Estimation of initial size distribution of expiratory droplets by particle counters and evaporation model

Research background

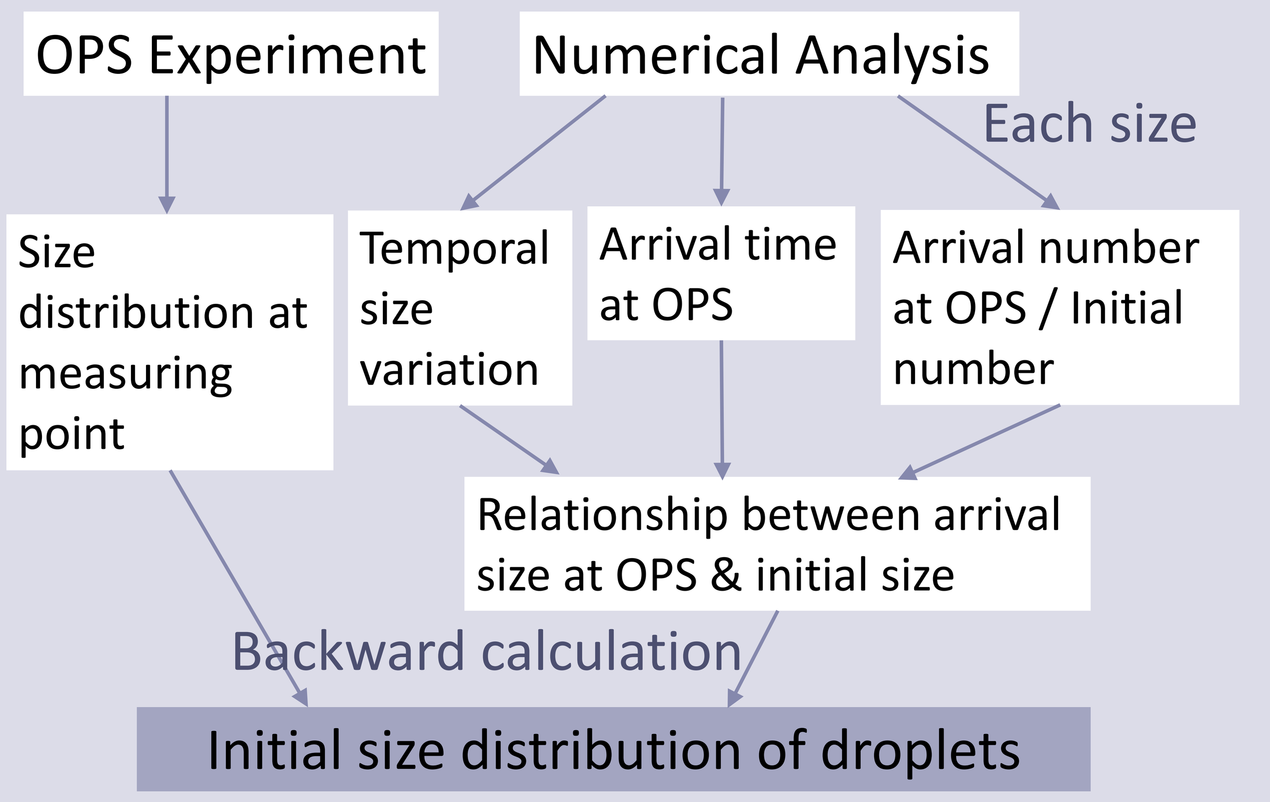
The size distribution of expiratory droplets at the moment they exit mouth is an important initial condition for predicting their indoor transmission path.

However, due to limits of experimental setup, droplets can only be measured at a certain distance from mouth, where the initial size distribution may have changed due to evaporation and dispersal.

Objectives

This study aims to back-calculate the initial size distribution of coughed droplets at the moment they leave mouth by means of Optical Particle Sizer (OPS) [1] and evaporation model [2].

Conceptual diagram



Arrival time at OPS = Arrival time at each plane center point + Time to pass through the tube(0.71 s)

Experiment Outline

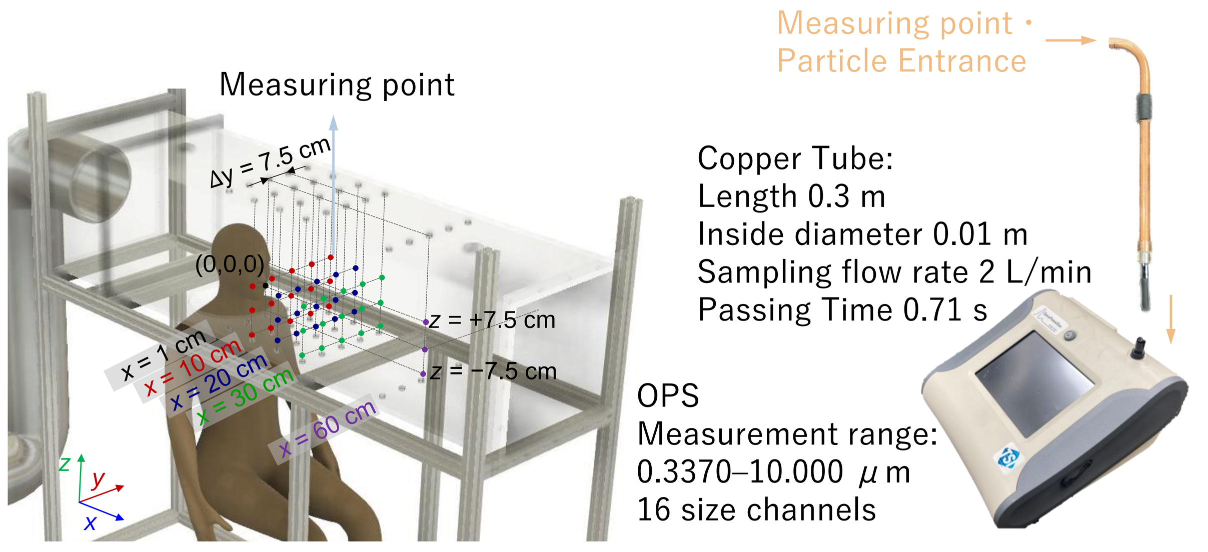


Fig 1 Measuring apparatus

◆ Number concentration normalized by logarithmic channel width

To remove the effect of channel width on particle number concentration for each particle size

$$N = dN/d\log Dp$$

$$d\log Dp = \log(D_{upper\ bound}) - \log(D_{lower\ bound})$$

dN： Particle number concentration in each channel [#/m³]；
Dp： Particle diameter [μm]；dlogDp： logarithmic channel width [-]
Dupper bound・Dlower bound : Upper and lower boundary of channel [μm]

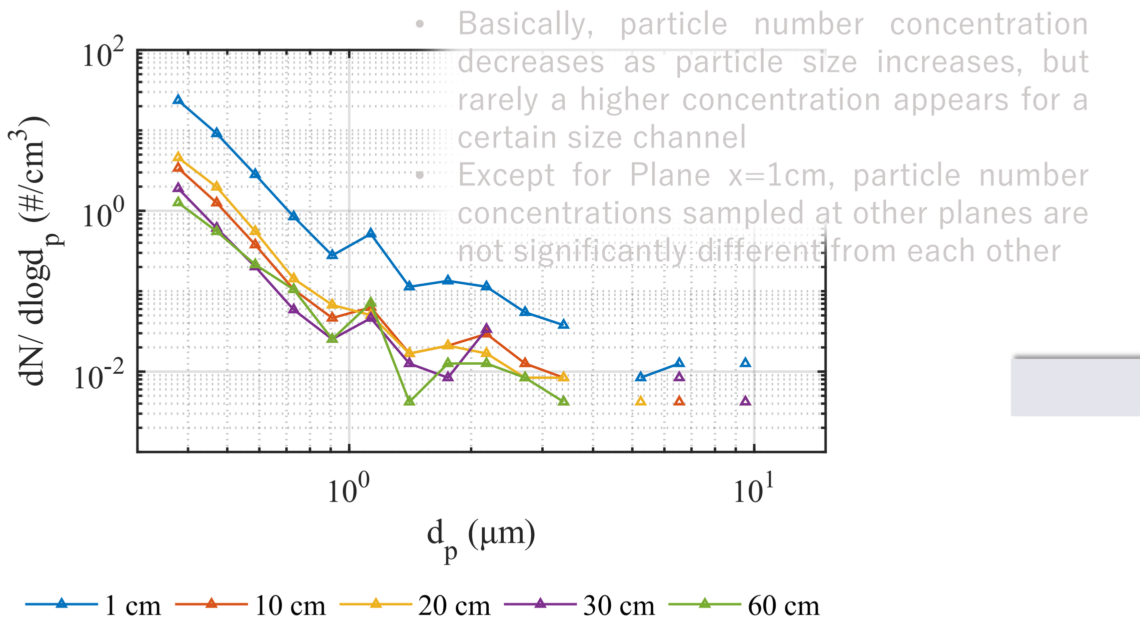


Fig 2 Particle size distribution at each measurement point by experiment

Simulation Outline

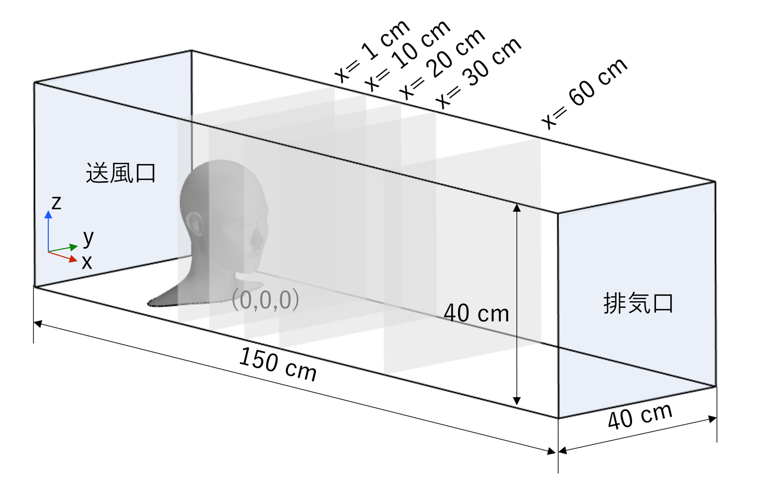


Fig 3 Calculation domain

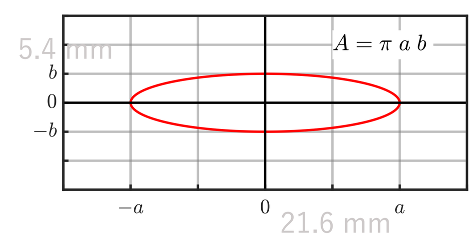


Fig 4 Mouth Shape

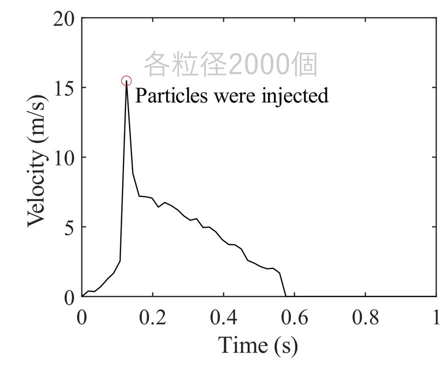


Fig 5 Flow velocity

◆ Droplet evaporation model：
Same as previous report [2]

Table 1 Calculation Condition

Wall	No-slip, Thermal insulation
Inlet	23.1 °C; 34.0% RH; V = 0.1 m/s; Turbulence Intensity 5%；Length Scale 0.07L m
Exhaust	Size: 0.4×0.4 m²；Ps = 0
Surface	No-slip, Convective heat transfer coefficient: 23 W/m²
Airflow from mouth	34 °C; 100% RH; Flow velocity: Fig 5 Area: Around 366 mm²； Turbulence Intensity 10%；Length Scale 0.07L m
Particle from mouth	Initial T = 34 °C; Initial V = 10 m/s Initial Ø: 1,2,4,8,16,24,32,40 μm Initial component V_{water}: $V_{non-volatile}$ = 98.2 : 1.8; Non-volatile part: ρ = 1000 kg/m³, $\bar{M}$ = 293 kg/kmol

Turbulence	RANS Realizable k- ε model
Mesh-division	Polyhedral meshとPrism layer
Total cell	Around 350,000
Software	STAR-CCM+ Ver.16.06
Time	Flow in chamber: Steady state Cough: Unsteady Δt =10^{-5} - 10^{-3} s

Simulation Results・Estimation

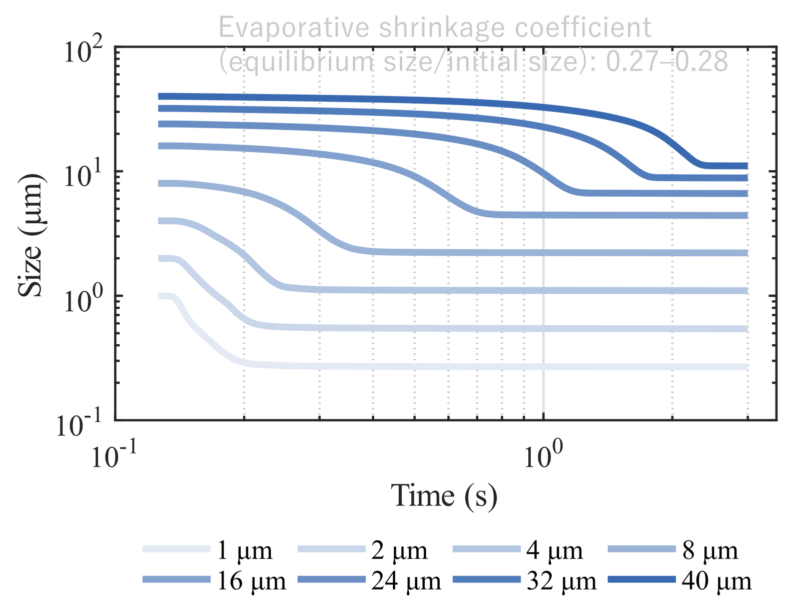


Fig 6 Temporal size variation

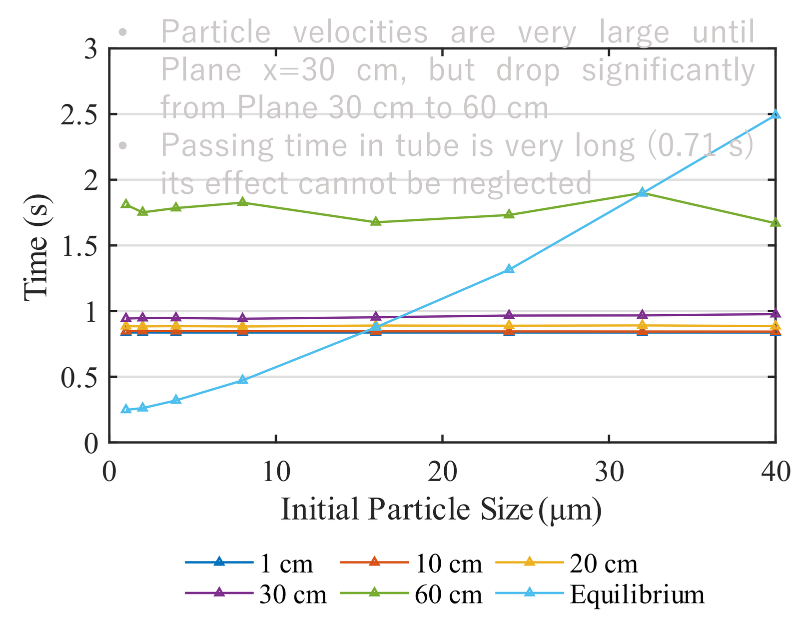


Fig 7 Relationship between initial particle size and OPS arrival time・equilibrium time of particles

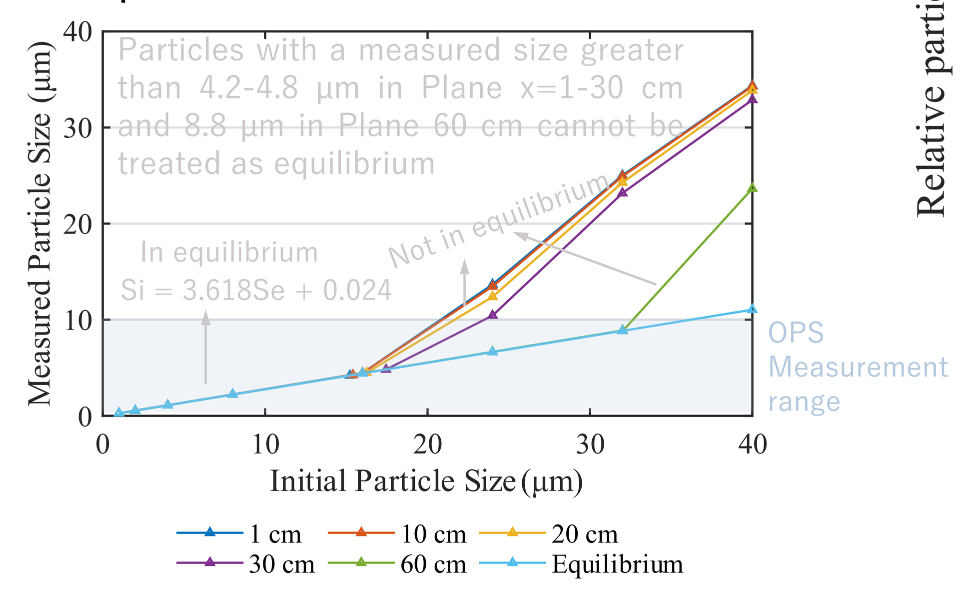


Fig 8 Relation between initial particle size and OPS arrival size・equilibrium size

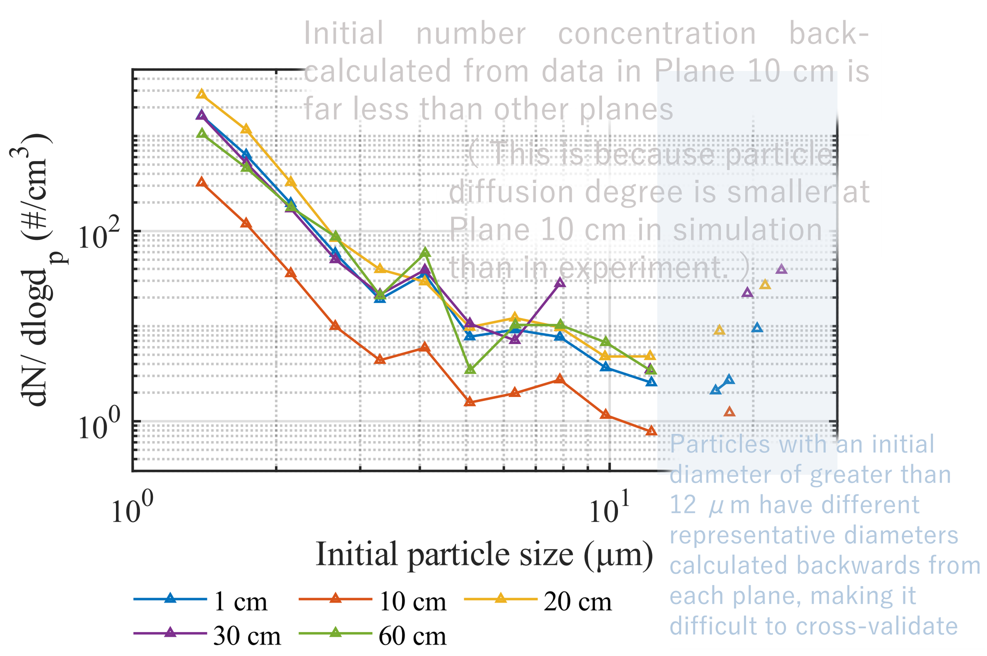


Fig 11 Initial size distribution of back-calculated droplets

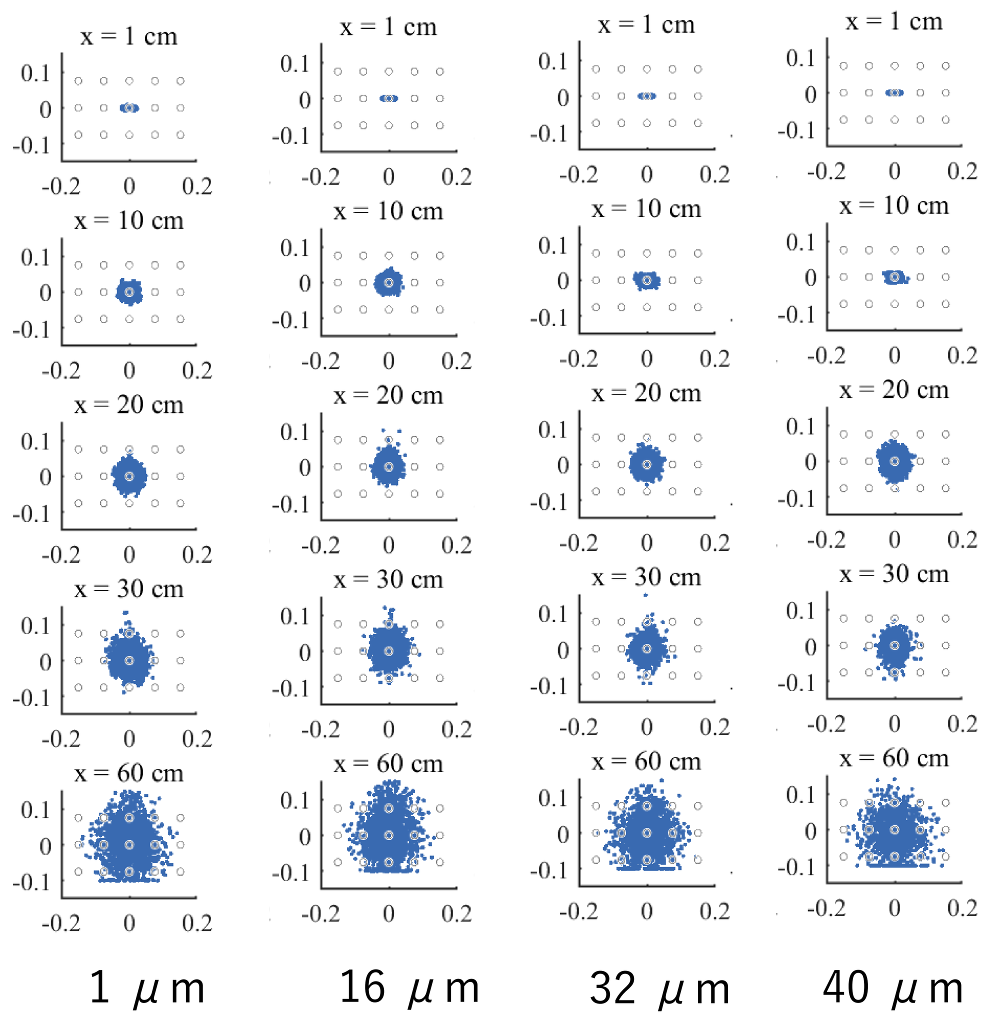


Fig 9 Distribution of particles reaching each plane

・ Larger particle size results in slightly lower arrival positions, but the effect is small

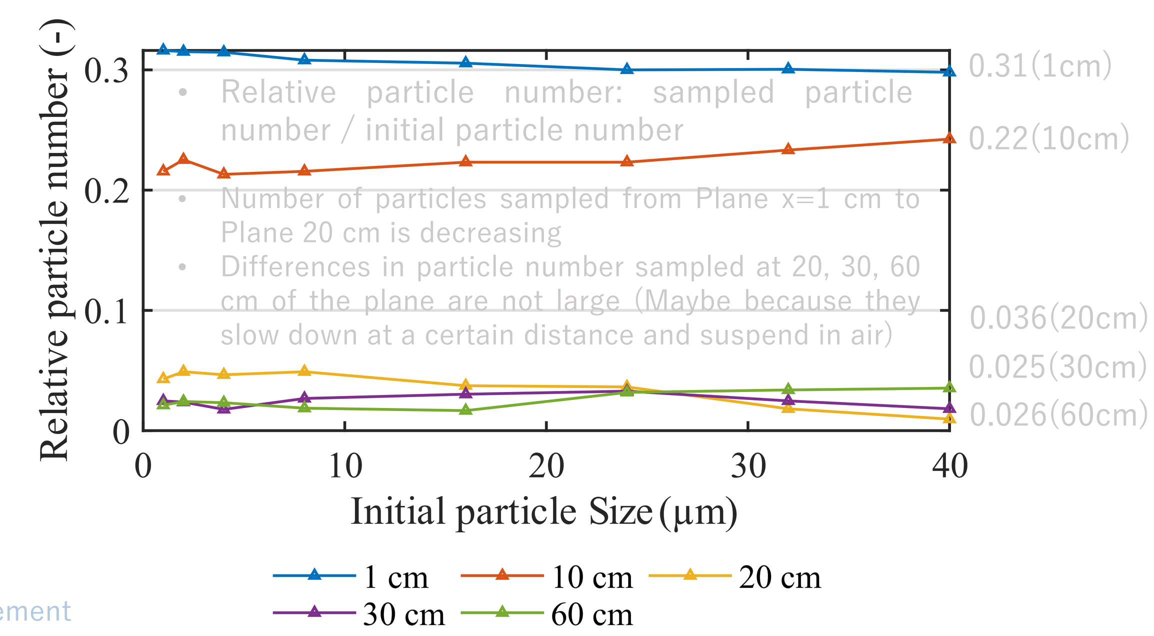


Fig 10 Relative particle number sampled at each plane center point

Conclusions

- Not all particles can be considered as in equilibrium when reaching OPS
- Initial size distributions back-calculated from each measuring point still differ
- In future, revision for evaporation model is needed to obtain a more accurate initial size distribution

Reference：[1] 呉元錫, 大岡龍三, 菊本英紀, 卜穎韻,人の呼吸器から噴出する飛沫の粒径分布に関する研究 （その１）呼吸・咳・会話の行動により発生するエアロゾル粒径の空間分布の計測, 日本建築学会大会学術講演会梗概集. (2022) 1323-1326.
[2] 卜穎韻, 大岡龍三, 菊本英紀, 呉元錫, 人の呼吸器から噴出する飛沫の粒径分布に関する研究, （その４）蒸発による飛沫サイズの時間変化に関する数値解析, 空気調和・衛生工学会大会学術講演論文集. (2022) 113-116.

Study on droplet size distribution ejected from the human respiratory system
Part 4 Estimation of initial size distribution of expiratory droplets by particle counters and evaporation model

大岡研究室・菊本研究室
Ooka Lab. and Kikumoto Lab.