Urban air quality simulations in a high-rising building area with various NO_2-to-NO_x emission ratios

Kyung-Hwan Kwak[1] and Jong-Jin Baik[2]

[1] Kangwon National University, Chuncheon, Republic of Korea
[2] Seoul National University, Seoul, Republic of Korea

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HARMO18, Bologna, Italy
2017. 10. 09 -12

Borge et al. (2016)

Gangnam street in Seoul – study area
(May in 2015)
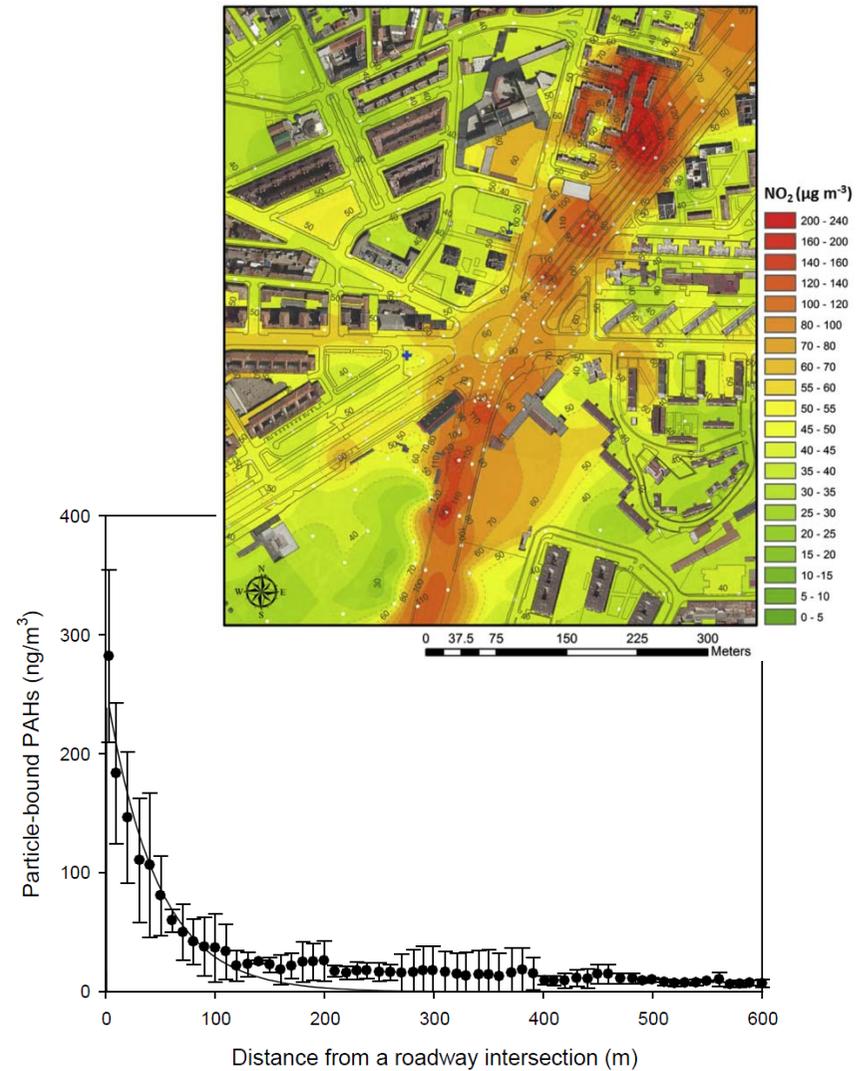
*Kim et al. (2015)*

On-road NO₂-to-NOₓ emission ratio

Ex) monitoring results
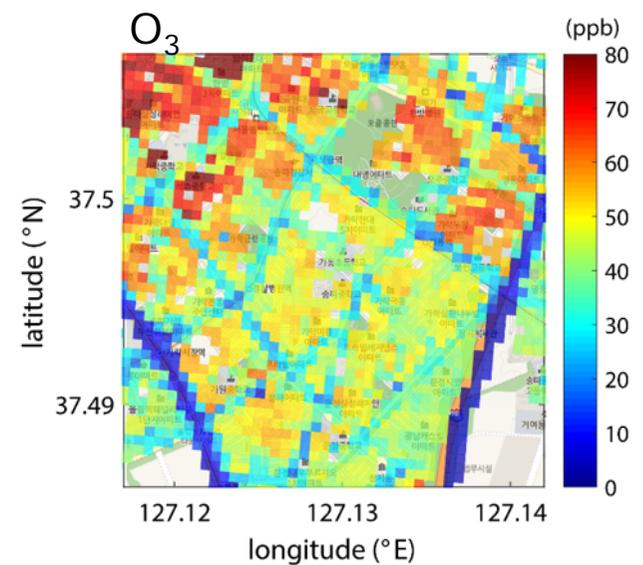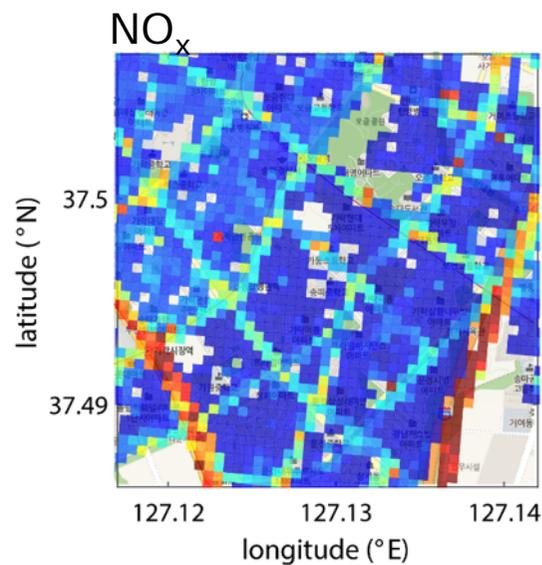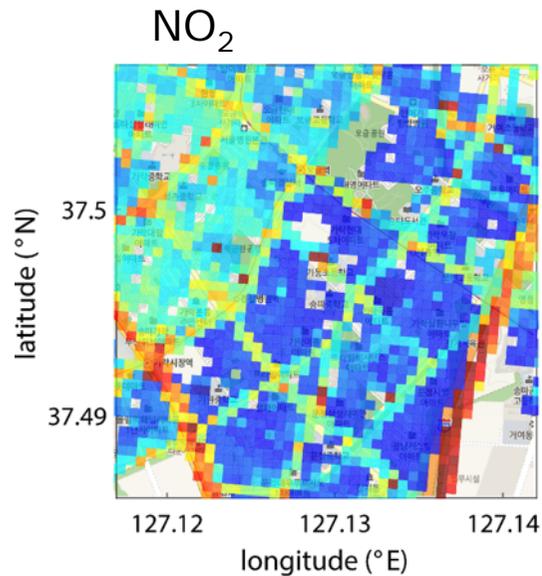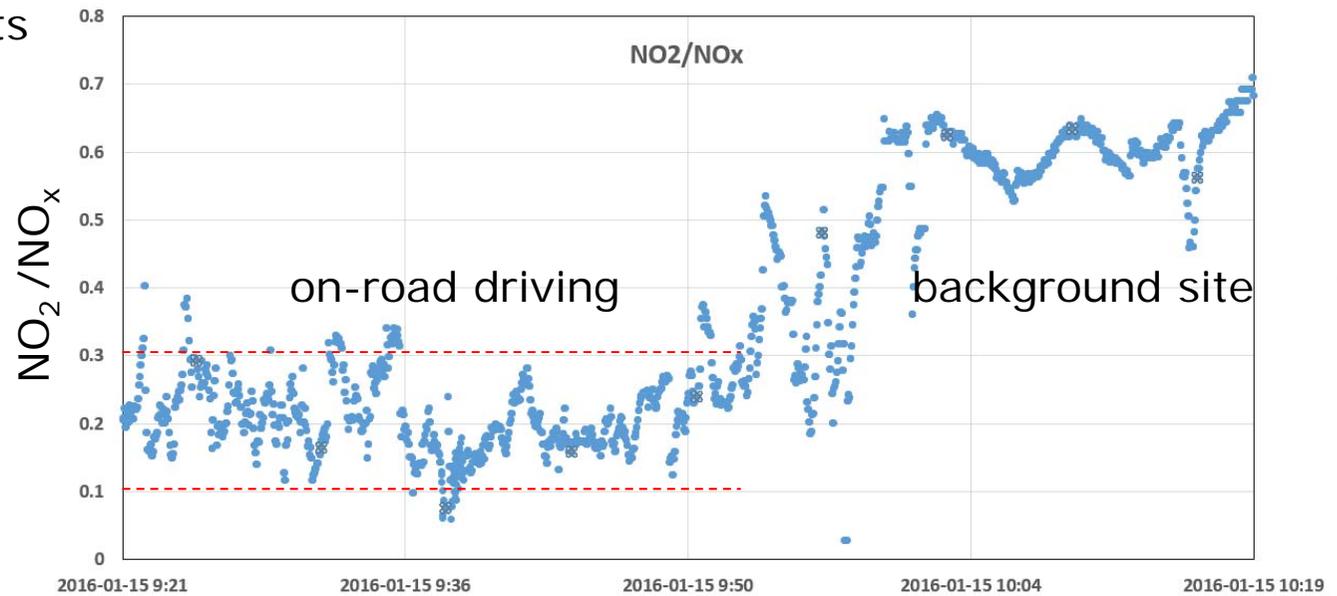
Regional scale

Local scale

Low-res. landuse

Regional

High-res. landuse

city scale

street scale
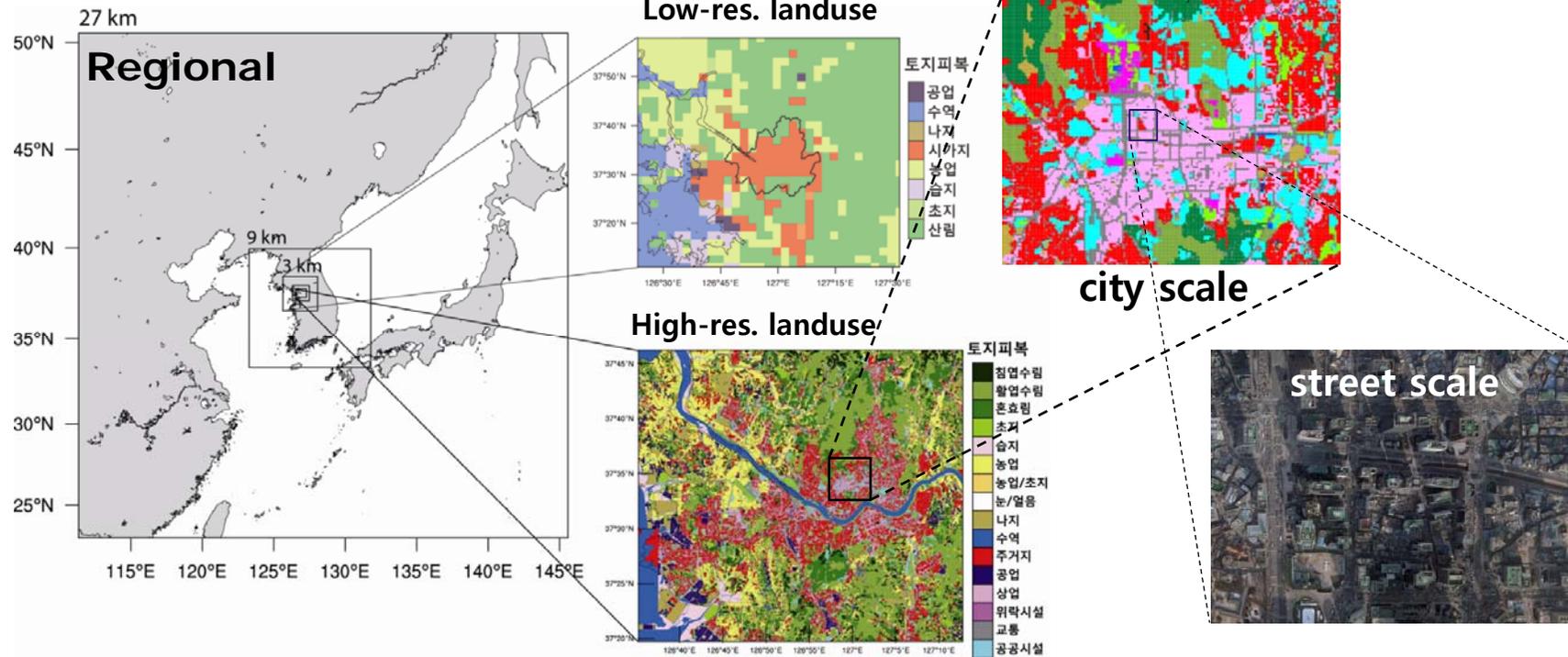
High resolution background data !

Development of integrated system !

# Integrated urban air quality modeling system

- **Coupled CFD model with mesoscale models**

- **Mesoscale meteorological model**: Weather Research and Forcasting (**WRF**) **v3.2**

- **Mesoscale chemistry-transport model**: Community Multiscale Air Quality (**CMAQ**) **v4.7.1**
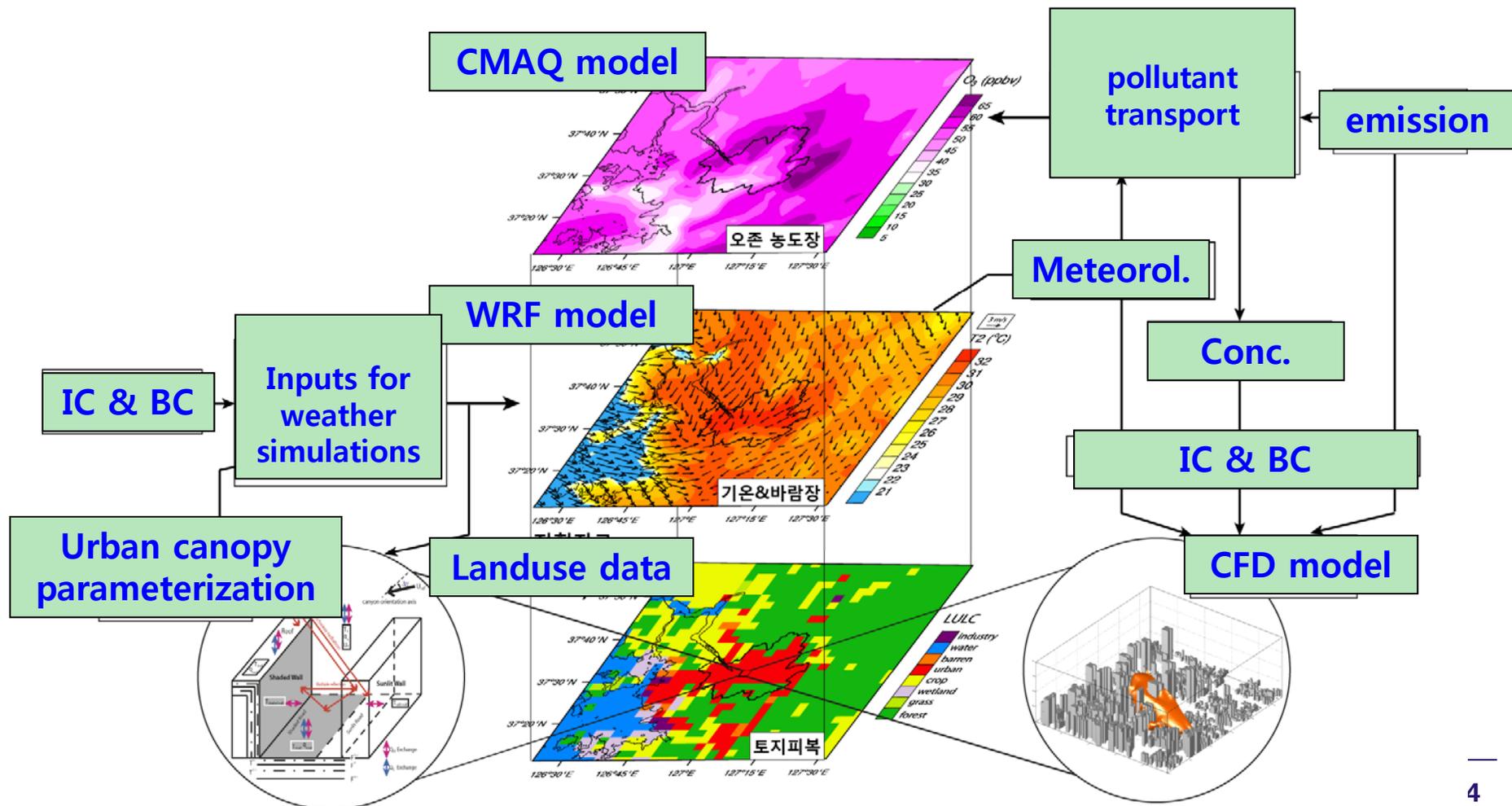
Computational Fluid Dynamics (CFD) model

RANS model with RNG k-ε turbulent closure scheme (Kim and Baik, 2004; Baik et al., 2007)

Governing equations

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial P^*}{\partial x_i} + \delta_{i3}g\frac{T^*}{T_0} + \nu\frac{\partial^2 U_i}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j}(\overline{u_i u_j})$$

$$\frac{\partial U_j}{\partial x_j} = 0$$

$$\frac{\partial T}{\partial t} + U_j \frac{\partial T}{\partial x_j} = \kappa\frac{\partial^2 T}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j}(\overline{T' u_j}) + S_h$$

$$\frac{\partial C}{\partial t} + U_j \frac{\partial C}{\partial x_j} = D\frac{\partial^2 C}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j}(\overline{c u_j}) + S_c$$

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = -\overline{u_i u_j}\frac{\partial U_i}{\partial x_j} + \frac{\delta_{3j}g}{T_0}\overline{T' u_j} + \frac{\partial}{\partial x_j}(\frac{K_m}{\sigma_k}\frac{\partial k}{\partial x_j}) - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} + U_j \frac{\partial \varepsilon}{\partial x_j} = -C_{\varepsilon 1}\frac{\varepsilon}{k}\overline{u_i u_j}\frac{\partial U_i}{\partial x_j} + C_{\varepsilon 1}\frac{\varepsilon}{k}\frac{\delta_{3j}g}{T_0}\overline{T' u_j} + \frac{\partial}{\partial x_j}(\frac{K_m}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}) - C_{\varepsilon 2}\frac{\varepsilon^2}{k} - R$$

con.field at 0900 LST 02 June
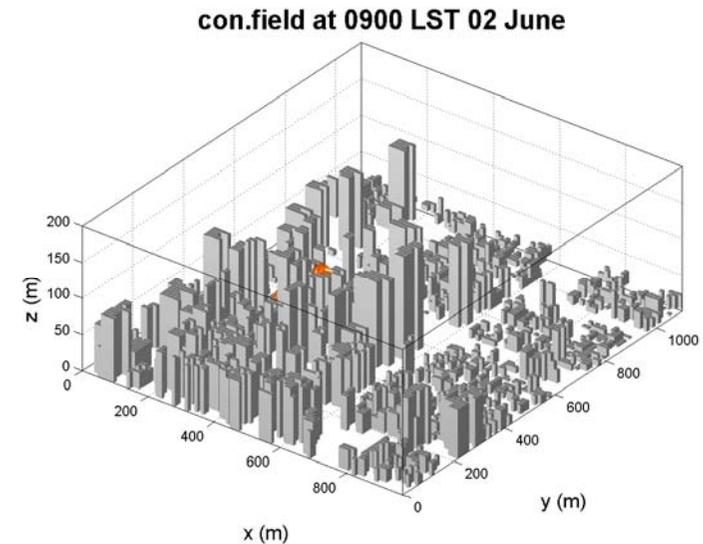
*Baik et al. (J Appl. Meteor. Clim., 2009)*

Integrated urban air quality modeling

:UCM-WRF-CMAQ-CFD modeling system

03 June 2013 from 0900 LT to 1800 LT

Downtown of Seoul, Republic of Korea

CFD domain: 1600 m x 1600 m x 997 m

CFD grid size: 10 m x 10 m x 4 m

**On-road NO_2-to-NO_x emission ratio: 0.1 / 0.2 (control) / 0.3**

On-road NO_x emission rates are obtained from the CMAQ model.

Surface temperature is implemented at surfaces.

Diurnal variations in traffic volume fraction

time (LT)

Kwak et al. (Atmos. Environ., 2015)

Δ = 1 km

WRF domain

124 m
AGL

Building and topographical heights (CFD domain)
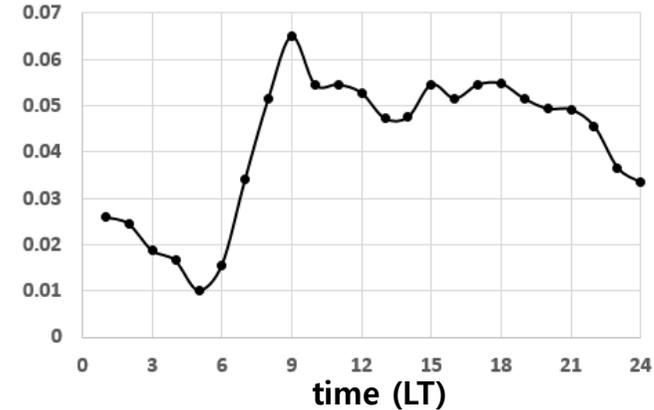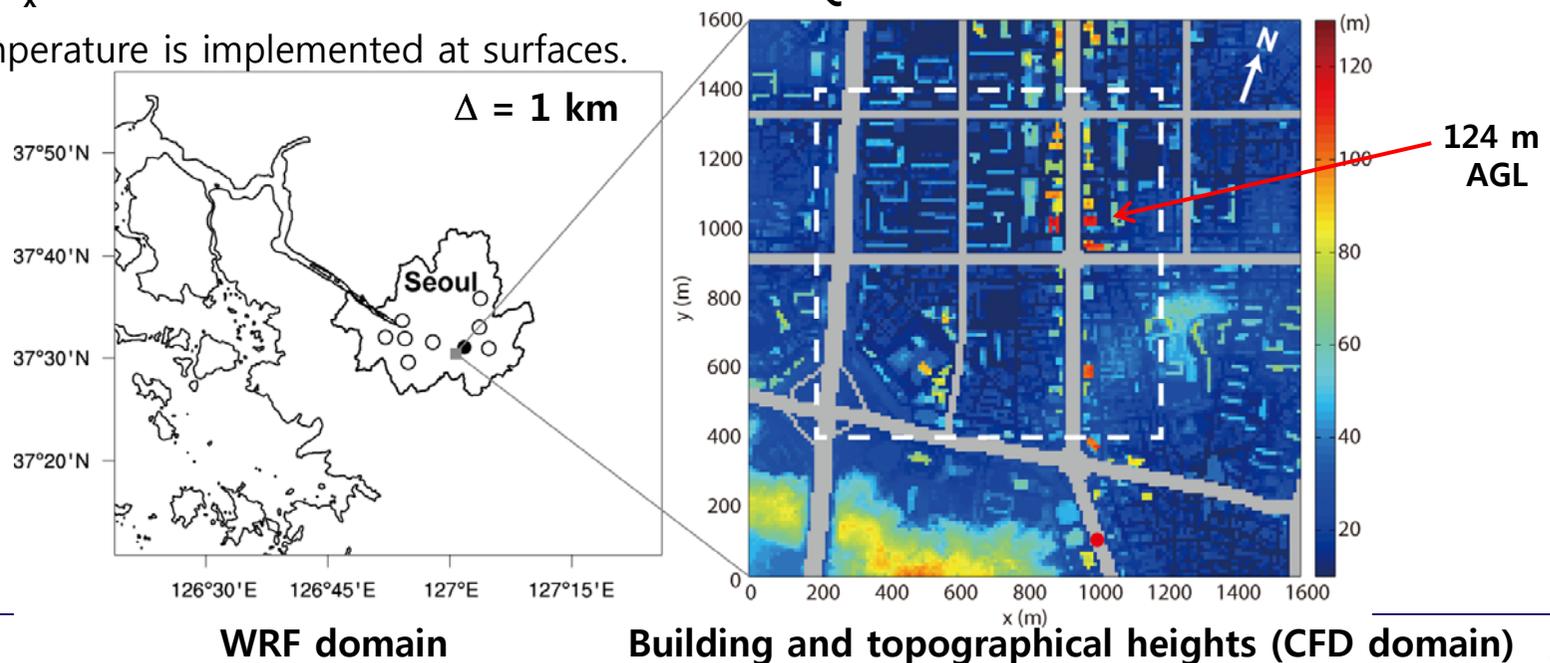
Control simulation

WRF simulation
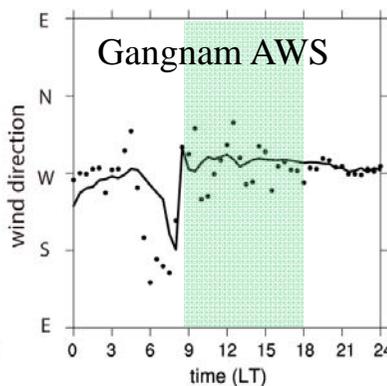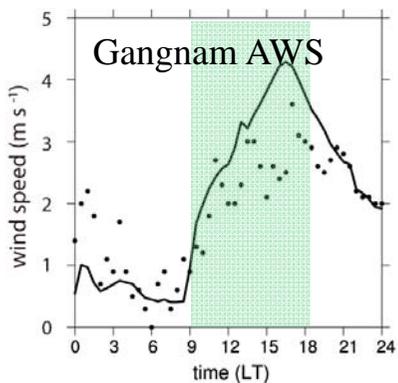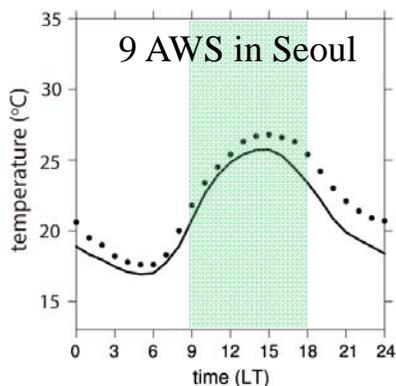
CFD simulation (on-road station)
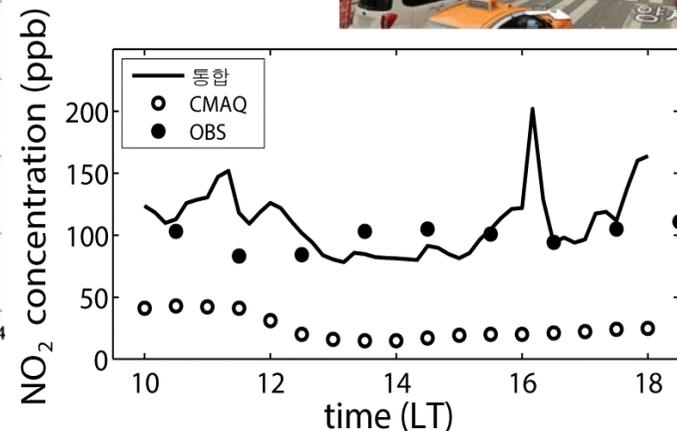
CMAQ simulation
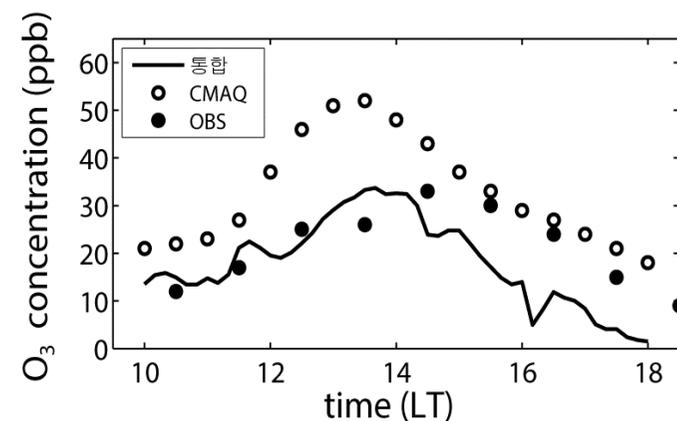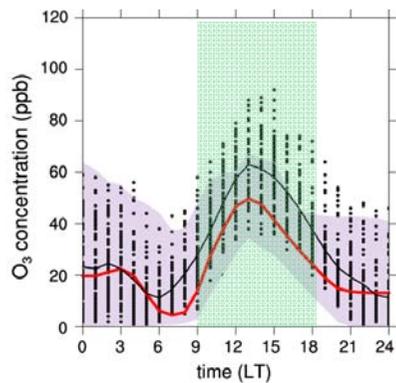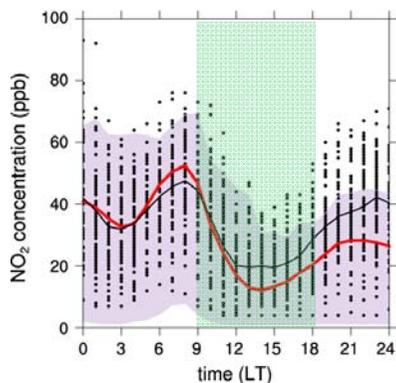
CFD simulation

—— OBS ave.

—— CMAQ ave.

Kwak et al. (Atmos. Environ., 2015)

Control simulation

Kwak et al. (Atmos. Environ., 2015)

Wind speed (m s^{-1})
z~30 m

NO$_2$ (ppb)
z~30 m
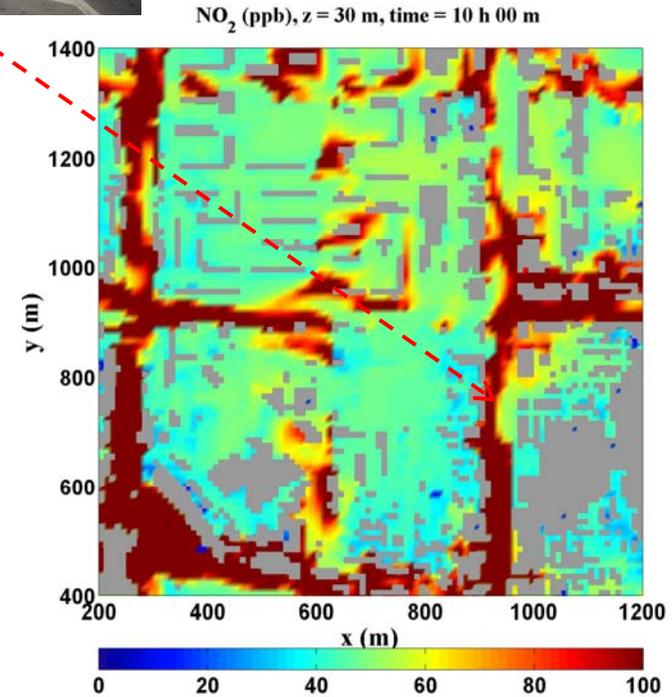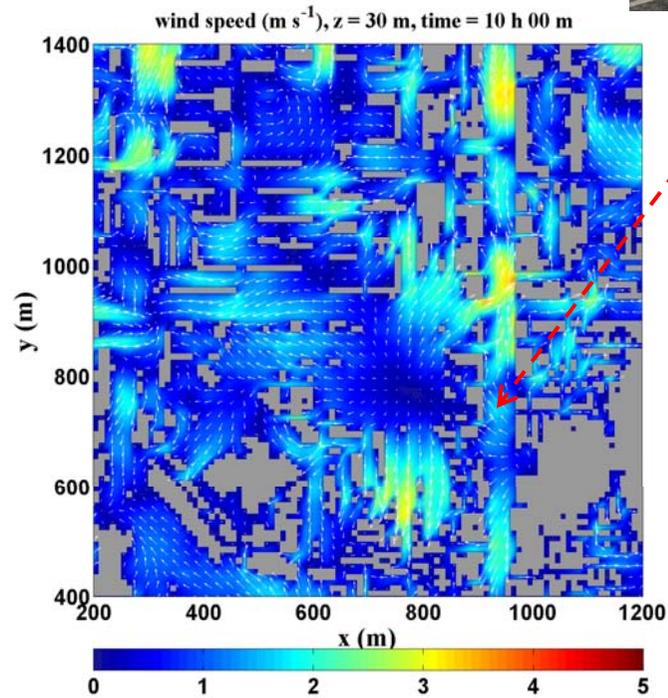
Control simulation: NO$_2$ and O$_3$ concentration fields   *Kwak et al. (Atmos. Environ., 2015)*

NO$_2$ at y = 1025 m

O$_3$ at y = 1025 m

1200 LT
Thermally-driven flow

1400 LT

1600 LT
Mechanically-driven flow
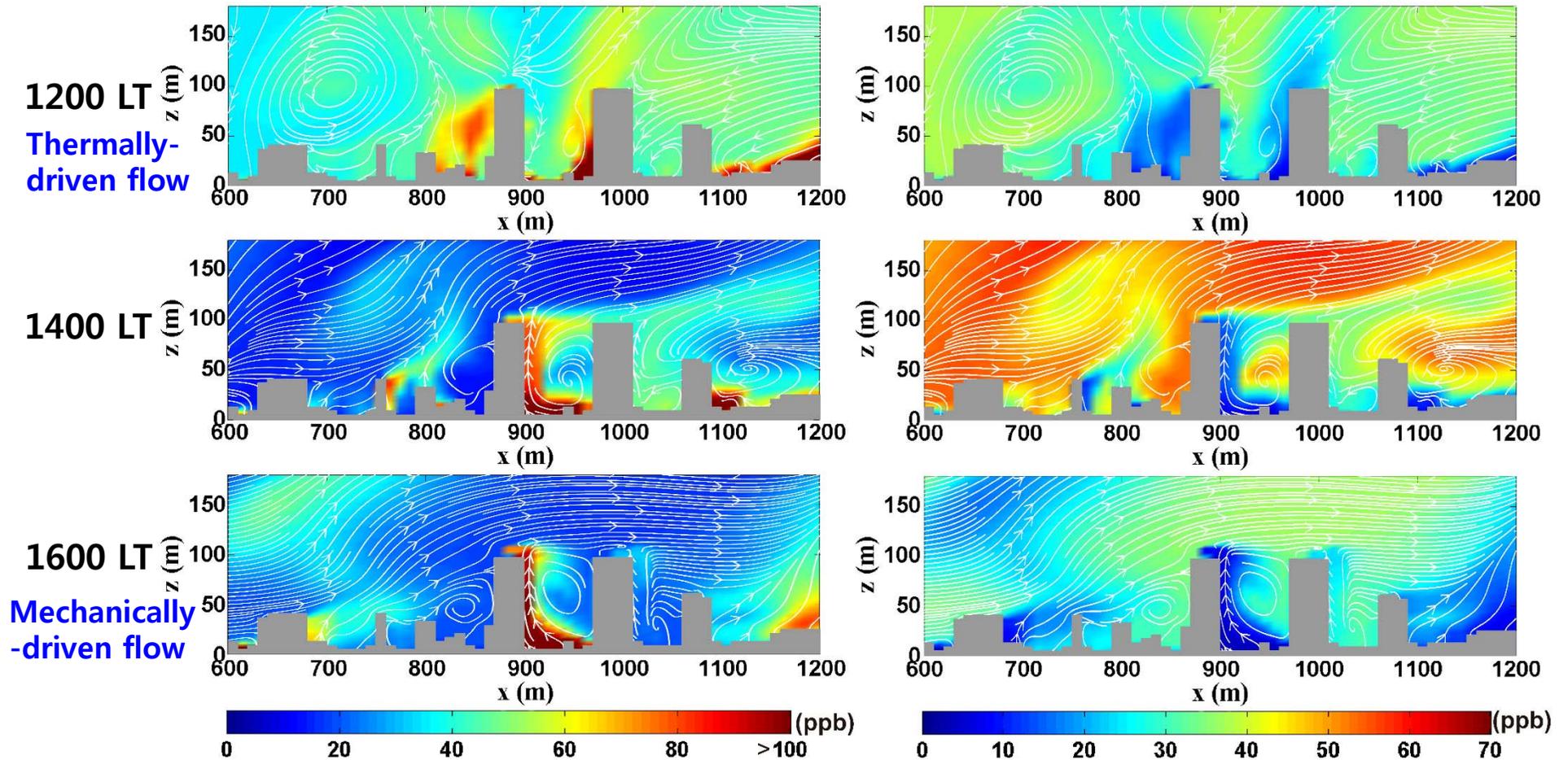
**NO$_2$ and O$_3$ evolutions with different NO$_2$-to-NO$_x$ emission ratios**

*averaged over roads
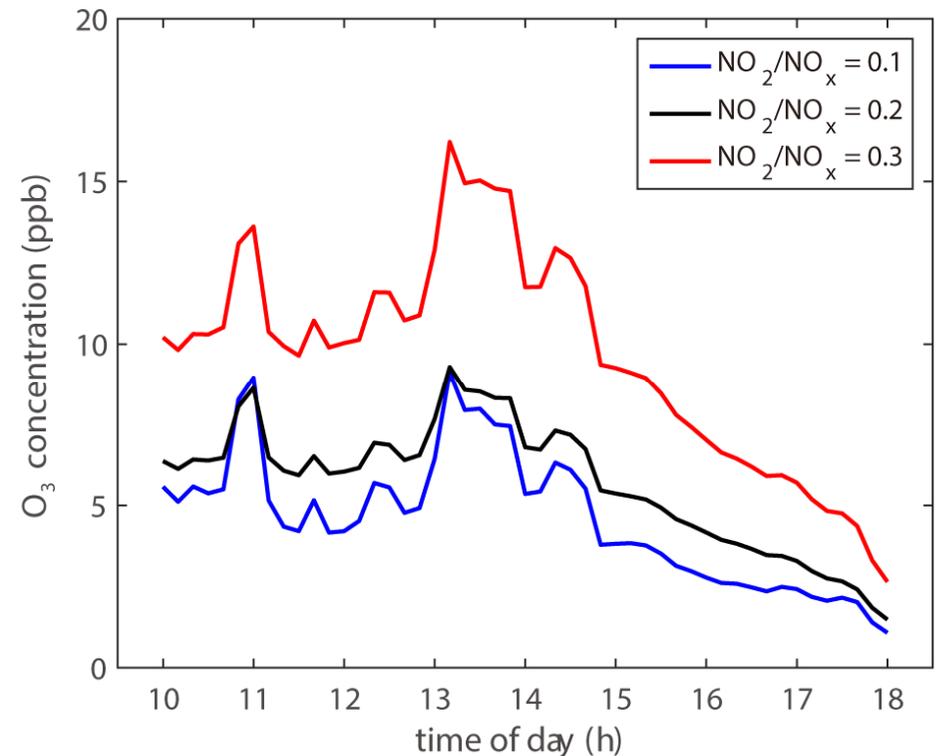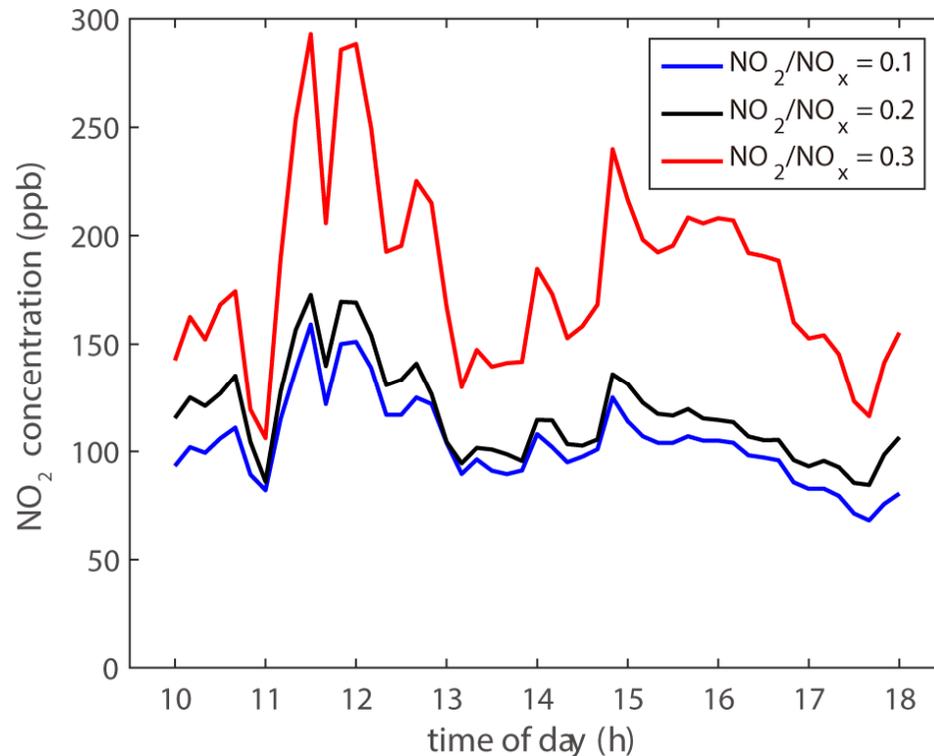
In presence of O$_3$ and VOCs, the on-road NO$_2$-to-NO$_x$ emission ratio has a significant impact on NO$_2$ and O$_3$ concentrations.

NO$_2$ and O$_3$ vertical profile with different NO$_2$-to-NO$_x$ emission ratios

*averaged over 1 x 1 km^2 area
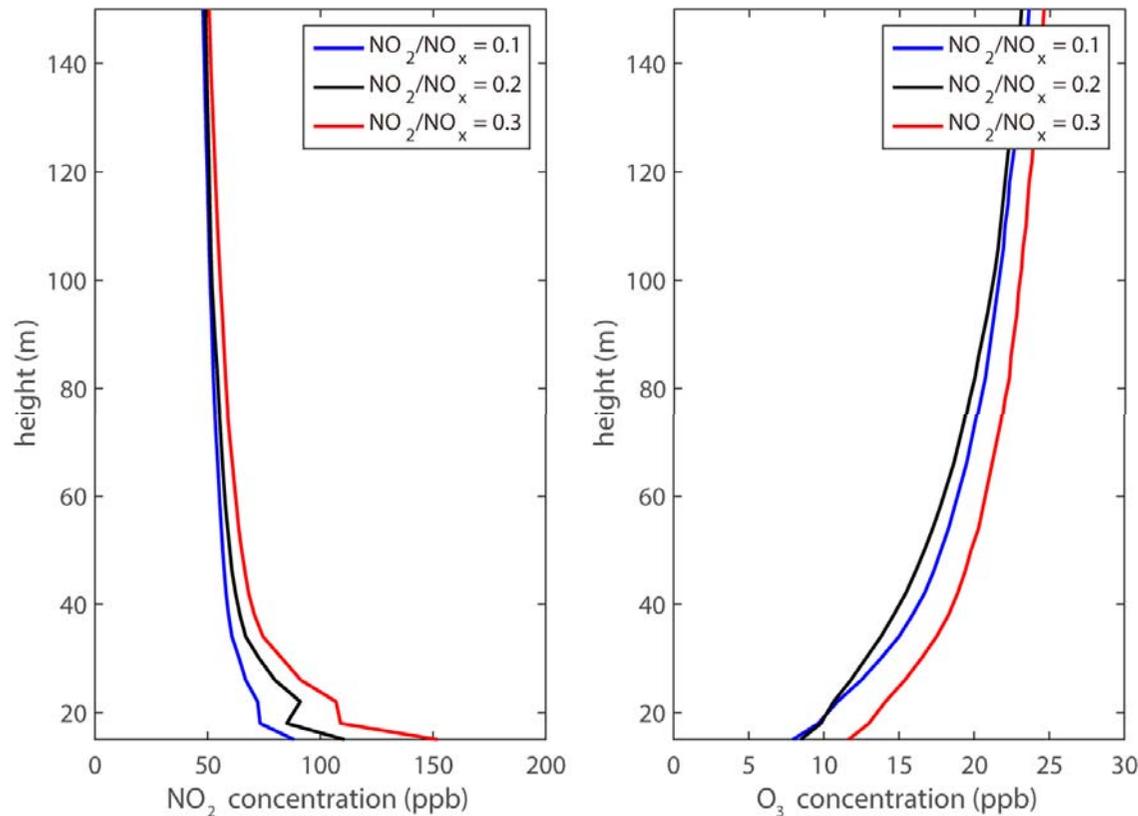
In presence of high-rise buildings, the vertical level of on-road NO$_2$-to-NO$_x$ emission ratio effect can be up to ~ 100-m height due to in-canyon vertical mixing.

On-road NO$_2$-to-NO$_x$ emission ratio

: tailpipe NO$_2$-to-NO$_x$ emission ratio x instantaneous mixing within a grid cell
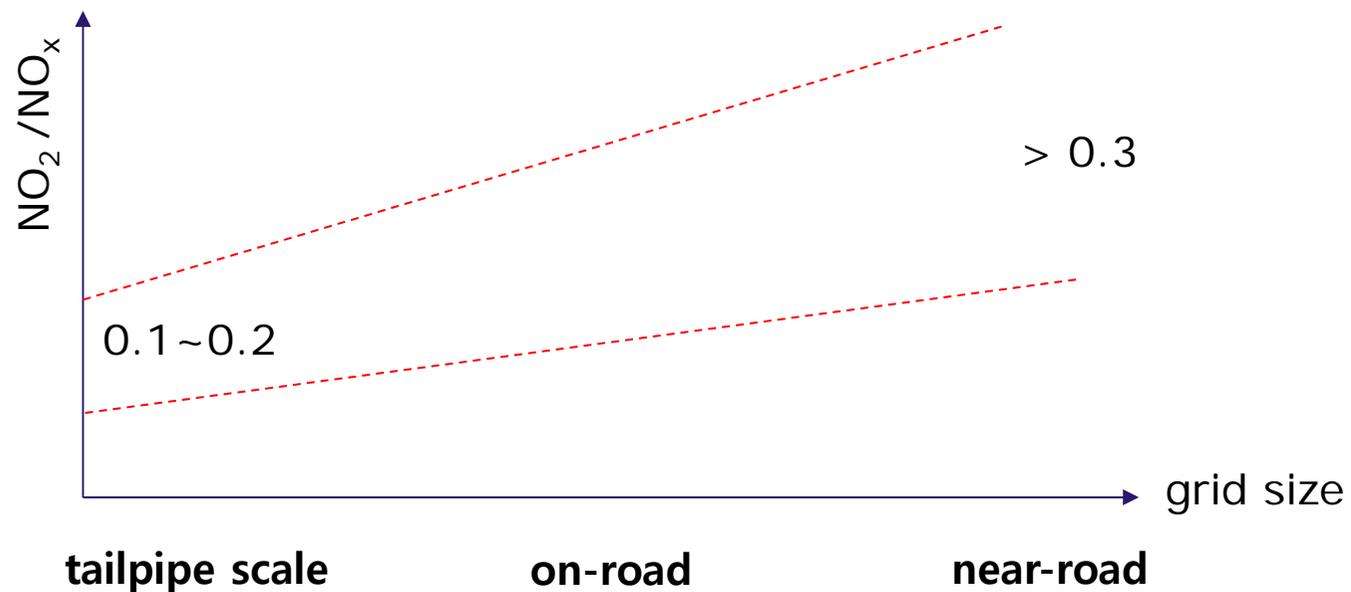
NO$_2$-to-NO$_x$ emission ratio is required to be carefully chosen based on a grid size.

Concluding remarks

- **Integrated urban air quality modeling system is a useful tool to simulated detailed urban air quality incorporating atmospheric chemistry and heterogeneous emissions.**

- **On-road NO_2-to-NO_x emission ratio has a significant impact on near-surface NO_2 and O_3 concentration levels.**

- **In CFD simulations with NO_x-related chemistry, on-road NO_2-to-NO_x emission ratio has to be carefully chosen based on a grid size.**

- **The WRF-CMAQ-CFD modeling system is planned to provide detailed urban air quality forecast in South Korea in the near future.**

Thank you for your attention.

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