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OFFLINE APPROACH FOR HIGHER ORDER CONCENTRATION MOMENTS

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Talk outline

- Motivations
- The basic idea of a fluctuating plume model
- Simulating plume centre of mass trajectory
- Parameterization of the relative dispersion
- Case studies:

  i) validation of the model in homogeneus isotropic turbulence

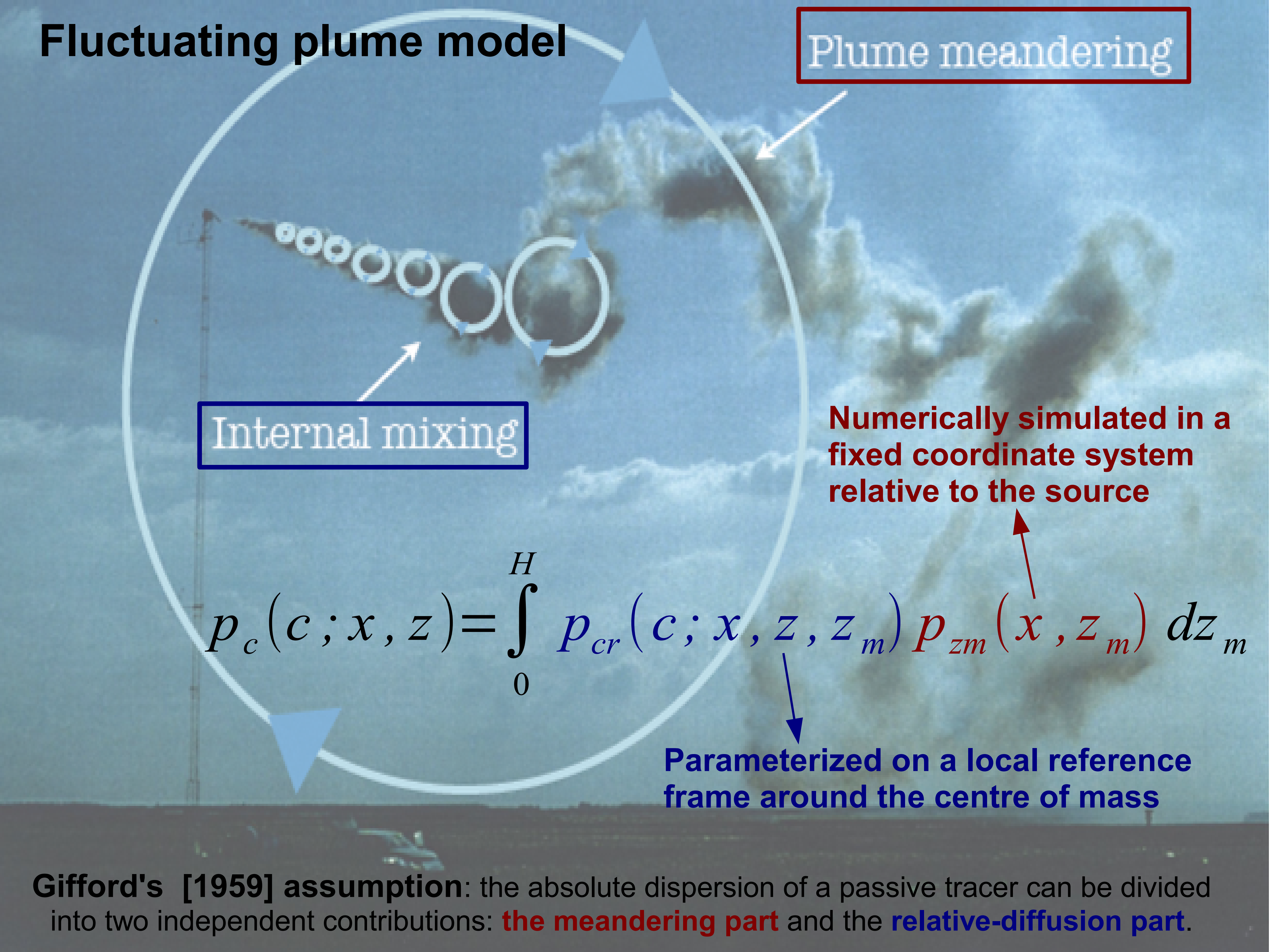
  ii) comparison with the water tank experiments by Willis and Deardorff (1978) and Hibberd (2000) in the convective boundary layer

  iii) comparison with the water tunnel measurements and Gaussian model by Huq and Franzese (2013) in a canopy layer

Concentration fluctuations

- The concentration fluctuations play an essential role in a great number of environmental issues, such as:
    - Prediction of air pollution especially in short scales
    - Determinations of chemical reaction rates of pollutants (e.g. No_x and O_3)
    - Estimation of odour threshold
    - Analysis of turbulent combustion
- Only a few models are available to calculate at least the second moment
- The available models are subject to limitations such as:
    - Applicability only in strongly idealised conditions
    - Very elaborate numerical implementation and expensive computation
    - Reduction of reliability for small-scale turbulence.

Fluctuating plume model



Numerically simulated in a fixed coordinate system relative to the source

$$p_c(c;x,z)=\int_0^H p_{cr}(c;x,z,z_m)\,p_{zm}(x,z_m)\,dz_m$$

Parameterized on a local reference frame around the centre of mass

Gifford's [1959] assumption: the absolute dispersion of a passive tracer can be divided into two independent contributions: **the meandering part** and the **relative-diffusion part**.

Fluctuating plume model FPM

$$p_c(c;x,z)=\int_0^H p_{cr}(c;x,z,z_m)\,p_{zm}(x,z_m)\,dz_m$$

Absolute concentration moments

$$<c^n(x,z)> = \int_0^\infty c^n\,p_c(c;x,z)\,dc$$

$$<c^n(x,z)> = \int_0^H \left[\int_0^\infty c^n\,p_{cr}(c;x,z,z_m)\,dc\right] p_{zm}(x,z_m)\,dz_m$$

Relative concentration moments

$$<c_r^n(x,z)> = \int_0^\infty c^n\,p_{cr}(c;x,z)\,dc$$

$$<c^n(x,z)> = \int_0^H <c_r^n(x,z)>\,p_{zm}(x,z_m)\,dz_m$$

Proposed FPM version

Input

$$< c(x,z) >$$

Computation

Output

$$< c^n(x,z) >$$

Evaluation of centre of mass vertical position PDF: Cassiani and Giostra's [2002] approach

Input: mean concentration field

$$< c(x, y, z) >$$

- Computation of $p_z(t, z), < z >, \sigma_z^2$ normalising the mean concentration

- Parameterisation of the relative spread:

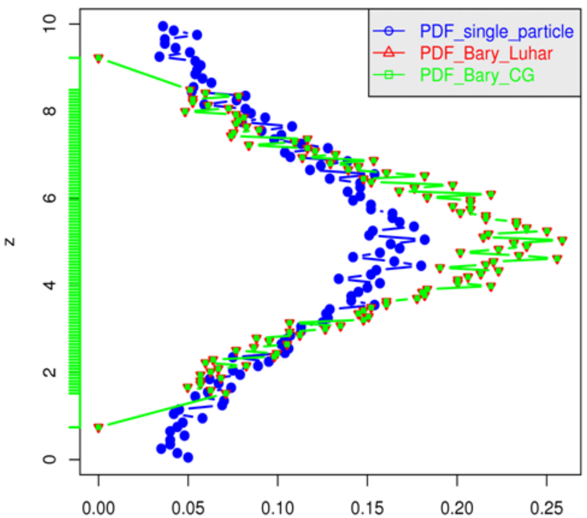
$$\sigma_{zr}^2 = \frac{g\,\epsilon\,(t + t_s)^3}{\left[1 + \alpha\left(g\,\epsilon\,t^3\right)^{2/3}\right]^{3/2}}$$

Franzese [2003], Mortarini et al. [2009]

Hypothesis: Luhar et al. [2000] **linear transformation** applied on the **calculation grid spacing**

$$z_{mi} = \frac{\sigma_z^2(t) - \sigma_{zr}^2(t)}{\sigma_z^2(t)}\left(z_i - < z(t) >\right) + < z(t) > \qquad \Delta z_m = \frac{\sigma_z^2(t) - \sigma_{zr}^2(t)}{\sigma_z^2(t)}\,\Delta z$$

Centre of mass grid compression



$$\frac{\sigma_z^2(t) - \sigma_{zr}^2(t)}{\sigma_z^2(t)} < 1$$

$$\Delta z_m < \Delta z$$

$$p_{zm} > p_z$$

$$p_z\,\Delta z = p_{zm}\,\Delta z_m$$

Output: centre of mass position PDF

$$p_{zm} = \begin{cases} p_z \dfrac{\Delta z}{\Delta z_m} & \text{in the compressed axis} \\ 0 & \text{out of the compressed axis} \end{cases}$$

Parameterisation of the relative concentration PDF

$$p_{cr} = \frac{\lambda^{\lambda}}{<c_r> \Gamma(\lambda)} \left(\frac{c}{<c_r>} \right)^{\lambda - 1} \exp\left(\frac{-\lambda c}{<c_r>} \right)$$

Luhar et al. [2000]
Gailis et al. [2007]

$$<c_r^n> = \int_0^{\infty} c^n \, p_{cr} \, dc$$

$$<c_r^n> = \frac{\Gamma(\lambda + n)}{\lambda^n \Gamma(\lambda)} <c_r>^n$$

$$\lambda^{-1} = i_{cr}^2 = \left(1 + i_{cr0}^2\right) \left(\frac{<c_r>}{<c_{r0}^n>} \right)^{\zeta}$$

Ferrero et al. [2012] Gailis et al. [2007]

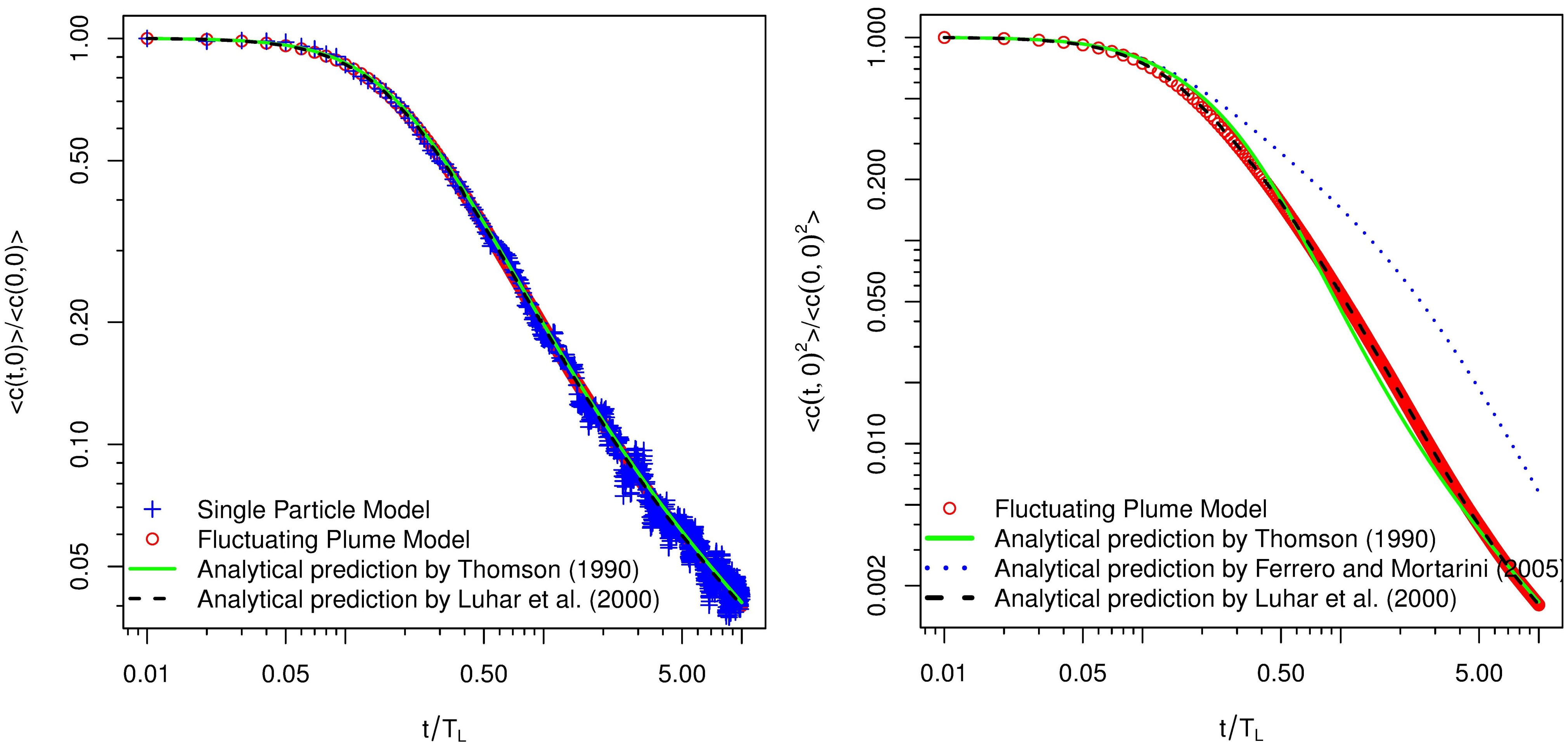
$$<c_r> = \frac{Q}{U} p_{zr}$$

p_{zr} Gaussian or skewed bi-Gaussian

Franzese [2003] Dosio and De Arellano [2006]

Case study (I): Homogeneus Isotropic Turbulence

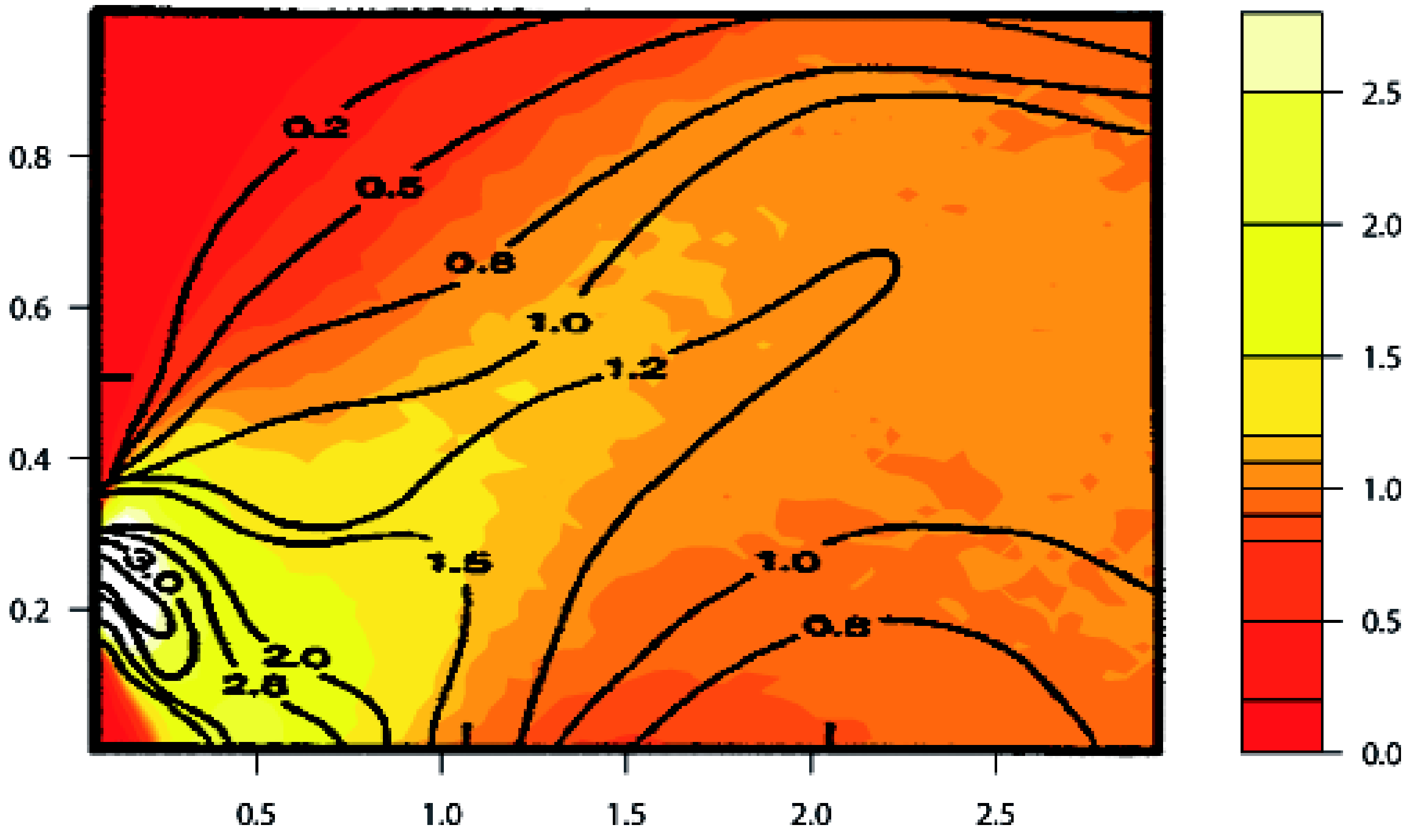
Comparison among the proposed fluctuating plume model and analytical previsions.



Case study (II): Convective Boundary Layer

Non-dimensional crosswind-integrated mean concentration field predicted by Franzese (1999) single particle model

$z_s = 0.24H$

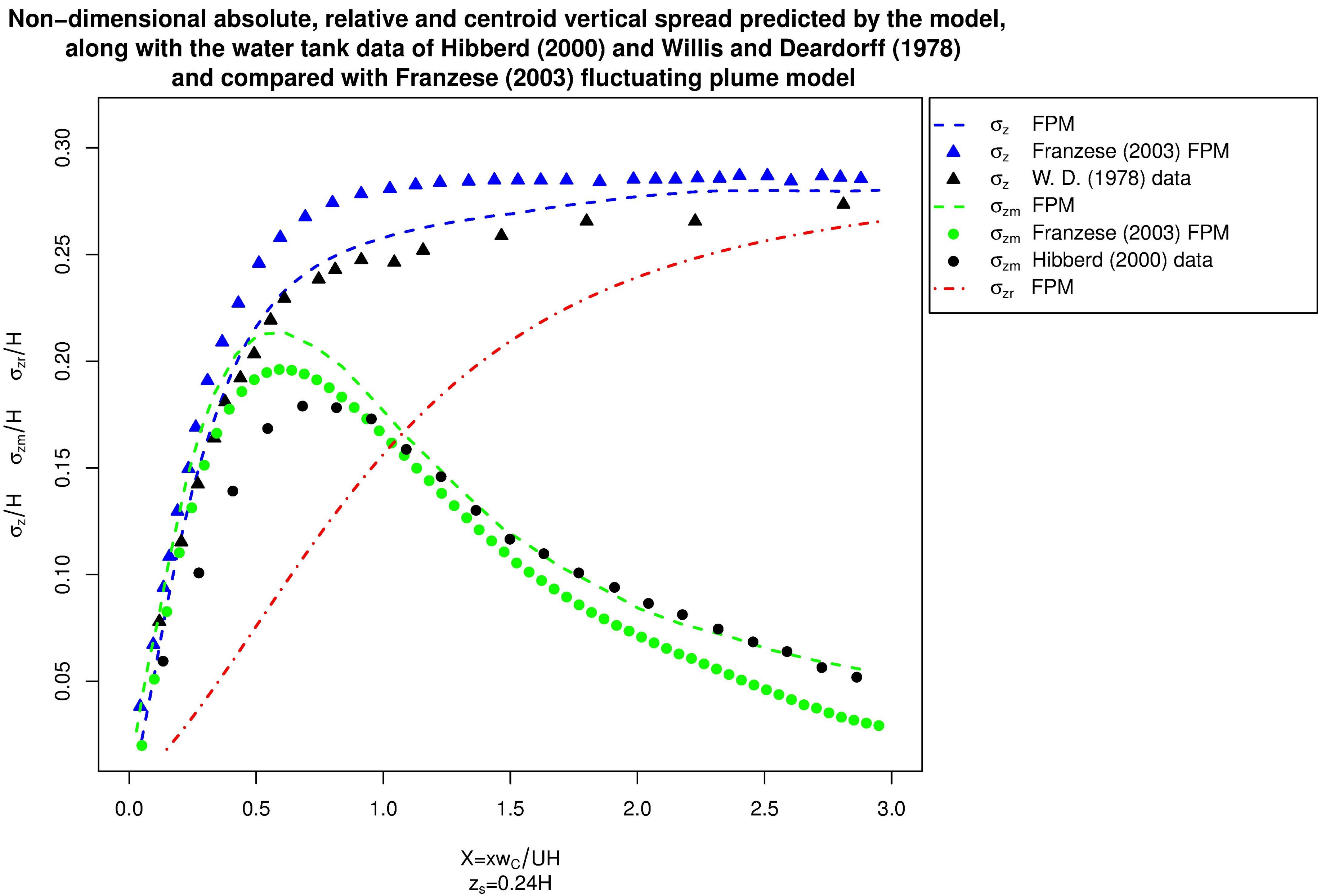


$\frac{z}{H}$

$X = xw_c/UH$

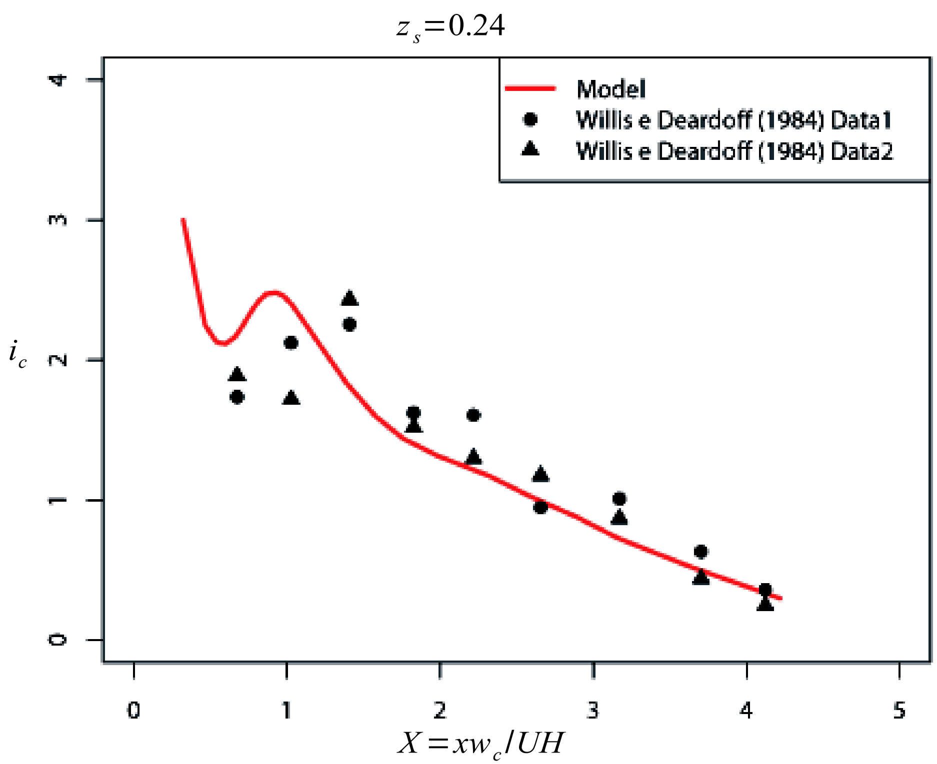
Filled surfaces for the fluctuating plume model presented
Black contours for Willis and Deardoff (1978) water tank data.

Case study (II): Convective Boundary Layer

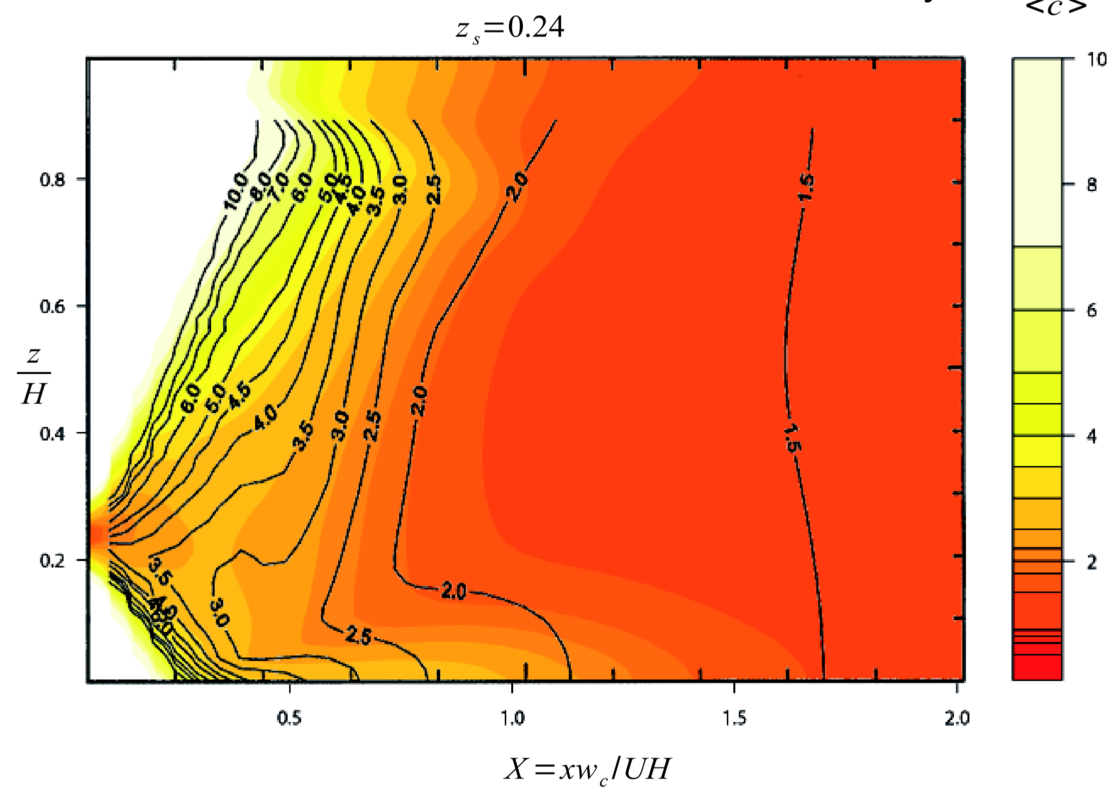


Case study (II): Convective Boundary Layer

Concentration fluctuation intensity at $z = 0.08\mathrm{H}$



Contours of the concentration fluctation intensity $i_c = \frac{\sigma_c}{<c>}$

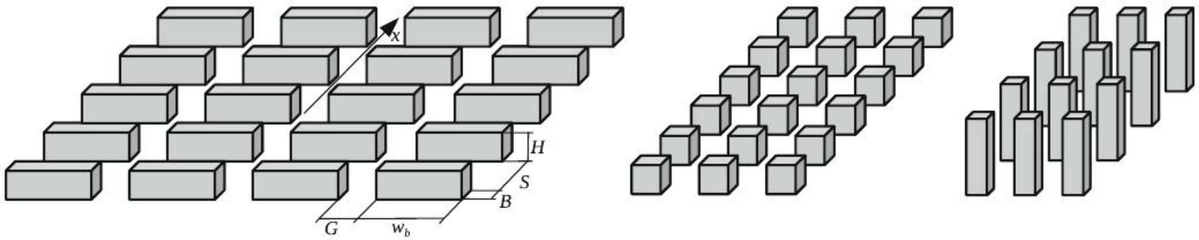


Filled surfaces for the fluctuating plume model presented

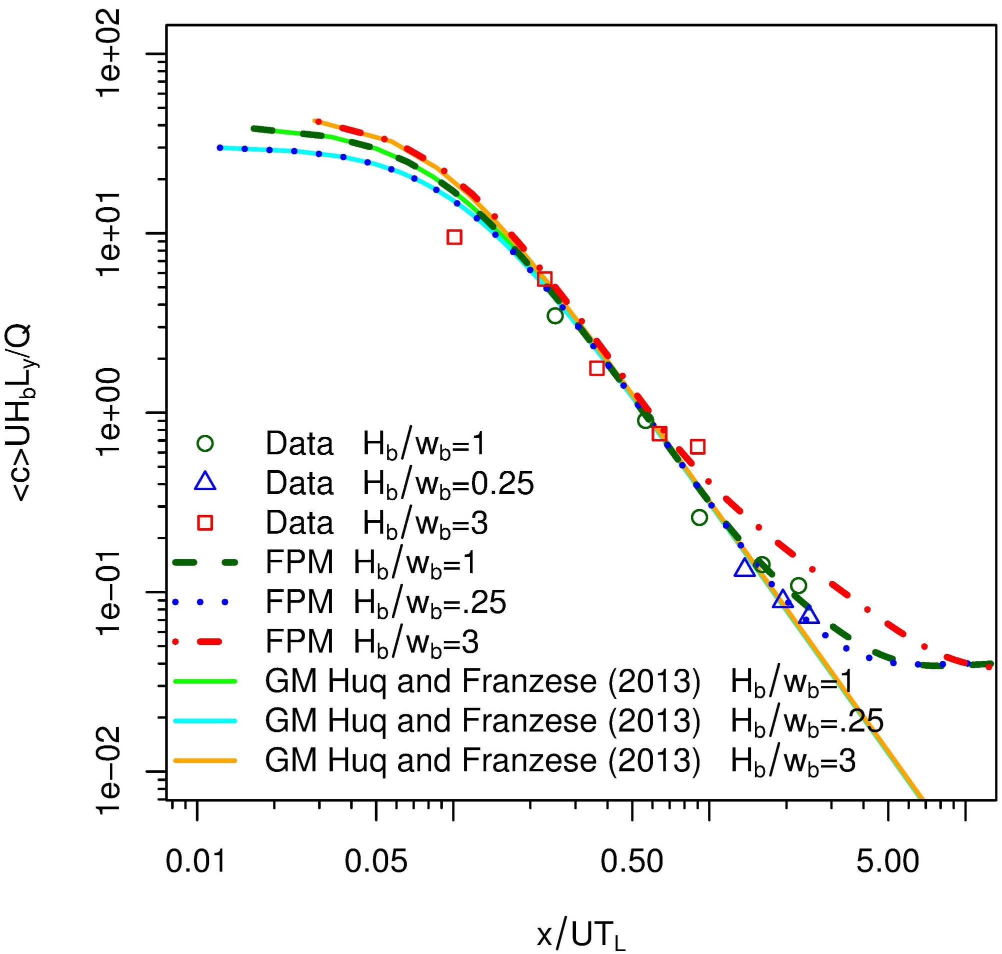
Black contours for the Luhar et al. (2000) fluctuating plume model

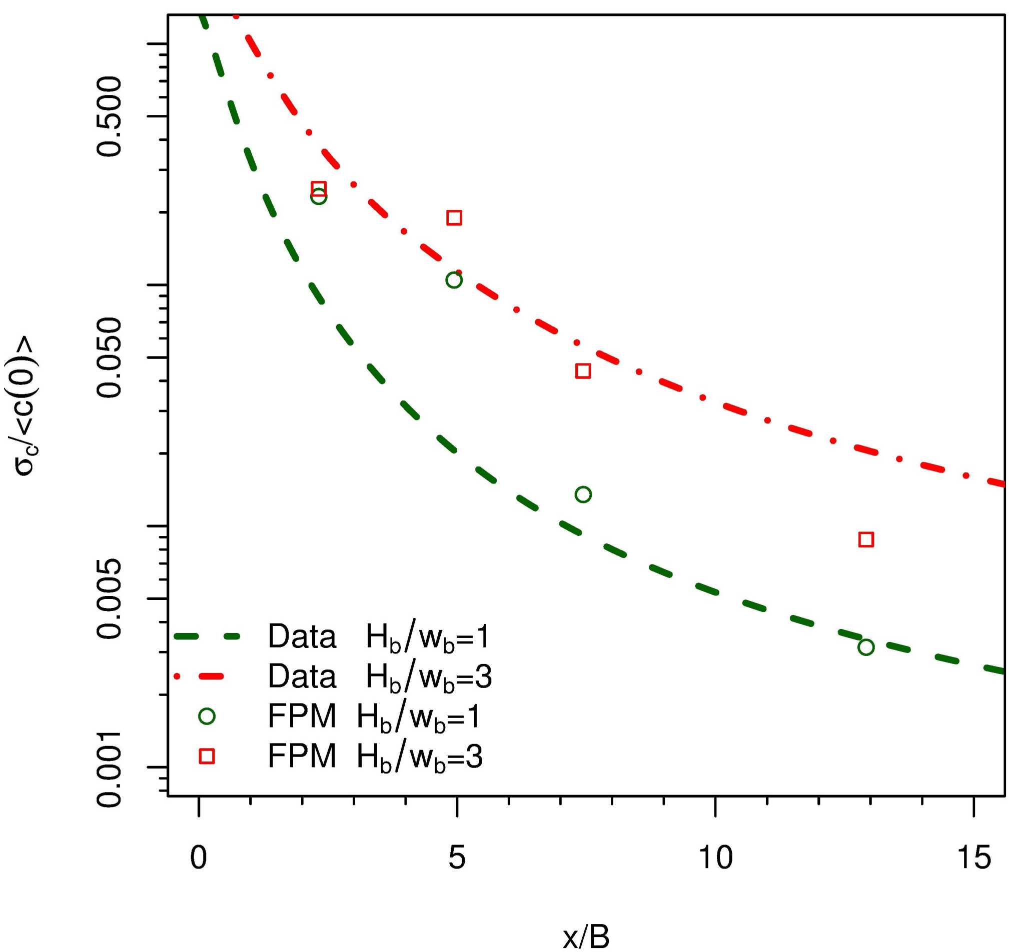
Case study (III): canopy layer

Comparison between the proposed fluctuating plume model and Huq and Franzese (2013) Gaussian model and water tunnel experimental data.



Schematic of the model urban canopies with H_b/w_b=0.25 (left), H_b/w_b=1 (centre), and H_b/w_b=3 (right). The measurements for H_b/w_b=0.25 were previously taken by Macdonald and Ejim (2002) to reproduce the set-up of the MUST experiment (Biltoft 2001).





Conclusions

- The model is able to simulate all the higher order moments of the PDF concentration given the first order one .
- It is independent of the method used to evaluate the requested mean concentration field which can be obtained either from models or from experiments.
- The need for Lagrangian modelling is thus avoided making the computational demand very low.
- The model can be easily adapted to different classes of turbulence modifying the parameterization of the relative-diffusion part and the mean field input data, for which both a single particle model (CBL) and a Gaussian model (canopy) have been considered.
- The overall agreement of the concentration results with the available laboratory data is good.