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Urban climate in the Tokyo metropolitan area in Japan

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ABSTRACT

Long-term climate changes related with urbanization in Tokyo, Japan, and recent temperature and heavy rainfall distribution in the Tokyo metropolitan area are reviewed. A relatively high temperature increase in annual mean temperature at the rate of 3.0°C/century was detected in Tokyo for the period 1901–2015. Some observational evidence showed the existence of both thermal and mechanical effects of urbanization on recent heavy rainfall occurrences, and modeling studies also support precipitation enhancement. Urban influences were recognized in other climatological elements, such as number of fog days, relative humidity, and wind circulation.

Contents

Introduction

Urban climate and global warming are two major climate changes induced by human activities. The former is more local in nature, and thus needs careful examination based on precise local information. The Tokyo metropolitan area, located in the Kanto Plain in Japan, is one of the largest urbanized areas in the world. Tokyo has developed into a big city over the course of a long history.

Population increase and urban expansion in the Tokyo metropolitan area started in the beginning of the 17th century when Ieyasu Tokugawa set up the central Shogunate at Edo (currently Tokyo) in 1603. After the collapse of the Edo Shogunate in 1868, the Meiji Era started. The city of Edo

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changed its name to Tokyo, which means eastern capital. The capital city of Japan moved to Tokyo in 1869 from Kyoto, which had been the capital city since 794.

At that point, the Japanese industrial revolution began. The population in Tokyo was approximately 860 thousand in 1872 when the official collection of population statistics started. The population of Tokyo steadily increased to 7.3 million until 1942, when many Japanese cities including Tokyo were burnt out by American bombing during World War II (WWII), drastically decreasing the Tokyo population by 1945 to less than 3.5 million. Part of the observed temperature decrease in Tokyo at that time may have been affected by such reduced urban population and activities (Fig. 1), although more detailed examination is needed to verify this statement. After the end of WWII, rapid population increase continued until the early 1960s, when the population of Tokyo exceeded 10 million. The rate of increase of population in the Tokyo metropolitan area slowed down, with a current population of approximately 11.3 million. On the other hand, the population of the three neighboring prefectures continued to increase until recently, and the total population including these neighboring prefectures exceeded 30 million in the 21st Century (Fig. 1).

Official meteorological observations in Tokyo started in 1875. Since then, the Central Meteorological Observatory (until 1956) and the Japan Meteorological Agency (JMA) continued their observations for more than 140 years, although they moved their observation site three times, in 1882, 1923 and 2014. As early as in the 1920s and 1930s, urban warming has been recognized by observational studies in Japan. For example, Fukui and Wada (1941) presented the temperature distribution during one night on March 1939, showing an approximately 5°C difference between the city center and suburban area (Fig. 2). Extensive research works have been conducted on the urban climate in Japan during the most recent six decades. They are reviewed by Yamashita (1990), Kusaka (2008), and Nakagawa (2011). More recently, Fujibe (2011) reviewed urban climate studies in Japan focusing on long-term warming. Fujibe (2012a, 2012b) further reviewed more general features of urban climate in Japan. Mikami et al. (2011a, 2011b) edited a special issue on urban climate in the Japanese Journal of Geography, and Kanda (2012) edited review articles in the Japanese Meteorological Research Note. JMA has reported their heat island monitoring results every year since 2005, and the latest report was published in 2016 (JMA, 2016). Although excellent reviews have been conducted (*e.g.*, Arnfield, 2003; Collier, 2006; Roth, 2007), these recent Japanese results have not been well known, since some of them were written only in Japanese. The present paper reviews urban climate, mainly in the Tokyo metropolitan area in Japan.

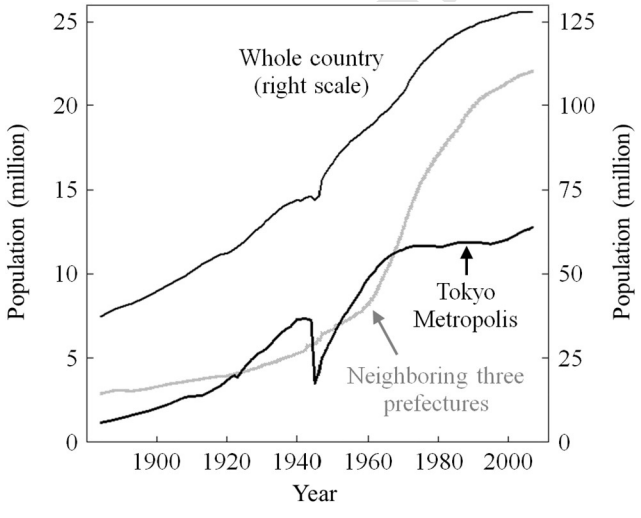

Fig. 1 – Long-term changes of population of Tokyo Metropolis and three neighboring prefectures (Saitama, Chiba and Kanagawa), as well as population changes in the whole country of Japan (Fujibe, 2011).

1. Urban heat island

After the pioneering study of Fukui and Wada (1941), the temperature field of the Tokyo heat island was studied by many researchers from routine (*e.g.*, Maejima et al., 1980; Kawamura, 1985) and mobile observations (*e.g.*, Aida and Yaji, 1979; Yamashita, 1996). As JMA operates only 4 Automated Meteorological Data Acquisition System (AMeDAS) stations in central Tokyo, complementary information based on routine data has been collected using networks of Air Quality Monitoring System (AQMS) stations deployed by municipalities to study the urban climate (*e.g.*, Yamazoe and Ichinose, 1994; Mikami et al., 2004). As introduced by Yokoyama et al. (2008) and Akasaka et al. (2011), the Tokyo Metropolitan Research Institute for Environmental Protection (TMRIEP) and Tokyo Metropolitan University (TMU) established a system for dense temperature and other meteorological observations named the Meteorological Environmental Temperature and Rainfall Observation System (METROS) starting in 2002. The wider metropolitan area over the Kanto Plain has been covered by the Extended-METROS system since 2006. The results of these observations are presented in Fig. 3 (Mikami et al., 2011a, 2011b). Since Tokyo is located in the coastal area, and is affected by the Asian monsoon circulation, the temperature distribution in summer and winter is somewhat different, and the urban effect is masked by the local land-sea effect. Takahashi et al. (2011a, 2011b) and Takahashi and Takahashi (2013, 2014) used the surface pressure data of METROS to detect a pressure deficit in central Tokyo resulting from the hydrostatic effect of the nighttime heat island. The effect of sea breeze on the daytime urban heat island in summer was presented in Yamato et al. (2011). Takahashi et al. (2014) showed the detailed temperature distribution in the Tokyo metropolitan area under clear sky and weak wind conditions in winter. They pointed out different nighttime cooling conditions within the city, implying the effect of the inner city building structure. For the vertical structure of the heat island, Yoshikado and Kondo (1989) found an enhanced mixing layer in central Tokyo in the summer daytime.

Fig. 4 shows the departure of the annual mean temperature (Tmean) from the average during 1901–1920 at Tokyo and Hachijo Island (Hachijo-Jima) in the North Pacific, which is located 300 km south of Tokyo and may indicate the

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