NUMERICAL SIMULATION OF TURBULENT DISPERSION ON A TWO-WAY FACING TRAFFIC ROAD

Ryusuke Yasuda, Takeyuki Miyajima and Atsumasa Yoshida
Osaka Prefecture University, Osaka, Japan

Background

Air pollution around heavy traffic road is one of major environmental problems in Japan.

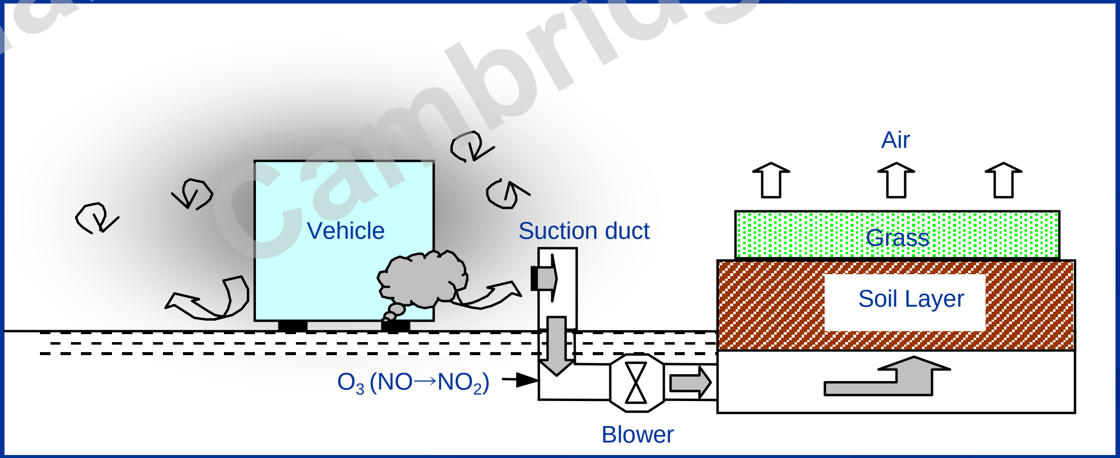
To reduce the local pollution level …

- ➢ Modification of the road structure
- ➢ Application of air purification method
  - Earth Air Purification (EAP) system
  - Utilization of Photocatalyst (TiO_2)

Prediction of the concentration level is necessary.

- ➢ Wind tunnel experiment
- ➢ Mathematical model
- ➢ Numerical model (CFD)
  - Reynolds Averaged Navier-Stokes (RANS) model （ex. k-ε model)
  - Calculations are made with steady state assumption
  - Meteorological condition is classified by wind direction and wind speed categories.

Earth Air Purification System



How do we include the effect of vehicle movements in CFD models?

- Source height :
  On the ground? At the tail pipe level?
- Cross wind :
  How is it affected by running vehicles?
- Distribution patterns of mean velocity, turbulence intensity and concentration:
  How do they distribute within a roadway?

Investigation of the turbulence and dispersion properties within a roadway is required, but measurement within a roadway is difficult and dangerous.
We conducted a series of numerical experiments by using a Large Eddy Simulation model.

Objective

- Develop a Large Eddy Simulation (LES) based model, which can express vehicles movement explicitly.
- Reproduce unsteady turbulent field to obtain the distribution patterns of mean statistics.
- Investigate Vehicle Induced Turbulence (VIT) effect on pollutant dispersion within a roadway.

Configuration of test cases

As a fundamental case …

- One-way and two-way facing traffic.
- Roadway is flat, straight and infinite.
- Sedan cars pass successively.

We focused on the distribution patterns of mean velocity, turbulence intensity and mean concentration within the roadway with/without cross flow.

Outline of our numerical model

Flow field

- Spatial derivatives
Advection terms: QUICK scheme
Diffusion terms: 2nd-order central difference
- Time derivative: Adams-Bashforth scheme
- SGS model: (standard) Smagorinsky model

Concentration field

- Advection terms: Walcek scheme(*JGR*,2000)
  positive definite, mass conservative and peak preserving
- Diffusion term: 2nd-order central difference
- Pollutant concentration is treated as a passive scalar.

Numerical method

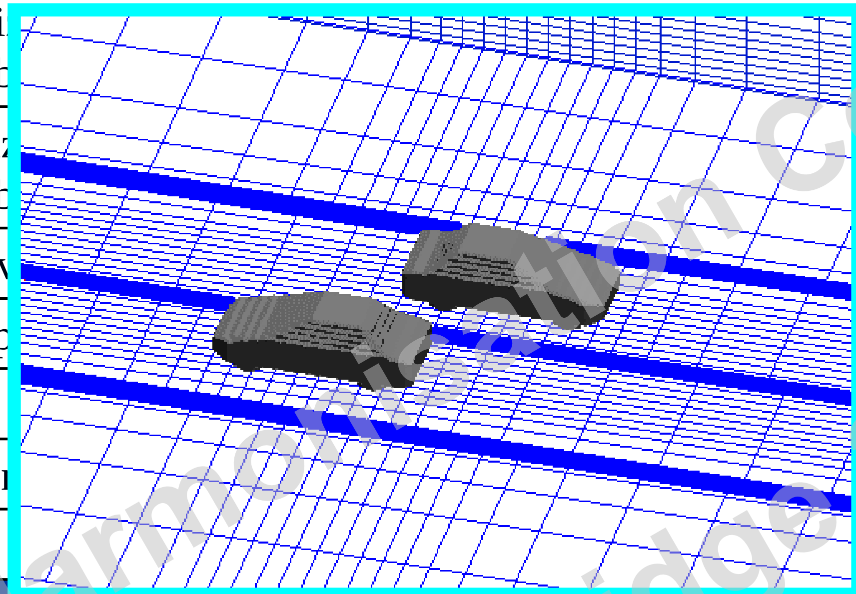
- Non-uniform, rectangle, staggered grid
- Control volume method
- SMAC method

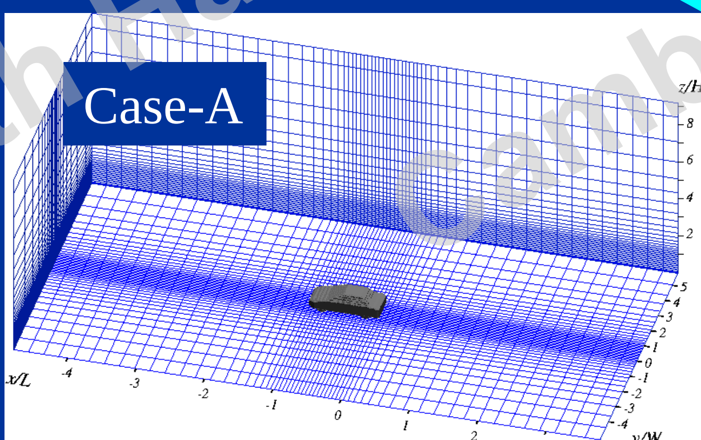
Expression of running vehicles

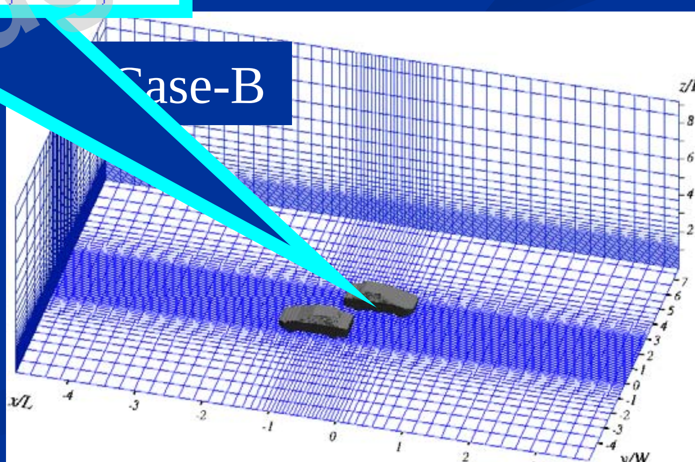
Running vehicles are expressed explicitly by sliding mesh method

Calculation conditions(1)

Cases	One-way (A0, A1, A2)	Two-way (B0, B1,B2)
Domain si Grid numb		(37.6, 21.6,12.9) (119,148,62)
Vehicle si Grid numb	1.70,1.46) ,25,23)	
Grid interv	.68, Δz =0.05~1.07	
Tail pipe p		(0.92,0.15), (2.00,0.15)
Time step	T^*, $T^*=W/U_c$	
Reynolds n	1.20×10^6	
Turbulent	c_t=0.5	







Calculation conditions(2)

Vehicles

- Vehicles pass successively
- Running speed (U_c) : 40 km/h(=11.1 m/s)
- Passing interval : 3 s
- Diameter of tailpipes : 0.07 m
- Emission velocity : 3.2 m/s
- Emission intensity : Constant
- **Rotation effect of tires and buoyant effect of emission gas are not considered**

Cross flow profile

$$v(z) = v_a\left(\frac{z}{z_a}\right)^m$$

- Reference height: Z_a=10 m,
- Power law index: m=0.25,
- Fluctuation velocities are not imposed.

Cases of the numerical experiments

Reference velocity (v_a)	One-way traffic	Two-way traffic
0 m/s (calm)	**Case-A0**	**Case-B0**
1.0 m/s	**Case-A1**	**Case-B1**
2.0 m/s	**Case-A2**	**Case-B2**

Boundary conditions

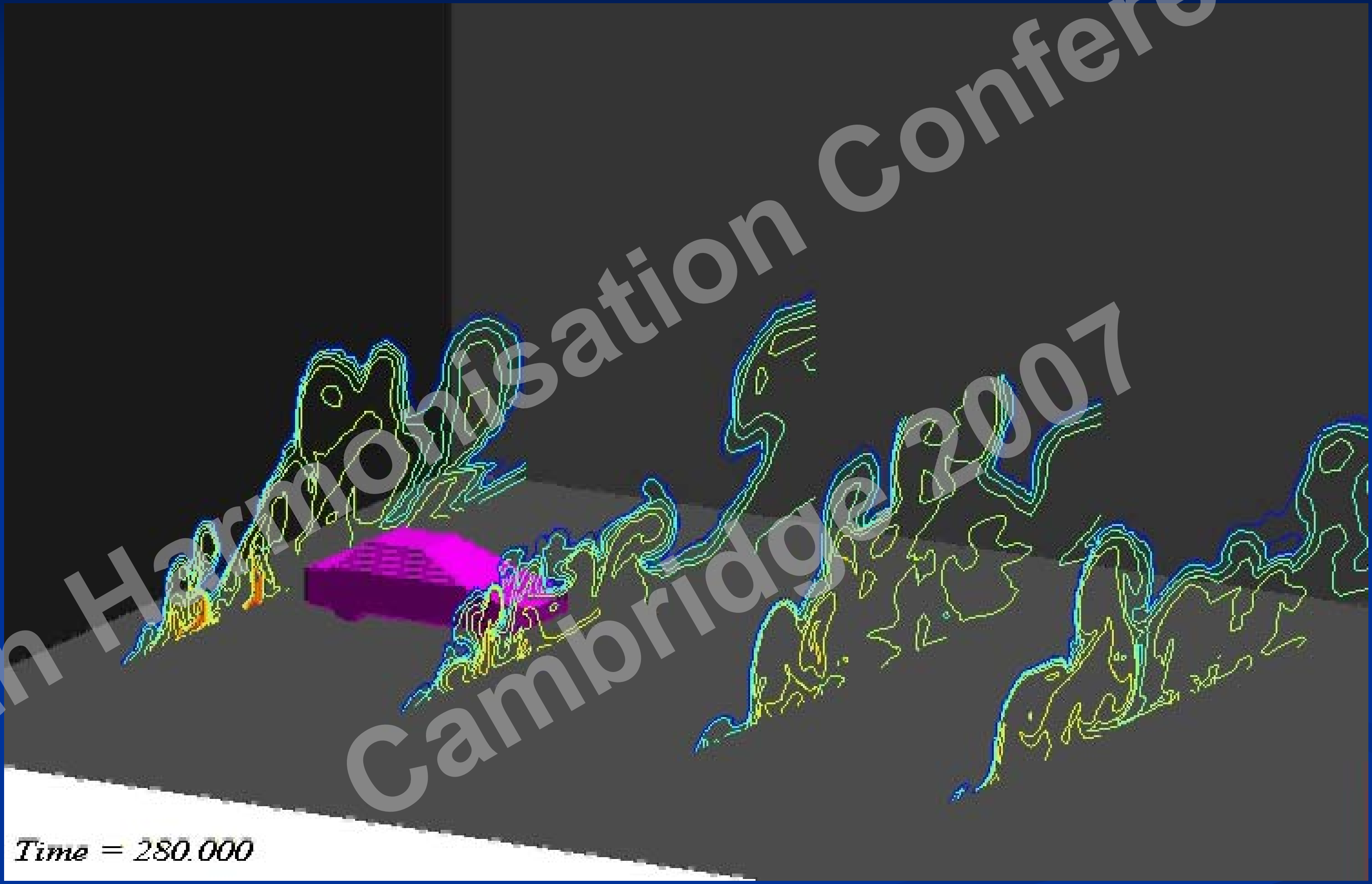
Boundaries	Without cross flow (A0, B0)	With cross flow (A1,A2, B1,B2)
X direction	Periodic	
Y direction	Slip condition $(\partial u/\partial y=\partial w/\partial y=0, v=0)$	Inflow boundary: Power law profile Outflow boundary: Convective outflow
Z direction	Upper boundary: $u=\partial v/\partial z=w=\partial c/\partial z=0$ Lower boundary: $u=v=w=\partial c/\partial z=0$	
Surface	Two-layer model (*Werner and Wengle,1991*) $\partial c/\partial n=0$	

Statistical procedure

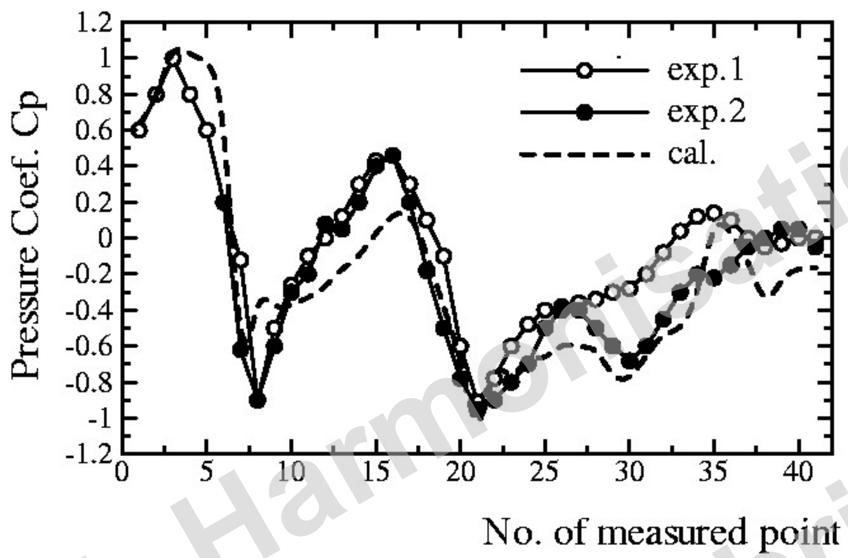
- Because the flow and concentration fields are uniform in the x direction from the view of the road-fixed frame, the both of spatial averaging (in x-direction) and time averaging are applied.
- The averaging time period; 240T^* (= 12 vehicles passing)
- For concentration field, the mean statistics were estimated during the last 120T^*.
- All concentration values are normalized by $C^*=CV_aW^2/Q$, where C: Concentration, V_a: Cross flow speed, W: Vehicle width, Q: emission intensity.

One-side traffic case(Case-A2)

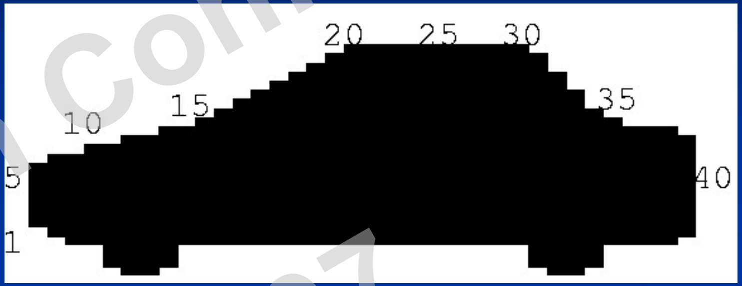
Two-side facing traffic case(Case-B2)



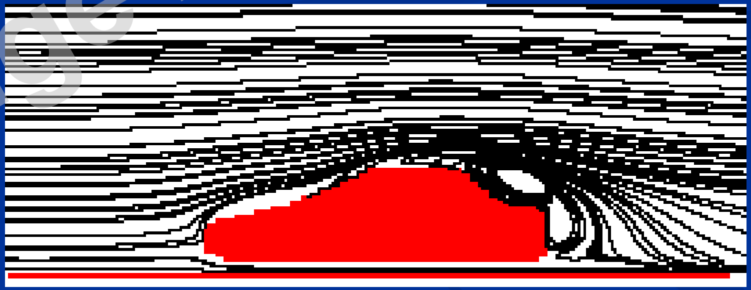
Flow around a sedan car
(Comparison with laboratory measurements)



The distribution of the pressure coefficient (Cp) around the body surface of the vehicle

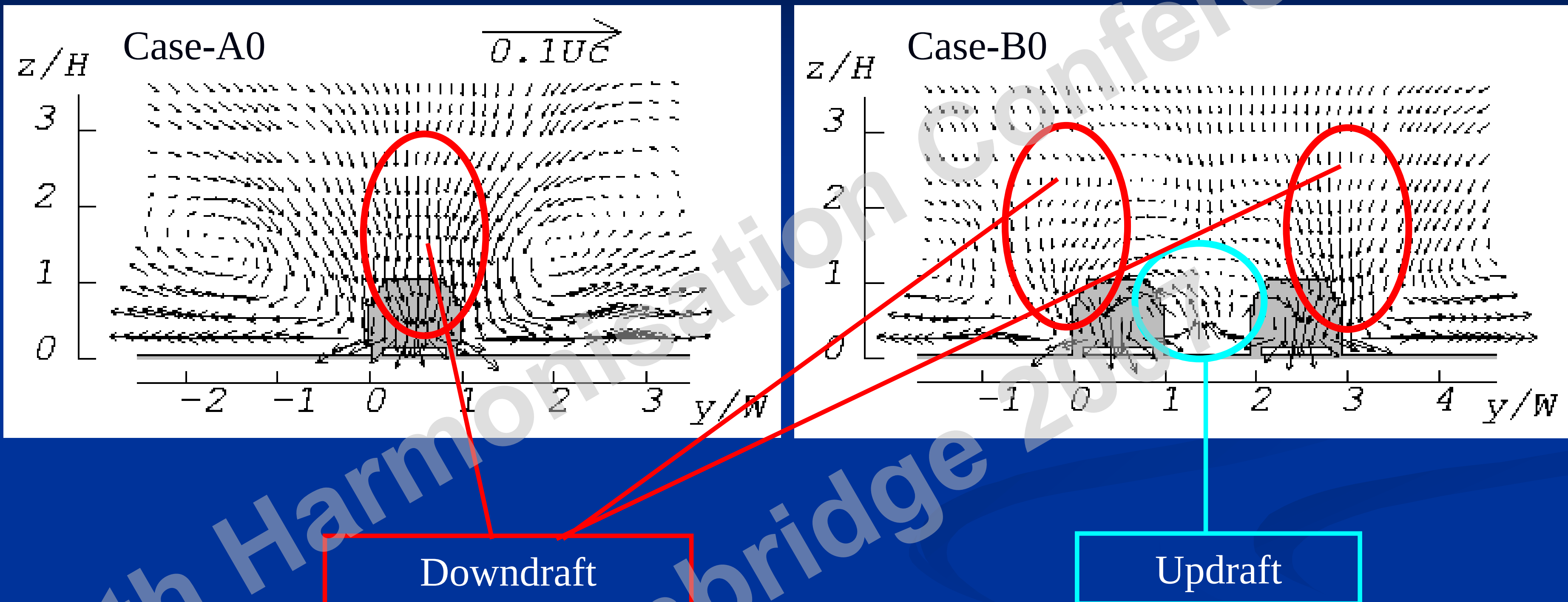


The shape of the vehicle and sampling point



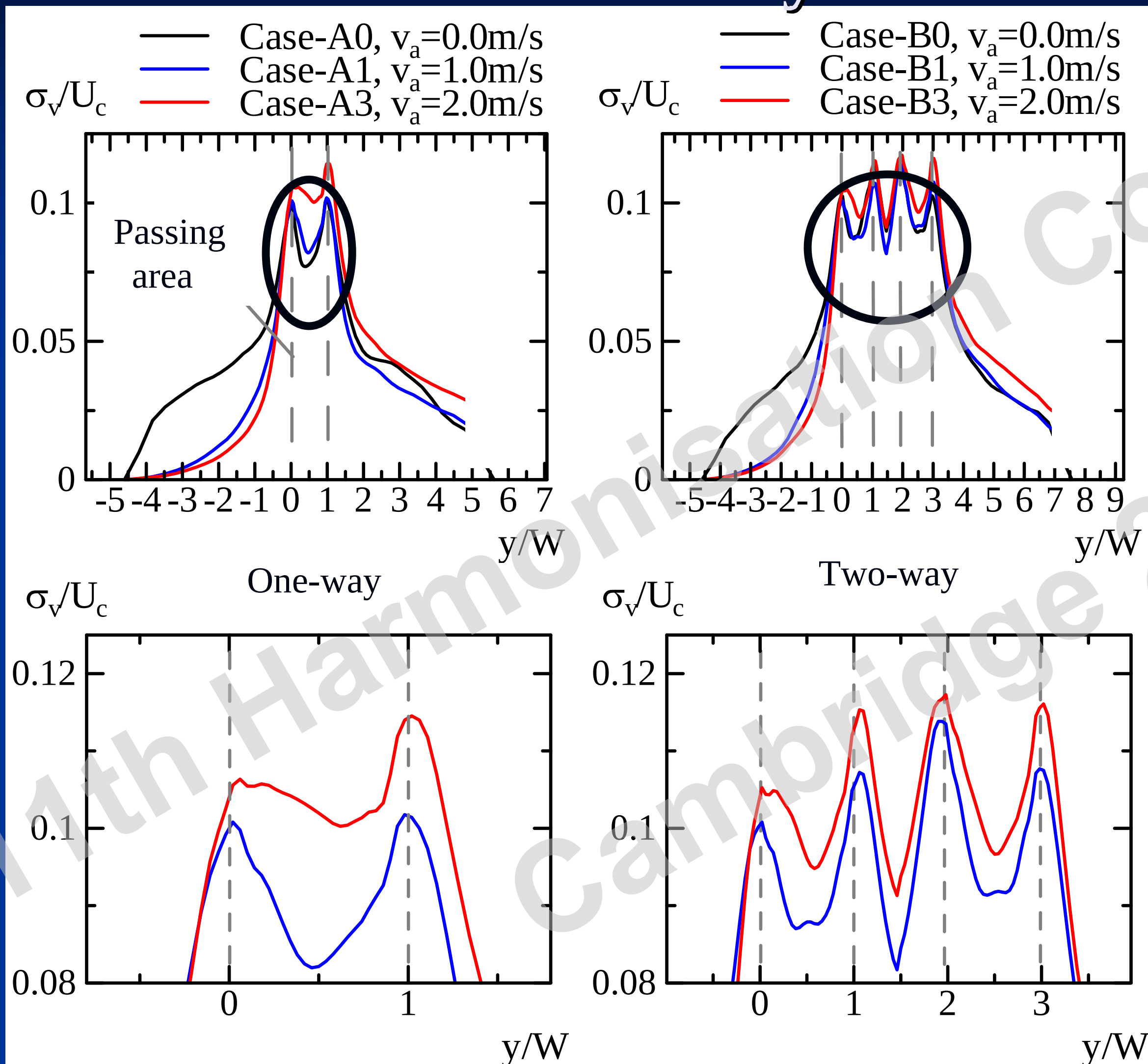
Mean stream line

The distributions of the mean velocities on the y-z cross section (in calm condition)



- The patterns of mean velocity distribution are different between one-way and two-way case.
- The magnitude of the mean velocity is small (less than $0.05U_c$).

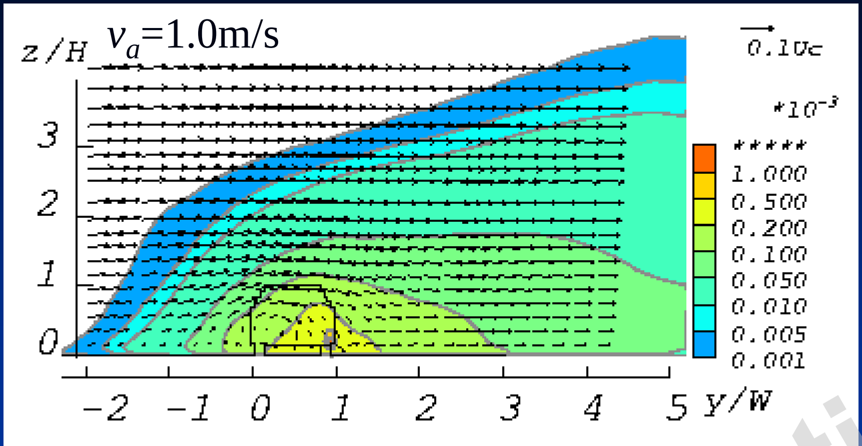
The turbulence intensities distributions on the y-z cross section

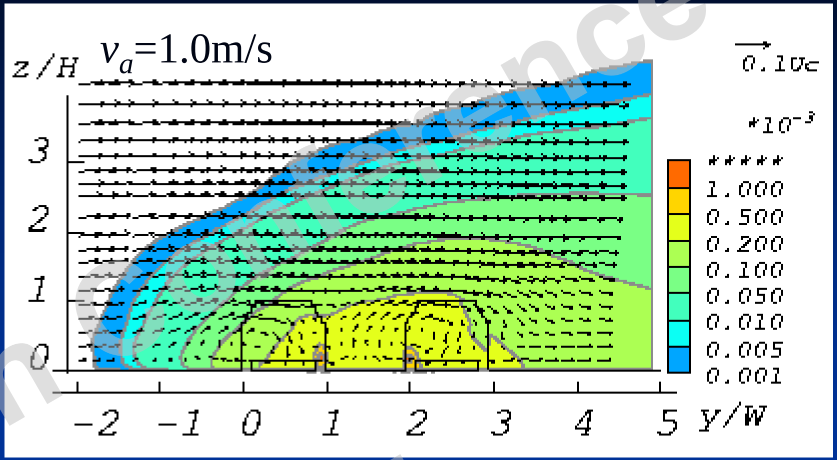


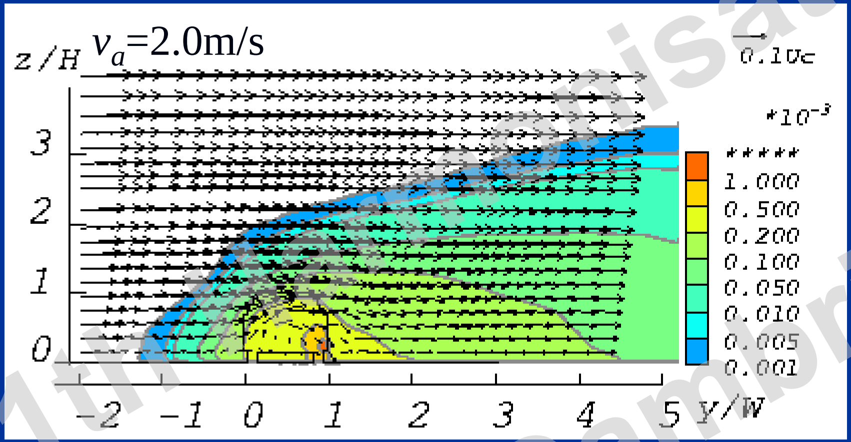
Spanwise profile of σ_v/U_c at z/H=0.05

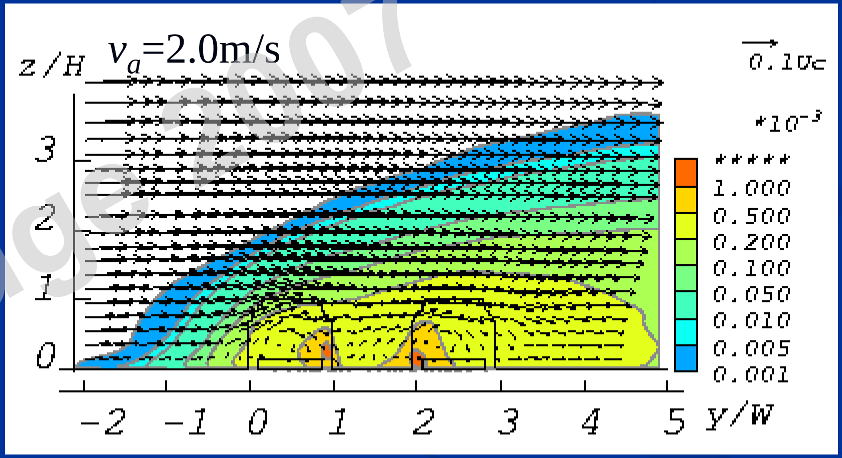
- σ_v/U_c shows large value at the edges of the passing area
- The value of σ_v/U_c is about 0.1 U_c.
- Difference of maximum values between the one-way and the two-way cases is small.
- Turbulence intensity within the passing area increases as the cross flow speed increases.

Mean concentration distribution



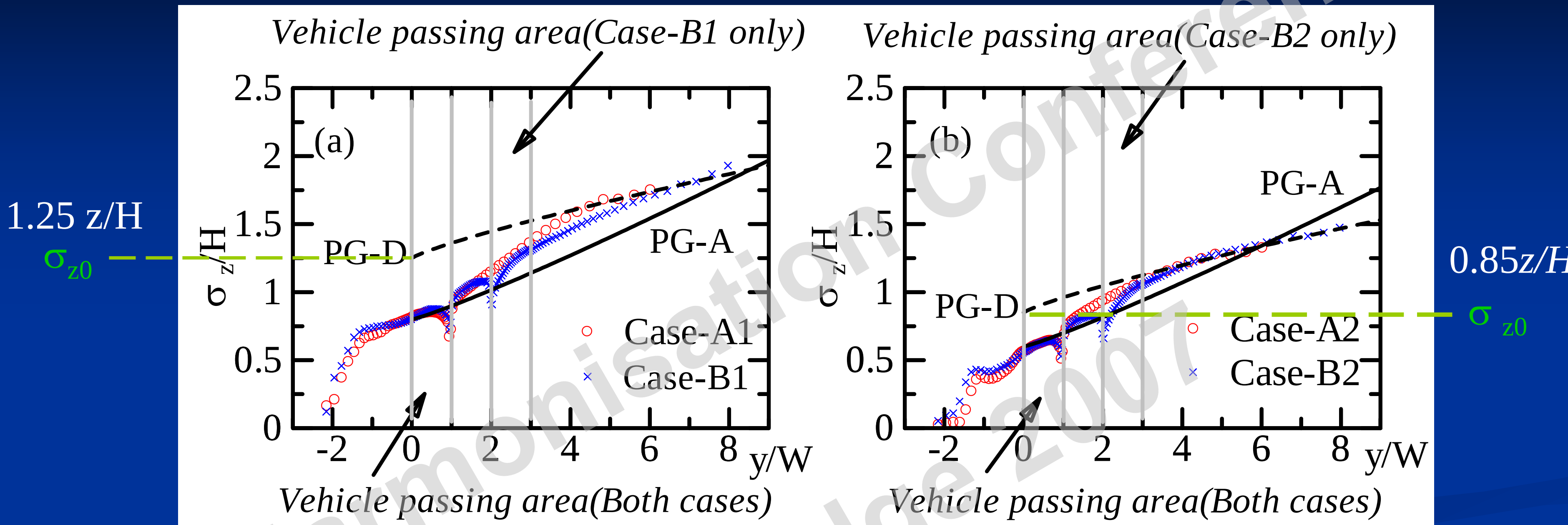






- Mean concentration distributes widely in spanwise near the ground level.
- The concentration level is monotonically decreases with height except in the vicinity of the source point.
- Normalized concentration level in the passing area increases as the cross flow speed increases.

Spanwise development of the vertical plume width (σ_z)



$$\sigma_z^{\ 2} = \int_0^\infty z^2 \langle C^* \rangle dz \ / \int_0^\infty \langle C^* \rangle dz$$

- Difference between the one-way and the two-way cases is small.
- Within the roadway, the growth rate of σ_z is lager than that of Pasquill's A stability.
- In the cross flow wake region *(y/W>5*), the growth curve asymptotes that of Pasquill's D stability.
- Initial diffusion width(σ_{z0}) depends on the cross flow speed.

Summary

The distribution patterns of the time-space averaged flow and concentration on a one-way/two-way road were estimated for sedan car passing cases.

(1) The mean flow pattern is significantly different between the one-way and the two-way facing traffic cases, but the magnitude of the mean flow is relatively small.

(2) On the other hand, the standard deviations of spanwise and vertical fluctuation velocities are two times larger than the maximum of the mean velocity in the vehicle passing area.

(3) The mean concentration monotonically decreases with height except for in the immediate vicinity of the tail pipes, so a ground level source approximation is justified.

(4) The growth rate of the vertical plume width in the cross flow wake region is not so much different between the one-way and the two-way traffic cases, and the rate is almost agreed with that of the category D curve in Pasquill's stability.

(5) Dependence of the initial dispersion width on the cross flow velocity is suggested.

The modelling of vehicle-induced turbulence and its effect on the turbulent dispersion of pollutants for RANS simulation is our future work.