CFD analysis of urban wind environment with actual inflow obtained by Doppler LIDAR measurement

Shintaro KOBAYASHI[1], Ryozo OOKA[2], Hideki KIKUMOTO[3], Jongyeon LIM[4]

1. Graduate school of Engineering, The University of Tokyo, Tokyo, Japan, skbys@iis.u-Tokyo.ac.jp
2. Professor, Institute of Industrial Science, The University of Tokyo, Tokyo, Japan
3. Research Associate, Institute of Industrial Science, The University of Tokyo, Tokyo, Japan
4. Postdoctoral research fellow, Institute of Industrial Science, The University of Tokyo, Tokyo, Japan

BACKGROUND & OBJECT OF RESEARCH

In CFD analyses of urban area, power law is widely used for inflow boundary condition. Although this law is experimentally obtained, its relevance is assured by previous observations. However, this law is applicable just only for a profile averaged by long enough timescale. For instance, we have found that ten-minute or one-hour averaged profiles which are recorded by a Doppler Lidar System (DLS) still have considerable differences with the power law. Therefore applicability of the power law as inflow boundary condition is limited by the range of averaging timescale. In addition, the air flow at the ground level is still remained to be determined under instantaneous profile (which is far from a smooth curve such as the power law).

METHOLOGY

We carried out a CFD analysis of model case. In this analysis we employ actual profiles obtained by DLS as inflow boundary condition. We used instantaneous profiles (ten minutes average) which measured during April to June 2014, and compared following two cases.

In addition, from result of CASE1, we can know mean and deviations of wind environment due to the change of wind profiles.

Comparing CASE1 and CASE2, on the modeling inflow condition, we can evaluate how the averaging operation affects the analysis of the air flow at the ground level. From this research, the relevance of the power law is also evaluated in terms of the range of averaging timescale.

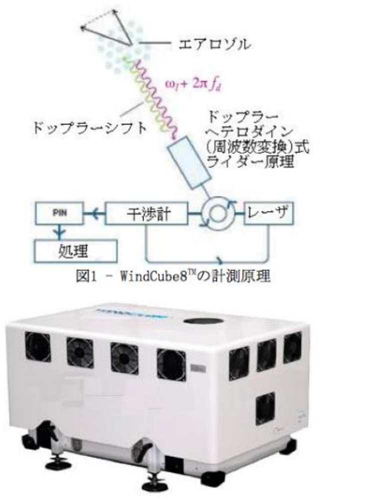

Fig. 1 Measuring Principle of Doppler Lidar System (DLS)


Fig. 2 A look of observation

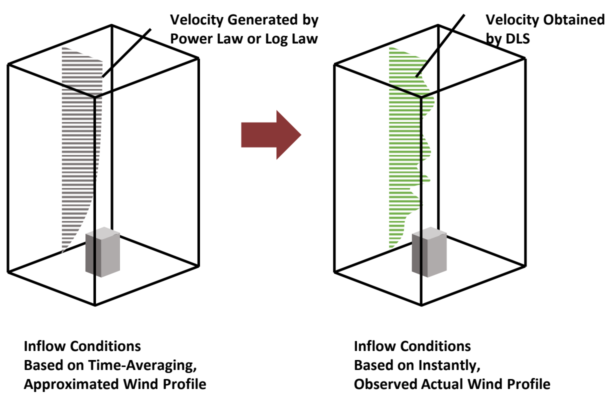

Fig. 3 Concept of this study

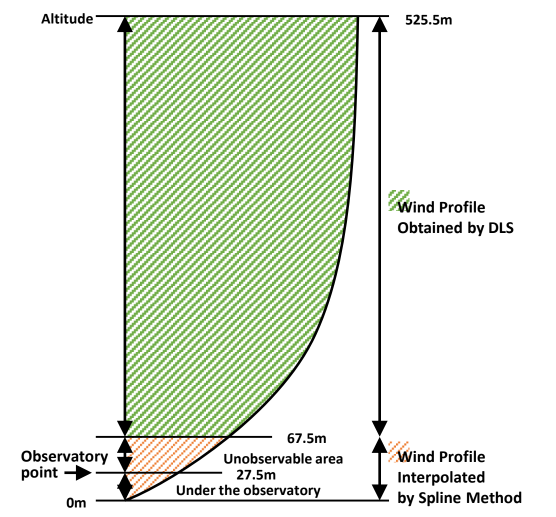

Fig. 4 obtained & interpolated profile

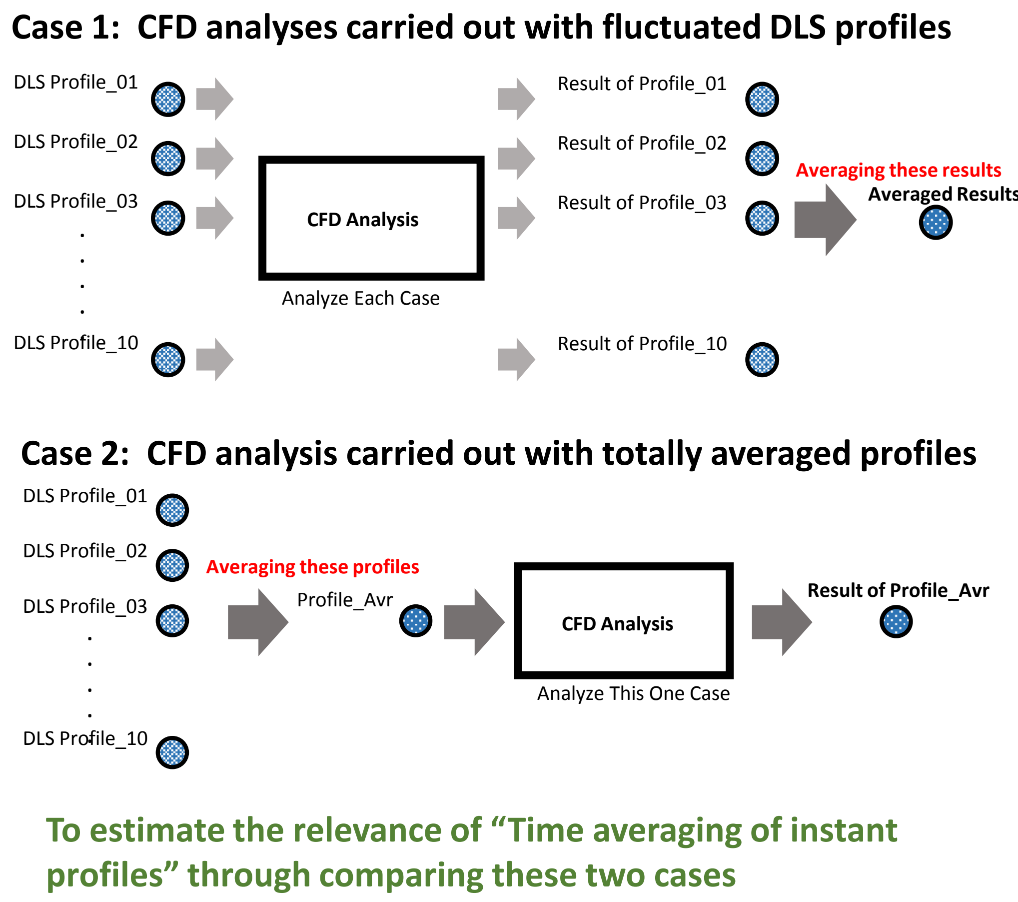

Fig. 5 Case setting of this study

CONDITIONS

Inflow Boundary Condition

Inflow Boundary Conditions are given by following methods. Equations are based on the thesis "AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings" (Tominaga et al.).

Velocity:

Observed Value from DLS (Refer to the diagram on the right)

Kinetic Energy:

$$k(z) = I_z U(z)$$

Where I_z is model constant (=0.1), $U(z)$ is obtained from DLS.

Dissipation Rate ε is given by assuming local equilibrium of $P_k = \varepsilon(z)$ (P_k: Production term for k equation):

$$\varepsilon(z) \cong P_k(z) \cong C_\mu^{1/2} k(z) \left| \frac{\partial u}{\partial z} \right|$$

Where C_μ is model constant (=0.09).

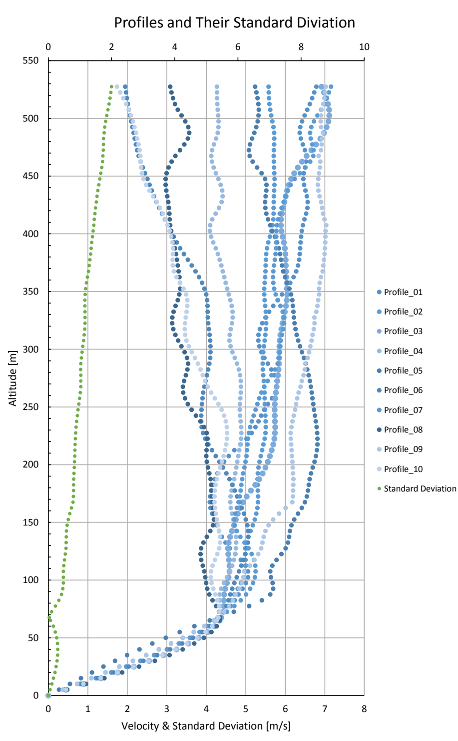

Fig. 6 Case profiles

Turbulence Model	k-ε
Method of k and e	Based on the guideline of Architectural Institute of Japan (Referring the equations on the left of this table)
Analytical grid	Orthogonal Mesh(Minimum Size; 2m)
Time discretization scheme	2nd order implicit scheme
Space discretization scheme	1st order upwind difference scheme
Inlet B.C.	Velocity Inlet
Outlet B.C.	Pressure Outlet
Side B.C.	Wall Function(Slip)
Top B.C.	Wall Function(Slip)
Ground B.C.	Wall Function(No-Slip)
Building B.C.	Wall Function(No-Slip)

Table. 1 Analysis conditions

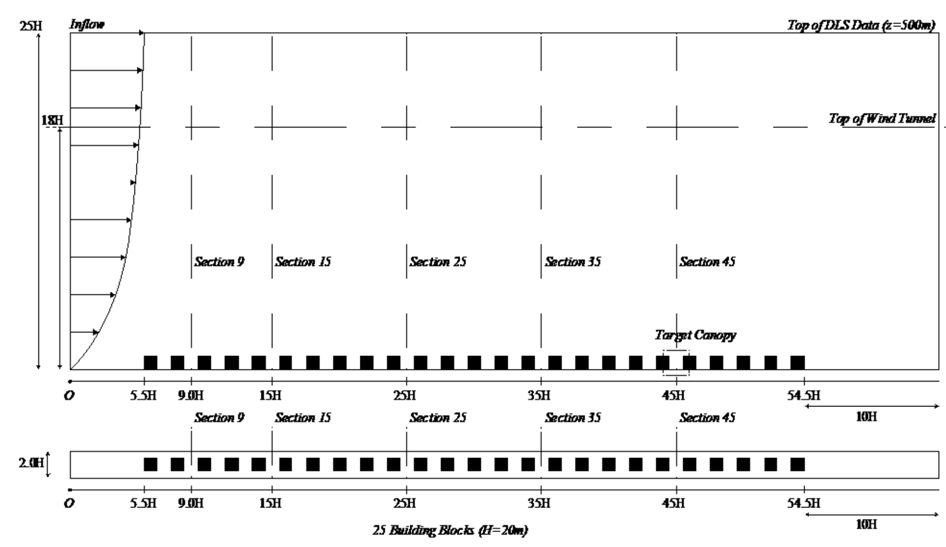

Fig. 7 Domain of numerical analysis

RESULTS

These sets of results are presented in these figures. First results show the transition processes of velocity, kinetic energy, dissipation rate, and pressure in one of the profiles(Fig. 8). The second set of results are comparison between case A & B(Fig. 9). The third result is the standard deviation of these profiles(Fig. 10). According to Fig. 8, it is observed that the transition of the profile of velocity is so few. But when it comes to kinetic energy, dissipation rate, and pressure, especially near the ground surface, there are some differences. It is seen from Fig. 9 that ensemble averaging operation barely affect to the velocity (As indicated by the green plots, difference of velocities is less than 1%. However, as shown on Fig. 10, deviation between each profile and averaged profile can take a high difference.

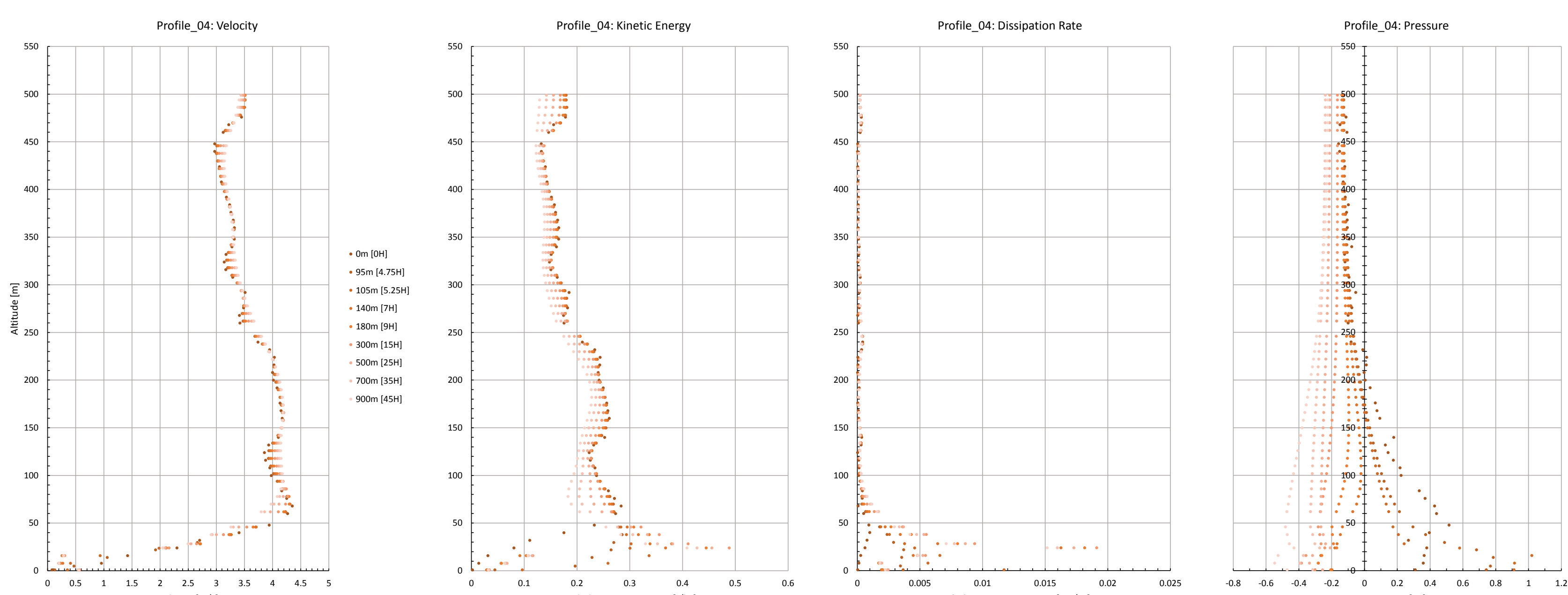

Fig. 8 Transition processes of one of the profiles

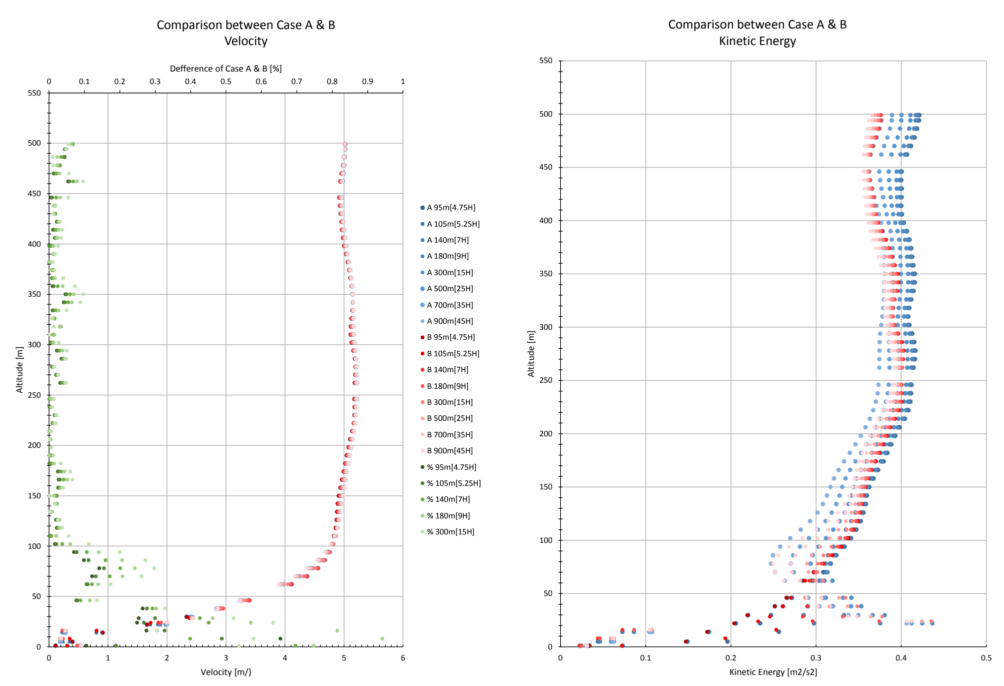

Fig. 8 Comparison of Transition processes between Case A & B

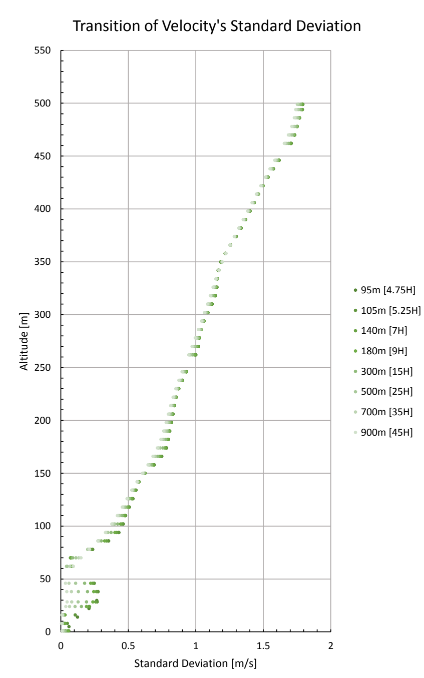

Fig. 10 Standard deviation of fluctuated profiles

CONCLUSION

We could reach the conclusion that ensemble averaging operation of inlet profile itself doesn't affect the CFD analysis. However, deviation between each profile and averaged profile can make a big difference.

Nowadays, CFD analyses are conducted for urban planning or designing. In most cases, actual inflow profiles are hardly available and the power law is still remained as an effective method to model the inflow. However inflow condition affects significantly to computational result of air flow. Therefore contribution of this research is to let people know the impact of inflow modeling on the urban wind environment.

Relevance of attempt to adjust the fluctuated profiles to k-e model still has been unproven. And each profiles certainly have a big differences from power law. So this remains an ongoing applying challenge. The author continue to pursue the present method attempted in this study.