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Investigation of the meteorological effects of urbanization in recent decades: A case study of major cities in Pearl River Delta

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ABSTRACT

This paper investigates the evolution of the climatological effects of urbanization in the major cities of the Pearl River Delta region of China during the summer season. Land use data representing the 1990s, 2000s, and 2010s are obtained by classifying the land use from collected Landsat images. This classification standard follows the guidelines of land use classification from the World Urban Database and Access Portal Tools (WUDAPT). Before the model simulation, the WUDAPT land use categorization was remapped according to the United States Geological Survey (USGS) land use classification. The Weather Research and Forecasting (WRF) model was then applied under the same initial and boundary conditions with respect to different land use data. Spatial comparison and statistical analysis reveal a general increase in temperature (approximately 1 °C) and heat index (2 °C at night) and a deceleration of wind speed over time (around 0.5 ms^{-1}) when compared with the 1990s. These impacts are due to urbanization. Moreover, simulation shows that the sensible heat flux is increased, whereas the latent heat flux is decreased because there was less vegetation and more impervious surfaces. These findings can let planners and governors have a quantitative understanding about the impact of urbanization on local climatic conditions.

1. Introduction

Habitat III, a conference on housing and sustainable urban development organized by the United Nations, created a new global urban agenda in 2016. According to the Quito Declaration, the agenda focuses on "Sustainable Cities and Human Settlements for All," and one of the main objectives is to create urban resilience (UN Habitat, 2016).

One of the major factors in building urban resilience is the ability to mitigate extreme weather events. Various models and simulations can be applied to understand the future urban environment and to review the effects of past urbanization. For instance, weather models have been used to predict heat stress for some metropolises in Japan in the 2070s (Kusaka et al., 2012). By referring to the simulation results, governments can make appropriate plans to mitigate the potential problems. Repetition of this process and

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analysis of more simulation results can allow a better understanding of the future environment and a consequent improvement in urban resilience.

Because of the increasing population in urban areas, it is also increasingly important to understand the urban environment and create urban resilience, especially in the Pearl River Delta (PRD) region in southern China. Since the Chinese economic reform in the late 1980s, the entire region has undergone rapid urbanization and has become a megacity. Such urbanization has inevitably modified the land surface properties and hence the local climate. Moreover, urbanization will continue according to The PRD region Reform and Development Plan (2009–2020), which may cause even greater changes. The associated environmental pressures will exacerbate the already serious urban heat island (UHI) effects, worsen heat stresses and cause high public health risks. Therefore, it is important for urban planners to understand the meteorological effects of urbanization when they plan the future development.

In recent decades, many efforts have been made to understand how urban development alters the weather. One well-known finding is the UHI effect, which accounts for the higher temperatures in an urban area than those in the surrounding rural areas. Many researchers have evaluated the intensity of the UHI effect in various cities by calculating the temperature difference between urban and rural areas in cities such as New York (Bornstein, 1968) and Seoul (Kim & Baik, 2002). Precipitation events are also modified in urban areas. From case studies with observation data, Bornstein and Lin (2000) found that the UHI effect could induce the formation of thunderstorms during calm wind conditions and that moving thunderstorms tend to split and avoid crossing urban areas because the buildings act as obstacles.

Given such profound effects of urbanization on the local weather, simulations from weather models are used to review the effects of urbanization. One of these weather models is the Weather Research and Forecasting (WRF) model (Skamarock et al., 2008), a nonhydrostatic mesoscale weather model that has been widely used for simulation. The WRF model can be coupled with different models during the simulation, such as a land surface model to consider modified physical properties due to different land uses or an urban canopy model to account for the effects of anthropogenic heat and buildings. It has thus been applied to evaluate the meteorological effects of urbanization in different regions; for instance, Miao et al. (2011) used the WRF model to understand the effects of urbanization on a strong precipitation event in Beijing, Zhang et al. (2010) applied it to review the effects of urbanization on the temperature in the Yangtze River Delta region, and similar review was also performed for the PRD (Wang et al., 2014). By incorporating the results from a global climate model into the WRF model, Kusaka et al. (2012) predicted the future strength of the UHI effect and its associated heat stress in major cities in Japan, and Chotamonsak et al. (2011) examined future temperature and precipitation changes in Southeast Asia.

Moreover, because this study focuses on reviewing past urbanization, land use data from the World Urban Database and Access Portal Tools (WUDAPT) are used. The WUDAPT aims to collect urban morphology and land use data for climate studies and modeling applications for different cities around the world (Ching et al., 2014). The collected information for a city can be divided into different levels of detail, from land use classification and ranges of related parameters ("Level 0 data"), gradually progressing to sufficient and precise parameters for boundary-layer models ("Level 2 data"; Mills et al., 2015).

Recent research focus has centered on the Level 0 data of the WUDAPT project. One study showed that such data improve simulation accuracy WRF (Brousse et al., 2016). More cities have undergone classification to obtain Level 0 data, including Chicago and Vancouver (Bechtel et al., 2015). And also when WUDAPT Level 0 data with resolution of 500 m, it may be suitable for WRF simulation as input data (Wang et al., 2018).

Although there is an active development of WUDAPT, research on using WUDAPT data to evaluate the meteorological effects of urbanization is yet to be fully established, especially applying multiple WUDAPT data to the WRF model to realize the urbanization process. As such, in this study, the WRF model was chosen to simulate and review the effects of urbanization in the PRD region. A simulation period from June to August, which is the summer season in the region, was used to highlight these effects. Because this study focuses on reviewing past urbanization, three sets of land use data from the WUDAPT are used in the WRF model to represent land use in the PRD region in the 1990s, 2000s, and 2010s so as to realize the urbanization process.

2. Method

2.1. The land use data

To investigate the climatological effects of the significant urbanization in the PRD over the past three decades (from the 1990s to 2010s), land use data from this period are necessary for model simulation. However, it is difficult to obtain accurate historical land use data from local governments. To overcome this issue, the land use products created by the WUDAPT are used (Cai et al., 2016).

Following the WUDAPT's guideline with similar techniques used by Cai et al. (2016), land use data covering the PRD region for 1988, 1999, and 2010 were produced. The accuracy of the classification method was also evaluated (Ren et al., 2016). The classification procedures are as follows.

1. The selected Landsat 5 images of 1988, 1999, and 2009 are collected and preprocessed by resampling and clipping.
2. Training samples of each local climate zone (LCZ) are created in Google Earth using the digitized neighborhoods that typify the LCZ types.
3. The Geographic Information System (GIS) is used to classify the selected Landsat 5 images into LCZ types by using the neighborhoods as training areas.

After obtaining the land use data, postprocessing is required. The land use classification system in the WUDAPT adopts the LCZ