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Sensitivity of precipitation statistics to urban growth in a subtropical coastal megacity cluster

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ABSTRACT

This short paper presents an investigation on how human activities may or may not affect precipitation based on numerical simulations of precipitation in a benchmark case with modified lower boundary conditions, representing different stages of urban development in the model. The results indicate that certain degrees of urbanization affect the likelihood of heavy precipitation significantly, while less urbanized or smaller cities are much less prone to these effects. Such a result can be explained based on our previous work where the sensitivity of precipitation statistics to surface anthropogenic heat sources lies in the generation of buoyancy and turbulence in the planetary boundary layer and dissipation through triggering of convection. Thus only mega cities of sufficient size, and hence human-activity-related anthropogenic heat emission, can expect to experience such effects. In other words, as cities grow, their effects upon precipitation appear to grow as well.

Introduction

In this short paper, we present the results of a numerical experiment to investigate how the size of an urban area can affect the local precipitation statistics. The question was motivated by observations made in Hong Kong, situated in the Pearl River Delta at the South China Sea. Mok et al. (2006) reported that urban and rural heavy precipitation trends diverge: heavy rainfall in urban Hong Kong seems to increase at a larger rate than heavy precipitation on offshore islands away from the city. This raises an important question as to whether the difference is locally forced or a side effect of larger scale changes of flow patterns in the atmosphere. From the Metropolitan Meteorological Experiment METROMEX (*e.g.*, Ackerman et al., 1978; Huff and Changnon, 1972; Changnon, 1979), intensification of rainfall downstream of St. Louis has been observed. Recently, similar observations were reported and studied in Beijing (Yu and Liu, 2015; Yu et al., 2013). Other authors reported that the affected areas also expand over cities (*e.g.*, Atkinson, 1971; Bornstein and LeRoy, 1990; Bornstein and Lin, 2000; Shepherd et al., 2002; Dixon and Mote, 2003; Mote et al., 2007; Meng et al., 2007; Krishtawal et al., 2010; Niyogi et al., 2011; Yu et al., 2013). Trenberth et al. (2003) gave an overview about the changes to precipitation statistics that are to be expected when evaluating footprints of climate change as a long-term forcing trend. Most studies related to local forcing emphasized the effects on the temperature and the secondary circulation (*e.g.*, Vukovich et al., 1976; Vukovich and King, 1980). Different interaction mechanisms of urban rainfall have been discussed in the past, mostly focusing on the mechanical and microphysical effects (*e.g.*, Pielke et al., 2007). Recently, we proposed a thermodynamic contribution as well based on the results of a numerical experiment in which the simulated rainfall statistics in the urban Pearl River

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Delta responded sensitively to anthropogenic heat flux (AH) at the urban surface, locally causing significant increases of heavy precipitation (Holst et al., 2016). Following up on this work, we now design a relatively simple experiment to test whether the previously described effect could occur in smaller towns as well, if forced by the same magnitude of AH. The setup of the numerical model and the method of modifying the land surface information about urban extend is described in Section 1. An important description of the sampling area and its implications is pointed out in Section 2 and the results are shown in Section 3 together with an interpretation. Finally, the portability and significance of the findings are discussed in Section 4.

1. Model system setup and experiment design

Wu et al. (2015) proposed an indexing method to evaluate the impact of rainstorms in Hong Kong and rank the storms. Their work suggests a number of interesting cases to study, out of which we chose the record-breaking case on 7 June 2008. The case is of substantial interest in several ways because it shows a rather typical synoptic pattern that recurrently has been the cause of rainstorms in the region in the past. Such a pattern consists of a monsoon trough, located slightly north of and parallel to the coastline. In this particular case, the trough formed south of the coastline and over the period of several rainy days the large scale-flow advected the trough towards the north (refer to Fig. 1 for the early development stage). This system draws moisture from the sea and if in the right position, such system has the potential to cause torrential rainfall wherever the moist air is forced to rise in the convergent belt. Rain gauge and anemometer observations show southerly winds causing high instantaneous rainfall rates in Hong Kong (not shown) and radar reflectivity imagery shows a rain belt swiping over the region (Fig. 2a). This storm has been chosen as a benchmark case to investigate as to how the spatial extent of an urban area affects the flow and precipitation behaviour.

We utilize the Weather Research and Forecast Model (WRF, Skamarock et al., 2008) to simulate this case under the influence of several different lower boundary conditions. The two-way nested daughter domains and their urban areas are shown in Fig. 3a, where the outermost domain resolves on 25×25 km^2 grid cells and the nests obey nesting ratios of 1:5. The initial and lateral boundary conditions were obtained from the National Center for Environmental Prediction Final Reanalysis data set (FNL; National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce (updated daily since 2000)), see http://dx.doi.org/10.5065/D6M043C6). The model physics and parameterization are set up in a similar way as described in Holst et al. (2016).

The essential and important modifications have been made in the realm of the lower boundary conditions, prior to pre-processing. The models pre-processing system evaluates the spatial structure of the domains lower boundary by analysing a stationary surface variable that stores the fraction of different land use categories as defined in the model parameters. This fractional variable should add up to one, if summed over all

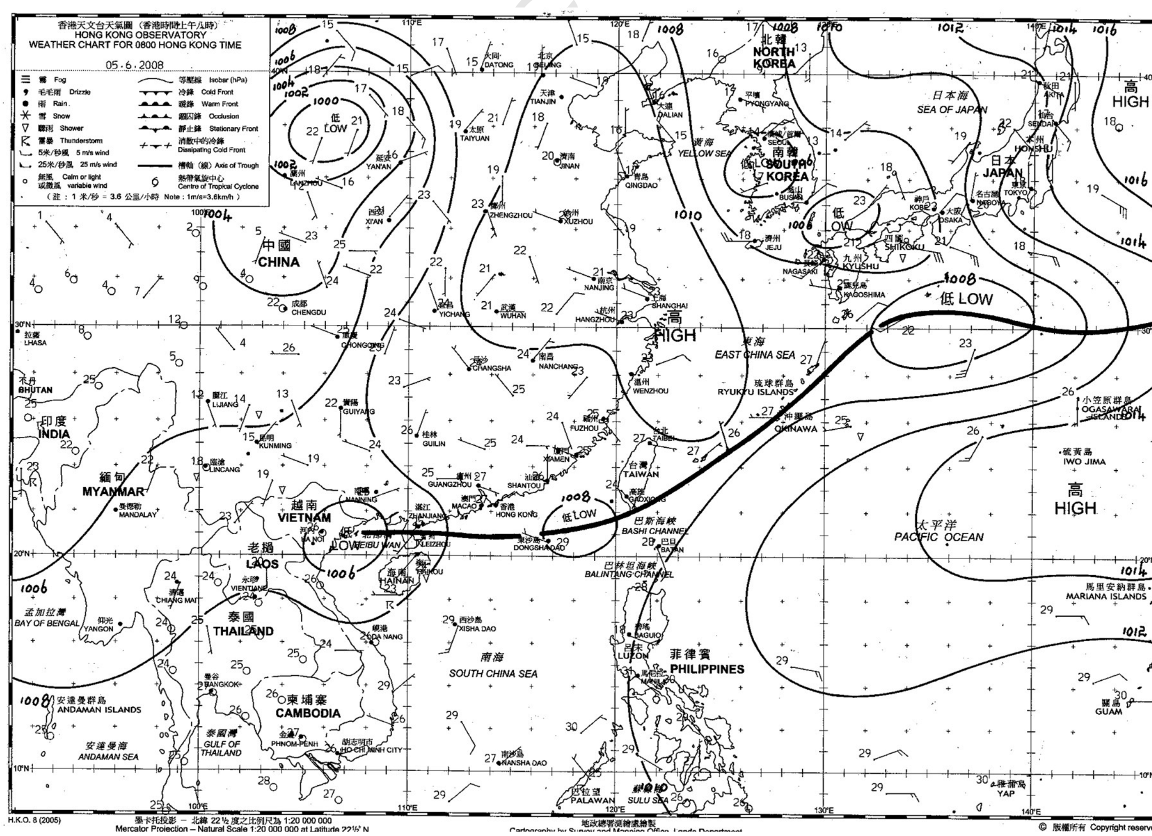

Fig. 1 – Surface weather chart depicting the mean sea-level pressure (contours) and station weather conditions on 5 June 2008, at 0800 Hong Kong time from the Hong Kong Observatory data archive (http://envf.ust.hk/dataview/hko_wc/current/.