Urban air quality simulation in a street canyon using chemistry-coupled CFD model

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【Background】Mesh resolution of air quality models to simulate the behavior of air pollution such as O_3 and $PM_{2.5}$ is at finest 1 km^2 or the larger. This resolution, however, is not sufficient to correctly evaluate the roadside air pollution caused by pollutants emitted mainly from automobiles. CFD models, on the other hand, can perform the 24-hour simulation of thermal environment of city-block scale with high spatial resolution. Thus a CFD model incorporated with an atmospheric chemical reaction mechanism which is generally used in air quality models has been developed in order to calculate the distribution of contaminants such as O_3 and NO_x in the street canyon with high spatial resolution.

【Methodology】In this study, an air quality simulation was performed with a chemistry-coupled CFD model. The CFD model consists of momentum, continuity and mass conservation equations, and is incorporated with urban surface radiation processes and an atmospheric chemical mechanism called CBM-IV. The size of the calculation domain is 400, 400 and 150 m with mesh number 68, 68 and 29 in the x, y and z direction, respectively. The street canyon is 20, 60 and 20 m within the 100, 100 and 30 m analytical area with a horizontal grid interval of 2.5 m, vertical grid interval of 2 m. The WRF-CMAQ model was used to determine the boundary conditions of air temperature and air pollutant concentrations of the calculation domain for 2–3 August 2010. In addition, emissions from automobiles in the street canyon were also considered. Road area is 15, 400 m in the center of canyon.

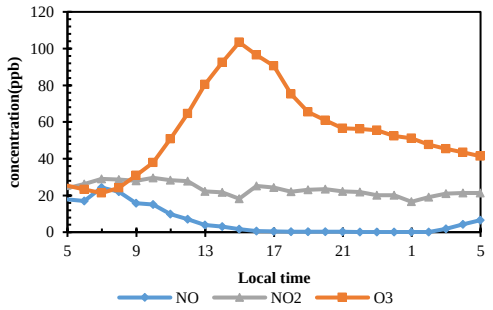

Fig.1. Temporal variations of the NO, NO_2, O_3 street canyon spatial average concentrations

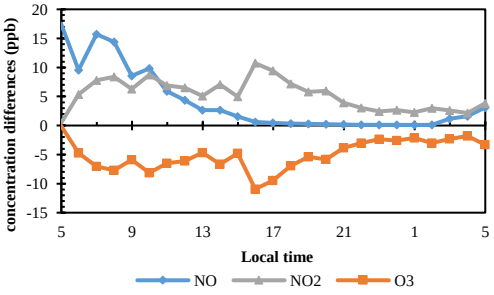

Fig.2. Temporal variations of the NO, NO_2, O_3 concentration differences (spatial average concentrations-background concentrations)

【Results】The diurnal variation of NO_x and O_3 exchange was investigated to understand reactive pollutants removal and entrainment across the street canyon. Fig. 1 shows temporal variations of NO, NO_2 and O_3 concentrations spatially averaged in the street canyon. NO concentration appeared peak value at the rush-hour around 7 am. The high concentration of the NO caused the low O_3 concentration by the reaction of NO and O_3. Fig. 2 shows the temporal variations of concentration differences between spatial average concentrations and background concentrations (concentrations at z=30m where there were almost no effects from the emission source). Due to the emission from the vehicles, the concentrations of NO_x were higher in the street canyon than the background concentrations during the whole day. Because of the titration with NO, the concentration of O_3 in the street canyon was lower than the background concentration during the whole day. Fig. 3 shows the O_3 concentration distribution and wind flow at the center of the canyon (y=200 m) at 3 pm when the O_3 concentration was the highest in the day. The distribution pattern of the O_3 was lower behind the upwind building than in front of the downwind building mainly due to the wind vector. The wind blew NO_x emitted by the vehicles to the upwind building area, then the concentration of O_3 was decreased because of the titration with NO.

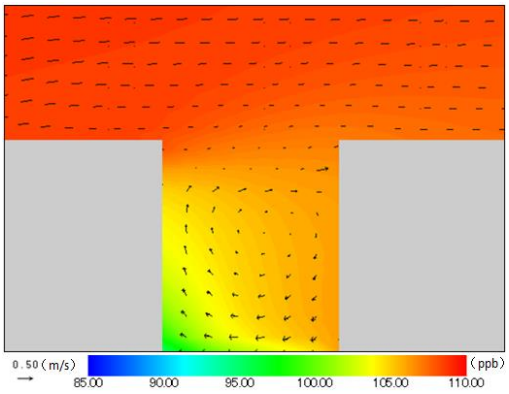

Fig.3. O_3 concentration distribution and wind flow at y=200 m at 3 pm