Chapter 24
Impact of Urban Land Use and Anthropogenic Heat on Air Quality in Urban Environments

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Abstract In the GEM-MACH URBAN project, Environment and Climate Change Canada (ECCC) high-resolution (2.5-km) Global Environment Multiscale-Modelling Air-quality and Chemistry (GEM-MACH) model and the Town Energy Balance Model (TEB) are being employed to examine the impact of the urban surface exchange scheme on the transport and diffusion of air pollutants in large cities such as Toronto, New York and Detroit. Simulation results show that while the TEB scheme causes O3 mixing ratios to increase, it leads to a decrease of CO and NOx mixing ratios and air quality health index (AQHI) values in the urban centers in both summer (July) and winter (January) months. The TEB scheme also has a big impact on the vertical diffusion coefficient, atmospheric boundary layer (ABL) height and air temperature. Comparisons against ECCC's meteorological and air quality (AQ)

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C. Mensink et al. (eds.), *Air Pollution Modeling and its Application XXVI*, Springer Proceedings in Complexity,
https://doi.org/10.1007/978-3-030-22055-6_24

observation networks suggest that the inclusion of TEB scheme improves the forecasts of both surface temperature and pollutant mixing ratios.

24.1 Introduction

With rapid urbanization, the population in cities has been increasing dramatically around the globe. The urbanization leads to the significant change in urban meteorological conditions such as meso- and microscale urban heat island (UHI) effects, urban flooding, precipitation, humidity, fog, visibility, street canyon winds and surface energy fluxes. In addition, the change of urban meteorology and climate can cause elevated concentration levels for gaseous pollutants and aerosols, and consequently change the urban air quality. These changes are the direct consequence of the change of land coverage [1] and large amount of energy consumption from heating or cooling buildings and from local transportation within big cities.

As the majority of exceedances of air quality (AQ) standards occur in urban areas, accurate predictions of the major pollutants are extremely important for the health of the urban population. In the GEM-MACH URBAN project, the Canadian air quality model (GEM-MACH) and the town energy balance model (TEB) [2] are employed to investigate the impact of the urban canopy on the production and transport of pollutants within urban areas. Some results are shown in the following sections.

24.2 Urbanizing GEM-MACH with TEB

The TEB model can describe the complex urban fabric and the heat and momentum exchange mechanism between the urban surface and the atmosphere. Figure 24.1 shows some TEB parameters describing the urban fabric in the Great Toronto Area (GTA). These parameters are important for computing the heat storage within the urban canopy. It can be seen from Fig. 24.1 that downtown Toronto has a very high density of high buildings, large aspect ratio and roughness height. A climatological sensible heat flux from traffic is used. The magnitude of the traffic heat flux in urban centers is about 20 W/m^2.

24.3 Impacts of TEB on Temperature and Air Quality Health Index

The energy balance above the urban canopy can be changed significantly by the trapped short and long wave radiations by buildings within the urban canopy, and by anthropogenic activities (e.g., [2, 3]). This change leads to higher temperature in

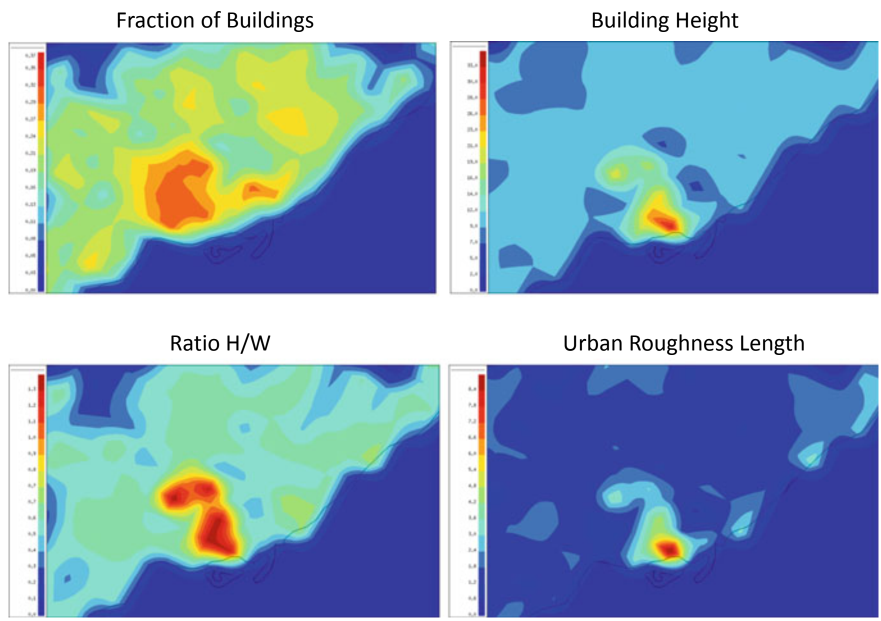

Fig. 24.1 Parameters characterizing the urban fabric in GTA including fraction of building, building height, aspect (height to width) ratio and urban roughness length

the urban area than the surrounding rural area, the so called urban heat island (UHI) effect [4].

The impact of TEB on urban temperature can be identified by comparing the simulation results with TEB and without TEB against temperature observed during the Pan Am games period (July, 2015). Figure 24.2 shows the diurnal variation of the monthly mean temperature bias from the two simulations at different locations in GTA. It is clear from the figure that at nighttime TEB generates UHI effect, and it significantly reduces the model temperature bias (observation minus model predication (O-P)) in both downtown and uptown areas. Noticeable improvements can also be identified in suburban and waterfront areas.

In addition to the impact on urban temperature, urban canopy has impact on the transport of chemical pollutants within the ABL by changing the turbulent mixing in vertical and the ABL height, as well as the production of chemical pollutants by changing the temperature and possibly altering solar radiation.

Figure 24.3 shows the diurnal variations of the monthly mean difference in air quality health index (AQHI) between the TEB simulations and non-TEB simulations in four big cities (within the model domain). It can be seen from the figure that while TEB can lead to reduction of AQHI, the patterns of reduction are different in each city and different season.

On weekdays in January, large reductions of the AQHI by TEB occur in the early morning and around noon in Toronto, New York and Detroit. Another big reduction

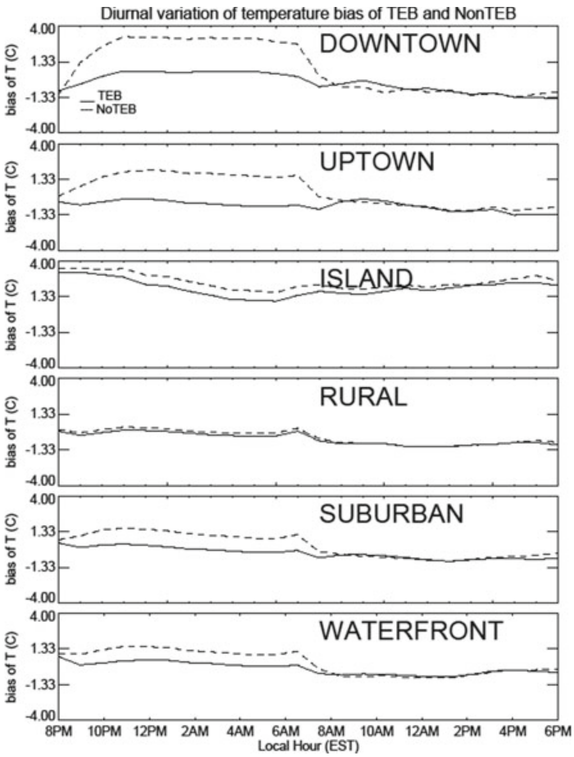

Fig. 24.2 Diurnal variation of the monthly mean temperature bias of the simulations with TEB (solid lines) and without TEB (dashed lines) over six land cover categories

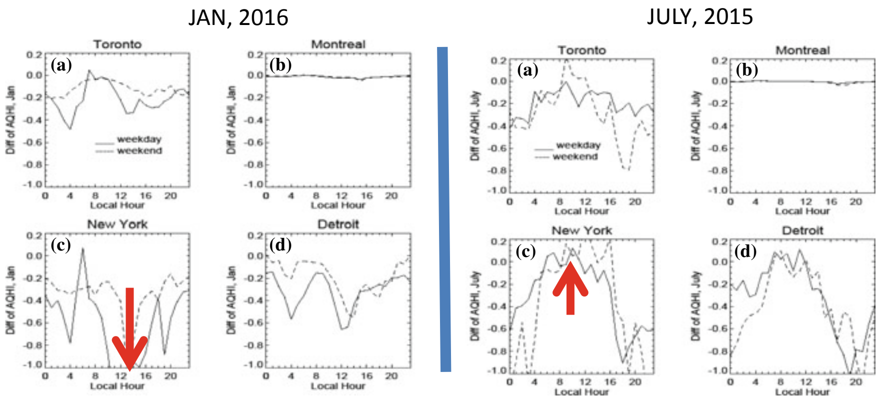

Fig. 24.3 Diurnal variation of the differences of monthly mean AQHI between the simulations with and without TEB in the four urban centers during weekday (solid lines) and weekend (dashed lines) in January 2016 (left) and July 2015 (right)

occurs at around 8 pm in New York. The reduction of AQHI in New York is much larger than the reduction in Toronto and Detroit. In July however, the reductions of AQHI occur in the early morning in the three big cities and large reductions occur not only in New York, but also in Detroit. Contrary to the big reduction at noon in January, AQHI has virtually no change at noon in New York and Detroit.

Figure 24.3 also shows that TEB has very different impact on AQHI during weekday and weekend. In January, the reduction of AQHI in early morning in weekday is much larger than the reduction in weekend in the three big cities. However, in July the reduction in early morning in weekend is much larger than the reduction in early morning in weekday in New York and Detroit.

24.4 Conclusions and Future Plans

Our simulations show that the inclusion of TEB in the GEM-MACH simulations can significantly reduce the cold temperature bias in the urban areas, and has big impacts on turbulent mixing coefficient and the ABL height (not shown). The simulation results also show that the change of meteorological condition leads the reduction of the AQHI in urban centers in both winter and summer.

In the current simulations, the climatologic traffic heat flux is used. In the future work, the diurnal variation of the traffic heat flux will be used to better describe the impact of the traffic patterns in urban areas on the UHI effect. In addition, the surface meteorological analysis data will also be used in future simulations to provide more accurate information of surface energy balance.

Question and Answer
Questioner: Alexander Baklanov
Questions:

1. Did you consider urban soil moisture processes and their effects?
2. In polluted cities, effects of urban aerosols on UBL and in particular UBL height can be comparable with UHI effects. Did you consider aerosol feedbacks in your studies?
3. You use the TEB model in the simulations of Masson [2], which was done for NWP and meteorological applications. For NWP applications, building effects on mechanical turbulence and on wind velocity structure in urban canopy is also important. In NEM/BEP parameterizations by Martilli et al. (2002) and latest version of TEB such effects are included more accurately. Did you analyzed/included these effects and other parameterizations?

Answer to (1): The air quality model (GEM-MACH) includes the land surface scheme which takes into account of urban soil moisture processes and their effects.
Answer to (2): The feedback of urban aerosols on simulations is not considered in this study. However, Wanmin Gong is going to discuss this effect in her talk. The same model is employed in her work.

Answer to (3): The TEB model used in this study is a single model with all the exchanges (of heat, momentum and chemical species) between the urban canopy and atmosphere occurring at the last model level. The scheme proposed by Martilli et al. can handle exchanges at several model levels. It may provide a better way describing the spatial distribution of air pollutants in urban areas particularly in the downtown core with high density of high-rise buildings.

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