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Editorial

Urbanization as a major driver of urban climate change

1. Definition

Urbanization is the process of urban development and is characterized by the expansion of built-up areas and the growth of population in cities and towns. In the contexts of global change research and climatic science, urbanization is usually regarded as a special manifestation of land use and land cover (LULC) change on a local scale.

Urbanization affects the local land surface, altering the surface climate in urban areas. The urbanization-induced change in surface parameters is a fundamental reason for the formation and evolution of urban climates. The urbanization-induced climate change (UICC) in urban areas becomes a major component of urban climate change (UCC) which is additionally affected by global climate change (GCC) and regional climate change (RCC) resulting from large-scale anthropogenic and natural forcings, and by natural climate variability (NCV) resulting from the internal oscillations of climatic system modes (Fig. 1). In decadal to centennial scales, the large-scale anthropogenic forcings include the increased atmospheric greenhouse gas concentration, aerosol emissions and LULC change, and the large-scale natural forcings include solar activity and volcanic eruptions. It is obvious that the UCC represents one of the most complicated changes in climate on the earth surface, caused by all the external forcings and internal variability in various spatial scales, but obviously urbanization is one of the major drivers. The climatic effect of urbanization or the UICC thus is a matter highly worthy of attention.

2. Urban climate

The surface climate within a city is obviously different from the climate of its surrounding suburbs (Oke, 1987). This unique local city climate is called urban climate and is generally characterized by higher surface air temperature, weaker mean wind speed, and lower relative humidity compared with the suburbs and countrysides (Landsberg, 1981; Oke, 1987). The phenomenon in which urban climates exhibit relatively higher temperatures is called the urban heat island (UHI) effect.

The features of UHI in major cities of the world have been extensively studied in the 20th century (Arnfield, 2003). Great UHI effects have been reported for big cities (Arnfield, 2003; Grimmond, 2006). For example, the annual mean UHI intensity of Beijing city within the Sixth Ring Road was 1.2 °C from 2007 to 2010, and the winter mean UHI intensity in the central urban area (within the Fourth Ring Road) reached 2.2 °C; the central urban area of winter nighttime registered a mean UHI intensity of up to 3.0 °C (Yang et al., 2013b). An UHI intensity of up to 10.0 °C has been reported for some big cities in the Northern Hemisphere on clear and calm winter nights (Stewart and Oke, 2012).

The formation of urban climates, including the UHI effect, is closely related to the structure, coverage, fabric, and metabolism of the built-up area, which results in the substantial modification of surface energy and water balance (Oke, 1988). The materials used for pavement and buildings in urban areas, such as concrete, asphalt, and bricks, have significantly different thermal bulk properties (heat capacity and thermal conductivity) and radiative properties (albedo and emissivity) from those of the surrounding suburbs (Oke, 1987). They also modify the surface hydrologic properties through the increase of impervious surface, which reduces rainwater infiltration and evaporation, and increases surface runoff. The multi-reflections of sunlight among high-rise buildings are important as well, which significantly increase the absorptivity of heat in the urban canopy (Fig. 2). Furthermore, waste heat from winter heating and summer conditioning along with the air pollution from other human activities within cities are important. Thus, changes in the energy and water balances in the urban surface will occur, resulting in an increase (decrease) in the absorbed (reflected) solar short-wave radiation during the daytime, a decrease in the emitted ground long-wave radiation into the sky, and an

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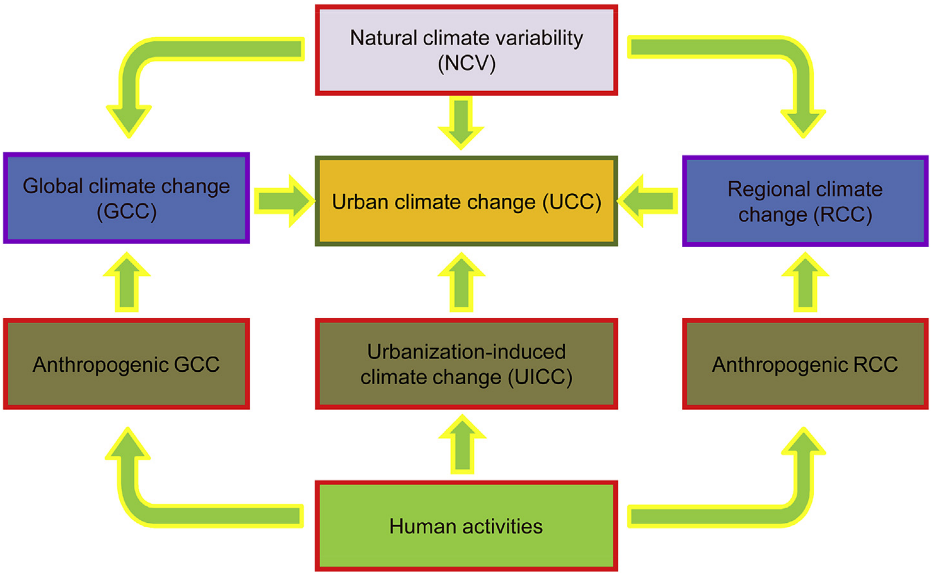

Fig. 1. Schematic diagram of interactions among various spatial-scale climate change and variability.

increase (decrease) of sensible (latent) heat flux. This, in mid- to high latitudes, in turn causes a higher surface air temperature, in particular during the nighttime, a smaller diurnal temperature range (DTR), a smaller near-surface wind speed, and a generally lower (higher) relative humidity in urban areas of humid (arid) regions.

The tall buildings in the urban areas of mega cities increase the surface aerodynamic roughness, strengthening the air convection and resulting in stagnant weather systems. These effects, in combination with the thermal effect from UHI, increase the precipitation amount and/or intensity in central urban areas and/or leeside areas of prevailing airflows, increasing the frequency and intensity of short-duration, intense precipitation events.

To a certain extent, anthropogenic air pollution within cities may weaken (strengthen) urban warming rates in the daytime (nighttime), leading to a further decline in DTR. The greater concentration of aerosols in the middle to lower troposphere will also affect precipitation in urban areas by modifying the micro-physical processes of clouds (van den Heever and Cotton, 2007; Rosenfeld et al., 2008).

3. Urbanization-induced climate change (UICC)

In recent years, the UICC is attracting much attention, largely because of renewed enthusiasm for investigations of systematic bias in the long-term land surface air temperature data series in East Asia (e.g., Ren, 2003; Ren et al., 2005;

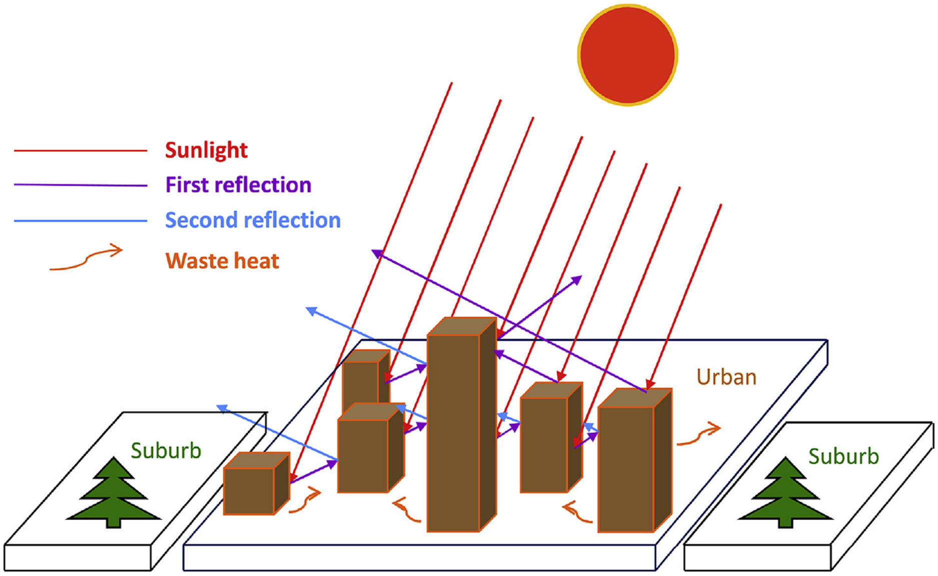

Fig. 2. Schematic diagram of UHI formation mechanism in a city.

Chung et al., 2004; Fujibe, 2009, 2011). These studies recognized that the urbanization-induced warming observed in urban stations is superimposed onto the regional background of warming climate, greatly complicating the determination of actual climate change in both regional and global scales.

A prominent manifestation of UICC is the ever-increasing UHI intensity and the generally consistently rising surface air temperature in urban and nearby areas. Kalnay and Cai (2003) employed the observation−reanalysis method to determine that urbanization and larger-scale land-use changes led to a 0.27 °C increase in mean air temperature and a significant decrease in DTR in the continental United States during the 20th century. Zhou et al. (2004) revealed similar significant warming from urbanization and land-use change in southeastern China using the same method with that by Kalnay and Cai (2003). Grimm et al. (2008) showed that downtown temperatures in cities of the United States increased by 0.14−1.1 °C per decade since the 1950s. However, until recently, the quantitative identification of the urban signal in historical surface air temperature series remained difficult because of its strong dependence on the selection of representatively rural stations and the data inhomogeneities of both rural and urban stations.

Applying the homogenized datasets from all the observational stations and more objective methods to select rural stations, Ren et al. (2005, 2008) and Zhang et al. (2010) identified the urbanization effects on the annual and seasonal surface air temperature trends for various urban groups and the national reference climate and basic meteorological stations (RCBMS) as a whole from 1961 to 2000 over North China and from 1961 to 2004 over all of mainland China. They found that the stations near large cities in North China registered the biggest annual mean urbanization-induced warming of 0.16 °C per decade, whereas the small city station group had the smallest urbanization-induced warming of 0.07 °C per decade. The RCBMS as a whole also witnessed significant annual mean urbanization-induced warming of about 0.11 °C per decade for North China and approximately 0.08 °C per decade for mainland China; the urbanization-induced warming accounted for 37.9% and 27.3% of the overall warming recorded at the stations, respectively. Obviously, the urbanization-induced changes in the temperature indicators are larger for the stations near big cities or the stations in central areas of the cities.

The abovementioned results are generally supported by the other studies that used different procedures (e.g., Zhou et al., 2004; Chu and Ren, 2005; Hua et al., 2008; Tang et al., 2008; Ren and Ren, 2011; Yang et al., 2011, 2012; Wang and Ge, 2012; He et al., 2013). Furthermore, the large and significant urbanization-induced warming has contributed to changes in extreme temperature indicators of the RCBMS in mainland China (Zhou and Ren, 2009, 2011; Zhang et al., 2011; Ren and Zhou, 2014). For example, in North China as well as in mainland China as a whole, the minimum temperature-related extreme temperature indices at the stations experienced much larger warming trends than the mean temperature (Zhou and Ren, 2009, 2011). Annual mean urbanization effects on the daily minimum temperature (Tmin), maximum temperature (Tmax), mean temperature (Tavg), and DTR trends of the RCBMS from 1961 to 2008 over mainland China reached 0.070 °C per decade, 0.023 °C per decade, 0.047 °C per decade and −0.049 °C per decade respectively, all statistically significant at the 0.05 confidence level (Fig. 3) (Ren and Zhou, 2014).

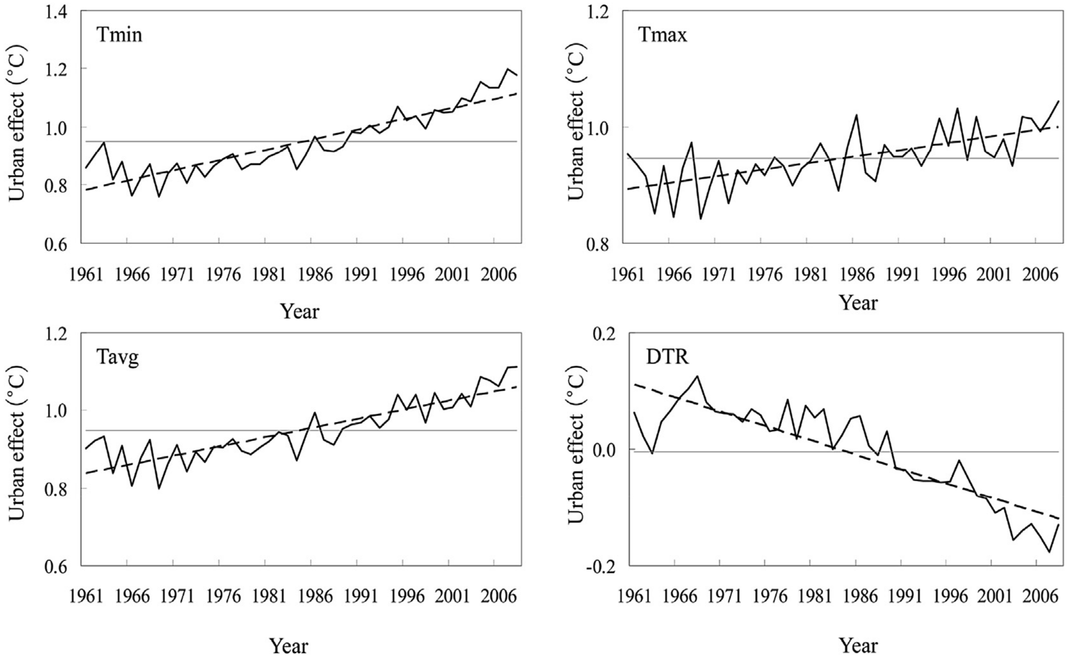

Fig. 3. Annual differences (urbanization effects) between the national climate reference/basic meteorological stations and the reference stations for Tmin, Tmax, Tavg, and DTR in mainland China during 1961−2008 (Ren and Zhou (2014), with permission from *Journal of Climate*).

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The waste heat released by heating is larger in winter nighttime in mid- to high latitudes, whereas heat released by conditioning is larger in summer daytime in mid- to low-latitude zones. This may partially explain the more rapid increases in winter (summer) minimum (maximum) temperature and mean temperature at the RCBMS in northern (southern) China observed over the past decades (Ren and Zhou, 2014).

It is worth indicating that the reported urbanization effects in the previous studies were actually observed assembly at the RCBMS or urban stations, which were typically located in the outskirts of cities and towns in mainland China, and the temperature increases occurring at the stations near big cities or in the centers of all the cities and towns would be larger.

Urbanization has also led to discernable changes in precipitation, relative humidity, and near-surface wind speed. Annual and rainy season precipitation generally increases, relative humidity usually decreases and near-surface wind speed mostly declines in urban areas compared to the surrounding suburbs.

Increases in the amount of precipitation and the frequency of short-duration, intense precipitation events over built-up areas and leeside of mega cities have been observed (Changnon, 1979; Landsberg, 1981). In the city of Atlanta in the United States, nighttime rain frequency during late spring and summer increased in urban areas compared to the rural areas, likely resulting from the enhanced UHI effect (Dixon and Motte, 2003). More frequent and intensive short-duration precipitation events during summer in built-up areas have also been reported for the Chinese mega cities Beijing and Shanghai for the past decades (e.g., Sun and Shu, 2007; Wang et al., 2007; Yin et al., 2011; Liang et al., 2011; Yang et al., 2013a). Yang et al. (2013a) and Song et al. (2014), for example, reported a generally larger warm-season total precipitation and more frequent late-evening short-duration rainfalls in the Beijing metropolitan area than the surrounding suburbs. The opposite effects have been observed in other studies, however, with Kaufmann et al. (2007) showing a rainfall reduction during dry season in the urbanized Pearl River Delta (PRD) of southern China over the period 1988–1996.

4. Main findings of the works included in this special topic

This special topic includes three papers: two examine the effects of urbanization on the thermal environment near stations in Anhui province, eastern China, and precipitation over the PRD in southern China, and one applies a climatic and environmental assessment approach to plan eco-city construction in the Lake area, Beijing.

Shi et al. (2015) used Landsat Satellite-based land surface temperature and LULC data from 1990 to 2010, to examine urbanization effects on the thermal environments around five meteorological stations of Anhui province. They found that LULC around the stations changed significantly because of urban expansion, leading to an obvious urbanization effect on the spatial–temporal distribution of land surface temperature, with the normalized land surface temperature and normalized difference vegetation index (NDVI) exhibiting strong inverse correlations. This finding suggests an important role of the specific station location in/near a city in monitoring surface air temperature along with the unavoidable urbanization-induced warming near the stations. The same group (Yang et al., 2012) applied satellite data to classify the 52 meteorological stations of Anhui province into urban, suburban, and rural stations and compared the linear trends of surface air temperature among the three station groups. They were able to determine urbanization-induced increases in annual mean minimum temperature, annual mean maximum temperature, and annual mean temperature of 0.238 °C per decade, 0.063 °C per decade, and 0.163 °C per decade, respectively, corresponding to urbanization contributions of 45.2%, 14.3%, and 35.8%, respectively, for the urban stations of the province from 1970 to 2008.

Chen et al. (2015) investigated the possible urbanization effect on precipitation over the metropolitan area of the PRD, southern China, based on high-resolution satellite data. The PRD metropolitan area has undergone rapid development and urbanization over the past three decades, becoming one of the three huge metropolitan areas in mainland China. Thus, the PRD area provides a good opportunity to examine the effects of urbanization on climate. By comparing precipitation in urban and rural areas, Chen et al. (2015) found that the urban areas experience less frequent and shorter-duration precipitation events and larger hourly mean rainfall in the afternoon. Interestingly, they also found significant differences in hourly mean rainfall diurnal variations between urban areas and rural areas; rainfall in the late afternoon, in particular, from 15:00 to 18:00 Beijing Time, usually exceeded 50 mm in the urban areas, almost 100% larger than the amount in rural areas (Fig. 7 in Chen et al. (2015)). This phenomenon might be related to the stronger convection and the stagnating effect of synoptic systems over tropical urban areas because of the larger late afternoon UHI intensity and the increased surface roughness.

Using the development of the Yanqi Lake area of Beijing as an example, Fang et al. (2015) developed a set of assessment methods for the climatic and environmental conditions to inform eco-city planning and construction. These methods mainly considered ventilation and thermal conditions. The results showed that construction according to the original development plan would result in a decrease in ventilation potential and poorer thermal conditions during summer due to the weakening near-surface wind speed and enhanced UHI intensity. The worsening climatic and environmental conditions will be more obvious in the core zone of the development demonstration area, although they are still at a favorable level according to the criteria set in the assessment. Accordingly, the authors suggest the construction of northwest–southeast-running ventilation corridors to allow the fresh air from the prevailing northwesterly to enter the urban area. They also recommend that the summer cold source lands like forests and lakes be retained in the core zone, among other measures. This study provides a good case for urban climatology and urban climate change research to participate in urban development planning.

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5. Conclusive remarks

Although urban climatology has a long history, urban climate change research has just come into being. The urban climate change results from urbanization processes as well as the background change in climate including low-frequency climate variability and the anthropogenic global and regional climate change (IPCC, 2013). Therefore, understanding the multiple drivers and their interactions within urban domains to predict the urban climate change and benefit society and urban development remains a big challenge for climatic researchers. Many scientific questions and technological problems need to be addressed in this field.

China and other East Asian countries have undergone an unprecedented urbanization in the last decades to century. The urbanization rates of both China and the world average (in terms of population) have just passed 50% (UNDP, 2013). The rapid urbanization processes have been accompanied by significant changes in climate over urban areas. Furthermore, Temperate East Asia is remarkably affected by larger-scale climate change and variability, including the East Asian monsoon variability and global warming. Thus, this region will provide a valuable opportunity for scientists worldwide to study UICC and urban climate change.

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