IMPACTS OF URBANIZATION ON A SUMMER HEAVY RAINFALL IN BEIJING

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Abstract

Fine-scale simulations (with 500-m grid spacing) using the Weather Research and Forecast (WRF) model were used to investigate impacts of urbanization on a localized summer heavy rainfall in Beijing. Evaluation with radar and gauge data shows that WRF can simulate this event generally well despite missing a small rainfall center at the east part of the city, and that correctly modeling urban canyon is essential to reproduce features of rainfall, especially its amount. WRF is used to test the sensitivity of simulation of this storm to different effects of urbanization and to different urban land-use scenarios.

Key words: Impacts, Urbanization, Summer, Heavy rainfall, Beijing

1. INTRODUCTION

Urbanization rapidly spreads all over the world, and markedly modifies, through altering surface energy budget in cities, local and regional atmospheric properties, especially the planetary boundary layer (PBL) structures including wind fields, atmospheric stability, and turbulence. In order to understand urban precipitation, improve air quality, and ensure a pleasant and healthy environment for urban dwellers, understanding the impacts of urbanization becomes more and more important.

In this paper, fine-scale simulations (with 500-m grid spacing) using the Weather Research and Forecast (WRF) coupled to an urban canopy model were used to investigate impacts of urbanization on a localized summer heavy rainfall in Beijing. The main objective of this study is to assess impact of treatment of various urban processes on the initiation and movement of a heavy summer precipitation. For this, WRF is used to conduct a number of sensitivity tests including different degrees of urban modeling and urban land-use scenarios.

2. CASE SELECTED: OBSERVED RAINFALL CHARACTERISTICS

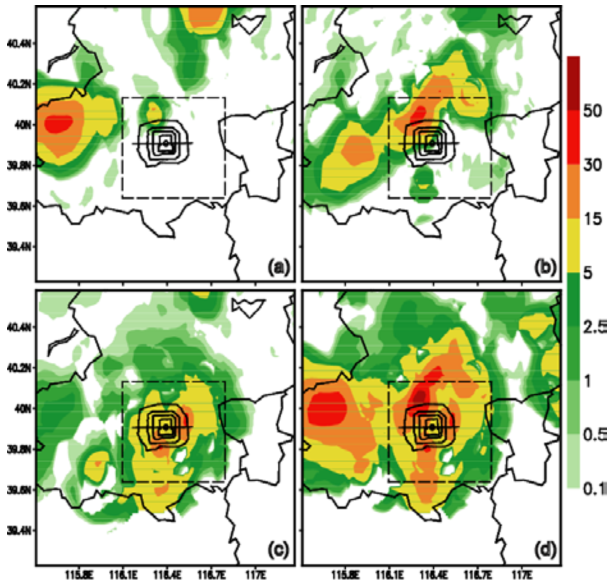

Fig. 1. Observed hourly (a-c) and 3-hour accumulated (d) rainfall (mm) on 1 Aug 2006 (The dashed rectangle shows the 5th domain (with 500-m grid spacing) for WRF numerical simulations. In the dashed rectangle, the circles from inner to outer are the 2nd, 3rd, 4th and 5th Beltway; the transverse line is Chang'an Street; and the symbol 'o' represents the position of Tian'an Men. The other solid lines represent province borders.): (a) 0900UTC, (b) 1000UTC, (c) 1100UTC, (d) 0800-1100UTC

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Because it is easier to discern urban effects during local convective heavy rainfall, a summer case is chosen to carry out this study. At 0000UTC (0800LST) 1 Aug 2006, a weak low-pressure system lies over the Beijing area at 500 hPa. As shown in Fig.1, from 1600 ~ 1900 LST on 1 Aug 2006, a squall line formed at high elevations west of Beijing and moved across the downtown, resulting in a heavy rainfall (maximum amount of 55 mm). There are three rainfall centers in downtown area.

3. WRF/NOAH/UCM NUMERICAL SIMULATIONS

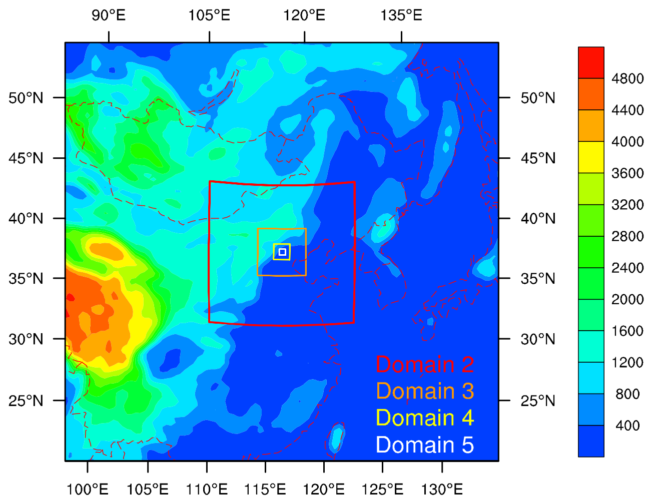

Fig. 2. Configuration of the five two-way nested domains for WRF/Noah/UCM simulation. Shaded is terrain height in meter.

The WRF model is a non-hydrostatic, compressible model with a mass coordinate system. We integrate the Advanced Research WRF (ARW version 3) described by Skamarock et al. (2005) over the five nested domains shown in Fig. 2. The grid spacing (grid numbers) of these five domains are 40.5 km (100x100), 13.5 km (100x100), 4.5 km (100x100), 1.5 km (100x100) and 0.5 km (118x109), respectively. The vertical grid contains thirty-eight full sigma levels from the surface to 50 hPa, of which the lowest thirteen levels are below 1 km in order to have finer resolution in the PBL. A single-layer urban canopy model (Kusaka et al. 2001) is coupled to WRF (Chen et al. 2006), and the coupled WRF-urban model was tested and evaluated over the Beijing metropolitan area (Miao and Chen, 2008; Miao et al., 2009).

In order to get better initial and boundary conditions for numerical simulations, WRF 3D-Var data assimilation system is used to assimilate local automatic weather station and ground-based GPS precipitable water data in Beijing area into the National Centers for Environmental Prediction (NCEP) operational Global Final (FNL) Analyses on a 1.0x1.0-degree grid and the US Air Force Weather Agency's (AFWA) Agricultural Meteorology modeling system (AGRMET) data. A 24-hr simulation (0300UTC 1 Aug 2006 – 0300UTC 2 Aug 2006) is conducted.

WRF is also used to test the sensitivity of simulation of this storm to treatment of various urban processes (e.g. dynamic and thermaldynamic effects), and to different urban land-use scenarios (e.g. no urban, urbanization prior to 1980, and further urbanization).

4. RESULTS AND DISCUSSIONS

Evaluation of control case with radar and gauge data shows that WRF can simulate this event generally well despite missing a small rainfall center at the east part of the city (Fig.3a). Correctly modeling urban canyon is essential to reproduce features of rainfall, especially its amount (Fig.3b).

Results from sensitivity cases show that the city does play an important role in determining storm movement and rainfall. Without urban, rainfall would not move to the city core and its amount is much reduced (Fig.3c). Among urban influences, the thermal transport (sensible and latent heating) (Fig.3f) appears more important than the momentum transport (Fig.3d). Among the thermal transport, latent heating (Fig.3e) and sensible heating are all very important. Early urbanization prior to 1980 decreases the rainfall (Fig.3g), while further urbanization is conducive to bifurcate the path of rainfall (Fig.3h).

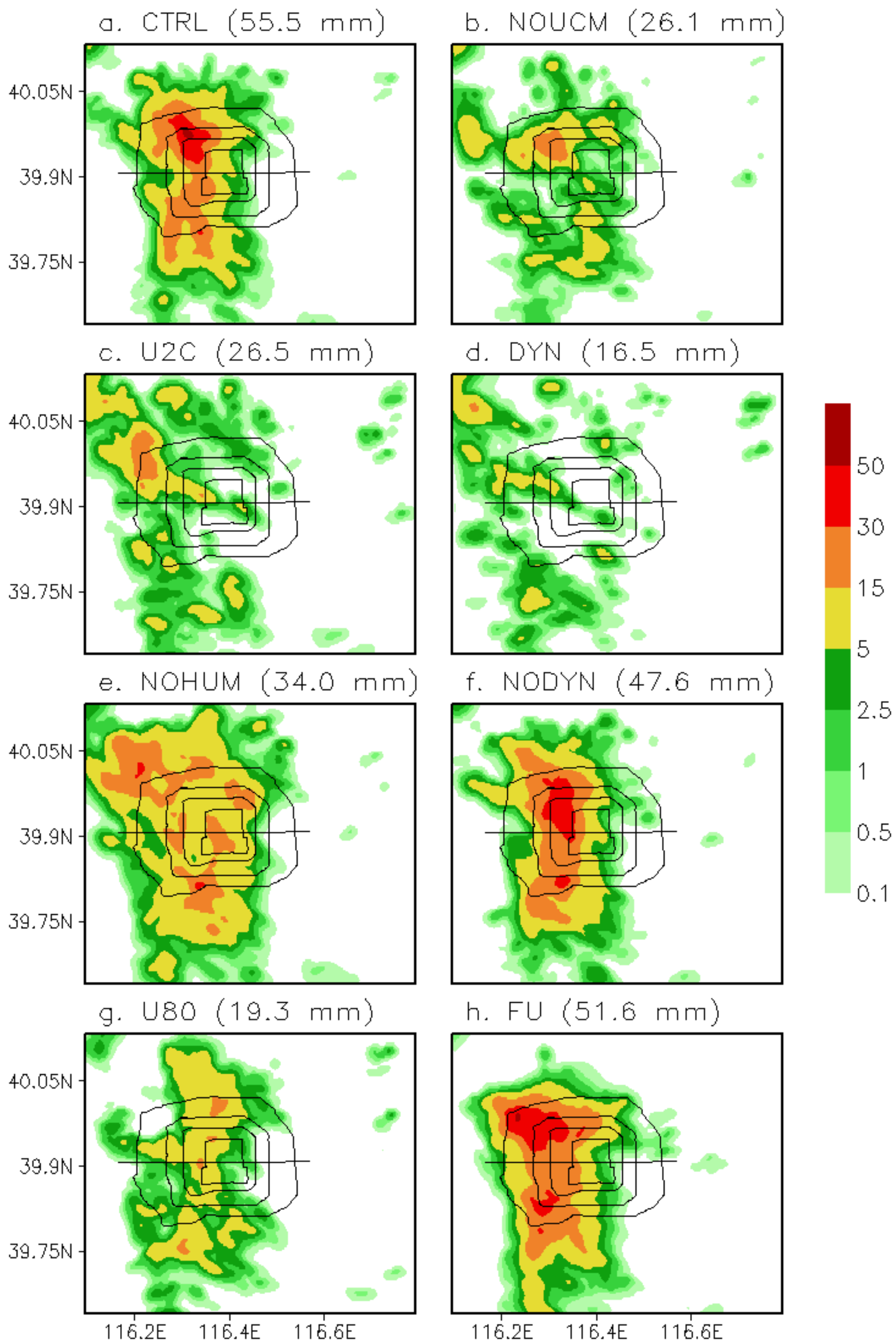

Fig. 3. 0800-1100UTC 3-hour accumulated rainfall (mm) on 1 Aug 2006 from numerical simulations (The number in brackets is the maximum rainfall): (a) control case: CTRL, (b) no UCM case: NOUCM, (c) no urban case: U2C, (d) urban dynamic effect only: DYN, (e) no urban humid effect: NOHUM, (f) no urban dynamic effect: NODYN, (g) urbanization prior to 1980: U80, and (h) further urbanization: FU

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