Asian Network on Climate Science and Technology (ANCST)

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# Parameterization of Plume Dispersion Coefficient over Rough Surfaces


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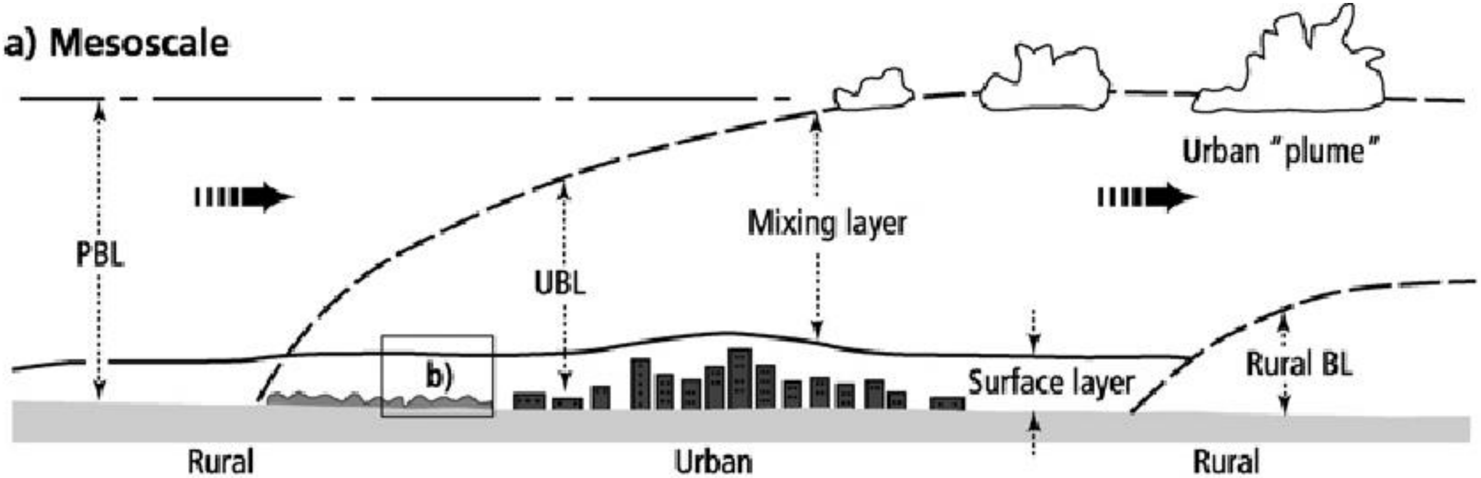
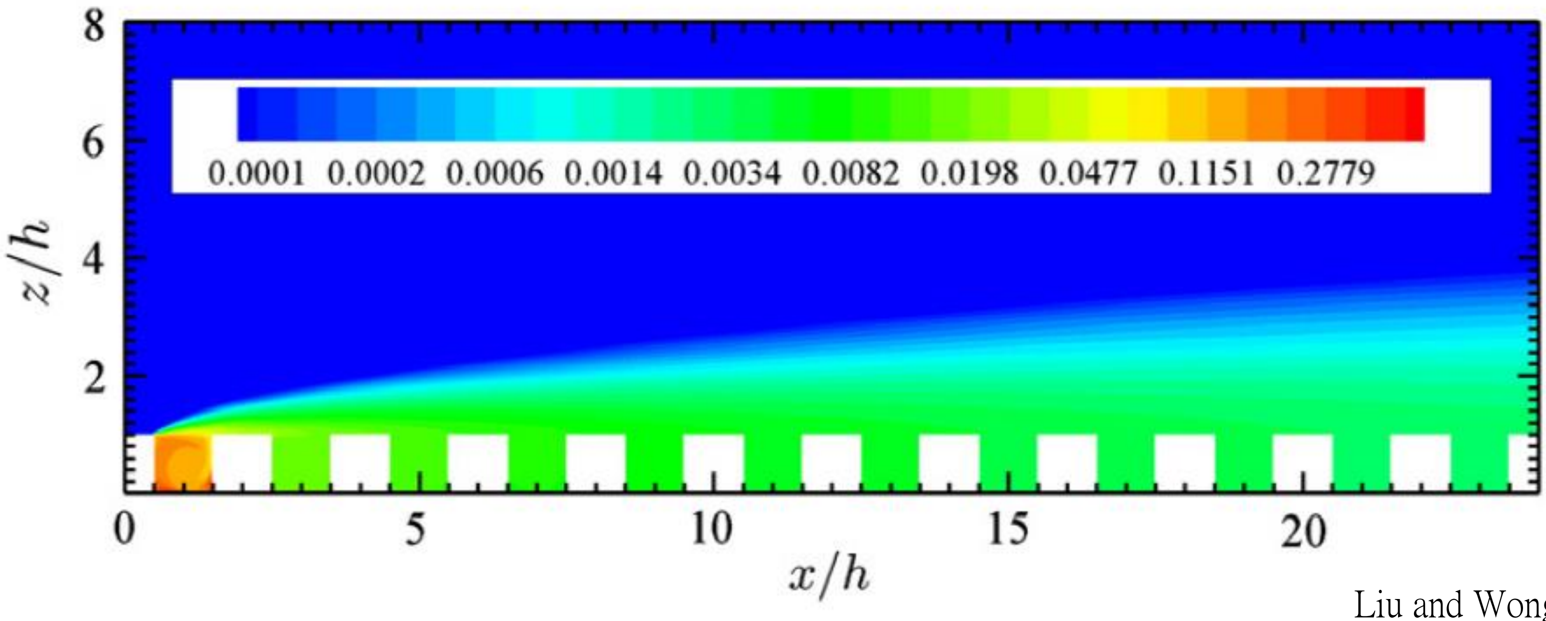
# Outline

- Background & objectives
- Theoretical analysis
- Methodology
- Results & discussion

# Urban Air Pollution




Piringer et al. (2012)




Liu and Wong (2014)

# Background

- Gaussian plume dispersion model

$$c(x,z) = \frac{Q}{\sqrt{2\pi}U\sigma_z}\left\{\exp\left[-\frac{(z-z_c)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+z_c)^2}{2\sigma_z^2}\right]\right\}$$

where $c$ is the mean pollutant concentration, $U$ the mean wind speed in the streamwise direction, $z$ the distances from the ground-level in vertical direction, $z_c$ the emission height, $Q$ the pollutant emission rate and $\boldsymbol{\sigma_z}$ **the vertical dispersion coefficient.**

- Friction factor

$$f = \frac{\tau_w}{\rho U_m^2/2} = 2\frac{u_*^2}{U_m^2}$$

where $\tau_w$ is the shear stress induced by the bottom rough surface, $\rho$ the fluid density, $U_m$ the average velocity in the turbulent boundary layer (Wong and Liu, 2013; Ho et al., 2015), $u_*$ the friction velocity estimated using Reynolds stress (Cheng and Castro, 2002; Ploss et al., 2000).

# Objective

- To parameterize the vertical dispersion coefficient $\sigma_z$ in the Gaussian model using friction factor $f$

# Theory

- Dispersion coefficient, which is a function of atmospheric turbulence, surface roughness & distance from the pollutant source $x$, can be described by the $K$-theory

$$\sigma_z^2 = 2Kt = 2K\frac{x}{U_m}$$

where $K$ is the diffusivity & $t$ the pollutant traveling time

- $K$ can be approximated by the friction velocity $u_*$ and mixing length $\delta$, as follows

$$K = u_*\delta$$

- Dispersion coefficient can thus be expressed in terms of $u_*$ & $U_m$

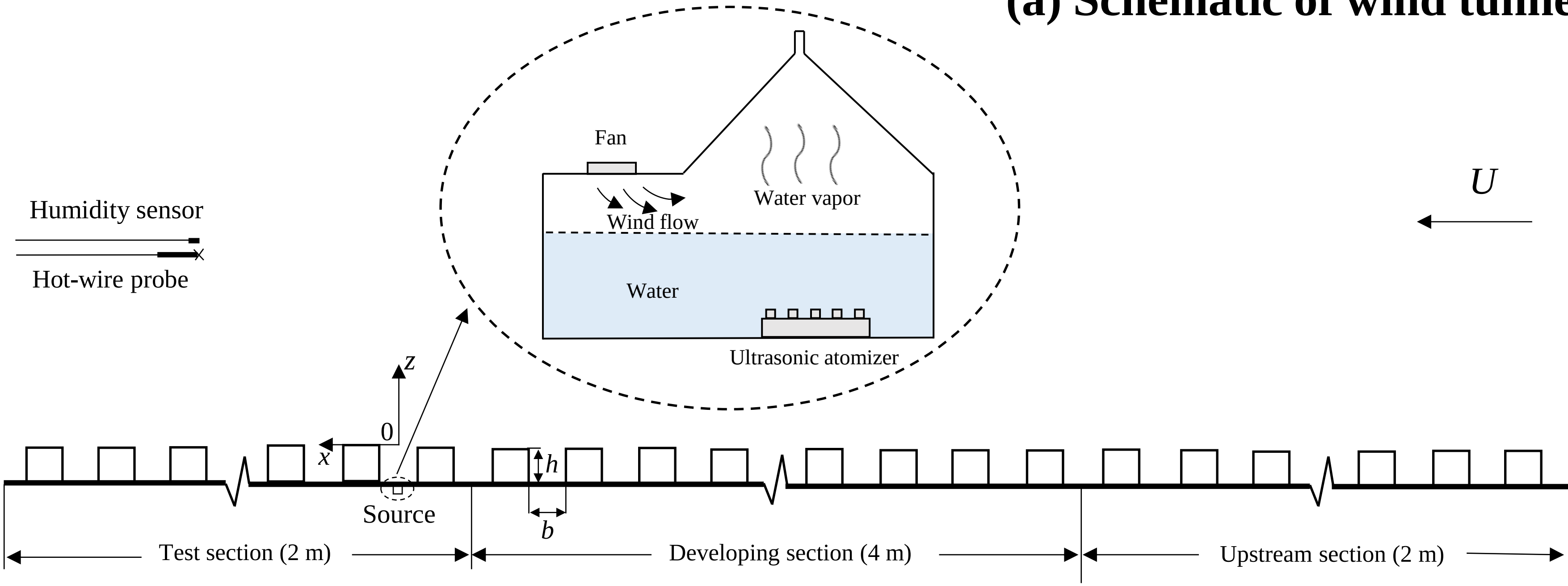
$$\sigma_z^2 = 2x\delta\frac{u_*}{U_m} = 2\times x\times\delta\times f^{1/2}$$

- OR

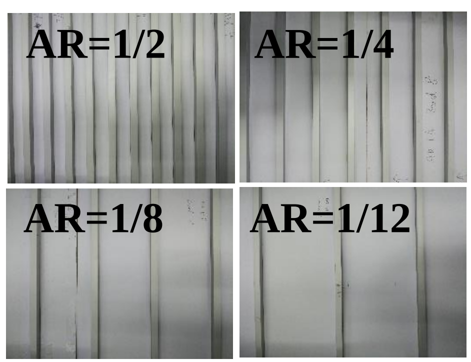
$$\sigma_z \propto x^{1/2}\times\delta^{1/2}\times f^{1/4}$$

# Methodology

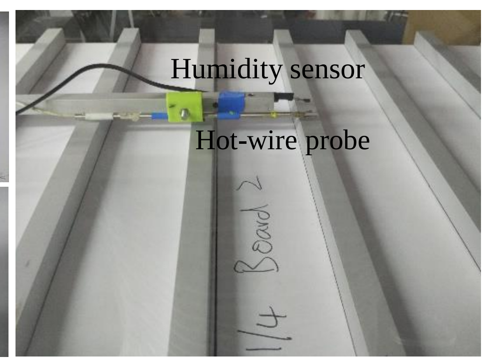
(a) Schematic of wind tunnel




(b) $H_2O$ atomizer



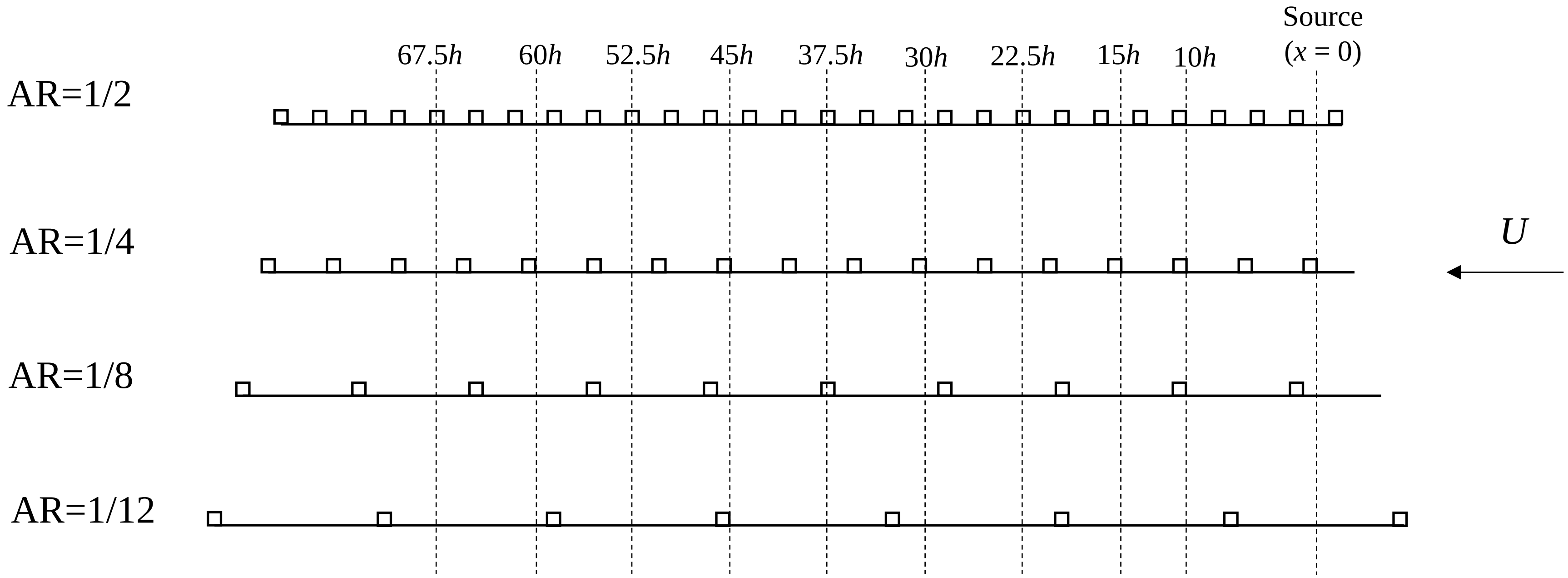

(c) Rib configuration




(d) Sensor location

(e) Source location

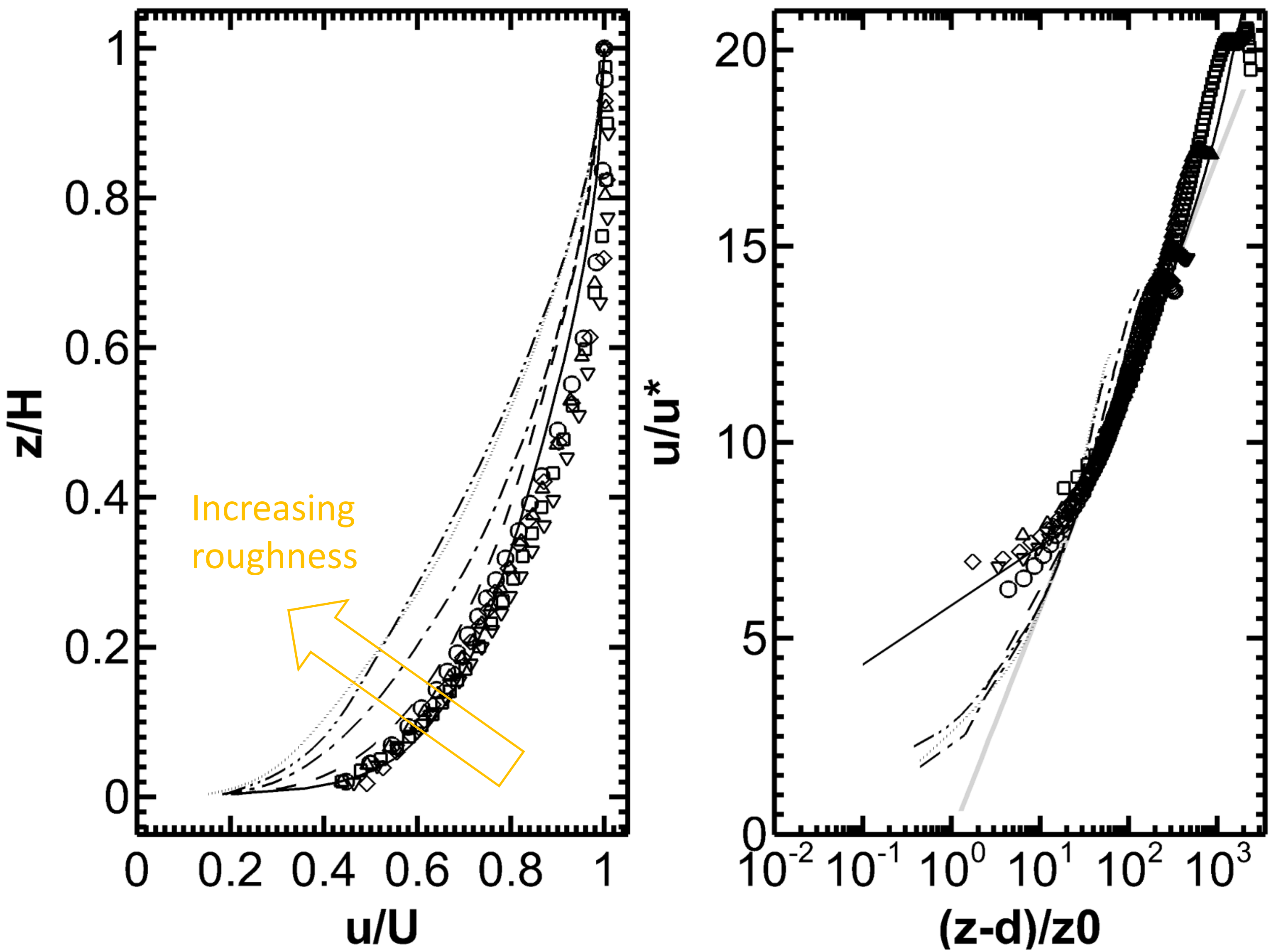
# Methodology



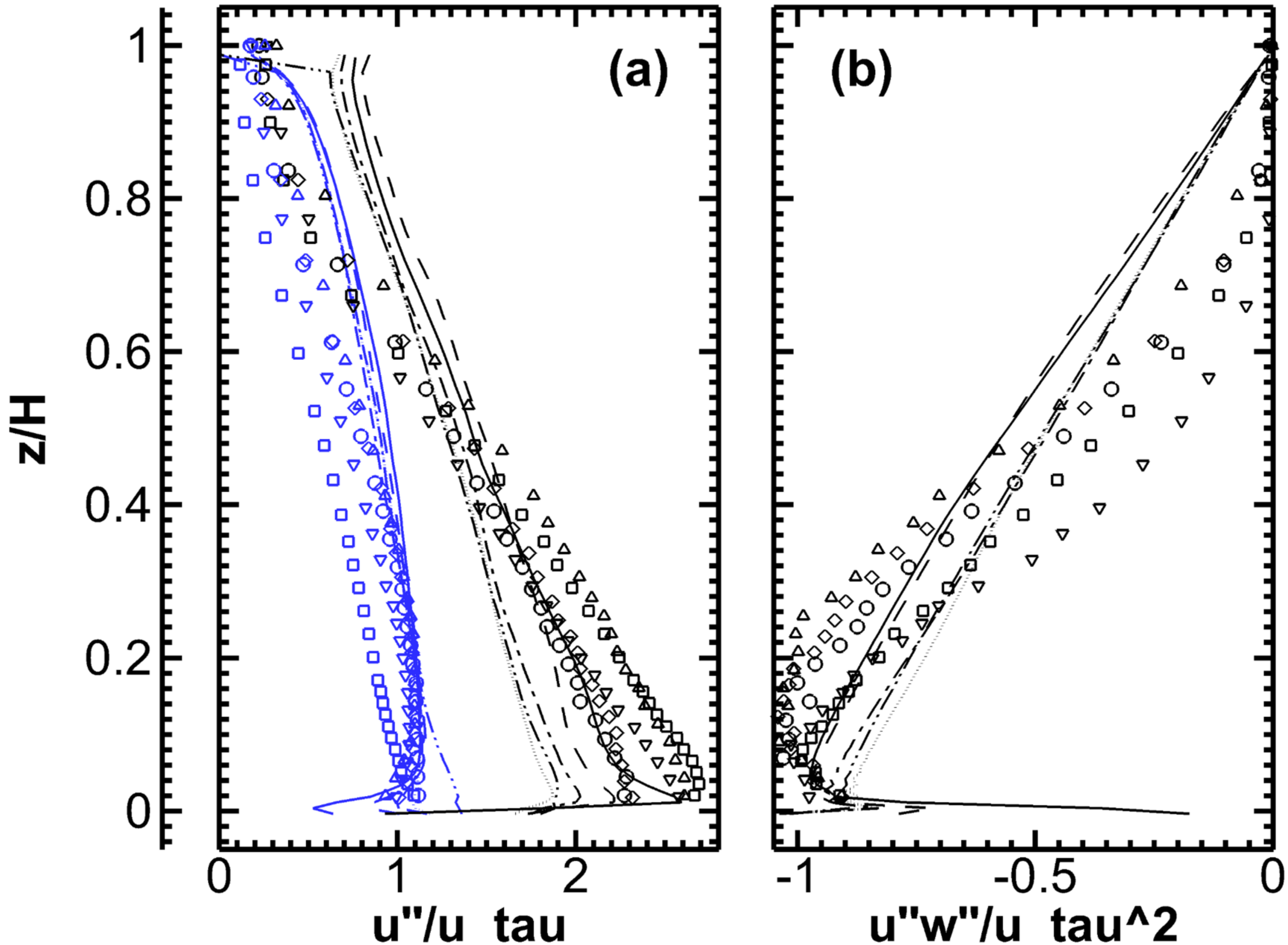

| Measurement cases | | Case L1 | Case L2 | Case L3 | Case L4 | Case H1 | Case H2 | Case H3 | Case H4 |
|---|---|---|---|---|---|---|---|---|---|
| **Free-stream** | $U_\infty$ | 3.28 | 3.31 | 3.28 | 3.29 | 6.66 | 6.61 | 6.70 | 6.60 |
| **Rib [mm]** | Size $h$ | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| | Separation $b$ | 38 | 76 | 152 | 228 | 38 | 76 | 152 | 228 |
| **Aspect ratio** | AR (= $h/b$) | 1/2 | 1/4 | 1/8 | 1/12 | 1/2 | 1/4 | 1/8 | 1/12 |

Note: L denotes lower wind speed measurements, H denotes higher wind speed measurements.

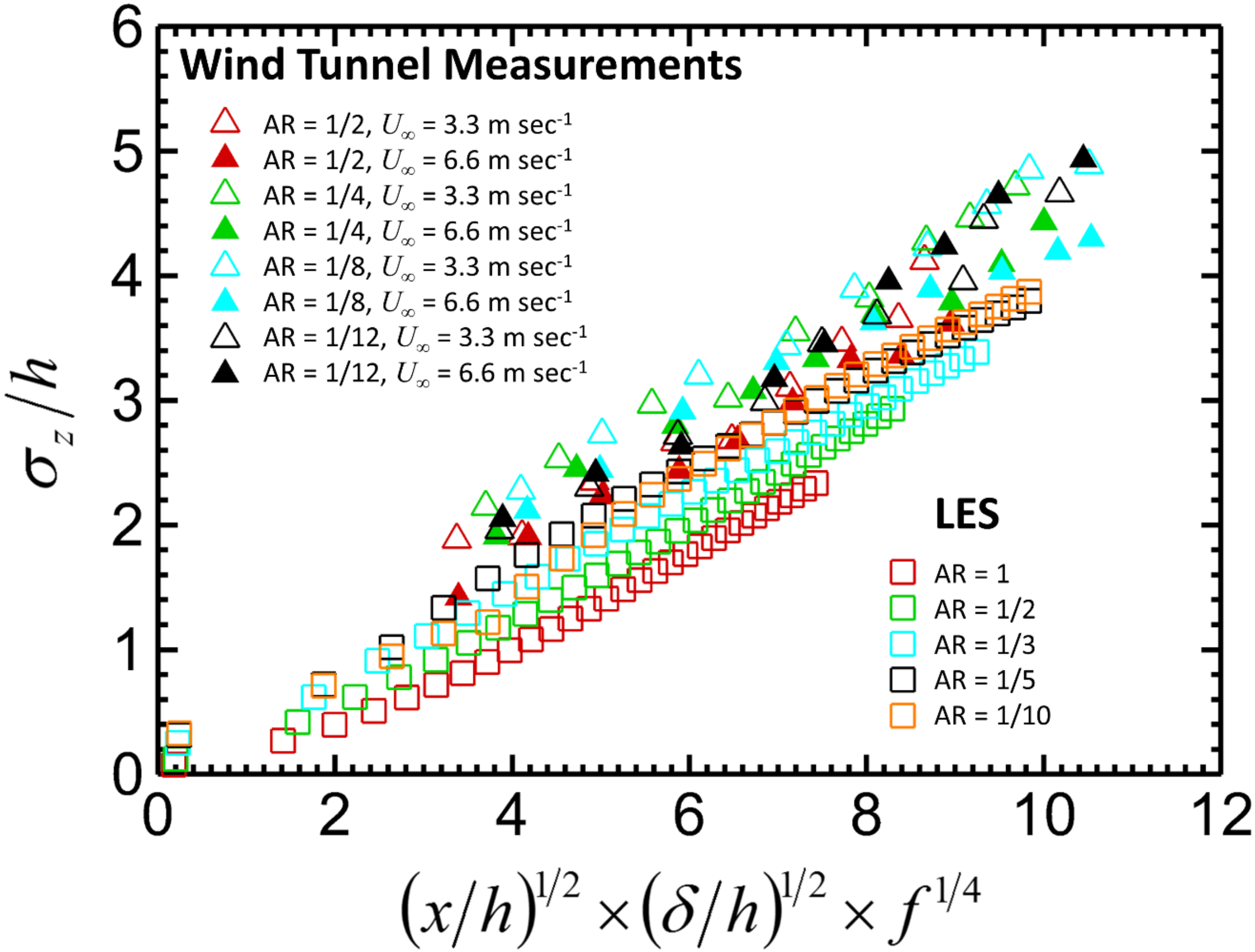
# Velocity Profiles



# Turbulence Profiles



# Dispersion Coefficient



# Summary

- The pollutant concentrations exhibit the conventional Gaussian distributions, suggesting the feasibility of using water vapor as a passive scalar in wind tunnel experiments.

- A strong positive correlation between $\sigma_z$ & $x^{1/2} \quad \delta^{1/2} f^{1/4}$ ($r^2$ = 0.933) is revealed from wind tunnel experiments. The analytical & empirical solutions formulate the basic parameterization of plume dispersion over urban areas.

# Acknowledgments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Thank you very much for your attention
Please feel free to ask questions