Numerical Study on the Effects of Street-Canyon Aspect-Ratio

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[Key words]
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CFD-chemistry model
Flow regime
Aspect ratio
Reactive pollutant

BACKGROUNDS & OBJECTIVES

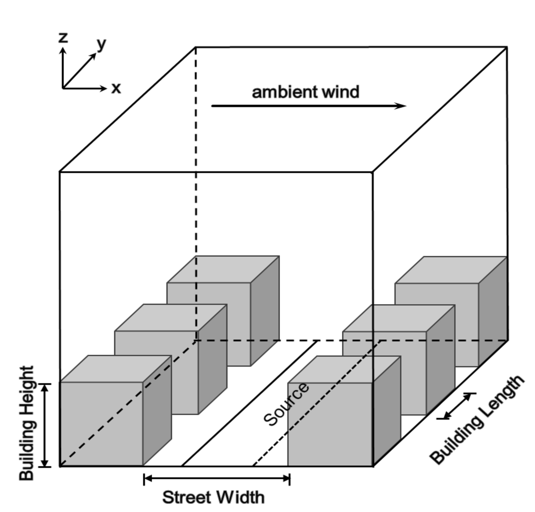
- **Urbanization has provided human beings as well as their properties with chances to be exposed to threats and damages of hazardous pollutants in urban areas. One of the intimidating causes is the increase in pollutant emission caused by the growth in traffic volume and associated traffic congestion.**
- **The important factors affecting flow patterns and associated dispersion of the passive scalar pollutants could be categorized into three, that is, inflow conditions, geometric conditions of building configuration, and ground– and building–surface conditions.**
- **In this study, flow characteristics were analyzed first with different street aspect ratios and flow regimes were classified into three. For each flow regime, dispersion characteristics were investigated in views of reactive pollutant concentration and VOCs–NO_X ratio. Finally, the relations between pollutant concentration and street aspect ratio in urban street canyons are investigated.**

METHODOLOGY

Numerical model

- **The coupled CFD–chemistry model used in this study is the same as Kim et al. (2012). The CFD model is essentially the same as Kim and Baik (2010) and it is based on the Reynolds–averaged Navier–Stokes equations (RANS) model. For simulating chemical reactions of reactive species in the CFD model, a full NO_X–O_X–VOCs chemical mechanism from the GEOS–Chem model is implemented.**
- **The CFD model transports, among 110 species, only 28 species of which chemical lifetimes are longer than the integration time step of 0.5 s.**

Building configuration and computational domain



- Grid intervals (x, y, z) : 2 m
- Run time : 1 hour 30 min
  - 0 ~ 30 min : No emission
  - 30 ~ 60 min : Passive pollutant emission
  - 60 ~ 90 min : emission and chemical production
- Time step : 0.1 s
- Initial value : 87 chemical species
- Variable : Building Length (L)

Summary of numerical experiments

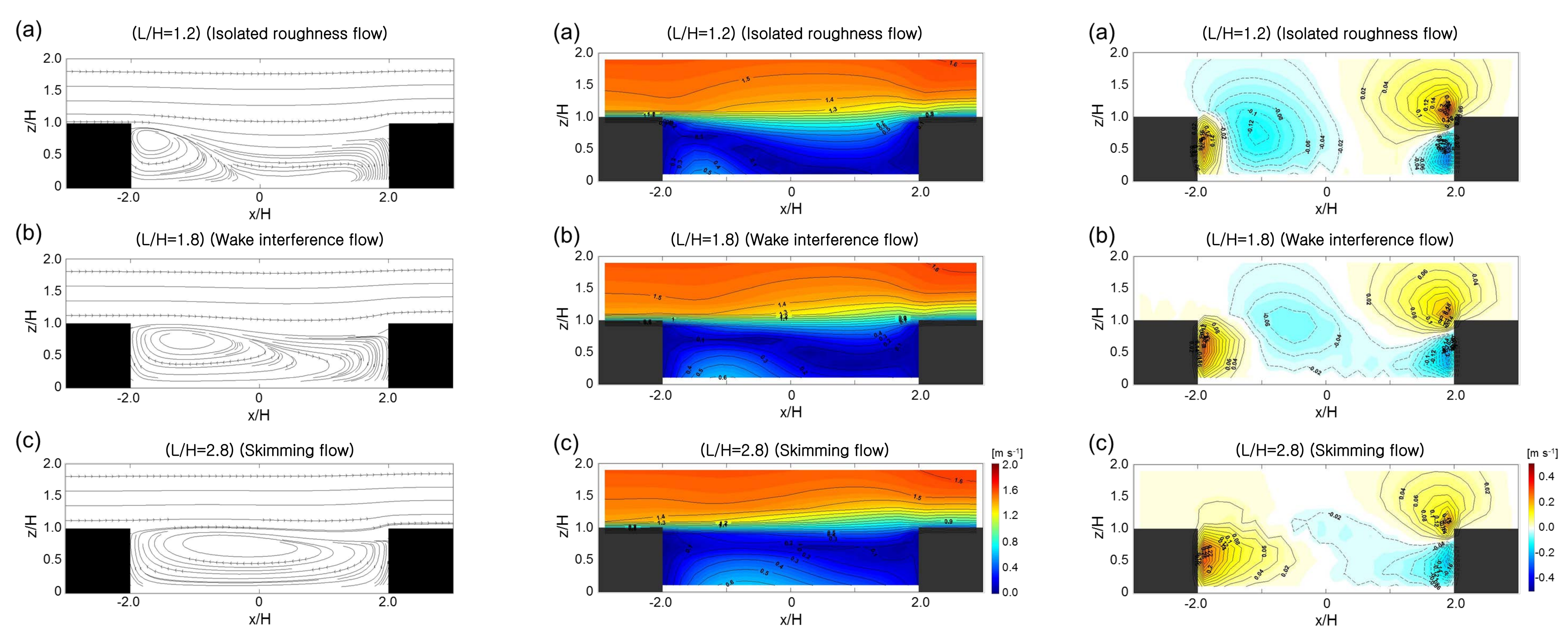
No.	Building Height (H) (m)	Building Width (W) (m)	Building Length (L) (m)	Street width (S_W) (m)	L/H	Flow regime
EXP_W1	10	20	12	40	1.2	IRF
EXP_W2	10	20	14	40	1.4	IRF
EXP_W3	10	20	16	40	1.6	WIF
EXP_W4	10	20	18	40	1.8	WIF
EXP_W5	10	20	20	40	2.0	WIF
EXP_W6	10	20	22	40	2.2	WIF
EXP_W7	10	20	24	40	2.4	SF
EXP_W8	10	20	26	40	2.6	SF
EXP_W9	10	20	28	40	2.8	SF

No.	NO_X (ppb/s)	VOC (ppb/s)	VOC/NO_X
EXP_C1	200	50	0.25
EXP_C2	100	50	0.5
EXP_C3	50	50	1.0
EXP_C4	25	50	2.0
EXP_C5	12.5	50	4.0
EXP_C6	8.33	50	6.0

RESULTS & DISCUSSION

Wind flow

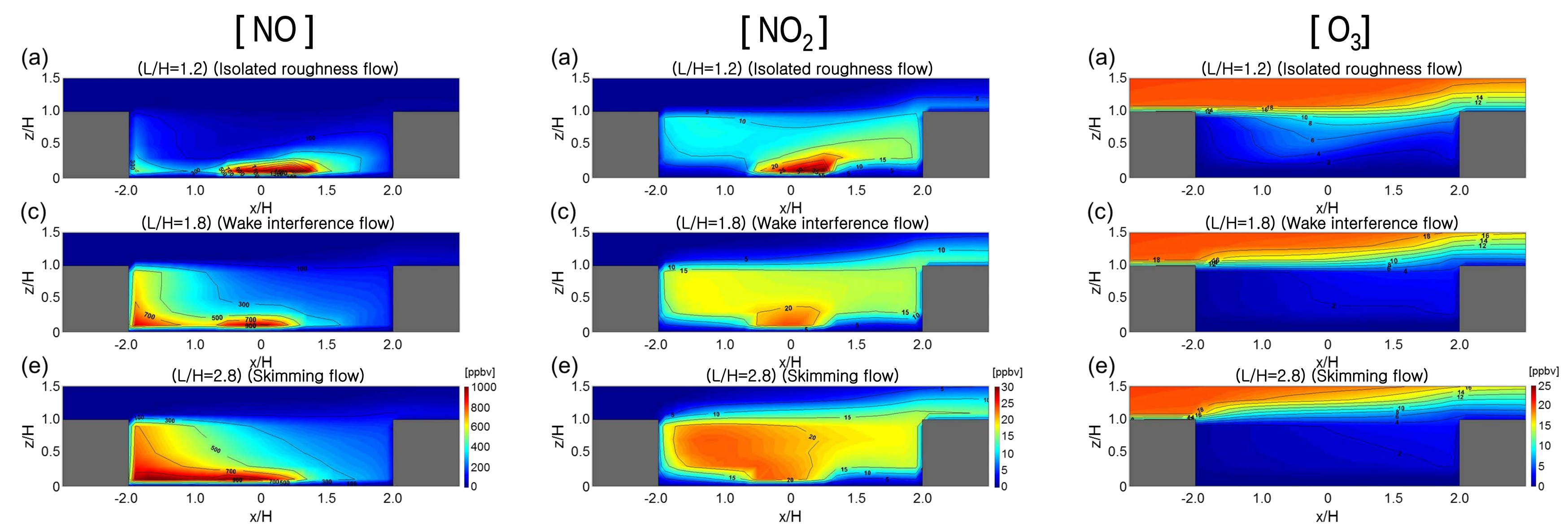
Fields of wind streamline | Fields of wind speed ($\sqrt{U^2+V^2}$) | Fields of wind speed (W component)



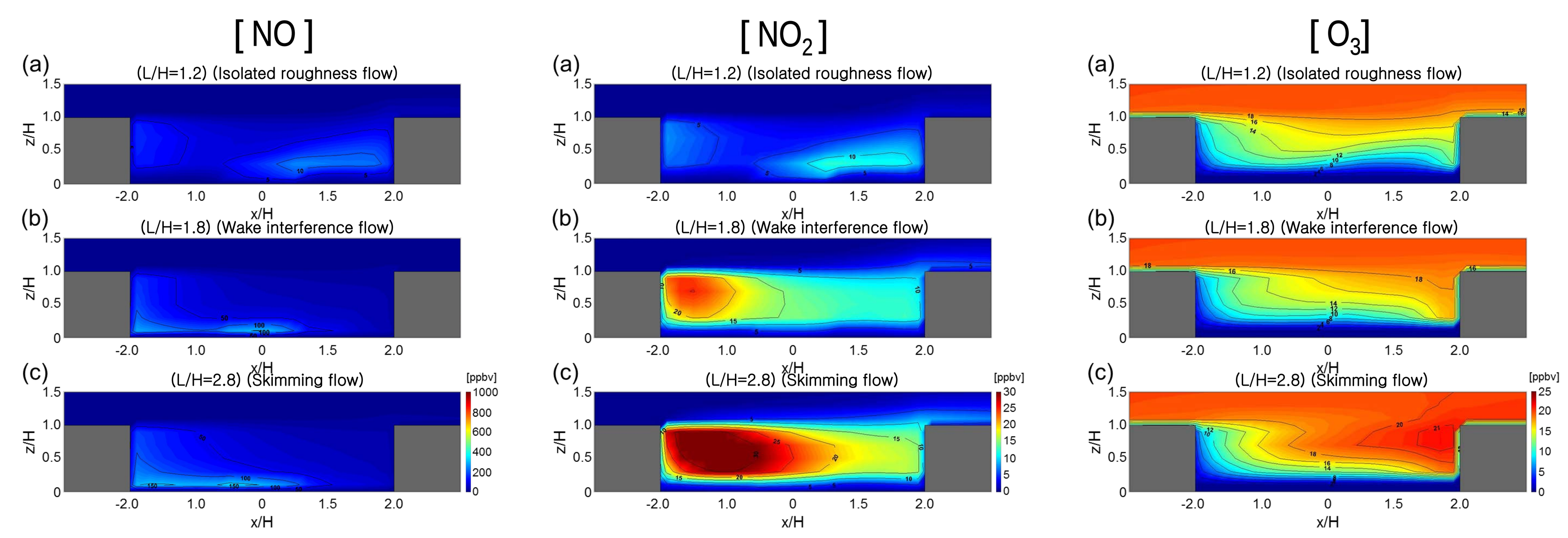
- **Isolated roughness flow : recirculation behind the upwind building is formed, and the flow before encountering the downwind building is similar to inflow.**
- **Wake interference flow : reverse flow is formed behind the upwind building, and the flow is insufficient to recover before encountering the downwind building.**
- **Skimming flow : single vortex is formed in the street canyon.**

Concentration

The mean concentration of NO, NO_2, and O_3 [VOC/NO_X = 0.5]

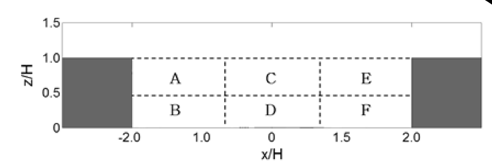


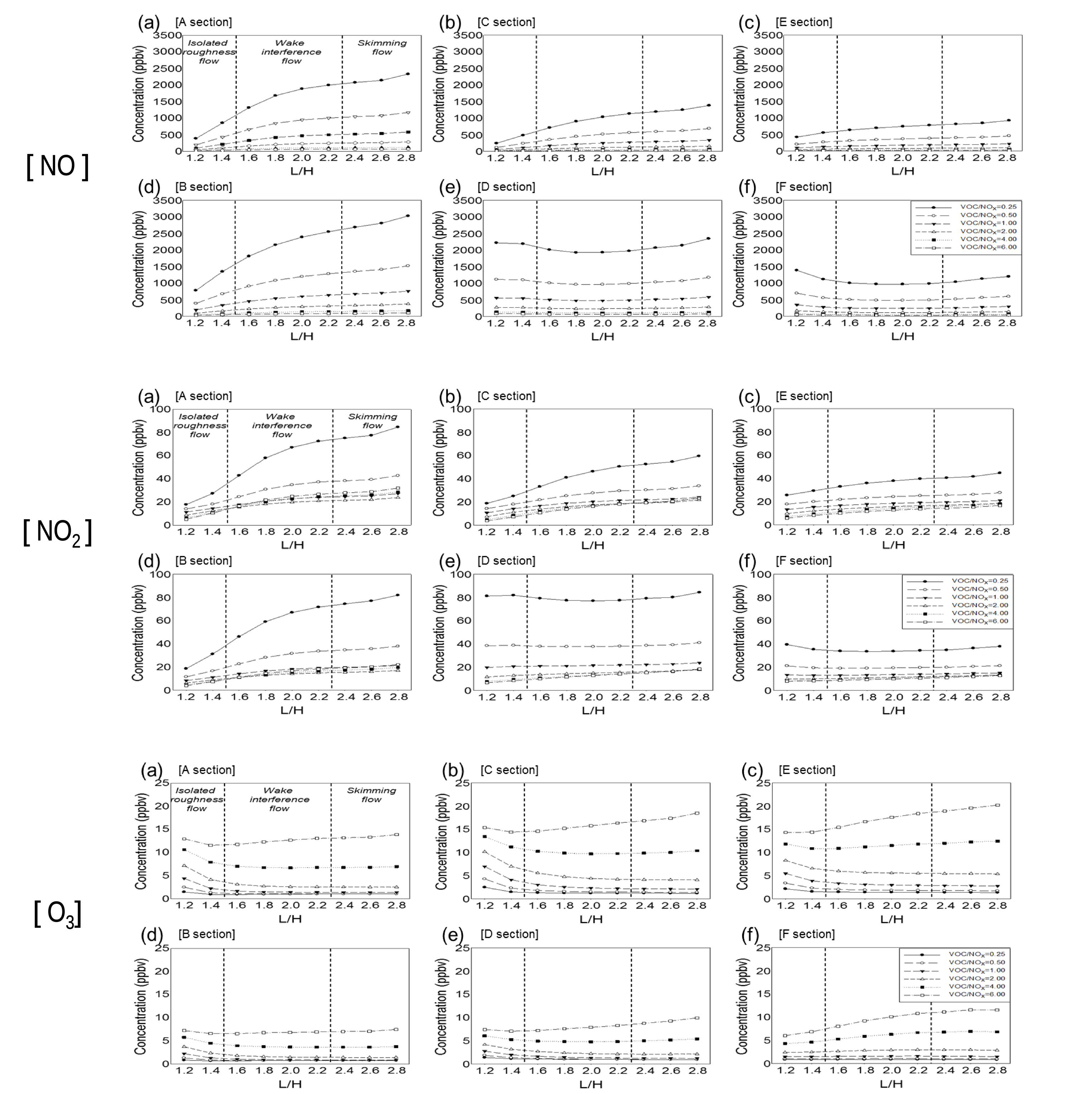
The mean concentration of NO, NO_2, and O_3 [VOC/NO_X = 6.0]



- **The flow regime in the street canyon is effect on the concentration of NO and NO_2**
- **The concentration distribution of O_3 appear in contrasted with that of NO_X because O_3 concentration is depleted by the NO.**
- **The concentration of O_3 (VOC/NO_X ratio = 6.0) is higher than those of VOC/NO_X ratio is 0.5.**

The mean concentration of NO, NO_2, and O_3 in each section





- **The concentration of NO increase as L/H ratio increases at A, B, C, and E section.**
- **The concentration of NO at D and F section depends on the flow regime.**

- **VOC/NO_X ratio = 0.5~2.0 : High-NO_X regime : increasing NO_X → decreasing O_3**
- **VOC/NO_X ratio = 4.0 : High- and Low-NO_X regime : depending on the L/H ratio**
- **VOC/NO_X ratio = 6.0 : Low-NO_X regime : increasing NO_X → decreasing O_3**

Summary and conclusions

- **In this study, we investigated the effects of street aspect ratio on reactive pollutant dispersion in urban street canyons, using the same coupled CFD–chemistry model.**
- **The flow in urban street canyons is separated as isolated roughness flow, wake interference flow, or skimming flow according to the systematic variation of the building length parameter.**
- **The concentration of NO and NO_2 is influenced by the flow regime in the urban street canyon.**
- **The concentration of O_3 depends on the concentration of NO_X because O_3 is depleted by the NO.**
- **VOC/NO_X ratio is effects on the concentration in the urban street canyon.**
- **High VOC/NO_X ratio increases the concentration of O_3 as the concentration of NO_X increases in the urban street canyon.**
- **Low VOC/NO_X ratio decreases the concentration of O_3 as the concentration of NO_X increases in the urban street canyon.**

References

- **Kim, J. –J., and J. –J. Baik, 2010: Effects of street–bottom and building–roof heating on flow in three–dimensional street canyons. *Adv. Atmos. Sci.*, 27, 513–527.**
- **Kim, M. – J., R. – J. Park, and J. – J. Kim, 2012: Urban air quality modeling with full O_3–NO_X–VOC chemistry: Implications for O_3 and PM air quality in a street canyon. *Atmos. Environ.*, 47, 330–340.**