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Numerical dispersion modelling of the droplets expired by humans

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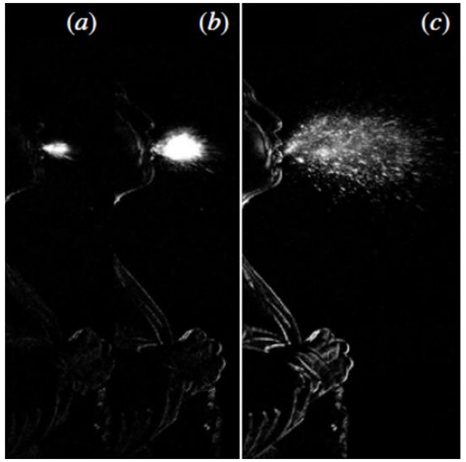
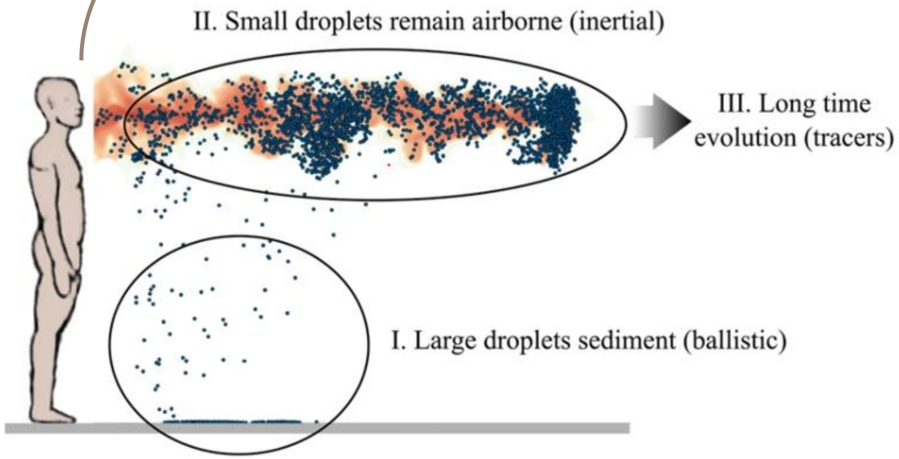
Introduction

- Since the first half of the 20th century several works have been carried out to study the emission and dispersion of the particle-laden air cloud ejected by humans during different respiratory activities, involved in the airborne disease transmission

- Providing realistic data as input to numerical and simplified models is of major importance to obtain reliable results

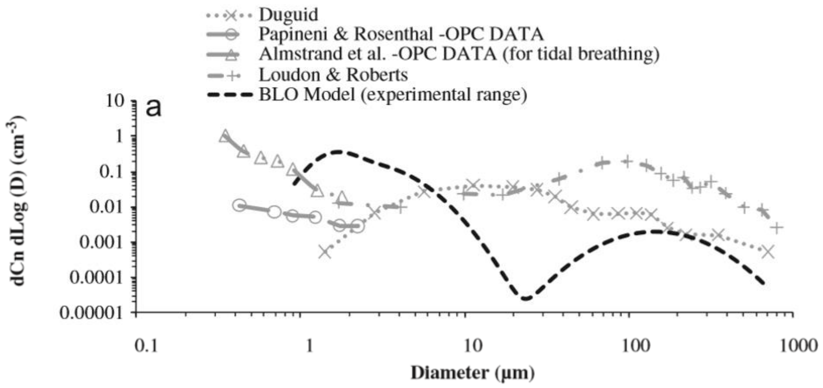


Source characterization
Bourouiba et al. (2014)



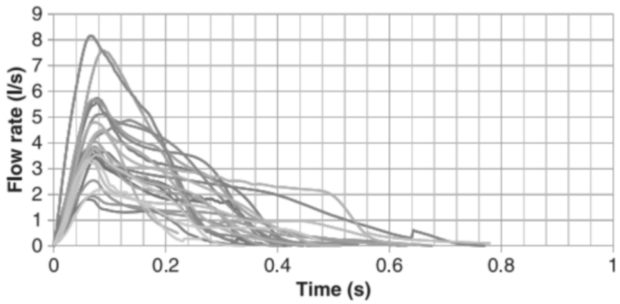
Example of CFD computation
Rosti et al. (2020)

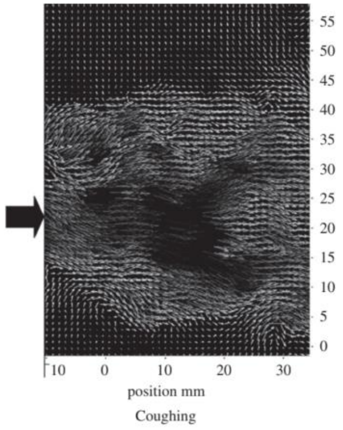
Introduction



Particles size

Johnson et al. (2011)

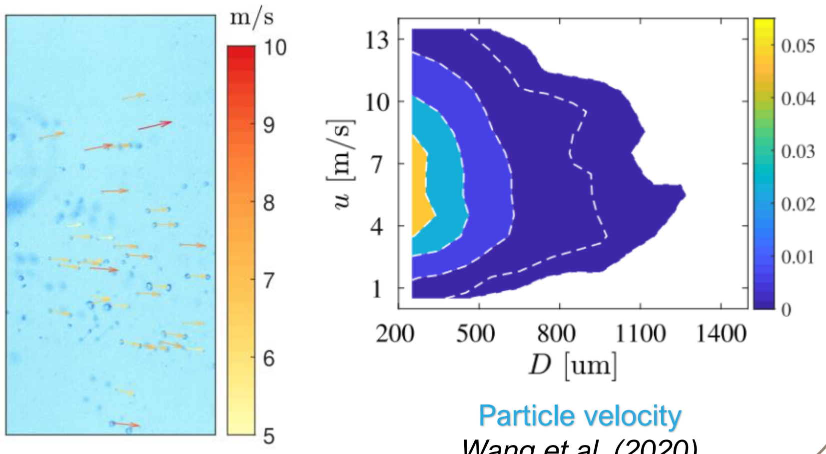




Air velocity

Goupta et al. (2009)

Chao et al. (2009)



Particle velocity

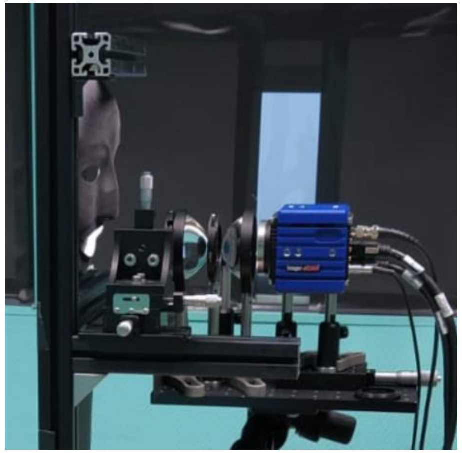
Wang et al. (2020)

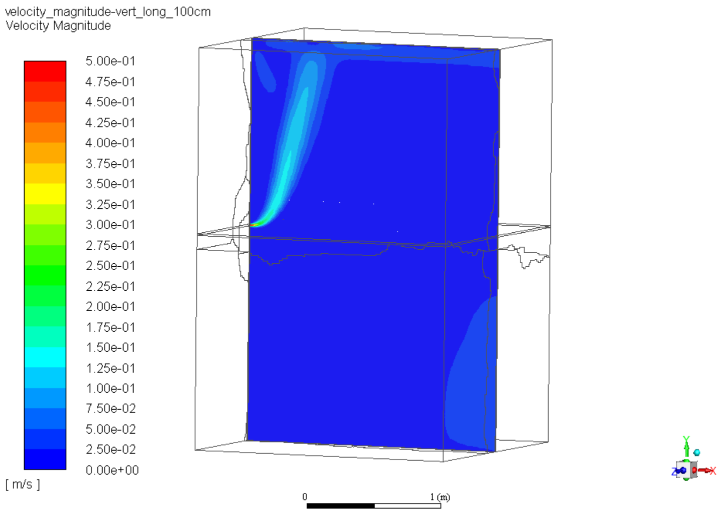
- Discrepancy among size distributions
- Particle velocity measurements are rare
- Particle velocity and size simultaneous measurements only for d>40 µm, 2 velocity components, extreme respiratory events

Aim of the work

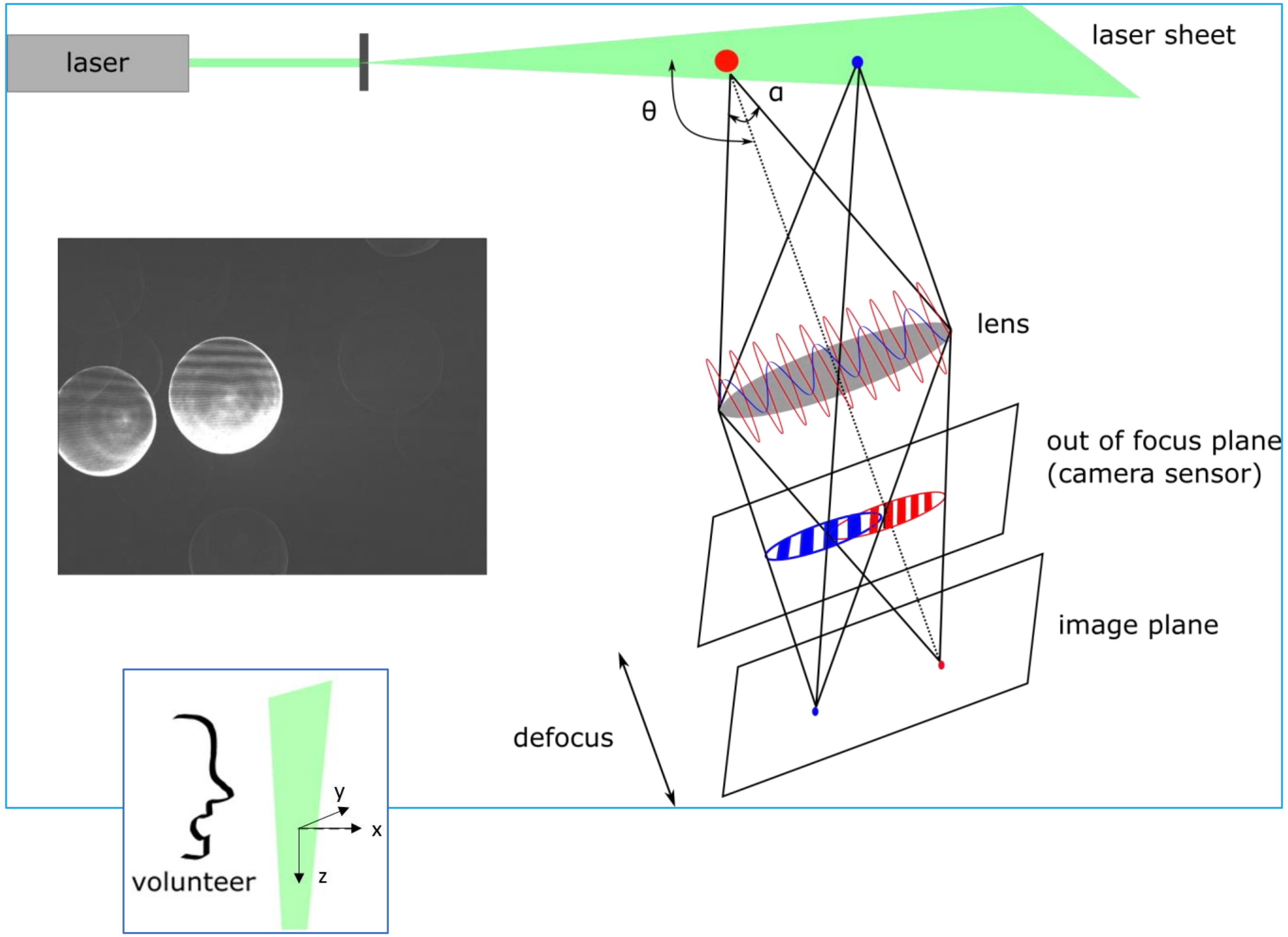
- **Better characterize the source measuring simultaneously particle size and velocity (size d > 2 µm, 3 velocity components)**

- **Use the detailed experimental data as input in numerical simulations**





Measurement campaign



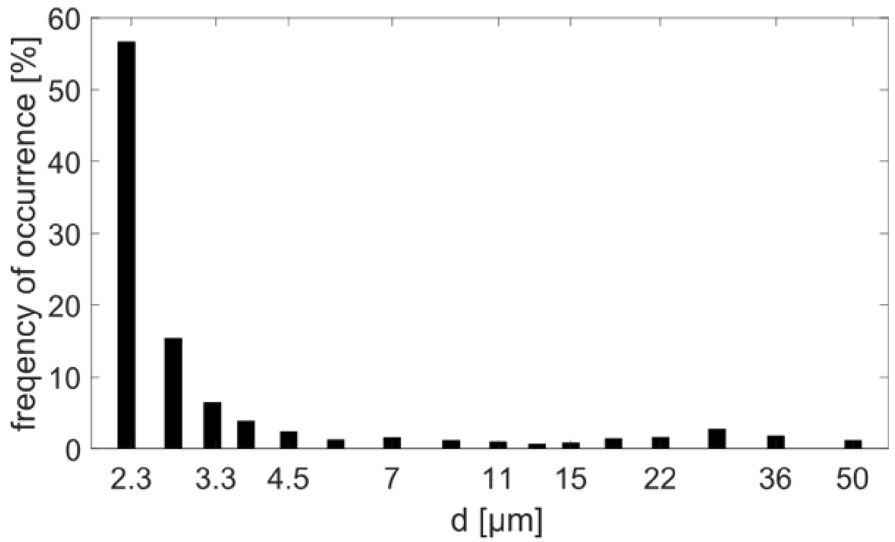
- Laboratoire de Mécanique des Fluides et d’Acoustique of the Ecole Centrale de Lyon
- **20 volunteers**
- Counting from “one” to “one-hundred” for 10 times (speaking)
- **Interferometric Laser Imaging Droplet Sizing (ILIDS) → improved** configuration and related image treatment to measure particles down to 2 μm and the 3 velocity components *
- ILIDS advantages: well suited for low concentrations, dusts easily discarded, measurements very close to the emission (no evaporation)

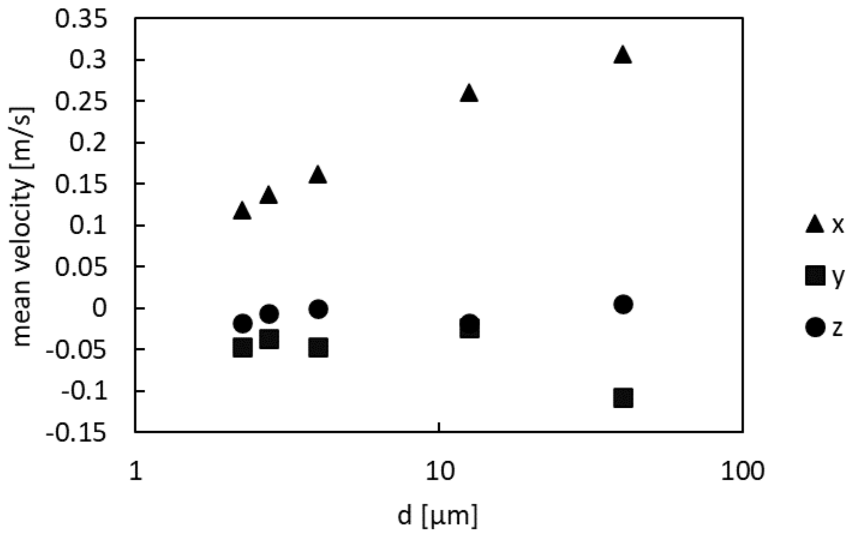
* *Grandoni, L., Méès, L. et al. “Interferometric laser imaging for respiratory droplet sizing” submitted to Experiments in Fluids*

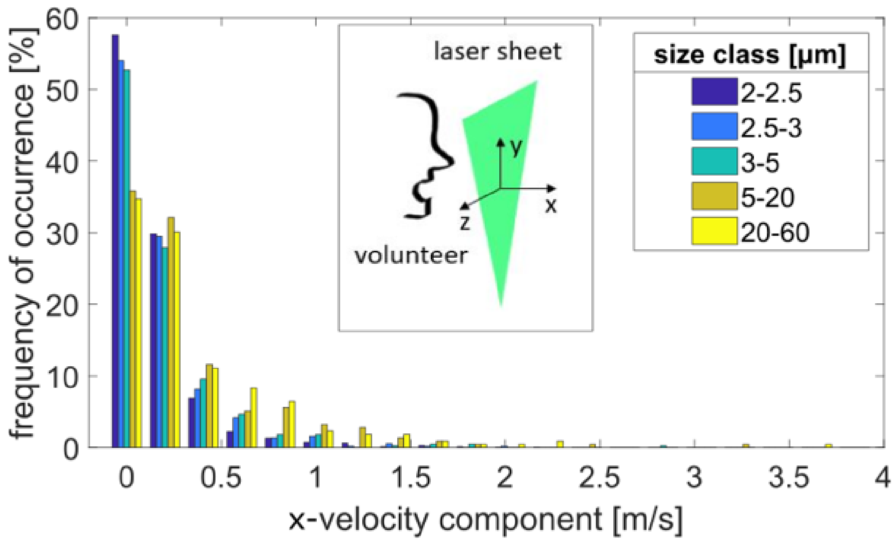
Source characterization results

- Most of the particles between 2 and 4 μm; relative maximum between 25 and 30 μm
- 5 different velocity distributions for 5 size classes
- Spanwise velocity around zero; vertical velocity higher (towards the ground) for larger particles, probably due to settling; streamwise velocity increases with size

(Results in Grandoni, L., Méès, L. et al. "Interferometric laser imaging for respiratory droplet sizing" submitted to Experiments in Fluids)

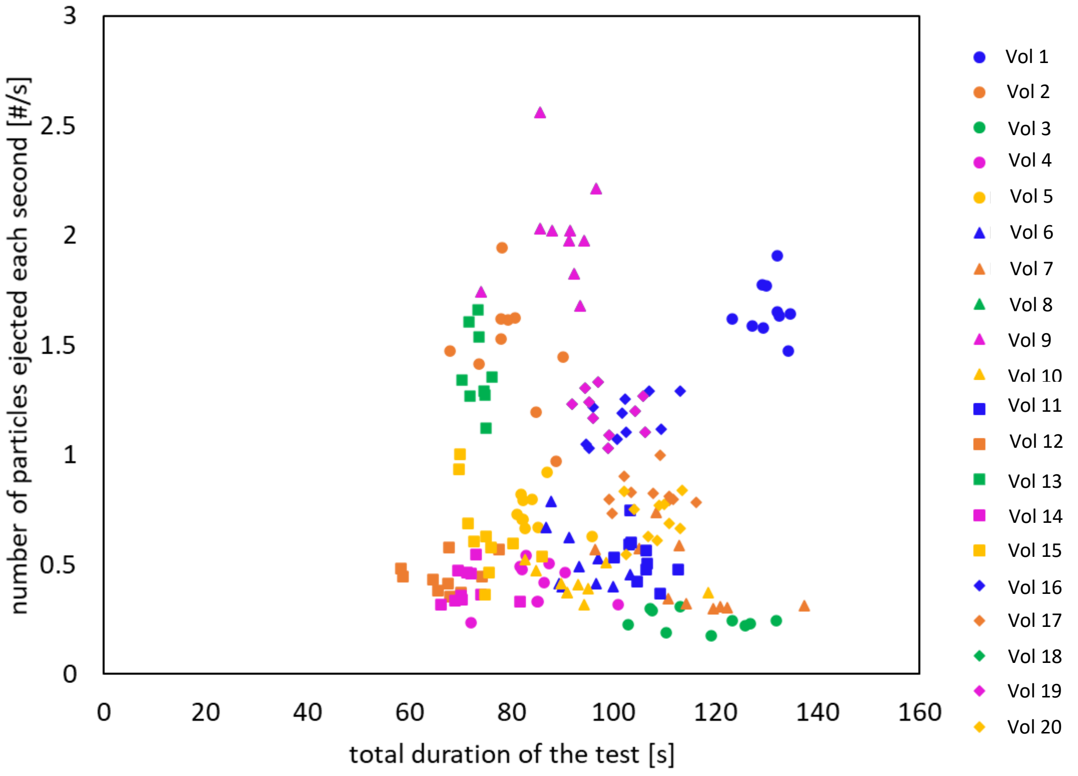


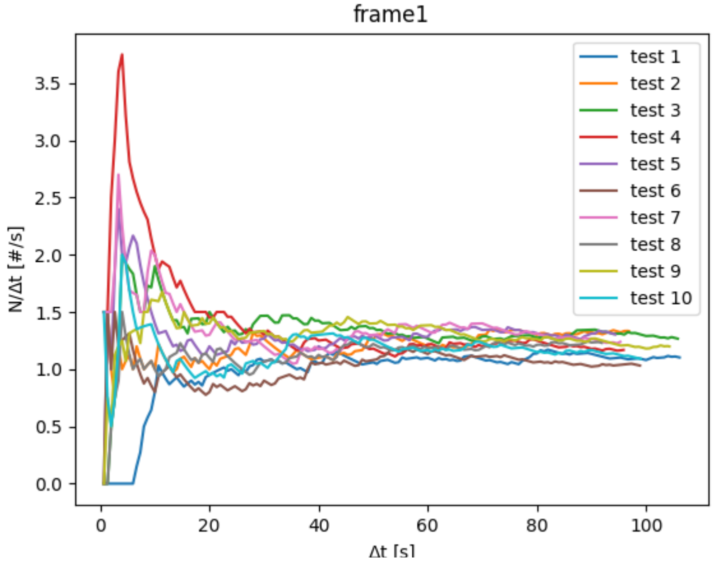


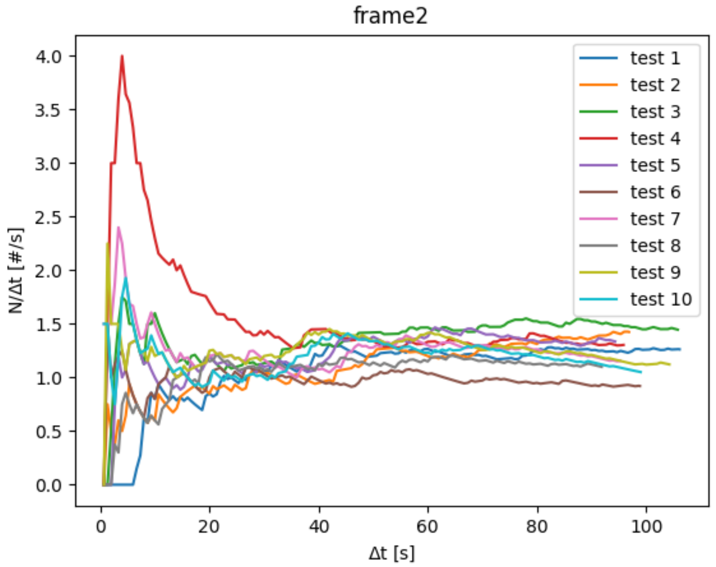


Source characterization results

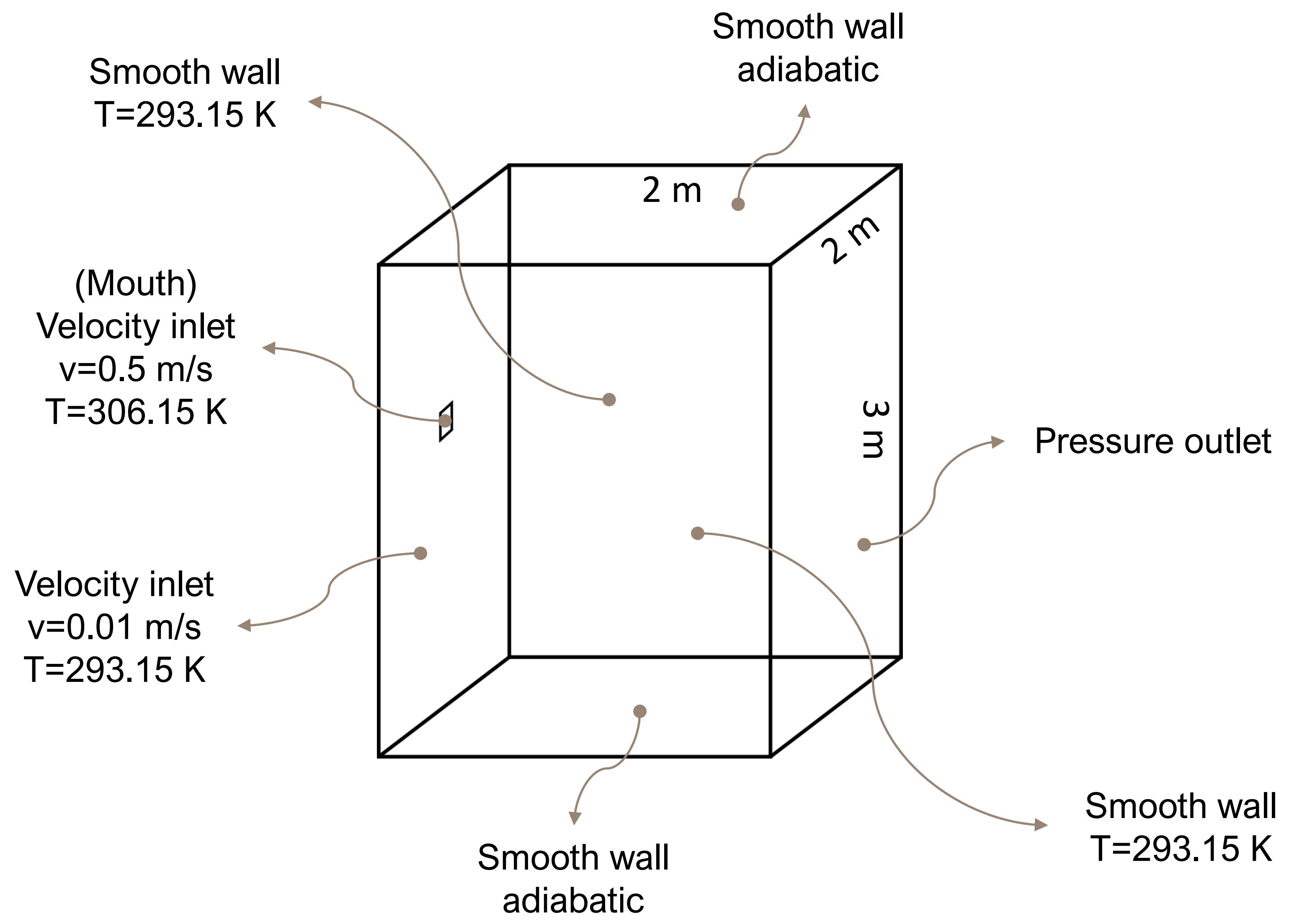
- 1 #/s ejected on average





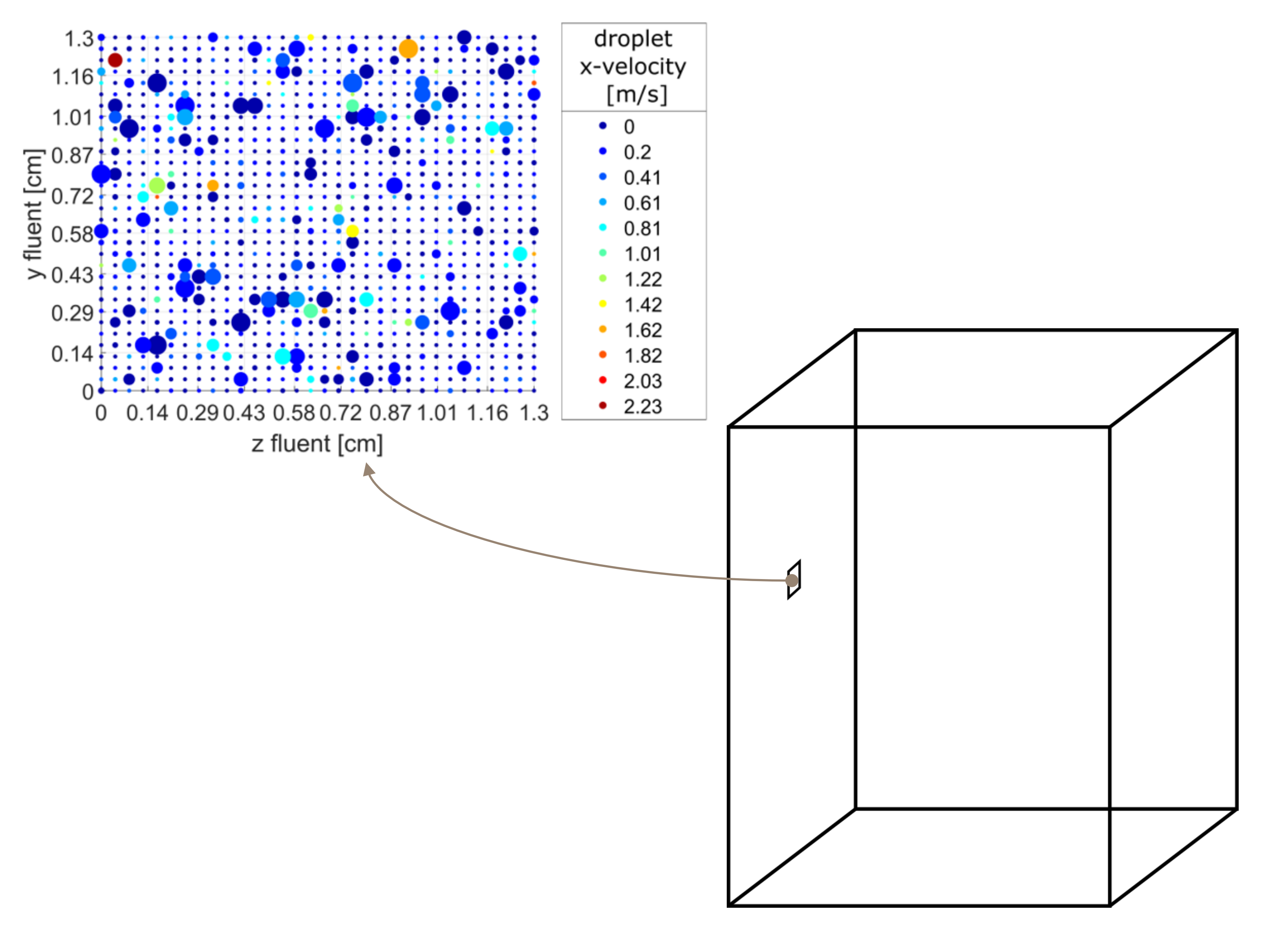


Numerical simulation setup



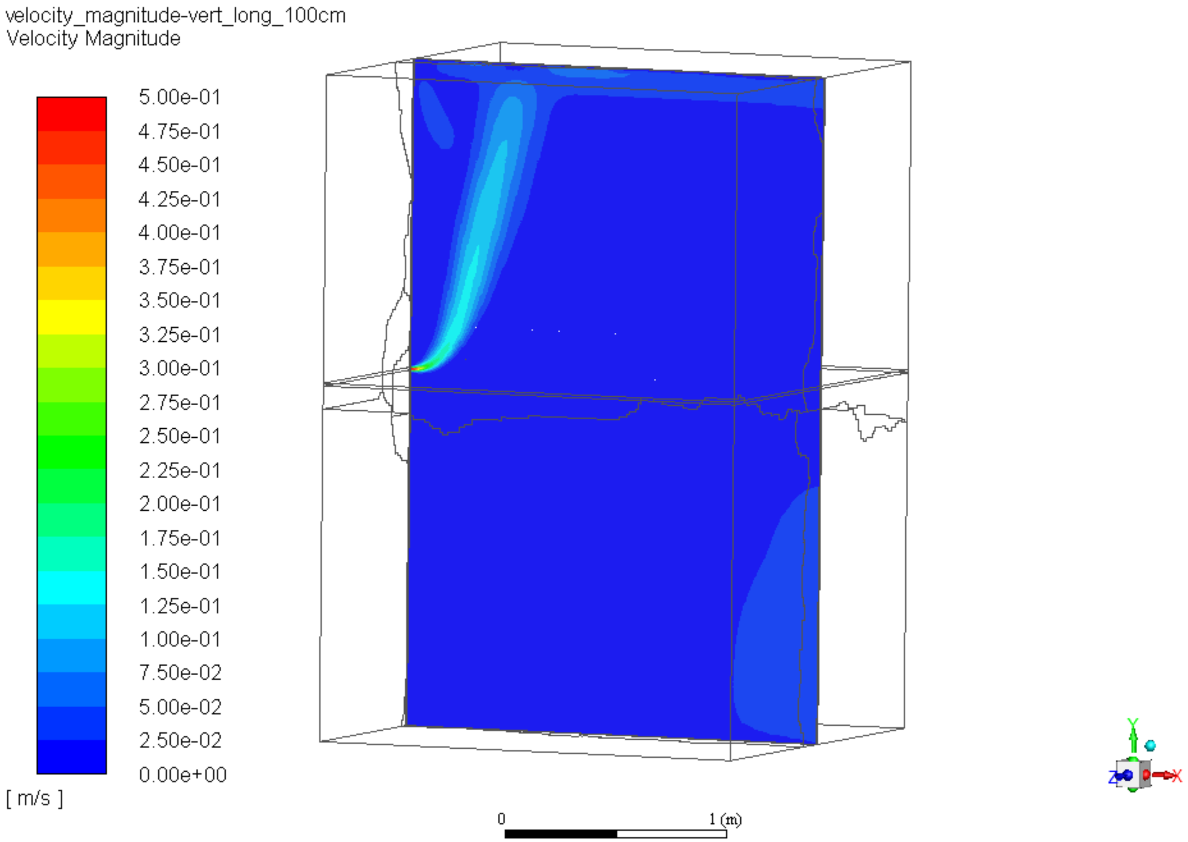
- **Ansys Fluent**
- Mesh refined closer to the mouth (larger cell of 1.3 cm, at the mouth cell of 0.16 cm)→ about $9 \cdot 10^6$ hexahedral cells
- Speaking modelled as a stationary jet (mean air ejection velocity f 0.5 m/s)
- standard k-ε turbulence model; buoyancy effect considered only on turbulence production

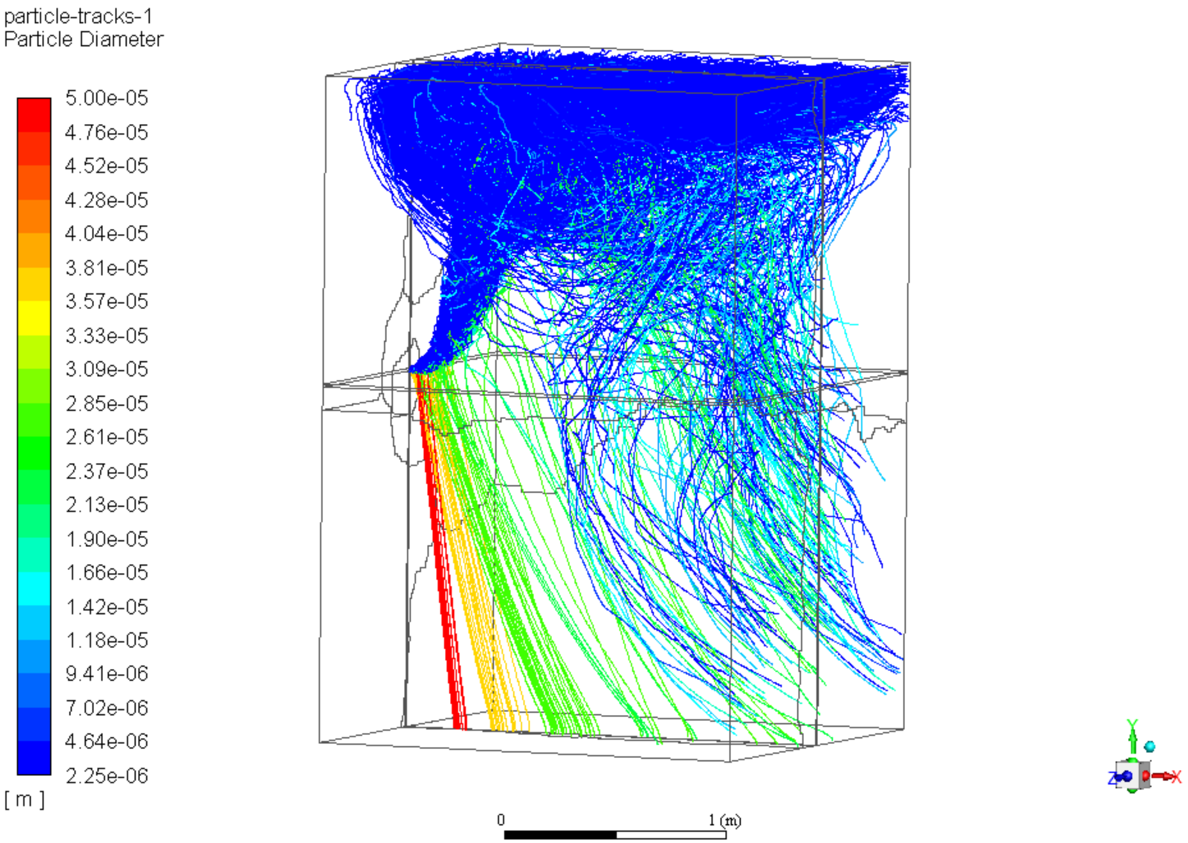
Numerical simulation setup



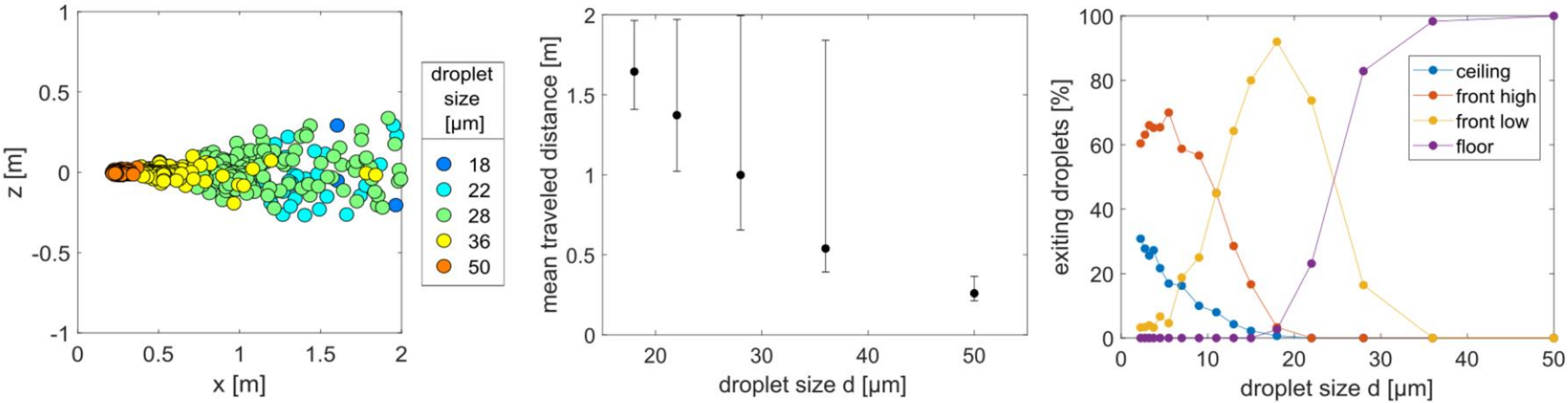
- **Discrete Phase Model (Discrete Random Walk activated)**
- Stationary injection of 1024 particle stream
- Inert spherical water particles

Numerical simulation results



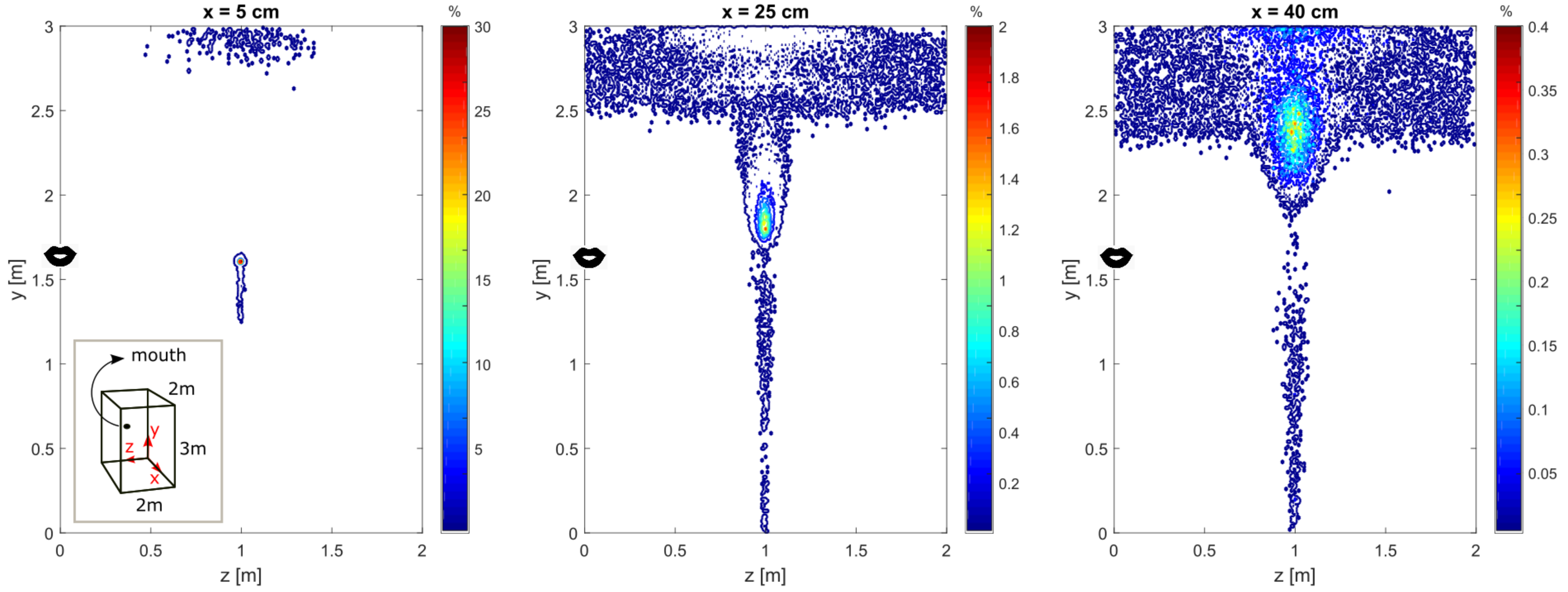


Numerical simulation results



- Only particles larger than 16 μm settle at the ground (within 2 m from the mouth)
- The mean traveled distance decreases with size; 24-40 μm particles span a wide range of distances
- Particles >32 μm completely settle at the ground within the domain (particles of about 50 μm within 50 cm from the mouth)
- Particles in the range 20-32 μm are probably will settle further than 2 m from the mouth
- Only a small fraction of particles of about 18 μm settle at the ground
- Droplets smaller than 16 μm rise with the gaseous phase; however, only the smallest remain close to the ceiling, larger droplets tend then to move downwards so that they exit the domain from the upper or the lower part of the pressure outlet.

Numerical simulation results



- Droplet concentration decreases (along with potential risk of infection) moving away from the mouth; however, the area contaminated by the droplet obviously becomes wider due to the spread of the particle loaden air cloud
- The high droplet concentration area moves upwards due to buoyancy effects (at about 40 cm from the mouth the height is >2 m)
- Normalized droplet concentration at mouth height (~ 1.6 m) decreases from ~ 15% to ~ 0.0073% and to ~ 0% at 1 mm, 25 cm and 40 cm from the mouth

Summary and conclusions

- **Numerical simulations** have been carried out to model the **dispersion process of droplets ejected by humans while speaking**. **Detailed input data** consisting in **droplet velocity and size distributions** have been obtained from a **measurement campaign involving 20 volunteers**
- The ejected particle loaden air cloud moves horizontally for a short distance, then it starts to rise due to buoyancy effects
- Only droplets larger than 16 μm settle on the floor; droplets of size d ~ 50 μm and 36 μm are removed from the air within 50 cm and 1 m from the mouth, respectively, the others can travel longer distances or remain suspended
- **Droplet concentration reduces moving away from the mouth due settling, to cloud spread and to the buoyancy effect that makes the cloud move upwards**
- High droplet number concentrations in the breathing zone are found within 30-40 cm from the mouth
- Typical winter conditions are considered in this work; other simulations with a weaker buoyancy effect are worth to be performed
- **Other simulations are needed to test the sensibility of the results to the detail of the provided input data**

References

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Thank you!

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