Regional Climate Change Induced by Land-Use Change and Impact on O_3 in the Pearl River Delta, China

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1. INTRODUCTION

Changes in land use and land cover (LULC) alter the exchange of energy, momentum, moisture and other trace gases within vegetation-soil atmosphere continuum, subsequently affecting the global and regional climate and terrestrial carbon cycle process. As a result, the LULC change has been recognized as one of the largest and most convincing mechanisms for the earth climate change. Recently, availability of higher spatial resolution land cover data, along with improved parameterization of the planetary boundary layer (PBL) and urban processes, has been used to improve mesoscale numerical simulations over urban areas. Numerical modeling is a powerful tool to investigate consequences of urbanization on regional climate, particularly for the Chinese Pearl River Delta (PRD) region, which experienced rapid urban development in the last ten years. The primary objective of this research is to quantify major impacts of LULC change on regional climate and potential impacts on O_3 concentration over the PRD.

2. MODELING SYSTEMS AND NUMERICAL EXPERIMENTS

The coupled fifth-generation Pennsylvania State University–National Center for Atmospheric Research nonhydrostatic Mesoscale Model (MM5)–land surface modeling system is used in this study. MM5 is configured for the current study with three two-way interactive grids having horizontal grid spacings of 27, 9, and 3 km and grid point dimensions of 127×118, 97×97, and 79×79 respectively[Lin et al. 2007, Wang et al., 2007]. To better capture influences of urban heat islands (UHIs) and urbanization on the PRD, a 3-km grid, in conjunction with high-resolution land-use maps, is used for the MM5 inner domain. The same 22 sigma levels are specified for all simulations. Pressure at the top of the model, where a radiative boundary condition is used, is 100 hPa. The lowest half-sigma level is located at 38 m above ground level. Since a major goal of the current study is to examine the effect of urbanization on PBL structures, vertical resolution is significantly enhanced in the lowest 1-km atmosphere. The Noah land surface model (LSM) with a simple urban parameterization is used in this study (Chen 2005). More details about the model parameterizations and initial and boundary conditions are described in Wang et al. [2007].

Two land cover data sets are used in the PRD within the domain D3 (Figure 1) in this case study. One land cover (namely NU) employs the original United States Geological Survey (USGS) land cover data with 24-category, corresponding to the 1990s land-use condition with less human disturbance, while the other land cover data (namely HU) is based on the urban data of 2004 (after urban expansion took place) derived from 2004 MODIS satellite images at 500m spatial resolution. October 2004 is chosen for this study bees of relatively high pollution index in autumn over the PRD.

In this study, STEM (Sulfur Transport and dEposition Model)-2K1 (Carmichael et al., 2003a) is executed on the same grids as MM5

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(i.e., 27-, 9-, and 3-km grid) using the PRE-URBAN (NU) and URBAN (HU) land use maps to investigate the influence of land use change on ozone over the PRD. This model was used in the TRACE-P (Transport and Chemical Evolution over the Pacific) experiment and compared with observed data in the PRD region by Wang et al. (2005). STEM-2K1 is driven by MM5 meteorological output in the three domains, which have the same vertical and horizontal resolution as MM5. For chemical species initial and boundary conditions, the profiles obtained from the TRACE-P aircraft observations are used for the coarse domain. The initial and boundary conditions for the inner two domains are interpolated from corresponding mother domain. Emissions are interpolated into each domain from 6 min resolution emission inventory. The simulation length is different from MM5. Because running the nested chemical model is expensive, we start, for this preliminary runs, with a 3-day simulation to assess impacts of land-use change on O3. The simulation started from 0000UTC 28 October and ended at 2300 UTC 30 October 2004. The whole month simulation by chemical model will be done in the near future. As our main objective is to explore the influences of urban-induced changes in meteorological conditions on air quality, we use the same surface biogenic and industrial emission rates (reflecting today's situation) in both simulations with different land use maps. The impacts of emission rate changes will be investigated in the future.

3. RESULTS AND ANALYSES

3.1 Regional Climate Change Induced by Land-Use Change

The observed monthly mean temperature (from six-hourly observations) and the simulated monthly mean 2-m temperature are shown in Figure 2. The magnitude of simulated results is close to the observed in the northern part of Guangdong province but lower than the observed near the coast. Different thermal properties (heat capacity and conductivity) for urban and rural resulted in faster daytime (nighttime) temperature increase (decrease) in urban areas than that in rural areas.

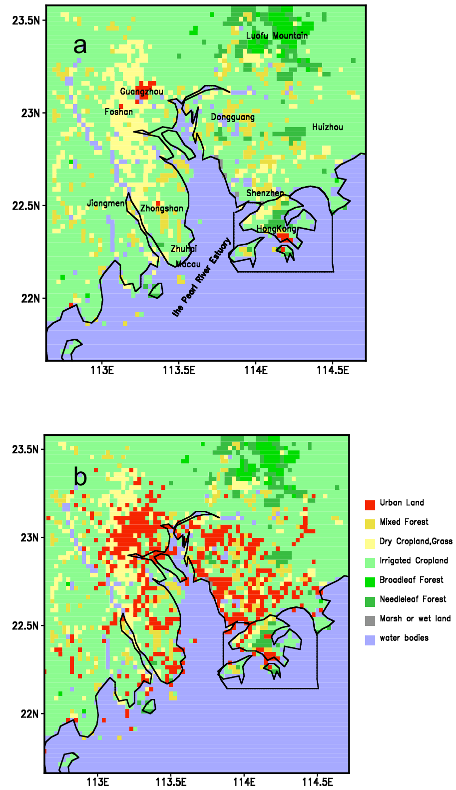

Fig. 1. Land-use data sets used for MM5 simulations. (a) USGS data, (b) Land-use data based on 2004 0.5-km MODIS products. The only change between (a) and (b) is the urban areas marked in red color.

The 2-m mixing ratio, 2-m temperature (℃) , sensible heat flux, and PBL depth difference between HU and NU are shown in figure 2. The spatial distribution of the urban expansion effect on humidity in the figure indicates that the maximum decrease of mixing ratio is about 0.4 g kg^{-1} in Guangzhou and Dongguan. Further calculations show that the mixing ratio decreases from NU to HU by 0.02, 0.02, and 0.01 g kg^{-1} for the domain-averaged value, land-averaged value and urban area averaged value, respectively. The maximum difference of monthly mean 2-m temperature is about 0.9℃ over urban areas in Guangzhou, Dongguan, Zhongshan and Shenzhen. Although warm centers dominate in the whole domain, there are some cool centers (minimum temperature difference <-1.2℃) in the Pearl River estuary with urban expansion.

The differences of monthly mean sensible heat fluxes between HU and NU indicate that there is an increase of sensible heat flux in the eastern, northeastern part of the PRD and all urbanized areas where maximum increase is about 90 W m^{-2}. The monthly mean surface sensible heat fluxes averaged for the whole domain, land area and urban area increase, respectively, from 24.8 W m^{-2} to 28.9 W m^{-2}, 16.6 W m^{-2} to 21.5, and 28.5 W m^{-2} to 86.0 W m^{-2} from NU to HU.

The spatial distribution of monthly mean PBL height difference between NU and HU shows that the PBL height over the urban areas increases significantly. The average increase is about 20-80 m near urban areas, and the maximum increase is about 180 m in Guangzhou. The monthly mean PBL height averaged for the domain D03, land, and urban areas increases, respectively, from 827 m to 839 m (12 m deeper), 765 m to 783 m (18 m deeper), 780 m to 855 m (76 m deeper) from NU to HU. This difference is a result of urban-expansion induced increase of daily mean PBL height which exhibits a diurnal variability of daytime increases but nighttime decreases in PBL height. But the magnitude of daytime increase is larger than that of nighttime decrease.

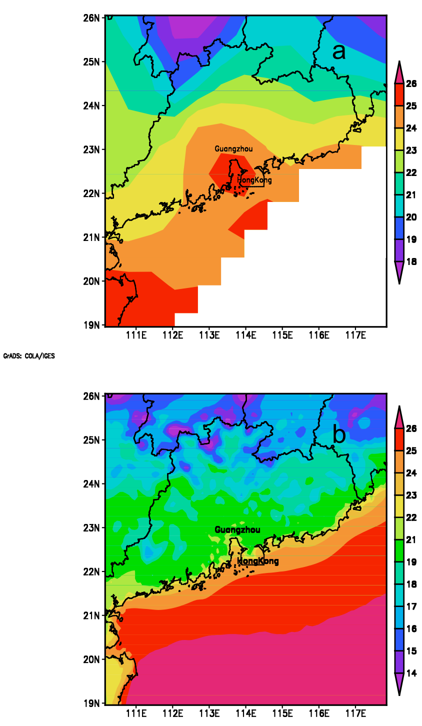

Fig. 2. Monthly mean 2-m temperature (℃) (a) Observation and (b) Simulation.

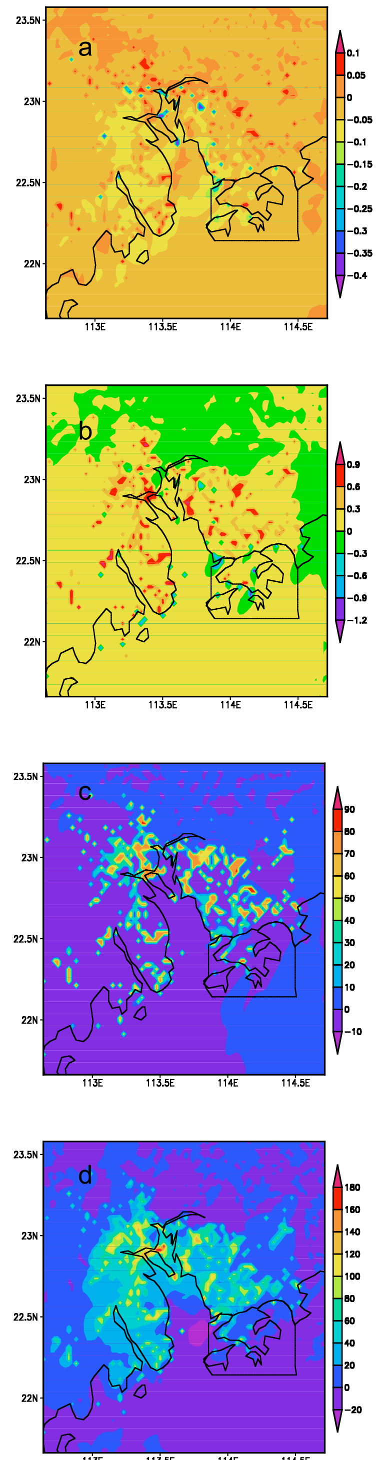

Fig. 3. Monthly mean difference between HU and NU. (a) 2-m mixing ratio (g kg-1), (b) 2-m temperature (℃) ,(c) Sensible heat flux, (d) PBL depth

3.2 Impact on O_3 concentration due Land-Use Change

We have seen so far that urbanization can modify temperature, humidity, sensible heat flux and the PBL mixing-layer depth and stability. In this section, we focus on impacts of those modified meteorological conditions on spatial and temporal distributions of ozone (O_3) concentration , because it is the traditional indicator of photochemical smog in the PRD. Figure 4 shows influences of urban expansion on daytime and nighttime averaged surface O_3 concentrations. While surface O_3 concentrations over major cities increase both during daytime and during nighttime, the nighttime enhancements in O_3 concentrations outpace those during daytime in the urban expansion regions. For instance, during daytime, the maximum O_3 concentrations augmentation occurs over the Hongkong area (~ 10 ppbv) with a second maximum over the Guangzhou area (~ 4 ppbv). The nighttime maximum O_3 increase has larger amount (> 15 ppbv) and is located over major urban expansion areas such as Guangzhou and Dongguan. Areas with main O_3 concentrations increase generally coincide with the areas of temperature increase, humidity reduction, sensible heat flux increase. These results are consistent with previous studies showing the direct link between increased ozone concentrations and higher temperatures. Nevertheless, it should be noted that, in the daytime, some urban regions such as Foshan and suburb of Guanghou experience slight reduction in surface ozone concentration even with higher temperature and lighter wind in those areas. This implies that the temperature enhancement alone is not sufficient to explain changes in surface O_3 concentrations. Because in the real world, temperature change will likely be coupled to changes in other meteorological variables such as the PBL depth that will in turn affect O_3 concentrations. In fact, deeper daytime, convective boundary layer over major urbanized areas can lead to stronger vertical mixing that dilutes surface O_3 concentrations. For example, over the Guangzhou district, the daytime increase in the PBL depth (> 400 m) is greater than the nighttime increase (~ 100 m). Hence, the surface O_3 is transported to upper mixing layer and the O_3 concentration increases throughout the entire mixing layer up to 1700 m (not shown). By contrast, despite the slightly unstable, nocturnal surface layer caused by more pronounced nighttime UHI, the increase of O_3 is mainly confined within the lowest 150 m above the ground, leading to higher surface O_3 concentration. Therefore, the more enhanced nighttime surface O_3 is a consequence of slightly higher surface temperature and, more importantly, of shallower mixing layer. The other reason for large nocturnal increase in surface O_3 concentration is weaker wind speed, which reduces horizontal transport of pollutants and results in local O_3 accumulation.

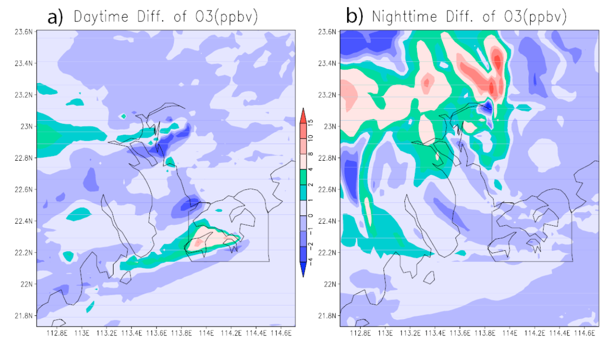

Fig. 4. Differences of surface ozone concentration (ppbv) between URBAN and PRE-URBAN simulations (URBAN minus PRE-URBAN). (a) averaged for the daytime and (b) averaged for nighttime simulation.

4. SUMMARY

Preliminary results show that urbanization can increase 2-m temperature, decrease water mixing ratio and sensible heat flux, increase the PBL mixing-layer depth over urban area in Autumn. These meteorological change can induce feasible surface ozone concentration through three days simulation. During daytime, the maximum O_3 concentrations augmentation occurs over the Hongkong area (~ 10 ppbv) with a second maximum over the Guangzhou area (~ 4 ppbv). The nighttime maximum O_3 increase has larger amount (> 15 ppbv) and is located over major urban expansion areas such as Guangzhou and Dongguan.

Nevertheless, our results may be limited due to the one season and three days simulation for ozone in this study. The seasonal simulations should be further investigated.

Acknowledgements

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