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# SPATIAL AND TEMPORAL CONCENTRATION DISTRIBUTIONS IN URBAN AREAS

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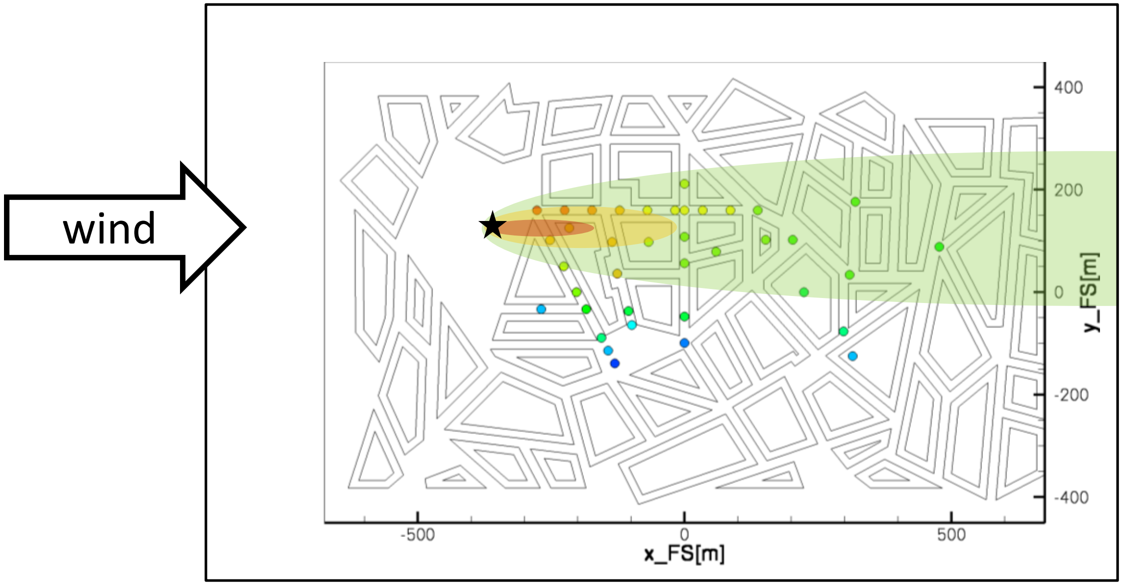
# INTRODUCTION

# Gaussian plume dispersion model



- Estimating the concentration above flat open terrain: Gaussian dispersion model:

$$C(x,y,z)=\frac{Q}{u}\frac{1}{2\Pi\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$




- How about in an urban environment?

# Constraints of the Gaussian plume model



- Vertical and crosswind diffusions: Gaussian distribution
- Downwind diffusion is negligible
- *Q* is continuous and constant
- Constant velocity
- No deposition, washout, chemical conversion or absorption of emissions, reflective ground
- No upper barrier to vertical diffusion and there is no crosswind diffusion barrier
- Homogeneous turbulence

$$C(x,y,z) = \frac{Q}{u}\frac{1}{2\Pi\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$

Source: Beychok, M. R., 1994: Fundamentals Of Stack Gas Dispersion, 3rd Edition, author-published. USA

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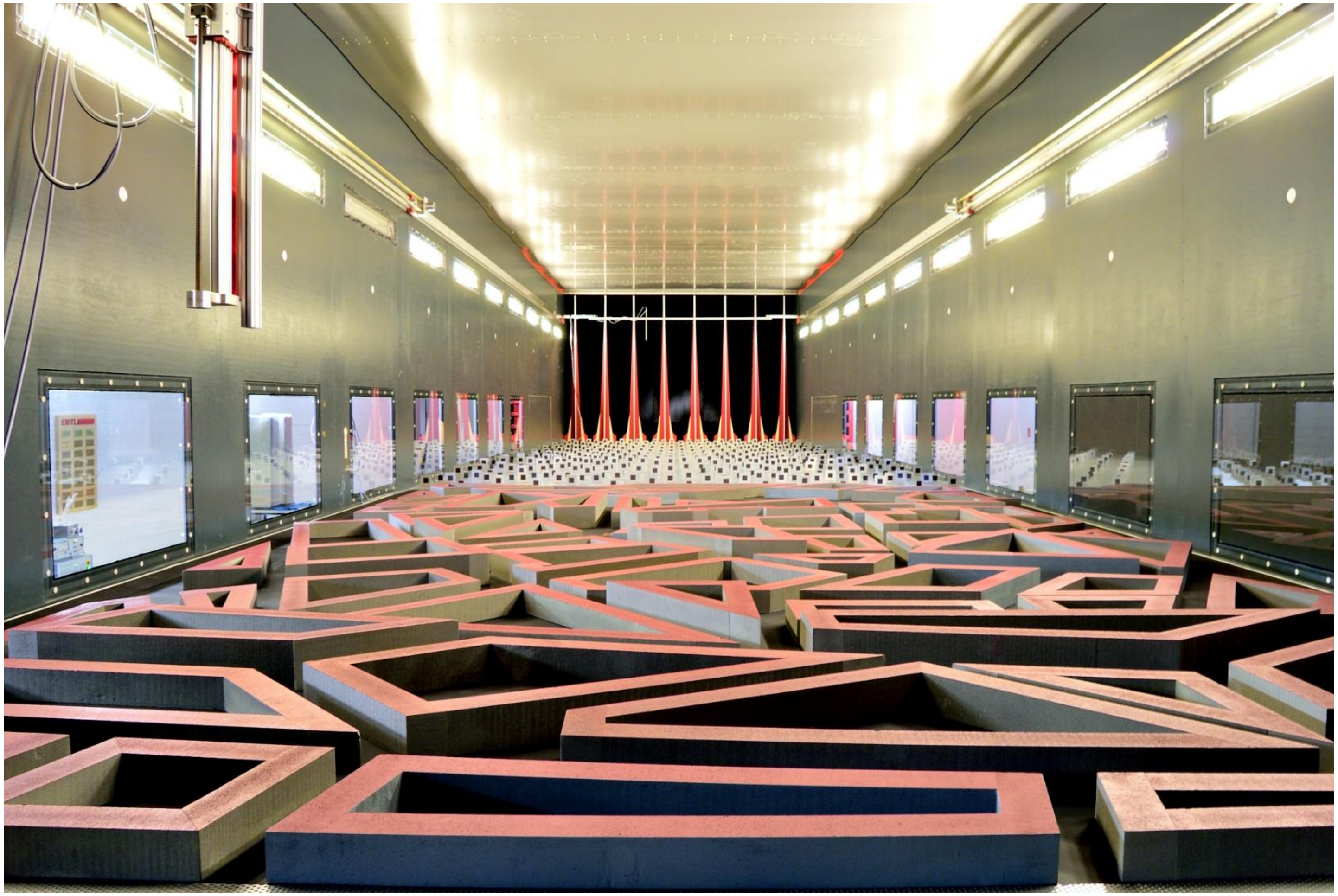
# EXPERIMENTAL SETUP

# Michelstadt test case



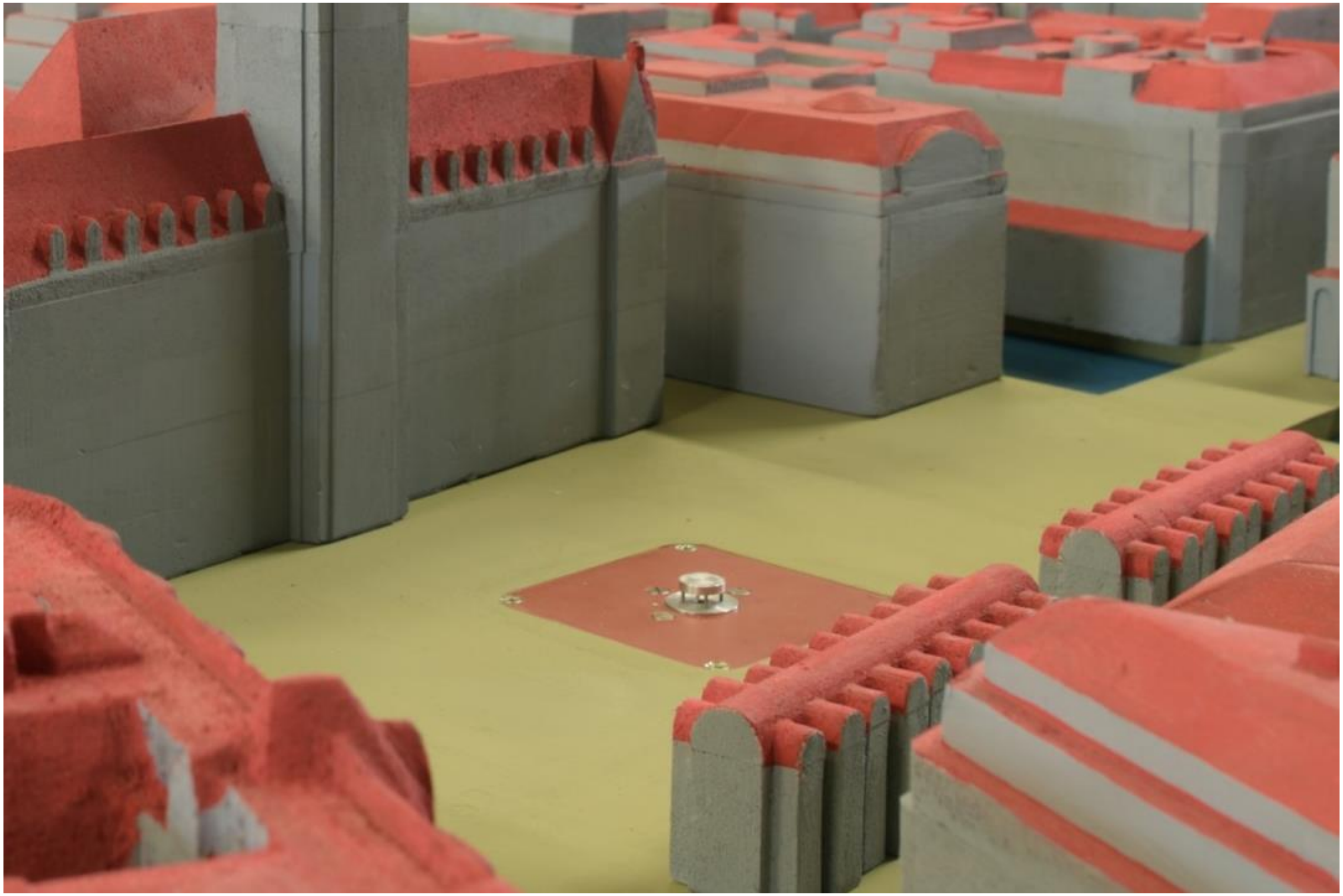


# Complex Urban Terrain Experiment (CUTE)



# Ground-level point source





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# Fast-FID concentration measurements

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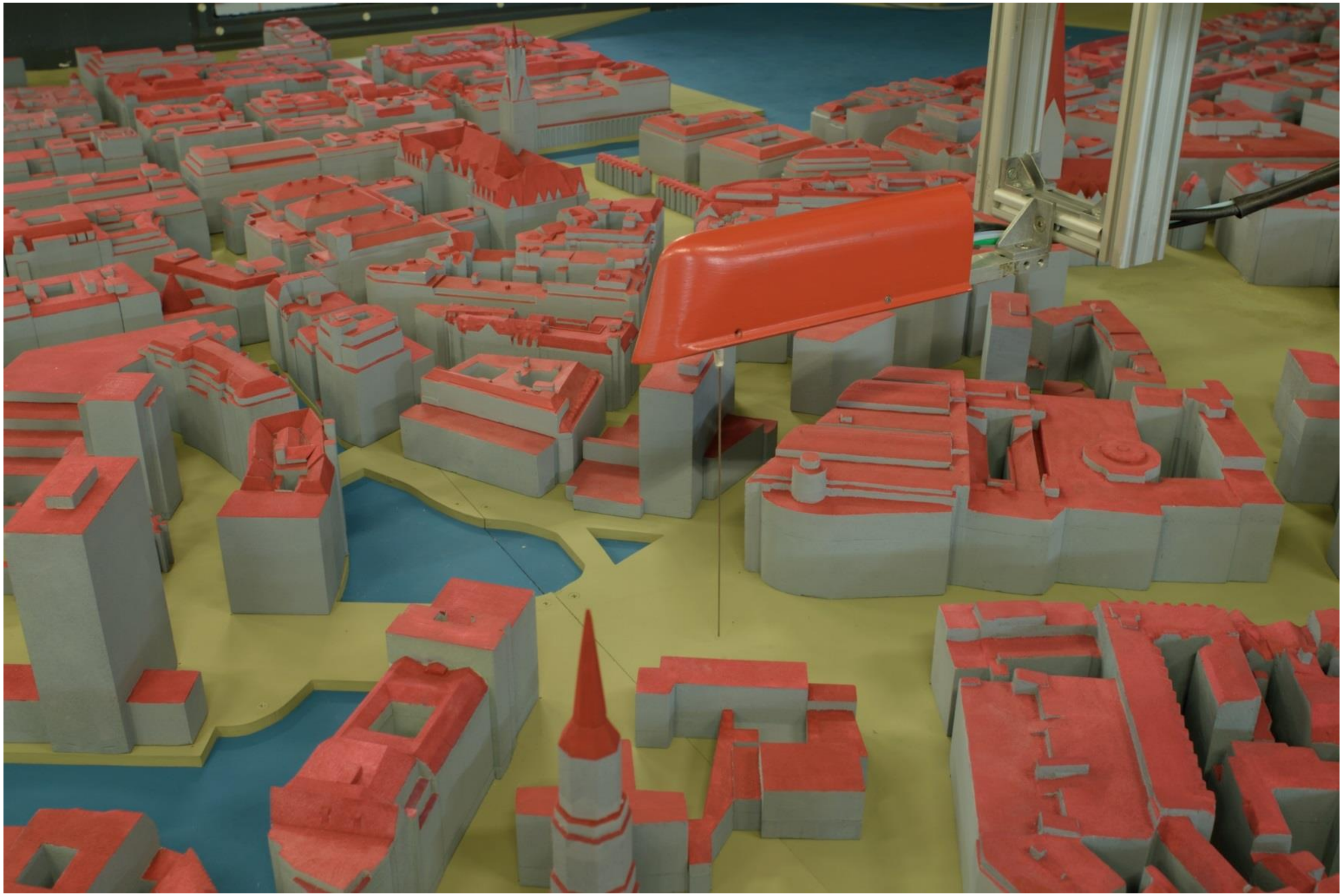

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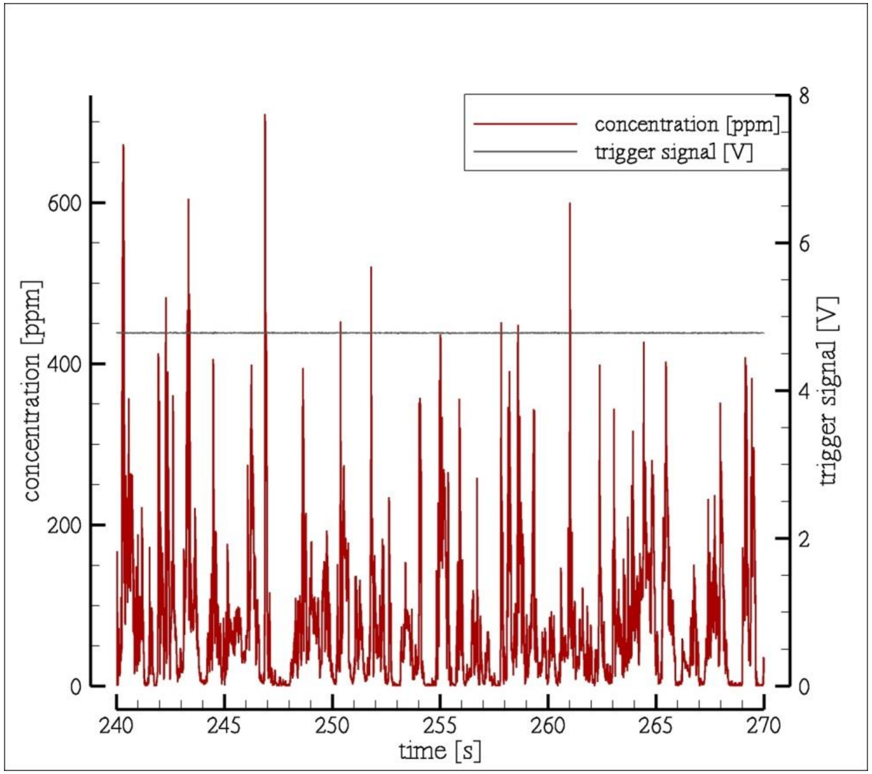
# Spatial Distribution: Methodology

# Spatial distribution



- Continuous-release ground sources

$$C^* = \frac{C U_{ref} L_{ref}^2}{Q}$$



# Dispersion in y direction



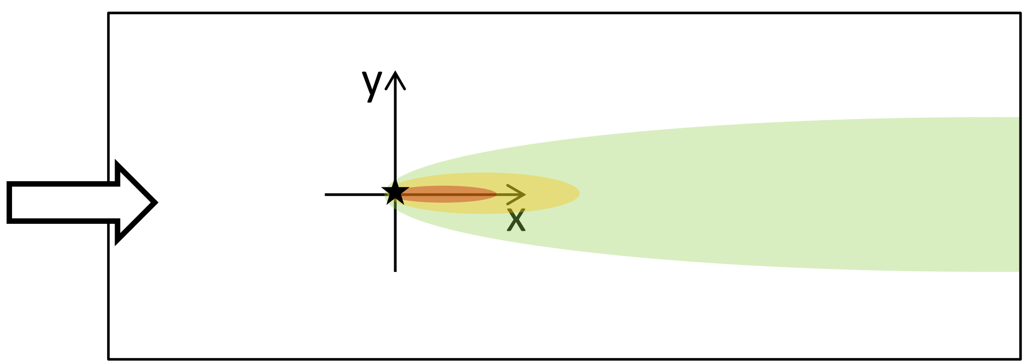
- Gaussian dispersion model:

$$C(x,y,z)=\frac{Q}{u}\frac{1}{2\Pi\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$

$$C^*(y)=\frac{a}{\Pi bc}\exp\left(\frac{-(y-d)^2}{2b^2}\right)\exp\left(\frac{-(z)^2}{2c^2}\right)$$

**Additional assumption**:

- maximum is independent from the source location



# Dispersion in x direction

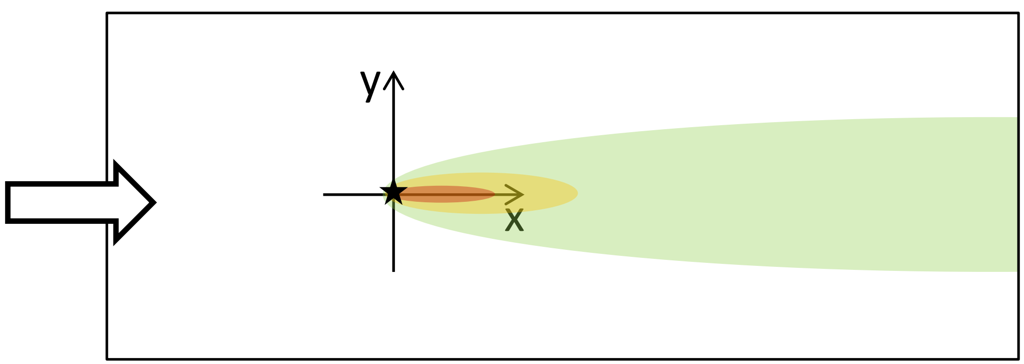
- Gaussian dispersion model:

$$C(x,y,z)=\frac{Q}{u}\frac{1}{2\Pi\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$

$$C^*(x)=\frac{a}{x^b}$$

**Additional assumptions**:

- similarity throughout the y axis
- measurement height = 0
- dispersion coefficients: power functions of the distance (Smith, 1968)




Smith, M. E.,1968: Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, 1st Edition, American Society of Mechanical Engineers, New York

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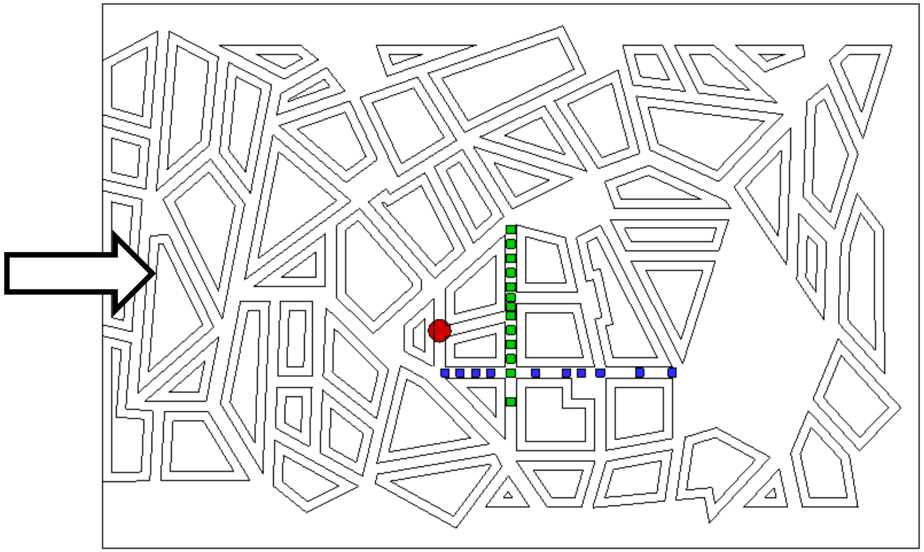
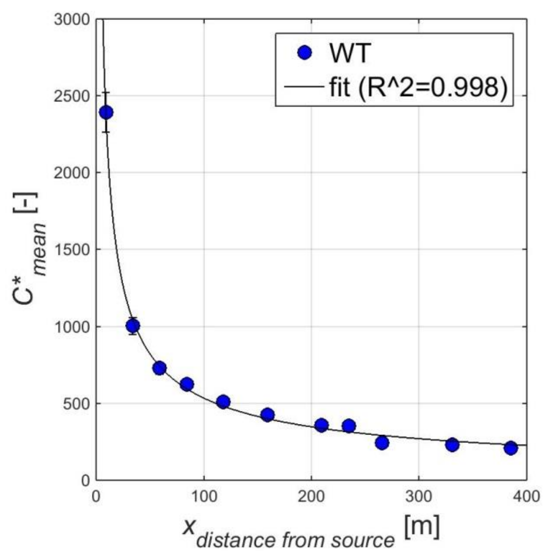
# Spatial Distribution: Results

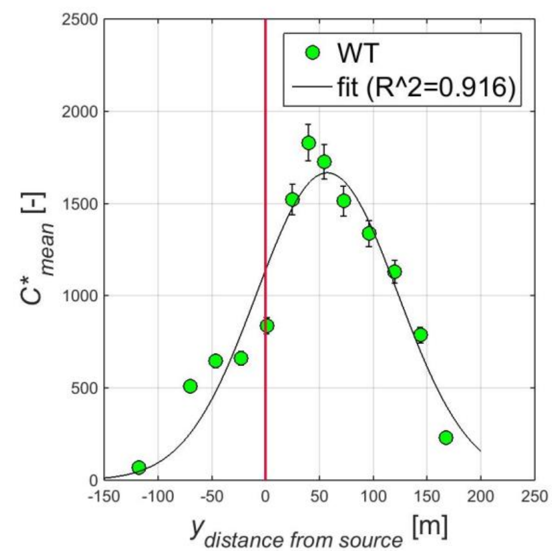
# Michelstadt results: spatial concentration distribution



$$C^*(x) = \frac{a}{x^b}$$

$$C^*(y) = \frac{a}{\Pi bc}\exp\left(\frac{-(y-d)^2}{2b^2}\right)\exp\left(\frac{-(z)^2}{2c^2}\right)$$



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# CUTE results: spatial concentration distribution

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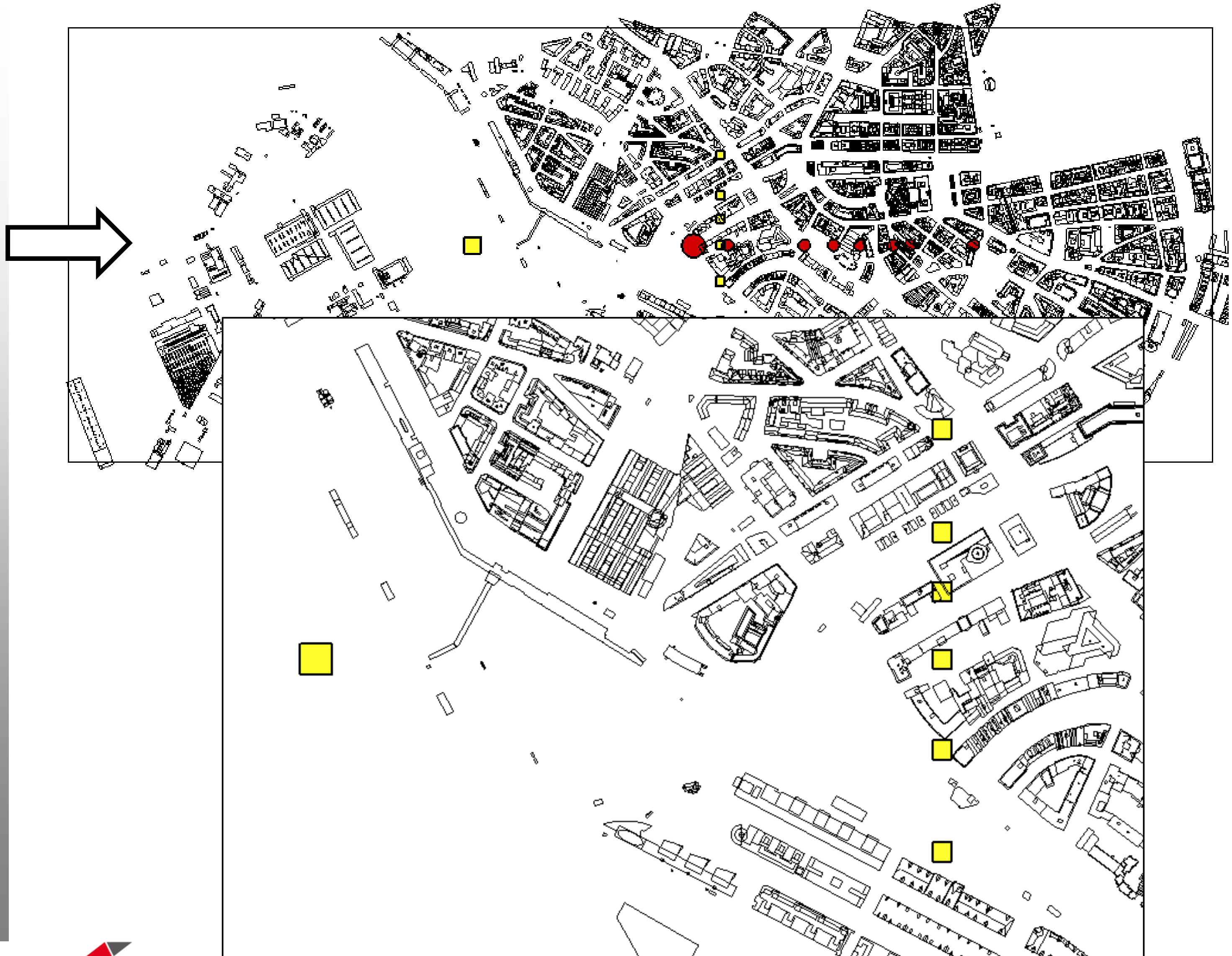
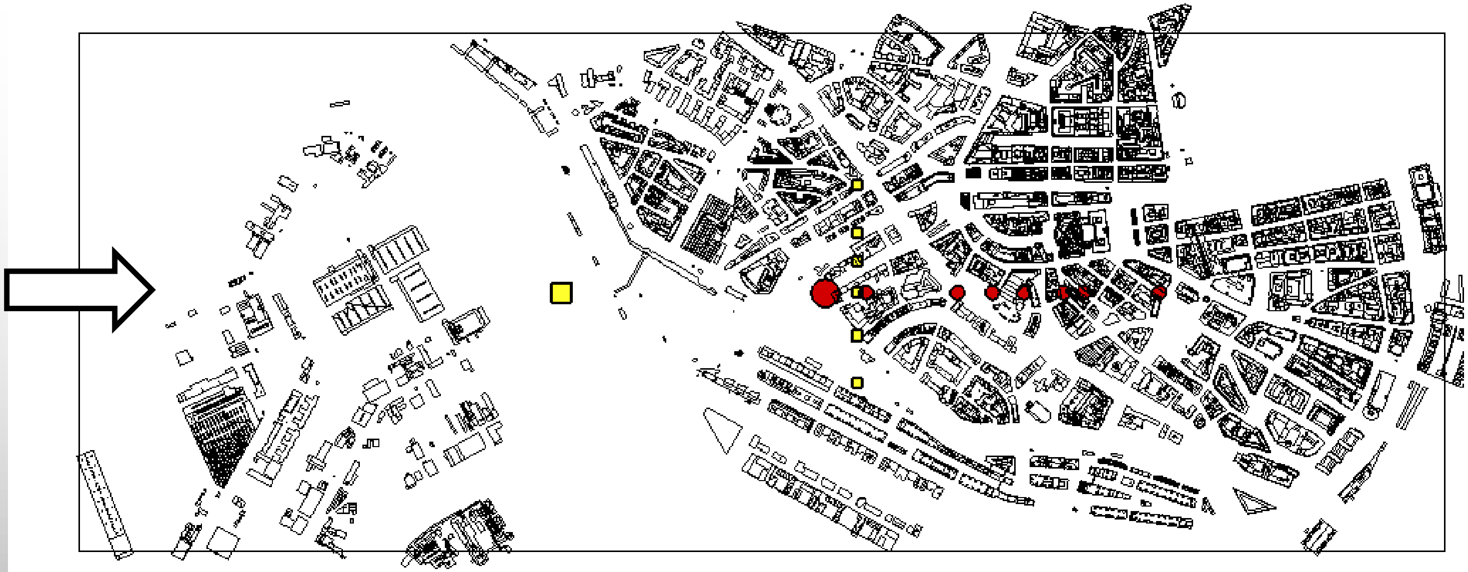
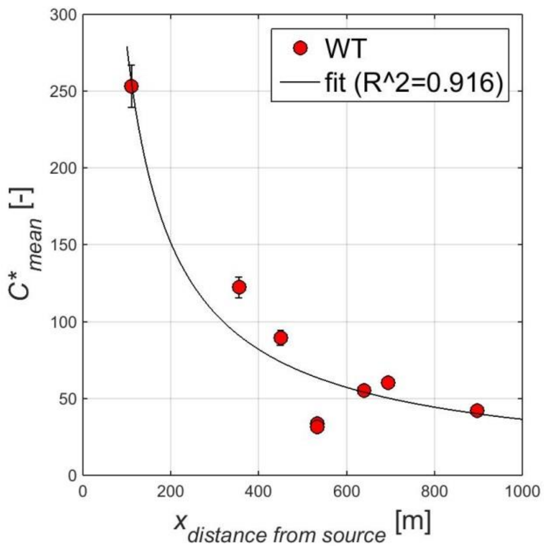
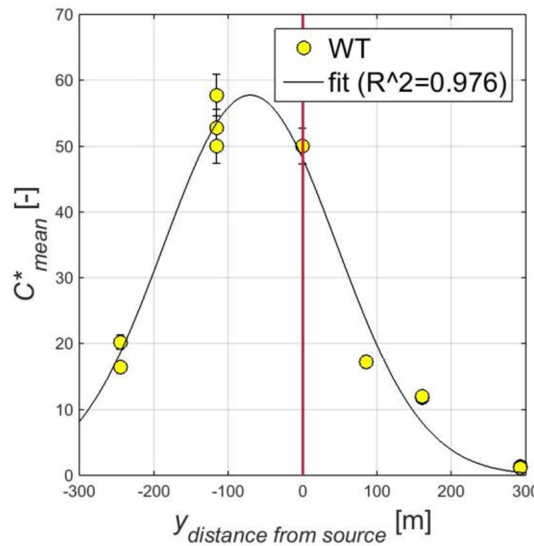


# CUTE results: spatial concentration distribution







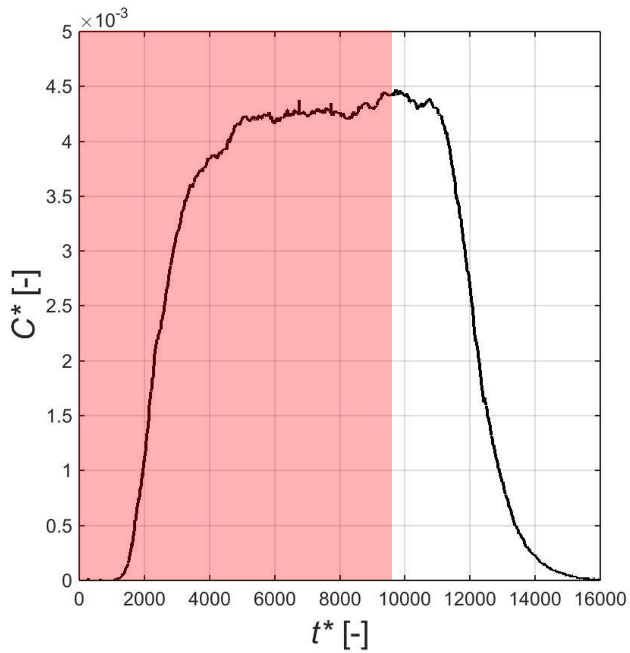
# Temporal Distribution

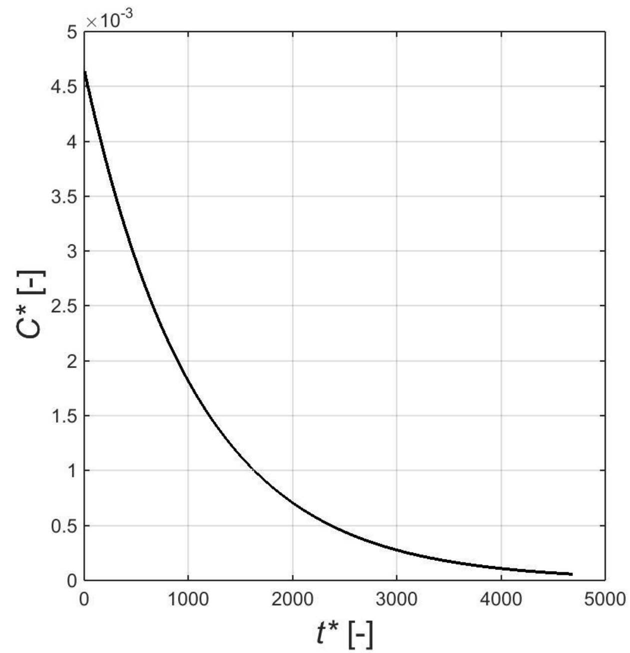
# Temporal concentration distribution



- Exponential decay:

$$C^*(t^*) = C_0^* e^{-\frac{t}{\tau^*}}$$

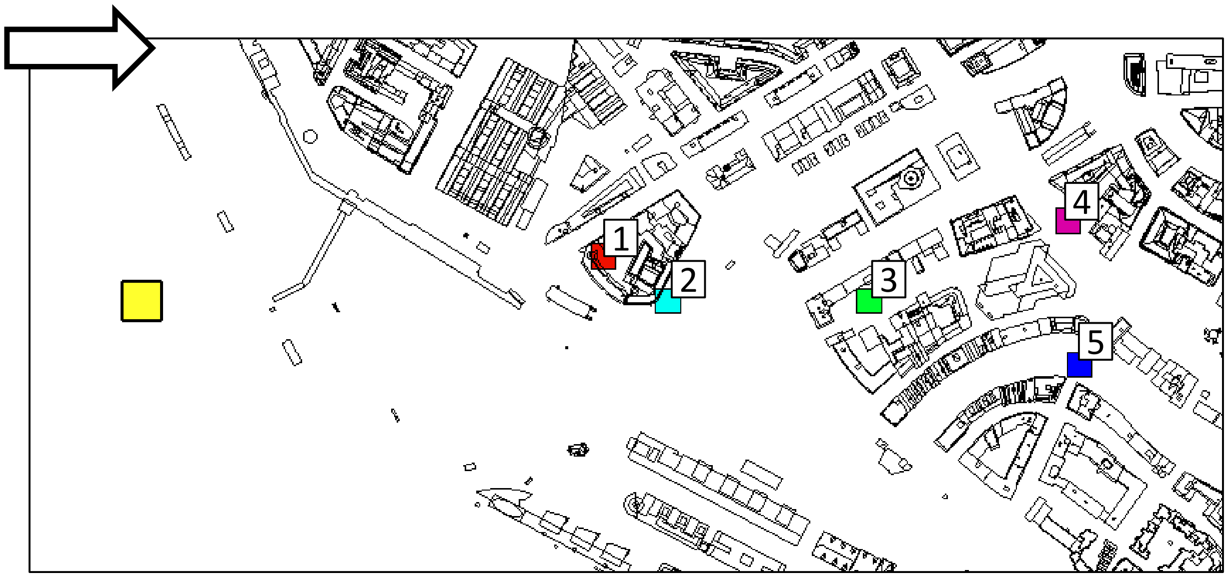


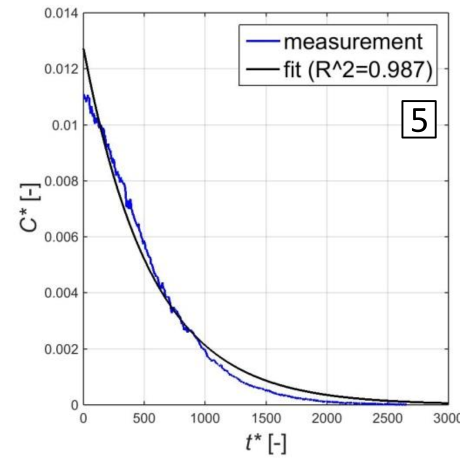



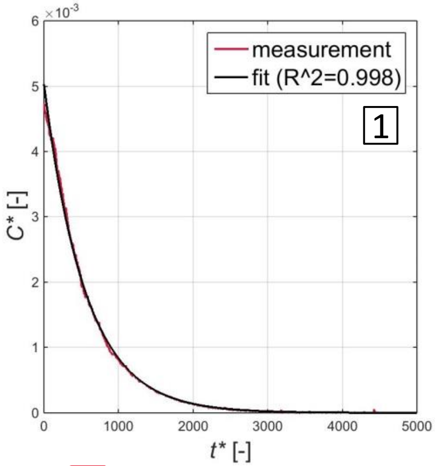
# CUTE results: temporal concentration distribution

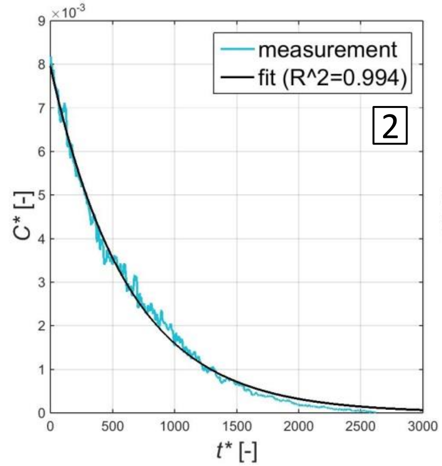


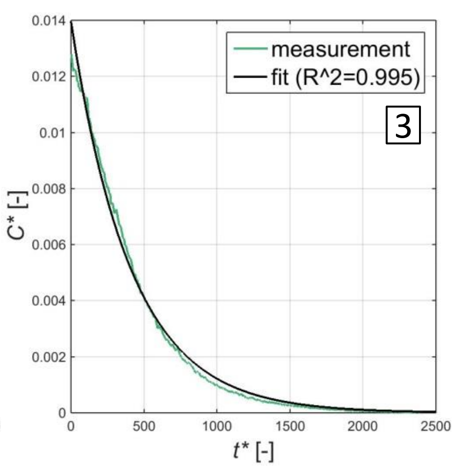
$$C^*(t^*) = C_0^* e^{-\frac{t}{\tau^*}}$$

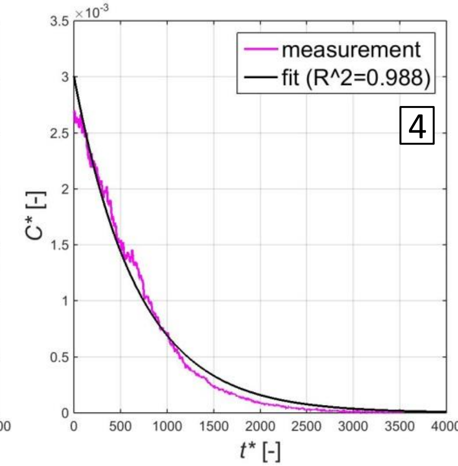


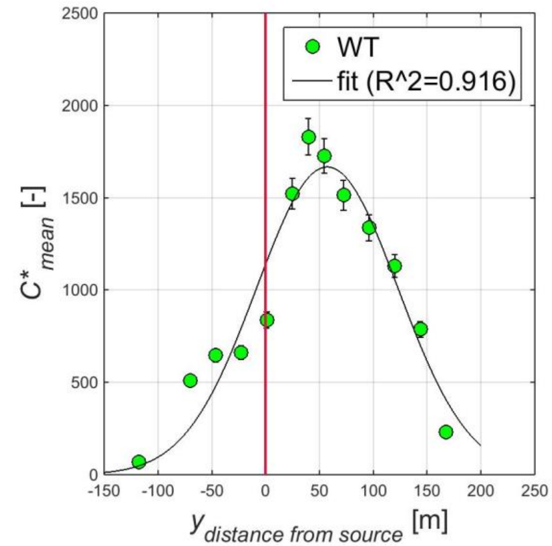



# Conclusions



- The Gaussian and exponential PDFs fit well to the mean concentration profiles.
- Extra degree of freedom: symmetry axis is not aligned with the source location.
- Does not imply the goodness of a Gaussian model!

- Future plans: investigating the parameters:
  - dispersion coefficients
  - time constant



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Questions?

Thank you for your attention!

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# EXTRA SLIDES

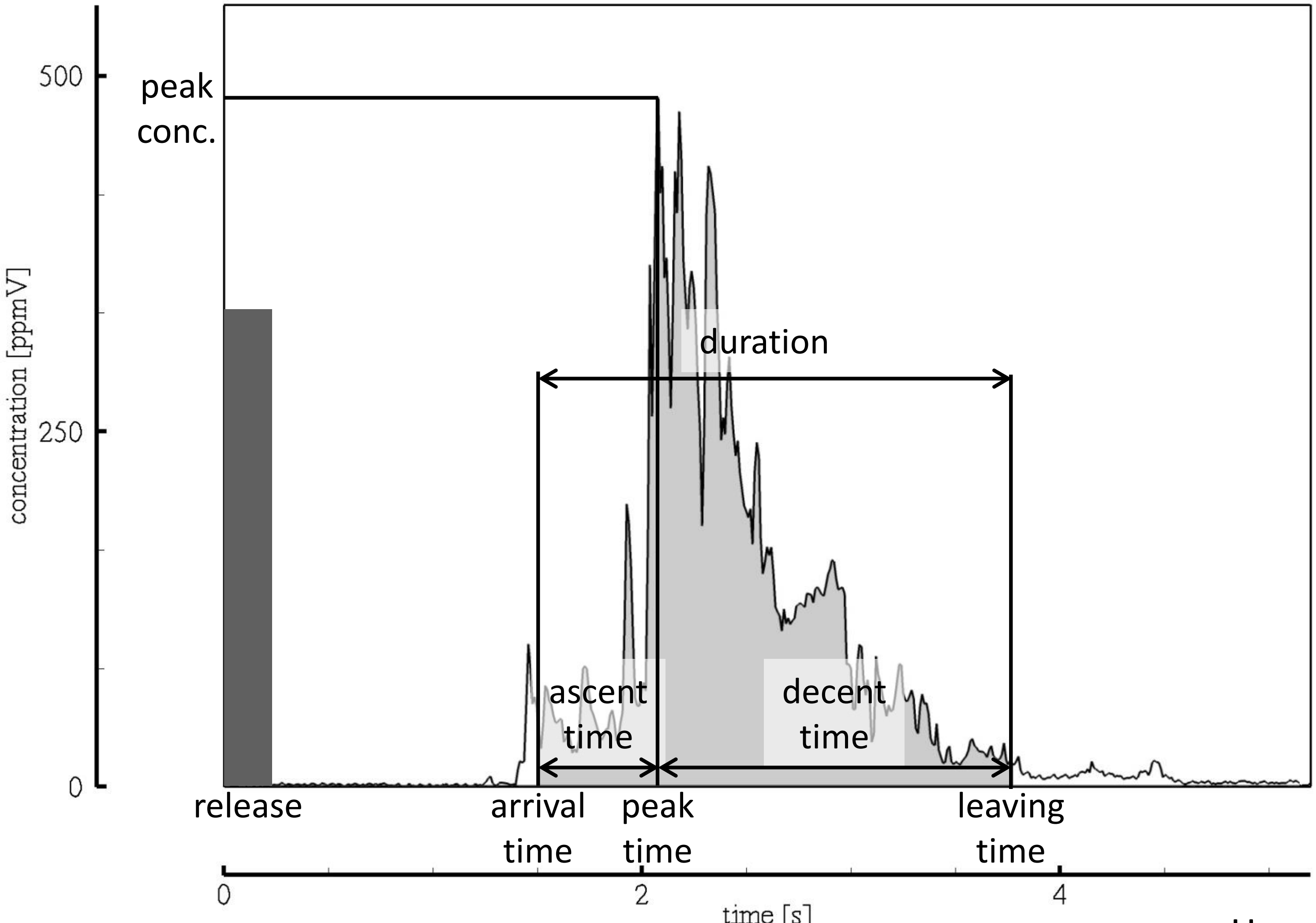
# Aim



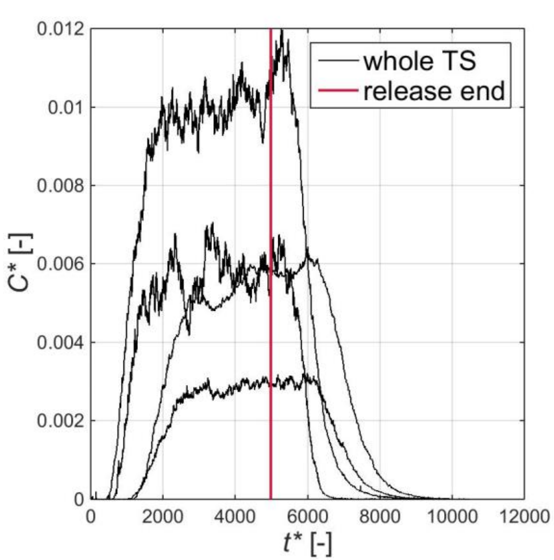
- vertical and crosswind diffusion occur according to Gaussian distribution;
- downwind diffusion is negligible compared to downwind transport;
- the emissions rate, Q, is continuous and constant;
- the horizontal wind velocity and the mean wind direction are constant;
- there is no deposition, washout, chemical conversion or absorption of emissions, and any emissions diffusing to the ground are reflected back into the plume (i.e. all emissions are totally conserved within the plume);
- there is no upper barrier to vertical diffusion and there is no crosswind diffusion barrier;
- emissions reflected upward from the ground are distributed vertically as if released from an imaginary plume beneath the ground and are additive to the actual plume distribution; and
- the use of yσ and zσ as constants at a given downwind distance and the assumption of an expanding conical plume require homogeneous turbulence throughout the x, y and z-directions of the plume.

# Dosage-based parameters






Harms, 2010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release end
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t* [-]
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0.01
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0.006
0.004
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6000
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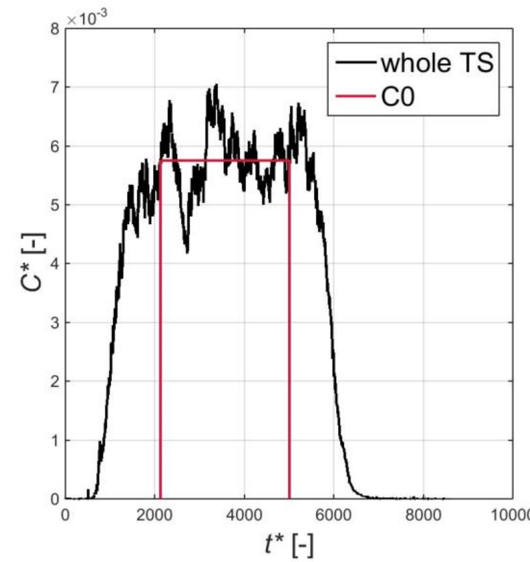
whole TS
C0
×10-3
C* [-]
t* [-]
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7
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000

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Thank you for your attention!