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Analysis of Impacts of Anthropogenic Heat and Urban Land on Extreme Rainfall over Pearl River Delta, China

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Abstract

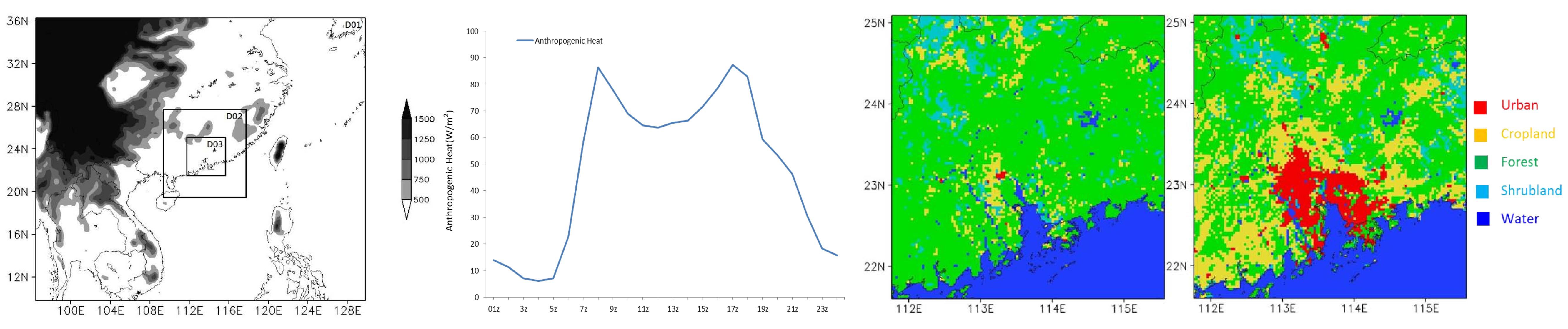
With the fast economic development, the Pearl River Delta (PRD) region has experienced more and more extreme rainfalls, including the severe storm with 319.8 mm within 24 h from 13 to 14 October 2011. To simulate this extreme rainfall, a non-hydrostatic, fully compressible, primitive equation model, the Advanced Research Weather Research and Forecasting Model 3.3 (WRF-ARW) coupled with Urban Canopy Model (UCM), was set up on HKU High Performance Computing (HPC) Power 2 cluster system. The comparison of controlled trail (CTL) with two experiments revealed that the impacts of the Anthropogenic Heat (AH) and urban land resulted in increasing of total precipitation of 6.30% and 7.44% over PRD, and increasing of hourly maximum precipitation of 21.21% and 21.04%, respectively. Furthermore, the differences of heat flux over the PRD and the rainstorm structure with low-level jets (LLJ), convective available potential energy (CAPE) and vertical upward motion in the mature rainfall were also presented and discussed.

Models design and data

- The numerical model used in this study is the WRF-ARW 3.3 coupled with UCM (Kusaka et al., 2001; Kusaka and Kimura, 2004), which is a non-hydrostatic, fully compressible, primitive equation model.
- According to Wang (Wang et al., 2011) taking into account different AH sources in Guangzhou, 2009, we estimated diurnal variation curves with dual-peak value in 08z and 17z of AH flux up to 87.3 $W \cdot m^{-2}$ over urbanization used in the UCM.
- One land cover employed the original United States Geological Survey (USGS) land cover data with 24-category spanning from April 1992 to March 1993 with less human disturbance, while another land cover used the urban data derived from moderate-resolution imaging spectroradiometer (MODIS) satellite images in 2004.
- One controlled trail and two scenarios were designed in this study: (1) MODIS land cover data with AH, hereafter referred to as 'CTL'; (2) MODIS land cover data without AH, hereafter referred to as 'MOD'; (3) USGS land cover data without AH, hereafter referred to as 'USG'.
- The initial and boundary conditions were interpolated from the 1° × 1° resolution global reanalysis data from NCEP FNL Operational Global Analysis data prepared operationally every six hours.

Domain	Domain 01	Domain 02	Domain 03
Resolution（km）	27	9	3
Grids	106×121	100×100	121×124
Time Interval（s）	150	50	16.7
Simulation Duration（h）	24		
Microphysics	WRF Single-Moment 6-class scheme		
Cumulus Parameterization	Grell 3	Grell 3	None
Planetary Boundary layer	Yonsei University scheme		
Shortwave Radiation	Dudhia scheme		
Longwave Radiation	Rapid Radiative Transfer Model		
Land Surface	Noah Land Surface Model		
Urban Surface	None	None	Urban canopy model

Table 1. Configurations of numerical model



A. Domains for the WRF-ARW simulation **B**. Hourly anthropogenic heat in urban in 2011. **C**. Two land use cover in domain-03 with resolution 3 × 3 km..

Fig. 1. Model design

Extreme rainfall and numerical simulation

- The simulated distribution of extreme precipitation center located over PRD in agreement with observation even though the location of simulated maximum precipitation was about 50 km northeast of the observed (Fig. 2).

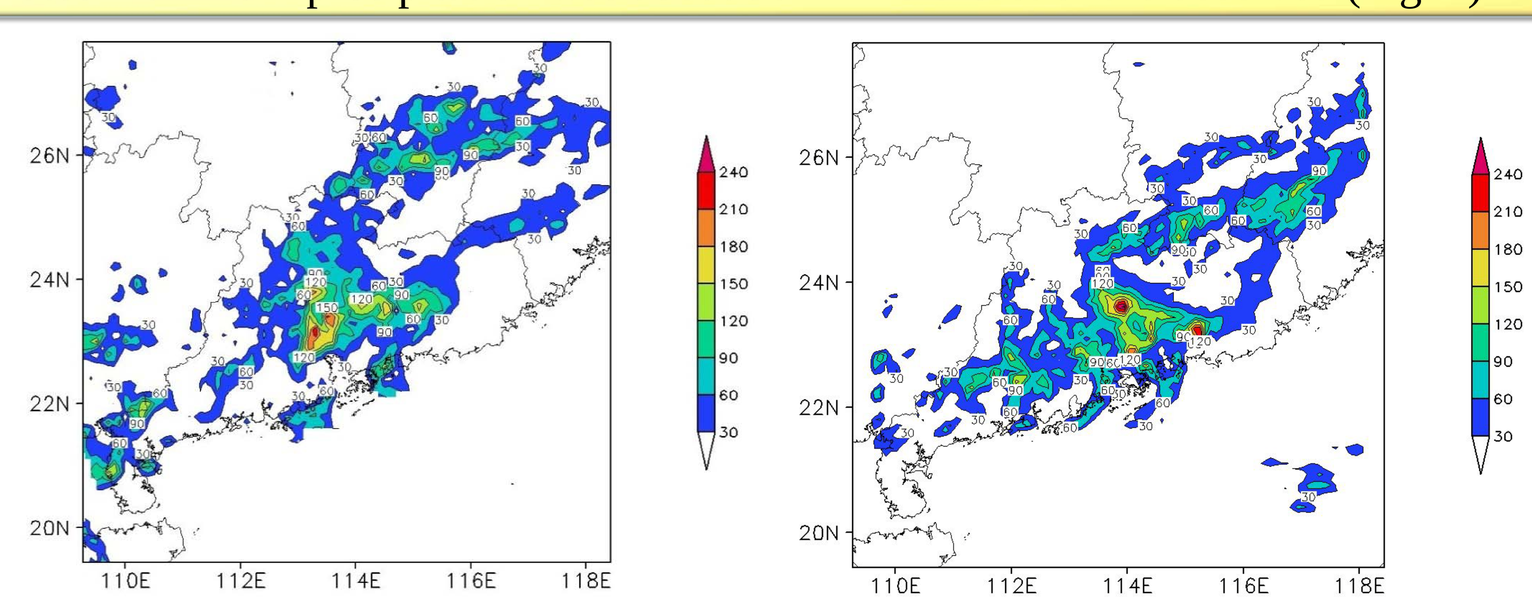


Fig. 2. Micaps observation and simulation 24-h accumulated precipitation(mm) in domain 02

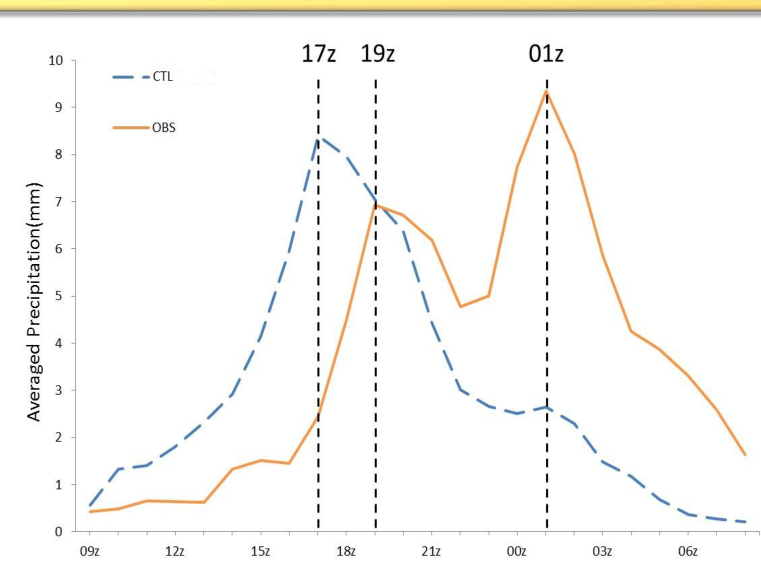


Fig. 3. PRD hourly averaged precipitation of Micaps observation and WRF predictions

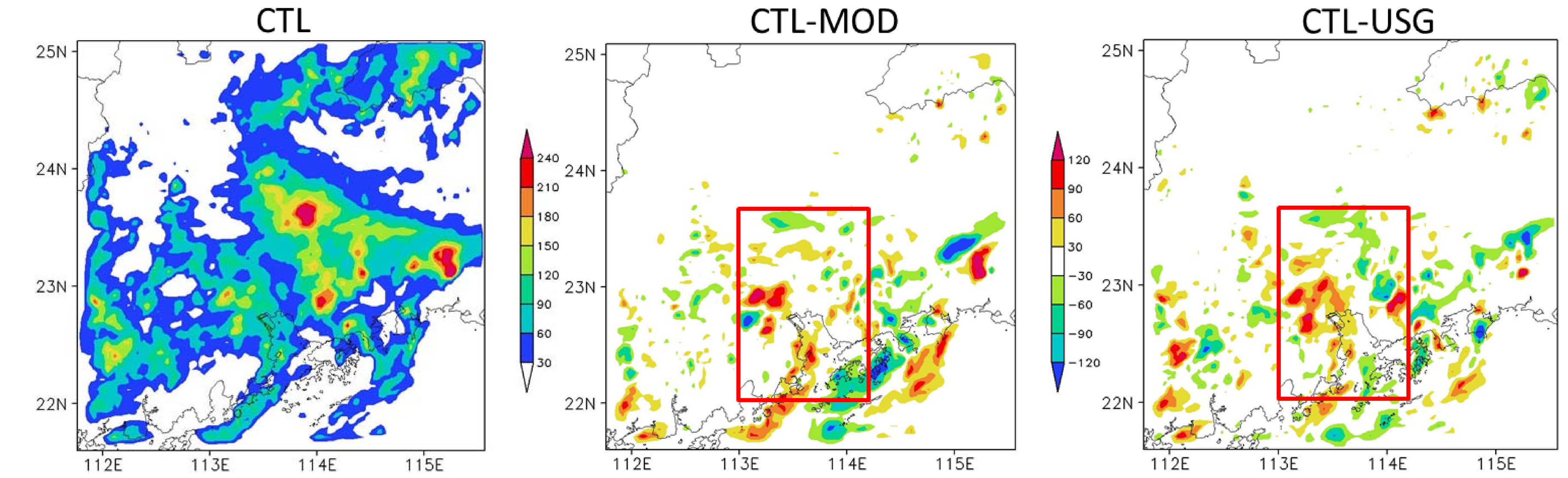


Fig. 4. Simulated 24-h accumulated precipitation in domain-03 of CTL and difference between CTL and MOD, CTL and USG

Experi-ment	PRD Accumulated Precipitation(mm)	Increasing Accumulated Precipitation in PRD(mm)	Increasing Rate (%)
CTL	71.89	—	—
MOD	67.63	4.26	6.30
USG	66.91	4.98	7.44

Table 2.Simulated 24-h accumulated precipitation in PRD

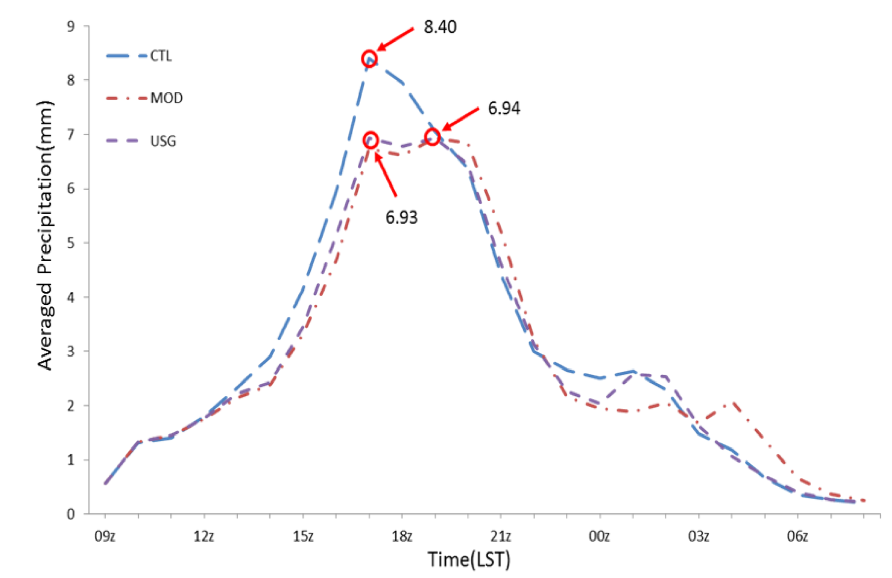


Fig. 5. PRD hourly averaged precipitation

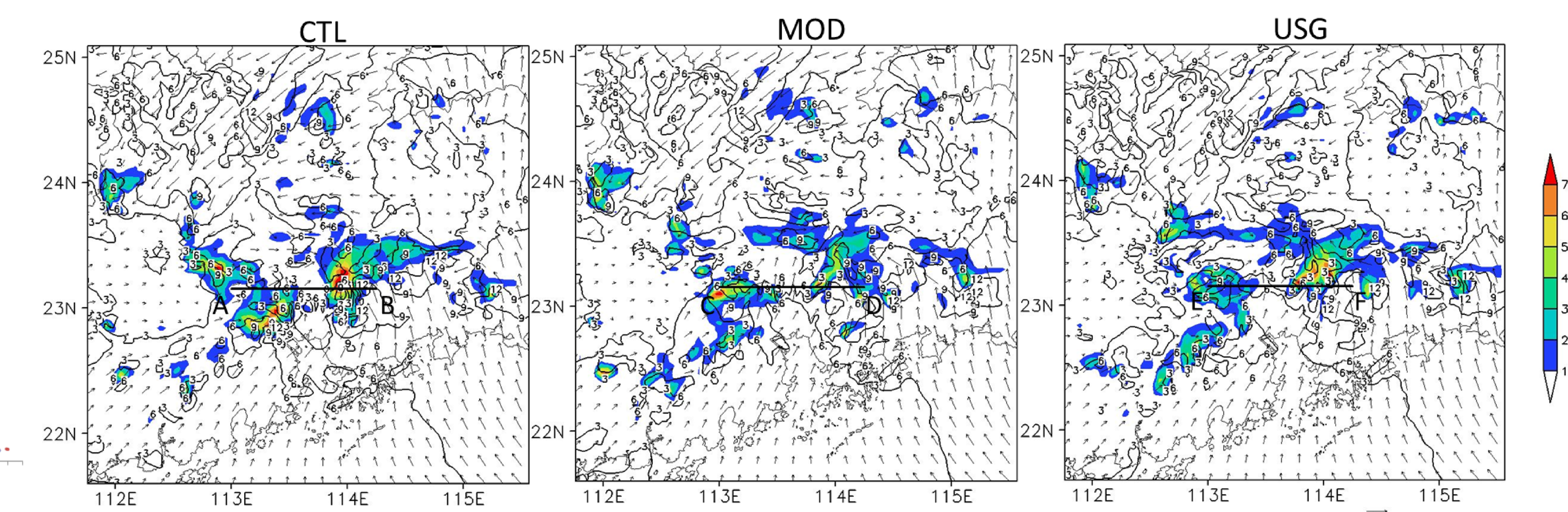


Fig. 6. Simulated precipitation (shaded: mm), winds (line: m s^{-1}) and wind vectors (m s^{-1}) at 850hPa level at 17z LST 13 October 2011

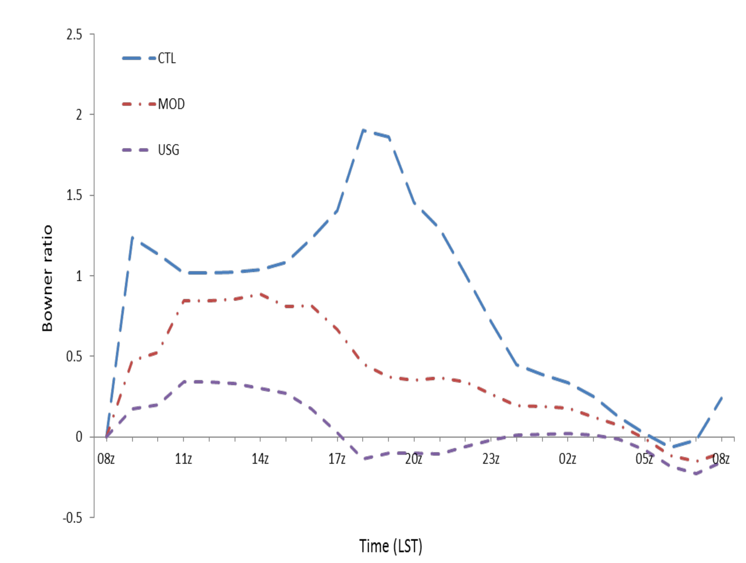


Fig. 7. Bowner ratio at the surface

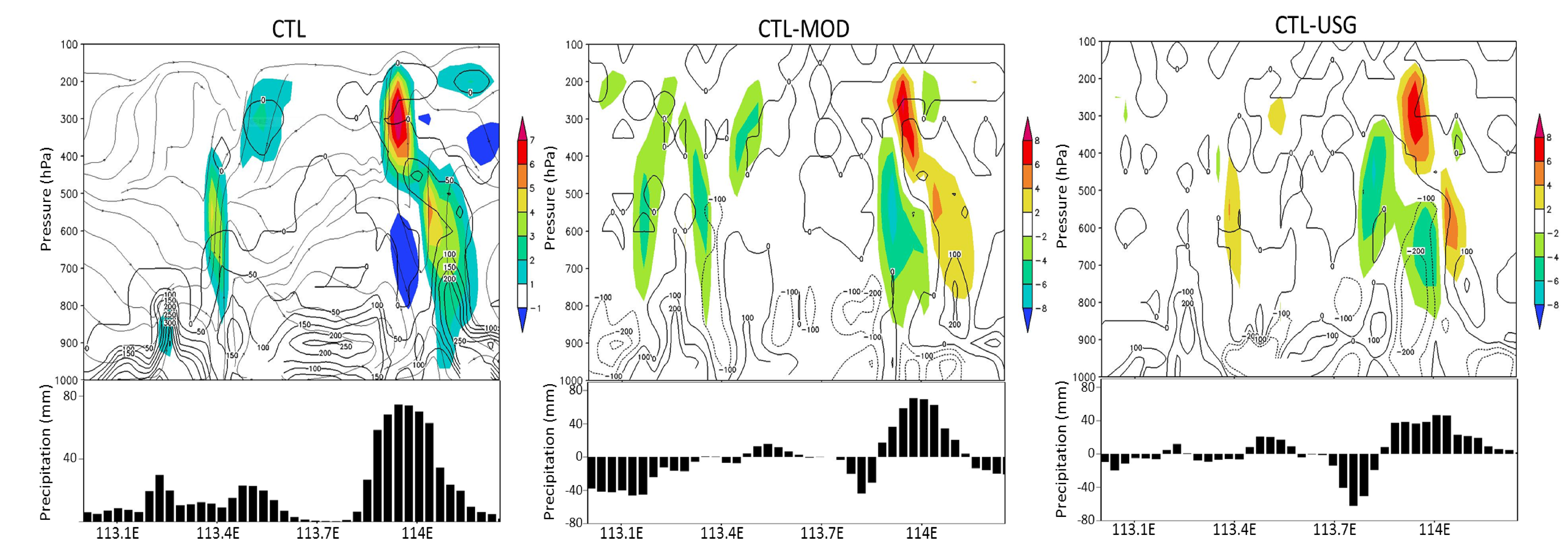


Fig. 8. Upper panel is longitude-pressure section of vertical wind (shaded: m s-1), CAPE (line: J kg-1) and the flow of zonal wind u with vertical wind w × 10 through the rainstorm center at 23.15° N at 17z LST 13 October 2011. Lower panel shading presents the precipitation.

Experiments Results

- AH marked a sharp increasing over 90 mm in 24-h accumulated precipitation mainly in Guangzhou, Foshan, Zhongshan (Fig. 4) with 6.30 % of increasing rate of PRD-accumulated precipitation while urbanization increased 7.44 % over PRD (Table 2). Also, the peak value of hourly rain rate was increased of 21.21% and 21.04% respectively showed in Fig. 5.
- Fig. 6. indicated that the differences of precipitation and convective cell characteristic might be understanded that the urban area expansion slowdown the cold front and AH provide more energy for the MCS of heavier precipitation inside center by strengthening the LLJ.
- Due to AH and urban expansion in the PRD, the simulated daily average surface temperature, upward sensible heat flux and Bowen ratio (Fig. 7) increased, whereas daily average surface relative humidity and upward latent heat flux at surface decreased (not showed).
- Finally, from the dynamic explanations, more CAPE coming from urbanization surface, that releasing at the middle and low level not noly sustain steady upward motion, but also create favorable conditions for downward motion which can create a huger convective cloud, longer life period and extreme precipitation of rainfall over PRD (Fig. 8).

Acknowledgements

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References

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