Numerical simulation of Bangkok heavy rainfall with urbanization effects

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Abstract:
*High-resolution local weather prediction for urban area is important and necessary in the planning to mitigate the impacts of weather and climate extreme events, and, in particular, the extreme heavy rainfall. Weather research and forecasting (WRF) model is one of the most well-known numerical models for mesoscale weather prediction. There have been great efforts in making a bridge between mesoscale to microscale for local weather prediction. This study presents an introduction to the coupling of WRF, land surface model (LSM), and urban canopy model (UCM) in order to gain a better understanding in the effect of urbanization on precipitation. The focus is on the comparison of precipitation patterns between 2 models for heavy rainfall events in Bangkok area: WRF without UCM model and WRF with single-layer urban canopy model (SLUCM) in WRF v.3.8.1 with the 0.*25º x 0.25º *Global Forecast system from National Center for Environmental Prediction (NCEP-GFS). The preliminary results showed that the coupled WRF-SLUCM is more suitable than WRF without UCM model and has potential to predict Bangkok heavy rainfall more accurately.*

Keywords: *WRF; Land Surface Model (LSM); Single Layer Urban Canopy Model (SLUCM); local weather prediction*

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1. Introduction

Urban environments, such as high-rise buildings, increased energy consumption, and anthropogenic aerosols, substantially alter the structure of the planetary boundary layer and radiation process that consequently affect all of the climatic elements. The local airflow and circulation are modified resulting in the local weather and climate change within the urban canopy. For rainfall, a significant urbanization effect on the local precipitation has been confirmed in the studies for many urban areas. Urbanization can change precipitation patterns and influence the rainfall level via complex mechanisms depending on many factors like the characteristics of the urban land use, topography, and local/regional water vapor supply. The amount of precipitation can either be enhanced or suppressed over and/or downwind of cities. Some early findings indicated that large urban areas could possibly intensify the rainfall associated with passing storms, while some studies demonstrated that urban and industrial air pollution could prevent precipitation in urban areas (Seino and Aoyagi, 2009; Lin et al., 2016; Li et al., 2013; Han et al., 2014). Therefore precipitation prediction for cities or urban areas must take into account the urbanization effects to improve the prediction.

Bangkok, the capital of Thailand, is the economic center and the heart of the country's investment and development. Bangkok has had rapid growth amidst little urban planning. Heavy rains in Bangkok easily lead to flooding which does not only disrupt normal life of the people, but also cause economic losses. A prompt warning of heavy rains and floods would allow people to prepare and assist in preventing further damage. This requires accurate prediction of local heavy rainfall events. Understanding the clear effects of urbanization on rainfall variability in Bangkok is very important for ongoing climate diagnostics and prediction. Most studies of urbanization impact on precipitation in Bangkok area apply statistical methods to ground based observations and remote sensing observations. Study using numerical simulation modeling for Bangkok is still lacking although there is overwhelming evidence in other urban areas suggesting that numerical prediction models are potentially capable of making accurate and reliable local weather forecasts. Numerical modeling for weather prediction is a scientific tool to simulate physics and dynamic processes of natural and anthropogenic phenomenon. It is the goal of this paper to illustrate the application of Weather Research and Forecasting (WRF) modeling system to Bangkok heavy rainfall events with and without urban parameters. In the next section, we describe the methodology which includes the integrated WRF/urban canopy model as well as data and model configuration. The results and discussion are presented in section 3, and the conclusion is in section 4.

2. Methodology

2.1 WRF-SLUCM model

Single Layer Urban Canopy Model (SLUCM) has a simplified urban geometry, where it takes the 2-D geometry of the buildings and road into account in its surface energy budgets and wind shear calculations. It assumes infinitely-long street canyons parameterized to represent urban geometry, and recognizes the three dimensional nature of urban surfaces. In a street canyon, shadowing from buildings, reflections of short and long wave radiations in the canyon, and trapping of radiation are considered, and an exponential wind profile in the canopy layer is prescribed. Prognostic variables include surface skin temperatures of the roof, wall, and road. These are aggregated into energy and momentum exchange between the urban surface and the atmosphere (Kusaka and Kimura, 2004). For these reasons, SLUCM has gained its popularity for modeling urban–atmosphere interactions. An SLUCM is coupled to the WRF model to better represent the physical processes involved in the exchange of heat, momentum, and water vapor in urban environment in mesoscale model. This improves the description of lower boundary conditions and provides more accurate forecasts for urban regions (Tewari et al., 2007). Thus in this study we used the coupled WRF/Noah/UCM land surface model along with WRF routines.

2.2 Observational data and model configuration

Bangkok is located in the central plains of Thailand at the east longitude of 100° 25′ 27″ – 100° 32′ 58″ and north latitude of 13° 42′ 30″ – 13° 47′ 42″. The city covers area of 1,568.7 km^2, and the number of population in 2015 is 5.7 million (Bangkok Metropolitan Administration, 2015) and hidden population about 2.6 million. The average population density is 3,631 people/km^2. Fig. 1 shows the land use zoning plan in the 2013 (B.E. 2556) Bangkok Comprehensive Plan.

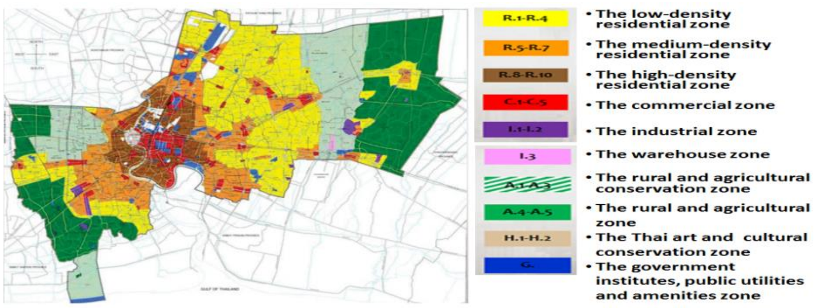

Fig. 1 Bangkok Land Use Zoning Plan in the 2013 (B.E. 2556) Bangkok Comprehensive Plan
Source: City Planning Department, Bangkok Metropolitan Administration (2013)

Two heavy rainfall events in Bangkok on September 13 and 21, 2016 were selected for this study. Rainfall data were from official daily Bangkok rainfall maps provided by the Department of Drainage and Sewerage, Bangkok Metropolitan Administration, http://dds.bangkok.go.th/. These maps were generated from more than 100 rain stations in Bangkok area. Numerical experiments to simulate rainfalls on these 2 days were conducted using the Advanced Research WRF (ARW) version 3.8.1. Quadruple nested domains (Fig 2 - a) with one-way nesting are constructed using spatial grid resolutions of 27, 9, 3 and 1 km, which contain 226x196, 430x340, 430x661, and 94x97 grid boxes, respectively, from north to south and east to west. The physics parameters of the

WRF model used in this numerical simulation include: the Mellor–Yamada–Janjić (MYJ) planet boundary layer (PBL) scheme, Noah LSM, Betts–Miller–Janjić (BMJ) cumulus parameterization option, Ferrier (New ETA) cloud microphysics, RRTMG long wave radiation, Dudhia short wave radiation, and 24 hours spin-up time. The moderate-resolution imaging spectroradiometer (MODIS) land cover was used. The Global Forecast system from National Center for Environmental Prediction (NCEP-GFS) on 0.25º x 0.25º grids were used for the initial and boundary conditions. Fig. 2 - b shows urban area (land use category 13) in the center of Bangkok and cropland area on the outskirts of the city (land use category 12). To investigate the urbanization effects, we set up two models, WRF without UCM and WRF-SLUCM.

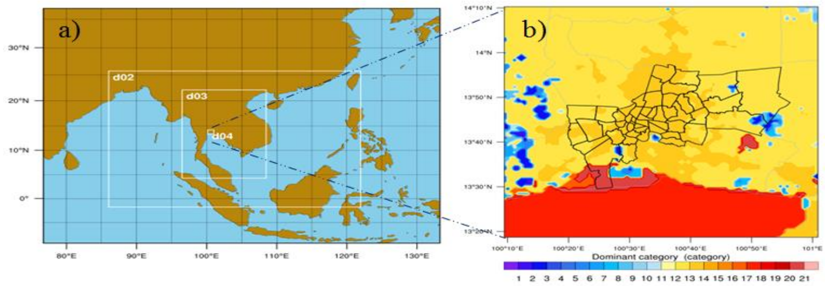

Fig. 2 a) WRF Quadruple nested domain configuration, b) The MODIS land use category of finest domain (d04: Bangkok area). Four dominant categories are: 12) Cropland, 13) Urban and Built-Up, 14) Cropland/Natural Vegetation Mosaic, and 17) Water.

3. Results and Discussion

September 13 and 21, 2016 are representatives of 2 different rainfall patterns; September 13 had isolated heavy rain while September 21 had abundant rain throughout Bangkok. A comparison of cumulative daily rainfalls on these two days between actual rainfall observations and simulation model outputs is shown in Fig. 3. As expected, the simulated heavy rainy (> 35 mm) area identified by WRF-SLUCM covered a larger area than that obtained from WRF without UCM. Simulated rain patterns agreed reasonably well with patterns in real data when rain was abundant and heavy, but the amount of rainfall was predicted higher. For isolated rain, patterns were different. This indicates the chosen physics parameters need some adjustments to work better for Bangkok rainfall simulation. WRF tended to underestimate rainfall in high density residential zone in the central Bangkok, whereas WRF-SLUCM gave a closer estimate. The model that considered urban effects clearly produced a better prediction of heavy rainfall.

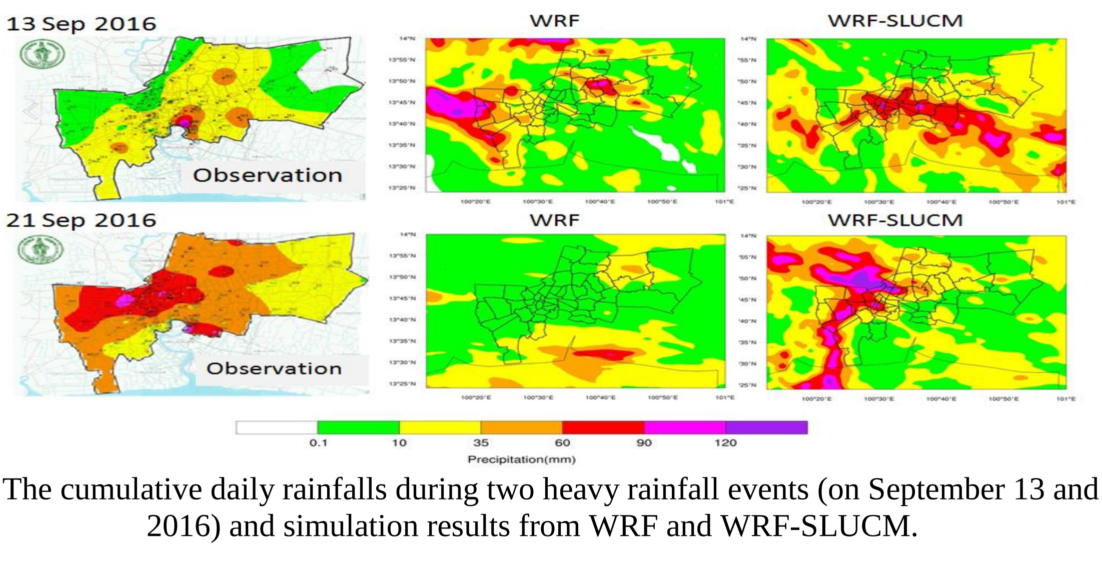

Fig. 3 The cumulative daily rainfalls during two heavy rainfall events (on September 13 and 21, 2016) and simulation results from WRF and WRF-SLUCM.

This study is a pilot study that attempted to explore the possibility of applying the coupled WRF-SLUCM, which is WRF with urbanization factors, to improve the prediction of heavy rainfall in Bangkok area. The land use/land cover information is static input data that must be adjusted to be more realistic and compatible with UCM land use parameters. The urban areas with low or high density residential and commercial/industrial/transportation areas must be separated when simulated. Higher resolution of such information would yield a better result. Many parameters of LSM, PBL, and UCM also need to be estimated and fine-tuned to suit Bangkok area.

4. Conclusion

Numerical simulations with coupled WRF-SLUCM showed promising results of identifying heavy rainfall patterns. They supported the fact that the inclusion of urbanization effects in numerical weather prediction models could improve the performance of heavy rainfall prediction for Bangkok. More experiments are underway to validate the approach and to examine the effects of factors that could be related to heavy rain, which will help in parameter setting.

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