Evaluation of ground level ozone change on introducing hybrid heavyduty vehicles

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1.Background

Vehicle exhaust emission is one of the most contributors to current atmospheric environment issues. To mitigate the consequence of vehicle emission, many acts and laws have been taken into practice. Exhaust purification technologies such as lean NOx trap and selective catalytic reduction system are adapted to reduce the NOx emission, regulations on volatile organic compounds (VOC) were published as well. As a result, the concentration of atmospheric primary pollutants is decreasing continuously. According to the Atmospheric Pollution Report for 2016 by Ministry of the Environment, NOx monitored by air pollution monitoring stations has reduced from 85 ppb (S46) to 12 ppb(H28), and for motor vehicle monitoring stations, decrease more significantly from 159 ppb (S46) to 29 ppb (H28). The non-methane hydrocarbons also have a high reduction ratio of 83 percent.

Fig.1 Photochemical oxidants concentration transition of annual average

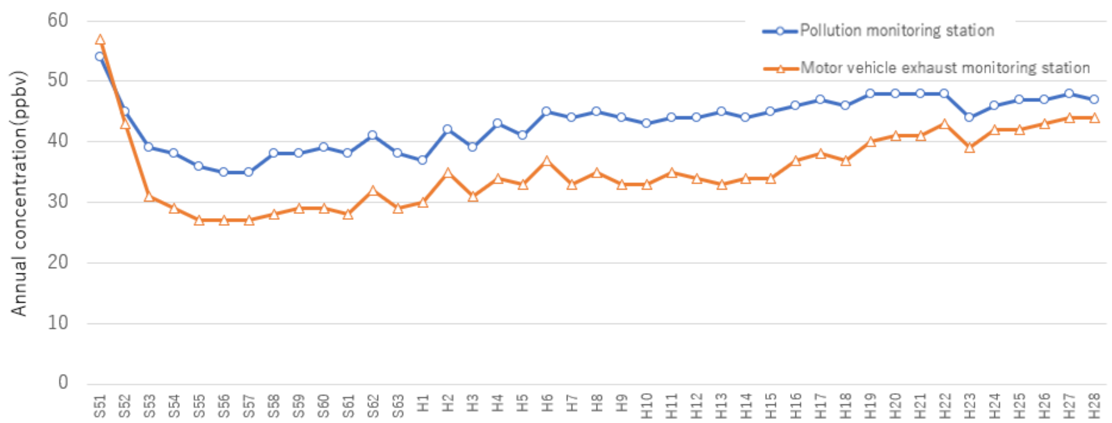


Fig.1 shows that the annual average oxidants concentration keeps stable, even increases in recently years [1].

In the diesel engine process, nitrogen from the ambient atmosphere reacts with oxygen atom inevitably owing to high temperature, which contributes to the high NOx concentration in diesel exhaust. For typical modern diesel cars, they emit around 20 times more NOx than petrol cars. According to the fuel consumption report for automobile vehicle, published by the Ministry of Land, Infrastructure and Transport [2], two third diesel are consumed by heavy-duty vehicle, and around 15 times of the consumption of gasoline for heavy-duty vehicles (Table 1). It is undoubtful that the heavy-duty diesel consuming vehicle should take most responsibility for NOx exhaust.

By introducing the hybrid diesel vehicle, NOx emission from business vehicle will decrease and must have certain environmental impacts on atmosphere. This research is to evaluate the impact of introducing heavy-duty hybrid diesel vehicles in terms of ozone.

Table.1 Fuel consumption for Kanto area, 2017

	Business Vehicle（kL）	Private Vehicle（kL）
Gasoline	310	13,544
Diesel	4,475	2,418

2 Method

In this research, two simulation software are adapted, weather research forecast (WRF) and community multi-scale air quality Model (CMAQ).

WRF is used for the necessary meteorological data of photochemical reaction, such as solar radiation, wind velocity and humidity.

CMAQ is a chemical transport model. CMAQ Mass conservation equation is showed below. Paragraphs represents advection, dispersion, diffusion, chemical reaction, deposition and emission for chemical i respectively.

$$\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}+w\frac{\partial C_i}{\partial z}=\frac{\partial}{\partial x}\left(k_x\frac{\partial C_i}{\partial x}\right)+\frac{\partial}{\partial x}\left(k_y\frac{\partial C_i}{\partial y}\right)+\frac{\partial}{\partial x}\left(k_z\frac{\partial C_i}{\partial z}\right)+R_i+D_i+S_i$$

3 Simulation scenarios

Table.2 Emission factors

	Emission	Nox	non-methane VOC
Diesel hybrid	cold start	0.918	0.050
	running	0.990	0.120
Gasoline hybrid	cold start	0.140	0.256
	running	0.339	0.467

Three scenarios are simulated in this research. Base scenario is based on the base emission inventory. Hybrid 1 scenario and hybrid 2 scenario are simulated with emission inventories modified by current diesel and gasoline emission factors respectively.

The simulation is conducted for two weeks of summer season, from 2013/7/21 to 2013/8/3 of Kanto area.

4 Results and discussions

Fig.2 Ozone concentration time series for Shinjuku

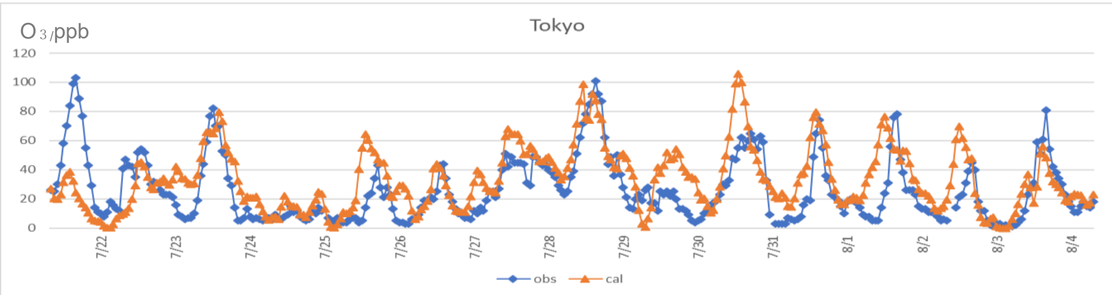
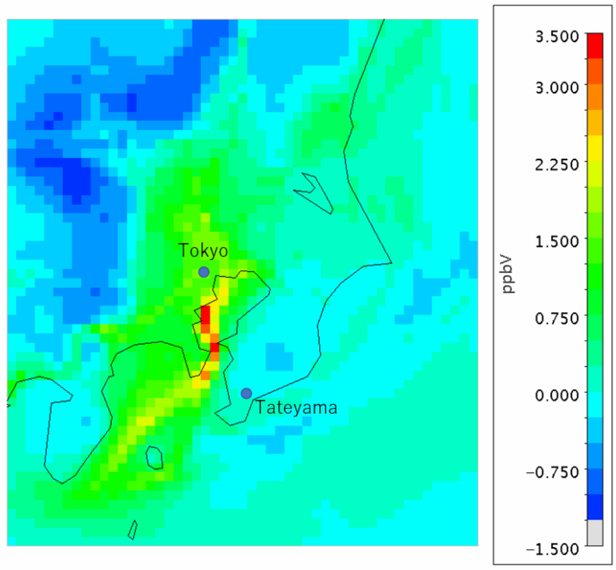


Fig.2 shows the time series of observed data and simulated data for Shinjuku, Tokyo.

There are some differences between these two data, however, the concentration changing trend is similar. With a correlation coefficient of 0.633, the simulation for the base scenario is proved to be quite reliable and can be used for further prediction.

Fig.3 Average ozone concentration change



Firstly, the calculation is done with current diesel hybrid emission factors, but current diesel-hybrid vehicles are so less effective on NOx removal that the concentration change of ozone is hard to be recognized. Even the largest concentration change is 0.057ppbv, rather small compared to background ozone concentration. Fig.3 shows the average ozone concentration change with the gasoline-hybrid emission factor scenario. Under this condition, the tendency is significantly differed: increase in urban area and decrease in rural area.

Fig.4 and 5 are the hourly concentration change based on the diesel hybrid vehicles with gasoline-hybrid emission factors. For the urban area, Shinjuku, the concentration of nighttime increases because of the decrease of NOx titration effect ($NO+O_3=NO_2+O_2$). And for the rural area, Tateyama, the daytime reduction of concentration is obvious, because the concentration of NOx is the rate determining factor, the reduction of NOx is effective in these areas.

Fig.4 Hourly ozone concentration change for Tokyo

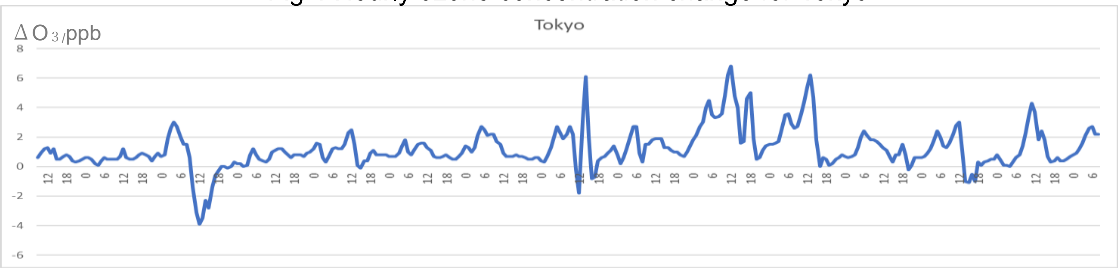


Fig.5 Hourly ozone concentration change for Tateyama

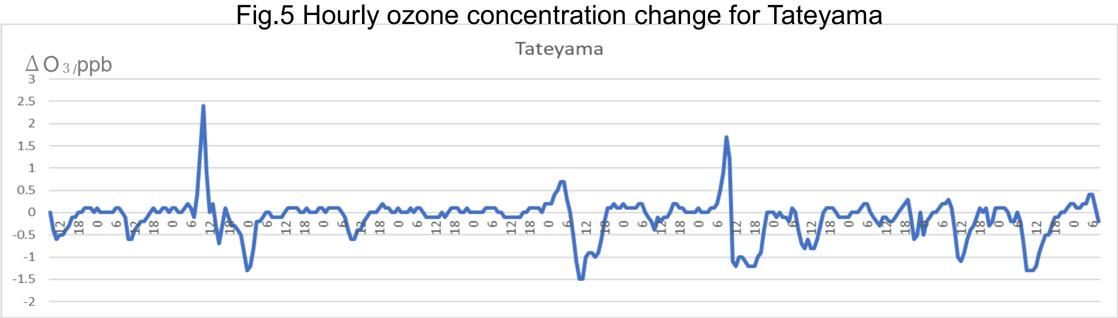
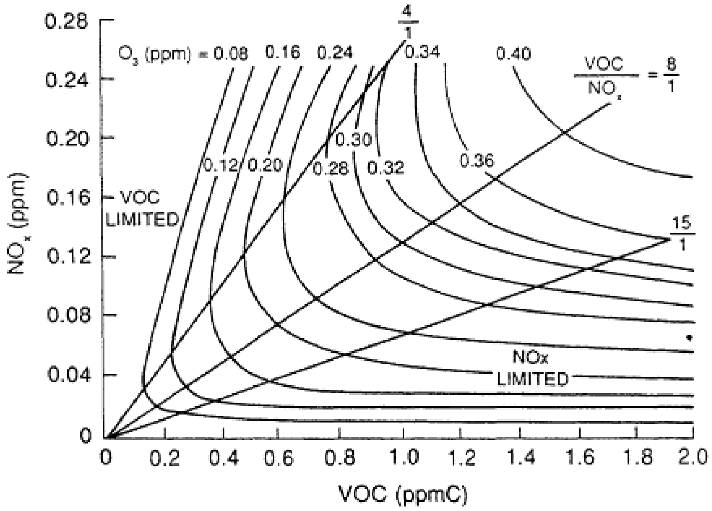


Fig.6 VOC-NOx-ozone relationship



As shown in Fig.6, equal ozone burdens can be caused by several different VOC/NOx ratios [4]. With the NOx concentration under 40 ppb, change in VOC has little effect on ozone yield. Under such conditions, NOx concentration is the limiting of ozone production. This condition can be found primarily rural area, so daytime ozone concentration in Tateyama decreases. Likely, for VOC limited regime, a decreased amount of NOx may enlarge ozone.

The premature mortality caused by ozone are estimated as well. The relative risk of ozone is 1.003 for 10 $\mu g/m^3$ increase in the maximum daily 8-hours average suggested by WHO [5,6]. Based on the population distribution and mortality report of 2013, the results of mortality change by introducing diesel-hybrid vehicles for prefectural capitals are shown in Table.3.

With the reduction rate increase, the mortality caused by ozone increase as well. Mortality change increase for high population density area cannot be ignored.

Table.3 Mortality estimation

		Mito	Utsunomiya	Maebashi	Saitama	Chiba	Yokohama	Shinjuku
Diesel-hybrid emission factor	ΔO_3/ppbv	0.03	0.03	0.02	0.04	0.03	0.03	0.04
	Mortality/person	0.84	1.23	0.54	2.30	1.66	2.10	4.55
Gasolinel-hybrid emission factor	ΔO_3/ppbv	0.85	0.52	-0.41	1.33	0.31	0.99	1.21
	Mortality/person	26.26	11.02	-8.92	82.23	16.94	73.97	137.26

5 Conclusion

With the introduction of hybrid engine to heavy-duty vehicles, the ground-level concentration of ozone change differs between the rural areas and the urban areas: increase in the urban and decrease in the rural. Mortality effect is also estimated. Further measures on VOC reduction should be enacted separately for the different VOC -NOx-ozone sensitivity.

References

[1] Air pollution condition report for 2016 (2016 年度大気汚染の状況 環境省) http://www.env.go.jp/air/osen/28taikiosen.pdf
[2] Annual report of automobile vehicle fuel consumption(自動車燃料消費量統計年報 国土交通省) http://www.mlit.go.jp/k-toukei/search/pdf/22/22201700a00000.pdf
[3] Carslaw D. Trends in NOX and NO2 emissions and ambient measurements in the UK. London: Department for Environment, Food and Rural Affairs, 2011
[4] Mathur, Multiscale air quality simulation platform: Initial applications and performance for tropospheric ozone and particulate matter, J. Geophys. Res., 2005
[5] Michael Jerrett, Long-Term Ozone Exposure and Mortality, March 12, 2009
[6] Effects of air pollution on children's health and development. A review of the evidence. Copenhagen, WHO Regional Office for Europe, 2005