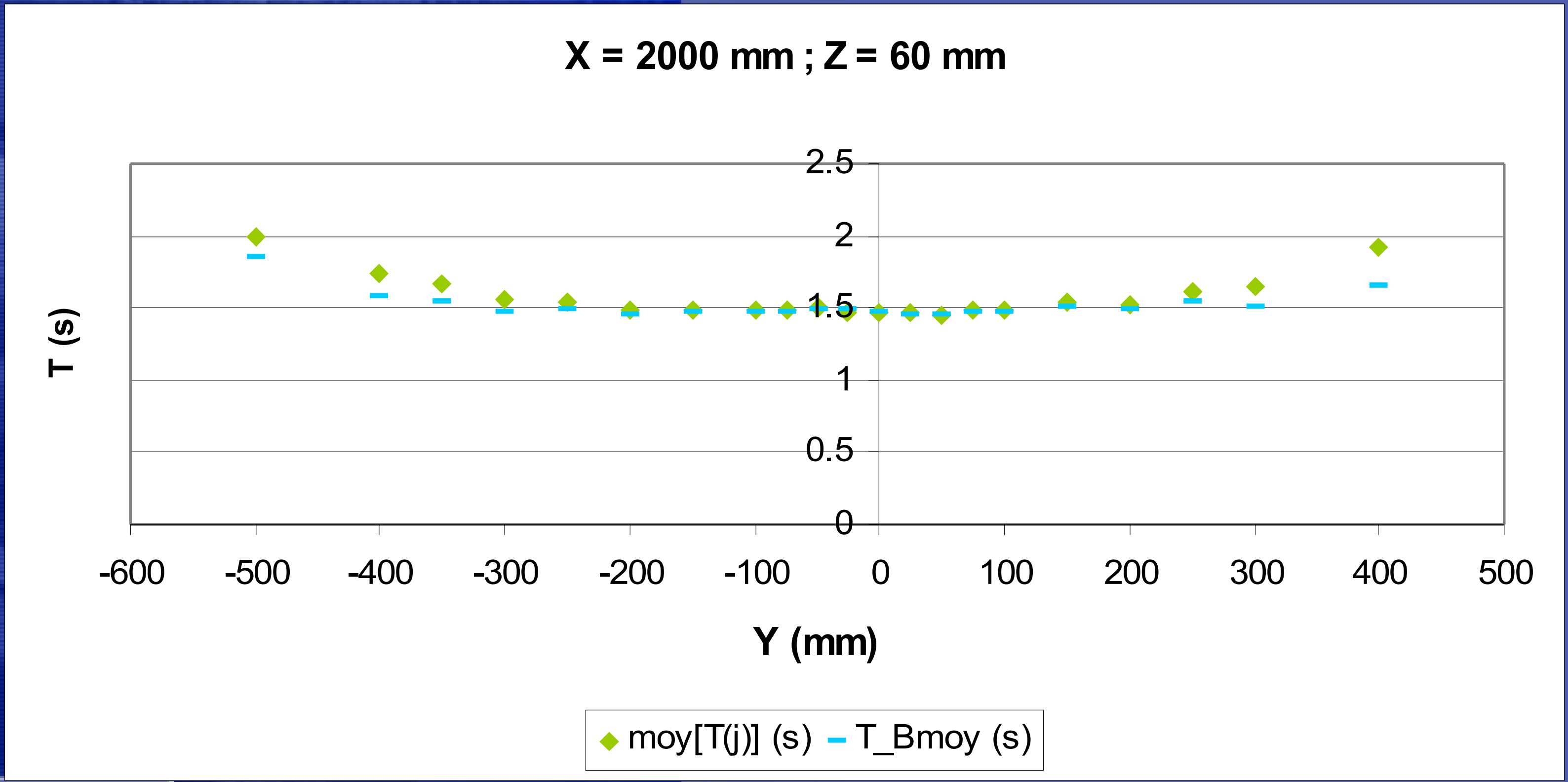
Experimental process

- Instantaneous Puff B_i : C_i (t), T_i, σ_i
- N_b different releases => $\langle T_i \rangle, \langle \sigma_i^2 \rangle, \sigma_{T_i}$
- Mean Puff B_{moy} : C_{moy}(t), $\sigma_C(t)$, T_{Bmoy}, σ_{Bmoy}



Main results

- Averaged time arrival of each release (moy[T(j)]) and time arrival of the mean puff (T_Bmoy); R50



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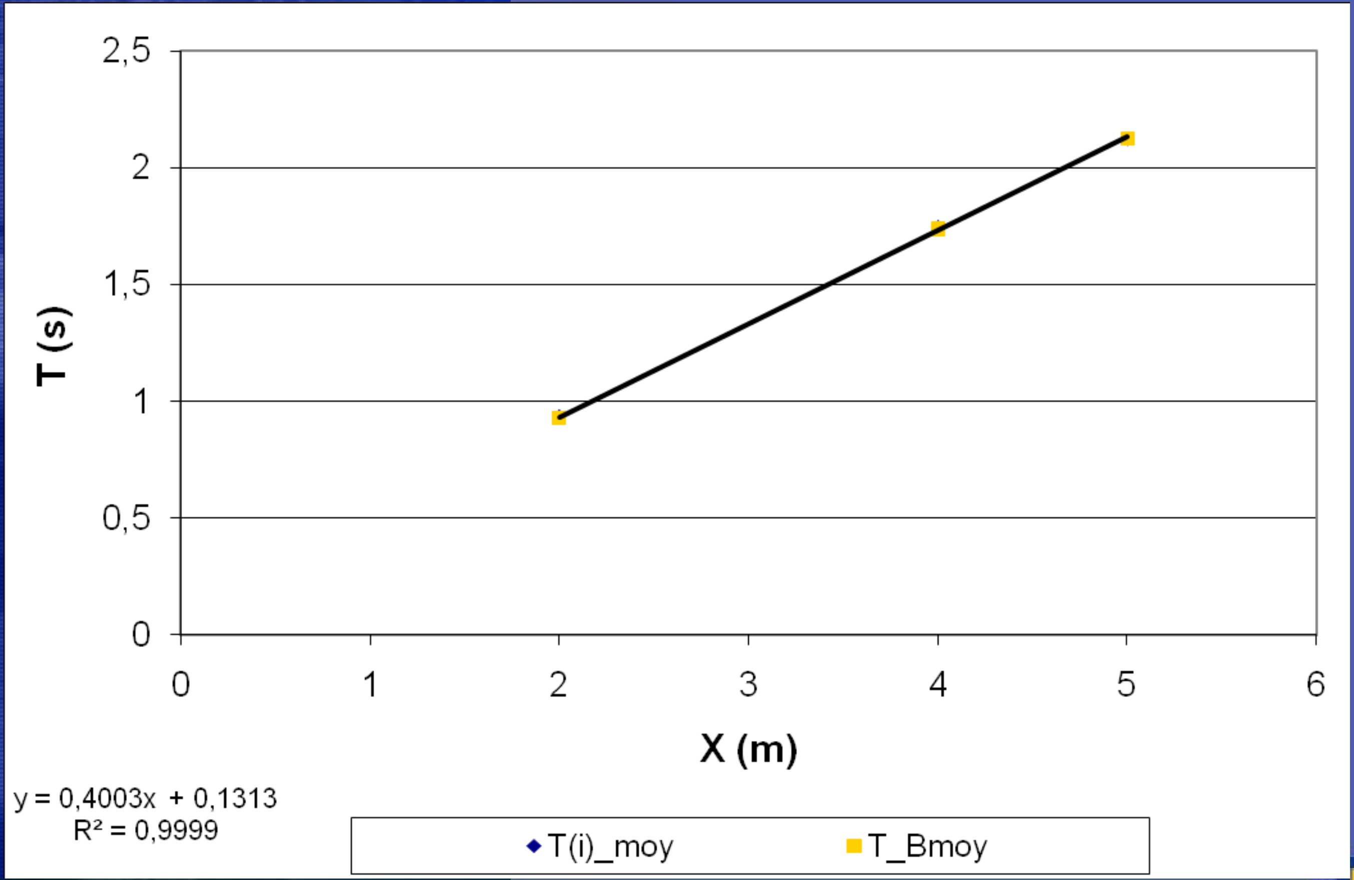

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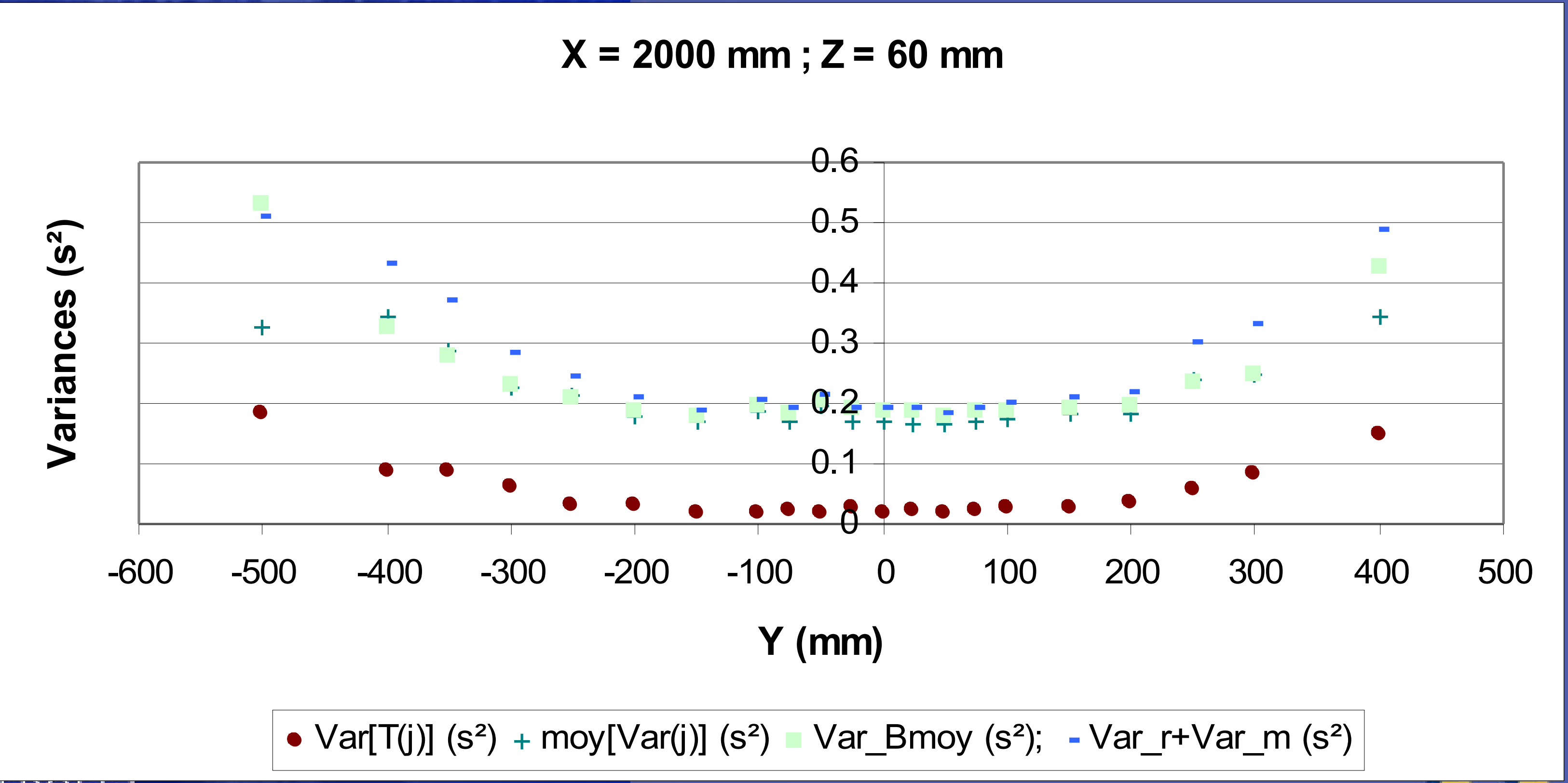
Mean results

- Mean and relative puff variances, (Var_Bmoy, Var-r = moy[Var(j)]), mass center spread variance (Var_m = Var_t_j.) ; R50



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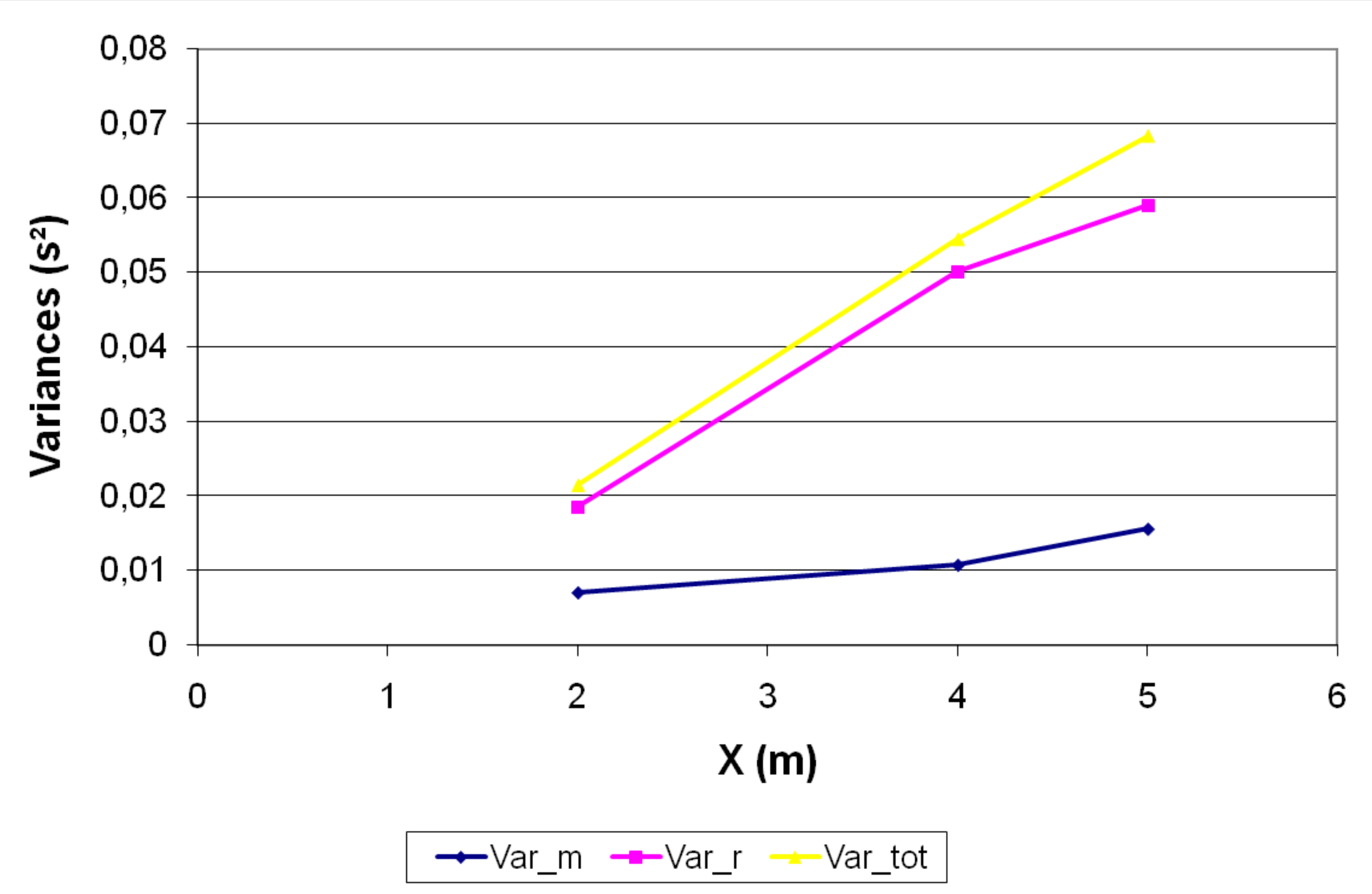
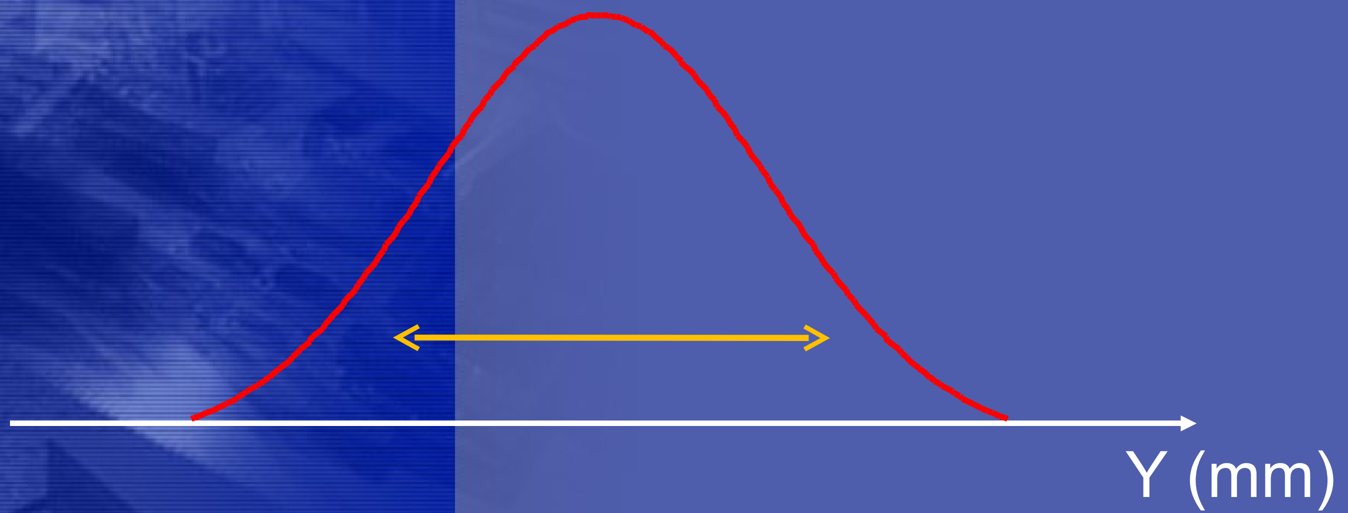


Experimental process

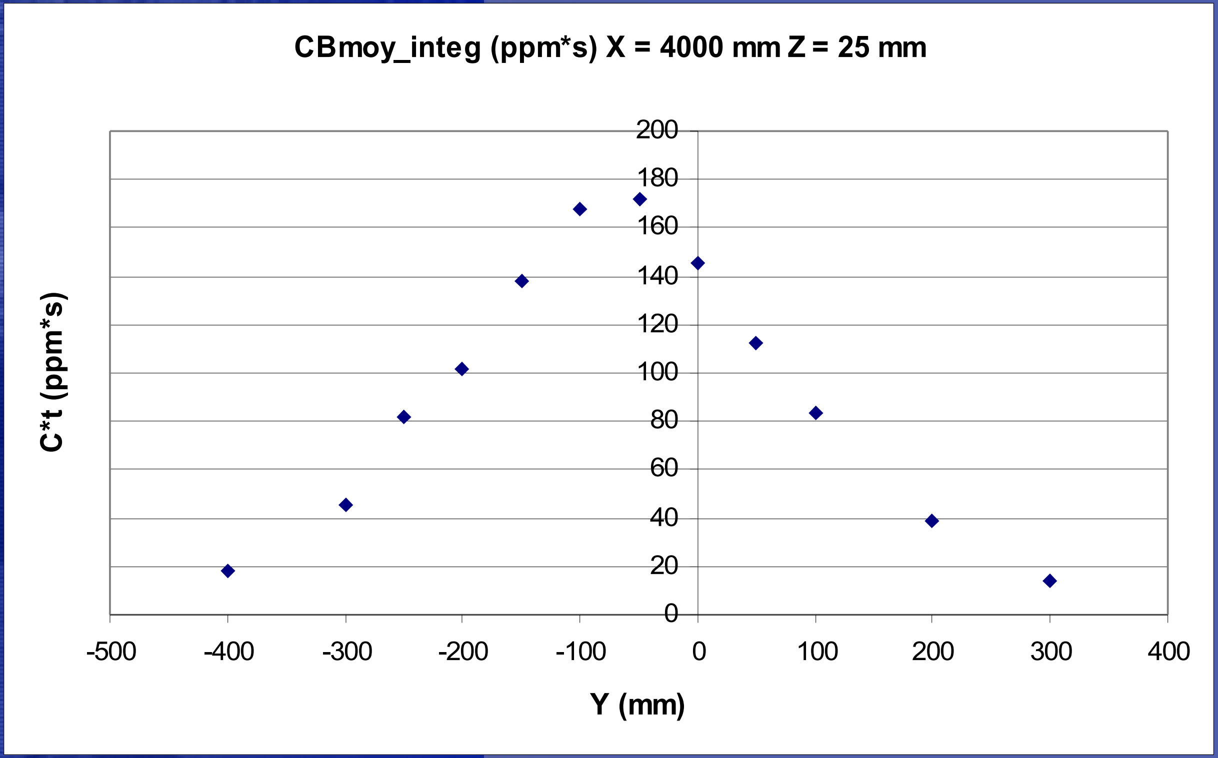
- Y transverse direction: C*t (Y) and other moments

$$\frac{\sigma^2_{tot,i}[n]}{\sigma^2_{tot,i}} = \frac{(1+nM_i)}{n(1+M_i)} \leq 1$$



Main Results

- Gaussian distribution of the time integrated distribution (which same std as the mean puff)



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Experimental process

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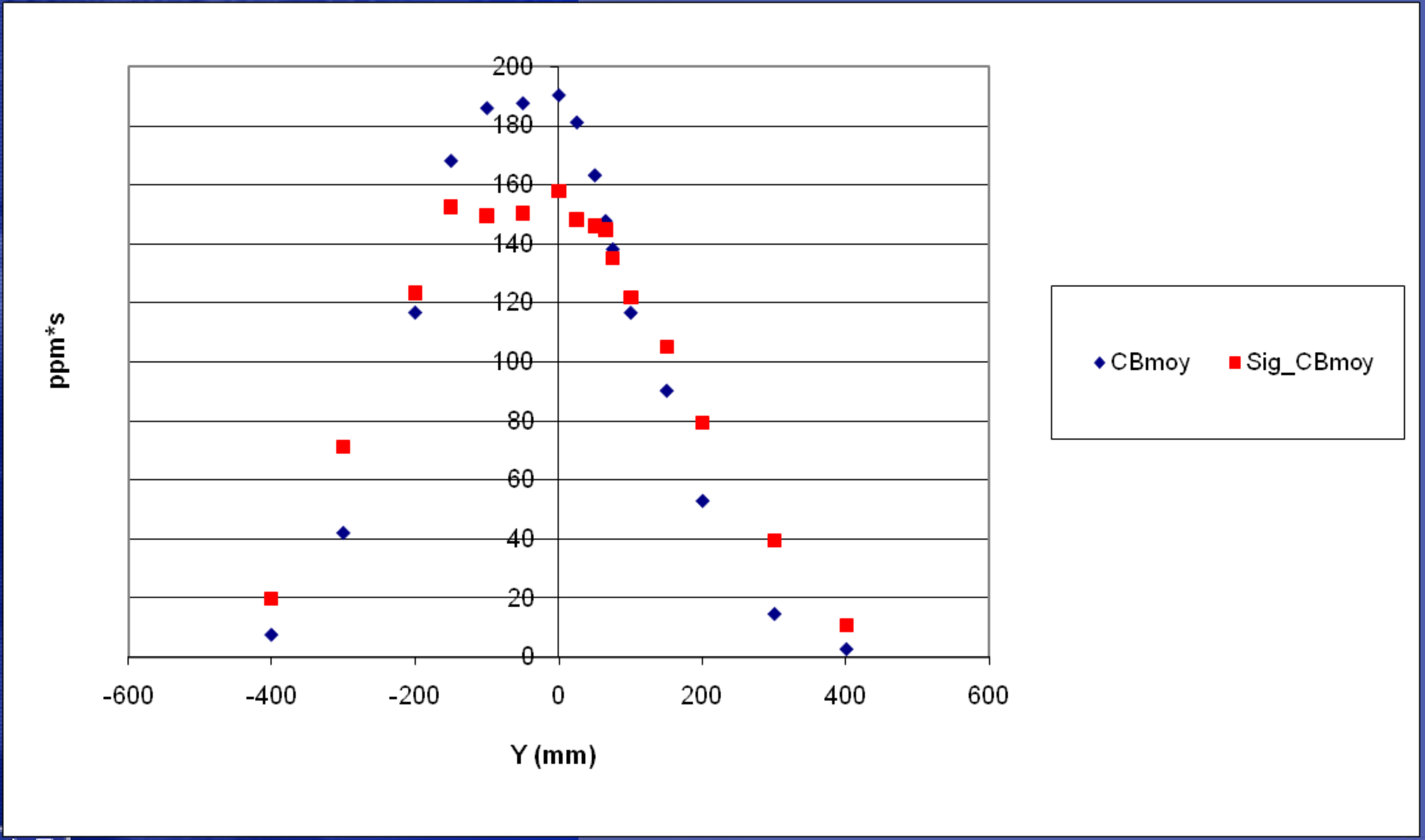
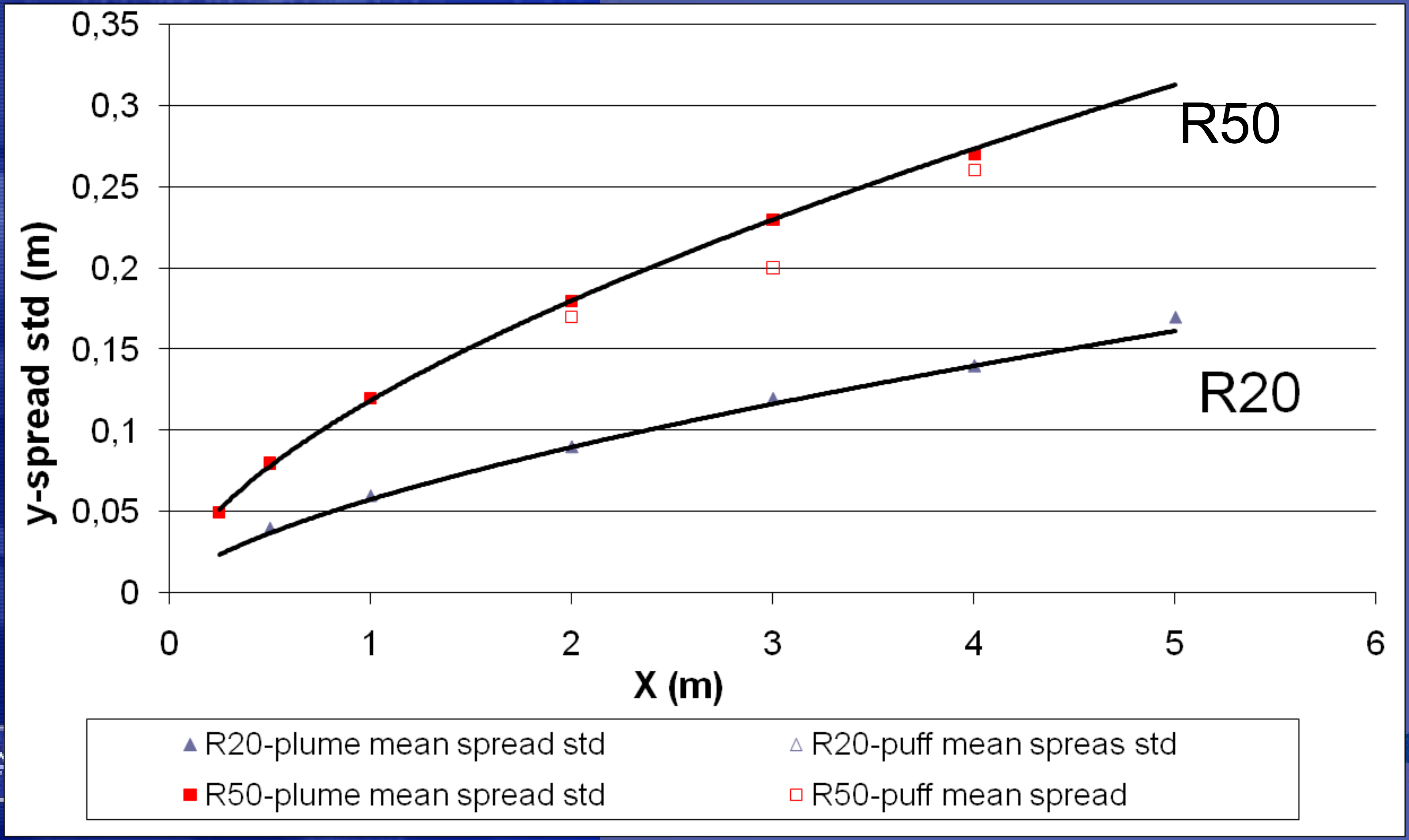


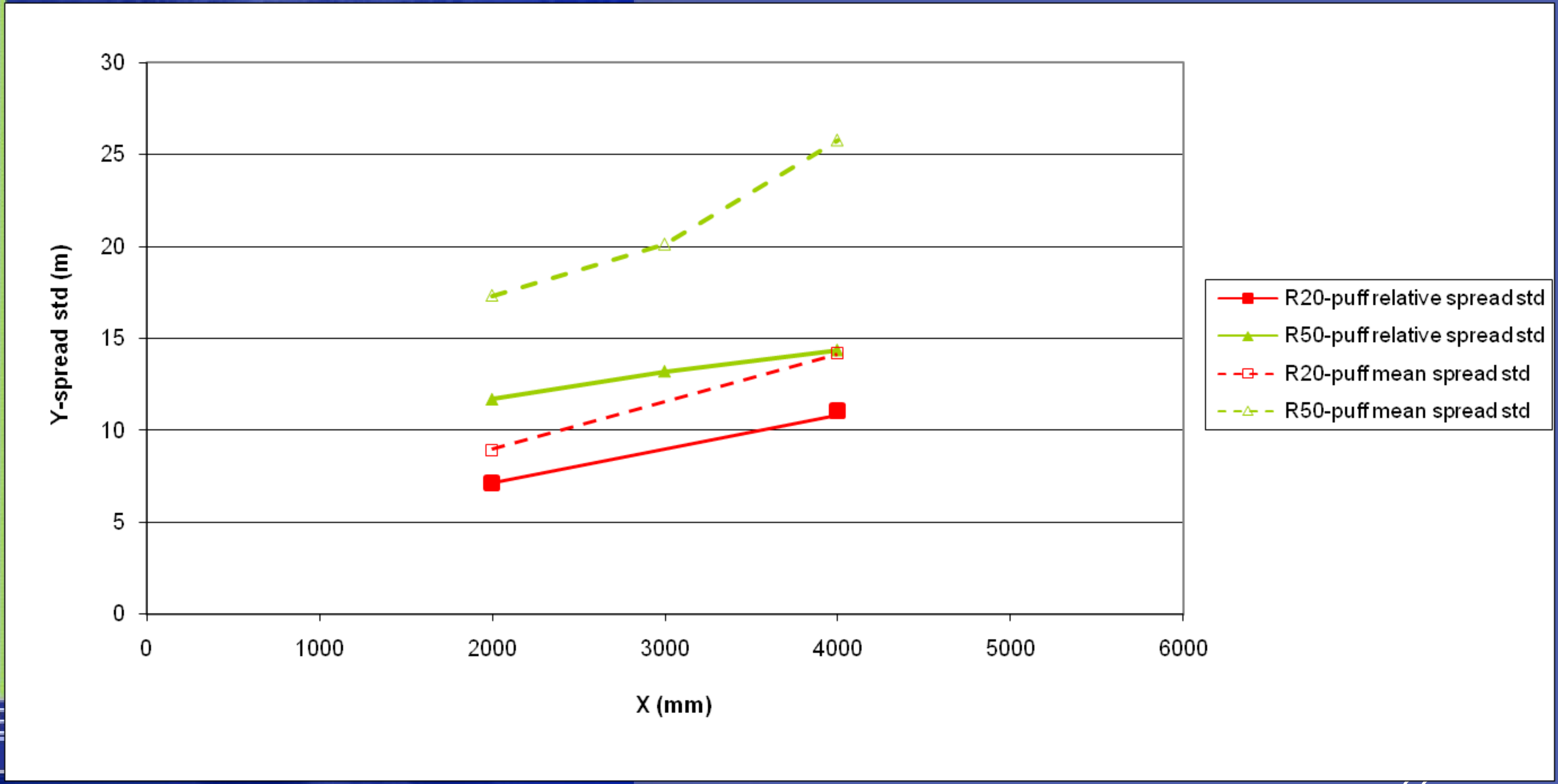
Mean results

- Y-puff mean spread std for steady and unsteady releases (R20/R50)



Main results

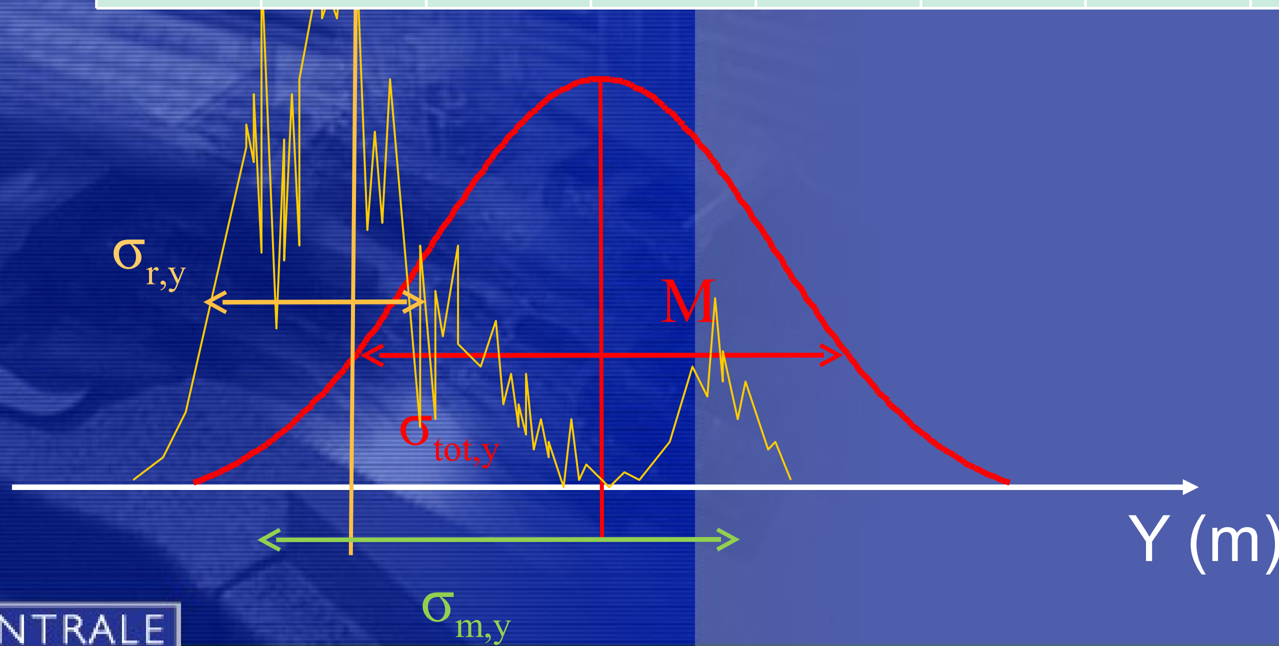
- Comparison of Y-relative spread std longitudinal evolution (R20/R50)



Main results

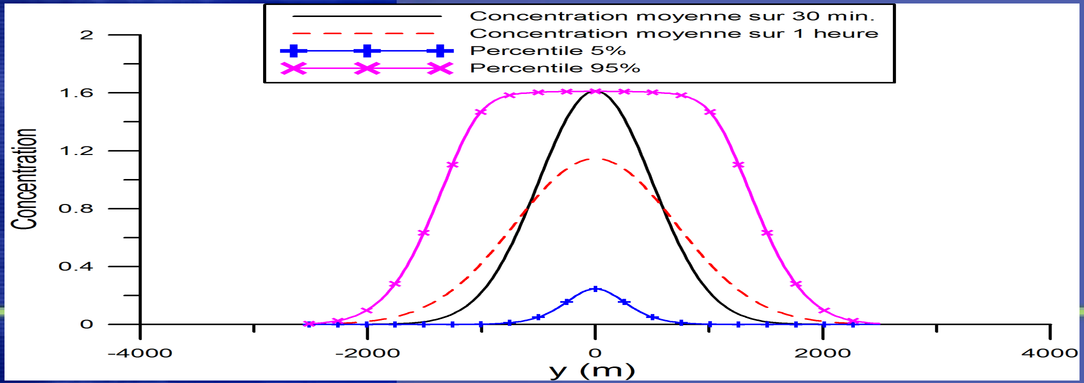
- Compulsed data for a sensor position (R50, X= 4 m)

$S_{tot,y}$	M_y	$S_{r,y}$	$S_{m,y}$	$S_{tot,x}$	M_x	$S_{r,x}$	$S_{m,x}$	I(y)	I_r
0.26m	2.22	0.14m	0.21m	0.9 m	0.09	0.46m	0.14m	0.57	0.54



Conclusions

- Specific experiment designed for short releases
- Main results :
  - Longitudinal dispersion dominated by relative spread
  - Longitudinal characteristics do not depend on Y
  - Plume and puff mean spreads are equivalent in the transverse direction
  - The methodology allows for the determination of the different physical involved parameters : i and M
- Application :



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Perspectives

- Simulations and wind-tunnel experiments of short releases on an idealised district
- Integration of a variability model in operational dispersion models (SIRANERISK)

Thank you for your attention

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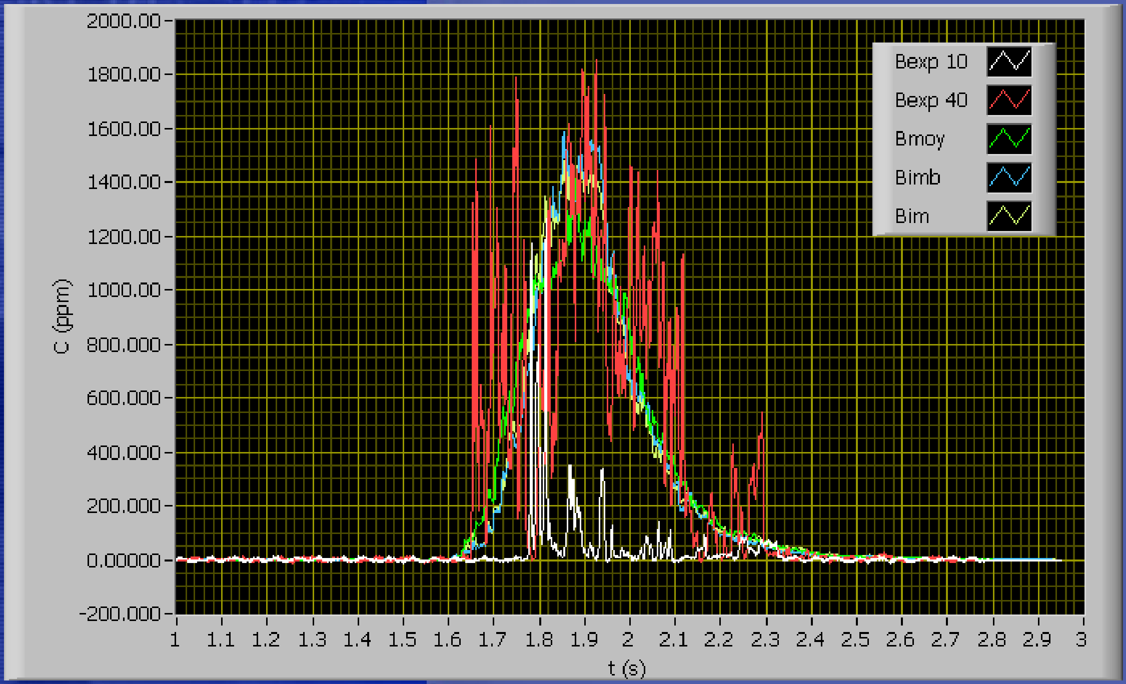
Experimental results

- 2 instantaneous puffs, mean puff, and idealized instantaneous puff (X = 2000 mm, R0)



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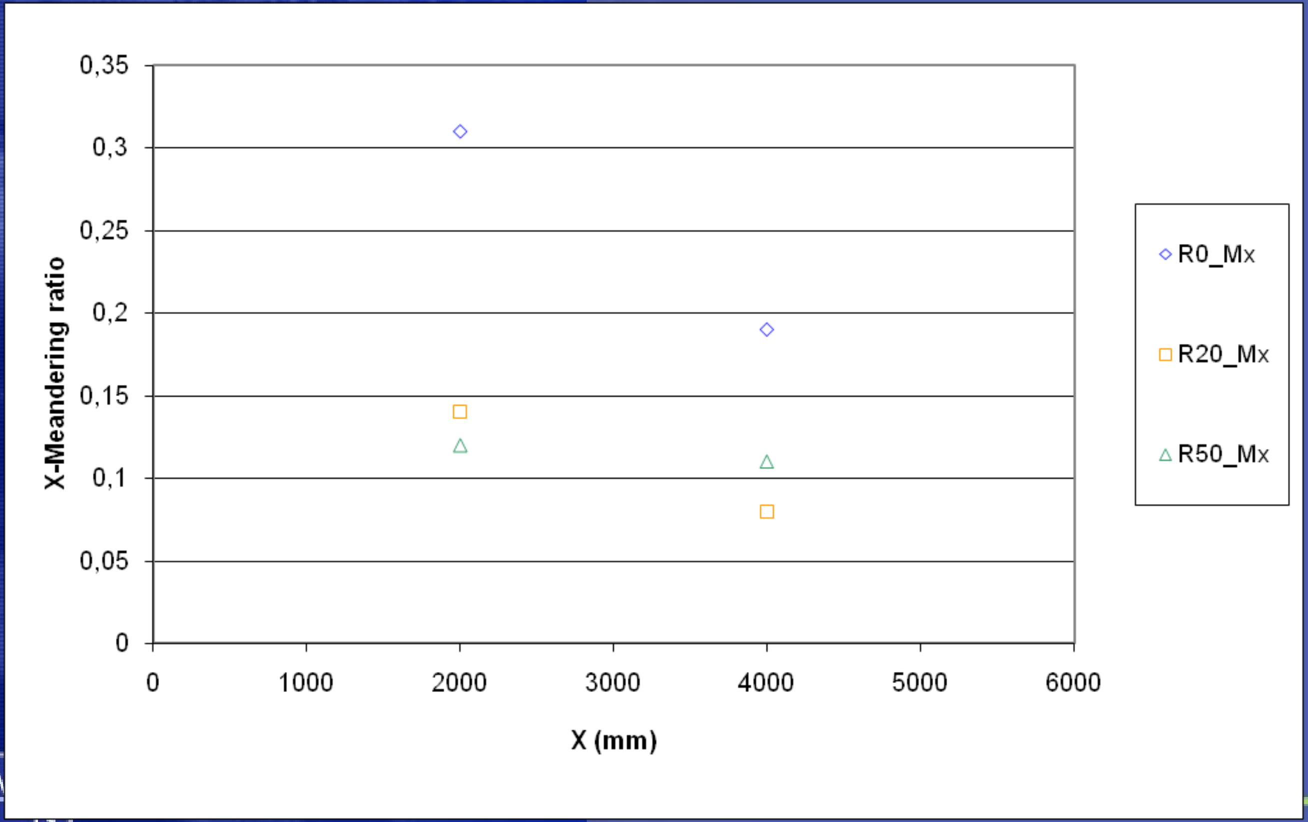
Main Results

- Comparison of X-meandering ratio longitudinal evolution (R20/ R50)



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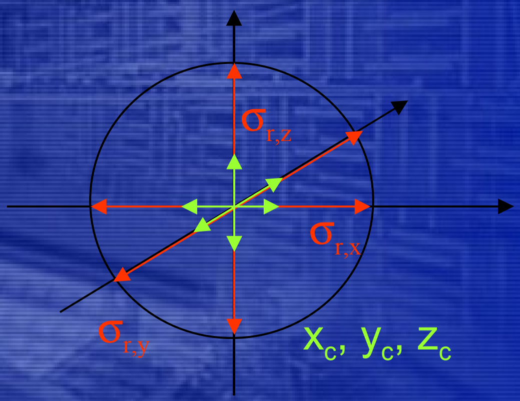
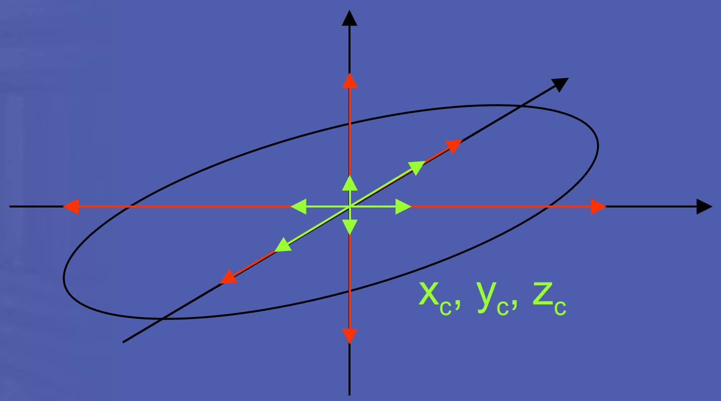
Gaussian puff descriptors



Idealized Puff in an uniform flow



Puff deformation in a shear layer

- $\sigma_{r,i} = g(t)$
- $\sigma_{m,i} = h(t)$
- $C(x,y,z,t)$

$$p_{m\_3D}(x_c, y_c, z_c) = \frac{1}{(2\pi)^{3/2}\sigma_{x,m}\sigma_{y,m}\sigma_{z,m}} \exp\left(-\frac{1}{2}\frac{x_c^2}{\sigma_{x,m}^2}\right) \exp\left(-\frac{1}{2}\frac{y_c^2}{\sigma_{y,m}^2}\right) \exp\left(-\frac{1}{2}\frac{z_c^2}{\sigma_{z,m}^2}\right)$$

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