New urban heat island monitoring system in Tokyo metropolis

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Abstract

Using high density temperature data (Extended METROS), interaction between the urban heat island and local circulation in Tokyo metropolis in warm season are analyzed. The study period is May to August in 2006 and 2007, and we selected the 14 days during which typical sea breeze fronts were found. Higher temperature area appeared in and around Kawagoe City at 14 o'clock and in northern Kanto plain at 16 to 18 o'clock. These regions are approximately anterior to the sea breeze front. A high temperature belt extending from Kumagaya city to central Tokyo is shaped when southerly wind flow is predominant all over Kanto plain.

Key word: urban heat island, Tokyo metropolis, high density temperature data, local circulation

1. Introduction

Tokyo metropolis is one of the largest urban areas in the world. The urban area extends to 50km from central Tokyo, and the population has about 30 million people. Therefore, urban heat islands have been rapidly intensified for the last several decades caused by the increase in anthropogenic heat release and the changes in surface materials in urban areas. In fact, as an urban area has spread out to the suburbs during the high economic growth period, urban heat island area also expanded, and daily mean temperature rises 3 degrees C at central Tokyo in 100 years during the 20th century. This increasing rate of temperature is larger than that of any other large city in the world.

Tokyo metropolis is placed in the southern part of Kanto plain which is surrounded by mountains and the Pacific Ocean. Local circulation develops in Kanto plain when the pressure gradient is weak, especially in the afternoon of

warm seasons. In such meteorological conditions, sea breeze penetrates into inland, flowing together to inland valley winds. Additionally, a flow into the thermal low pressure which is developing on the mountains around central Japan also join that flow. As a result, southerly wind from the sea toward the inland can be seen over Kanto plain in the afternoon. This southerly wind is called "extended sea breeze" (Kondo, 1990). This local circulation affects urban heat island in the daytime during warm seasons. In the coastal regions including central Tokyo, a temperature rise is suppressed due to the advection of cold air from the sea (Kuwagata et al., 1990). On the other hand, northwestern central Tokyo becomes hot in the afternoon. When the southerly sea breeze flows into central Tokyo area, the northerly wind blowing into central Tokyo exists (Yoshikado, 1992). This direction is a reverse of the sea breeze, and thus the timing of sea breeze penetrating into the inland becomes



Fig.1 Location of study area. Red box represents the range of Fig. 2 and 3.

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late. As a result, the lee area of central Tokyo may become hot (Kusaka et. al., 2000) .

In order to verify and clarify the mechanism of interaction between the urban heat island and the local circulation, detailed temperature variations in time and space should be analyzed. However, official meteorological stations such as AMeDAS by JMA(Japan Meteorological Agency) are sparsely distributed in urban area, which makes difficult for analyzing urban heat islands in detail. Therefore, our study group constructed a new temperature observation network in the Tokyo metropolis for the purpose of clarifying the mechanisms for urban heat islands based on the observational data. This network is called "Extended METROS", which were developed and distributed by the Extended METROS Research Group including 12 university laboratories in Tokyo metropolitan area since August 2006. This network observe air temperatures in every 10 minutes using small data loggers installed in the instrument screens at many elementary schools (about 200 points) in the Tokyo metropolis. The purpose of this study is to clarify the interaction between the urban heat island and the local circulations in Tokyo metropolis in warm seasons utilizing the Extended METROS.

2. Method

Study period is May to August in 2006 and 2007. In this study period, the days when typical sea breeze front could be detected were analyzed. We selected the days with weak pressure gradient, clear sky, and no precipitation as an essential condition. 14 composite dates were analyzed based on the time variation of temperature and wind, and the position of sea breeze front was estimated for 11 to 14 o'clock in every one hour.

3. Spatial and temporal variations of temperature / wind fields in Tokyo metropolis

The temperature distribution pattern around sunrise is typical for urban heat islands. At about 9 or 10 o'clock, the sea breezes around coastal region and the valley winds around inland area begin blowing, during which sea breeze and valley wind is calm in between both area. The sea breezes spread through the inland with passage of time. At 12 o'clock, a sea breeze front existed at the border of Tokyo Metropolitan area and Kanagawa prefecture, which extended to the Tokyo wards area. High temperature area can be found in front of the sea breeze front, where it becomes calm. On the other hand, quantity of the temperature rise is restrained with a sea breeze front advances to inland, and reaches in around Saitama City. High temperature area appears in Saitama prefecture,



Fig. 2 Distribution of temperature anomalies from spatial means and wind vectors

where temperature shows highest value just in front of the sea breeze front (around Kawagoe city). This heart area corresponds approximately to the region where large quantity of temperature increase continues from the morning. This high temperature area spreads to western Tokyo wards area like a belt. In western part of this area, southwesterly winds are blowing from Sagami Bay, and southeasterly winds are blowing from Tokyo Bay in eastern part of this area. This means that winds are converged at this area. Meanwhile, low temperature area is seen around coast except for southwestern Tokyo wards area. At 16 o'clock, heart of high temperature area moves to northern Saitama prefecture and Gunma prefecture where a sea breeze front does not yet penetrate. Sea breeze front have passed and temperature rapidly decrease around Kawagoe city. At 16 o'clock or later, sea breezes combine with valley wind around northern Saitama prefecture, and southerly wind is seen in the whole area of Kanto plain. Thus, sea breeze front cannot be detected by wind speeds and wind direction, but can be detected by quantity of temperature change. At 17 o'clock, the sea breeze front reaches northern Kanto plain. While southerly wind blows whole over Kanto plain, a high temperature belt from Kumagaya city to central Tokyo is formed. At 20 o'clock or later, southerly wind becomes weak from the northern part and heart of high temperature area move to south. Finally, it returns to central Tokyo in midnight.



Fig. 3 Distribution of hourly temperature changes (temperature difference from previous one hour) and the wind vectors

4. Time variation of temperature in each observation stations.

In suburban area where the sea breeze penetrates from the Sagami Bay, quantity of temperature rise rate becomes smaller in the morning(8 o'clock) around coastal area (Chigasaki) as compared to the inland area. However, timing of the reduction of temperature rising rate at Kawagoe is almost same as Kumagaya. Maximum temperature is large in order of distance from Sagami Bay. However, maximum temperature at Kumagaya is smaller than that at Kawagoe, because the quantity of temperature rising rate at Kawagoe is larger than that at Kumagaya consistently until the sea breeze front reaches Kawagoe. As easterly wind continues to blow at Kawagoe until the sea breeze front reaches, where the effect of down flow would be intensified. This is why Kawagoe has large quantity of temperature rise.

In the highly urbanized Tokyo area where the sea breeze penetrates from the Tokyo Bay, quantity of temperature rise is relatively small around coast (Kachidoki) from about 8 o'clock, although quantity of temperature rising rate recovers the previous level at 11 o'clock. The same phenomenon can be seen in the other Tokyo wards area observation stations (central Tokyo, Waseda, and Akabane). On the other hand, in southwestern Saitama City, where quantity of temperature rise is larger than that in Tokyo wards area, a temporary lowering of temperature

rise cannot be found. Around 12 o'clock, quantity of temperature rise becomes smaller in all Tokyo wards area observation points. This means that cooling effect of the sea breeze which has passed through the highly urbanized area becomes smaller.



Fig. 4 Time variation of temperature in each observation stations

Left side chart is the case of suburban area where the sea breeze penetrates from the Sagami Bay Right side chart is the case of highly urbanized area where the sea breeze penetrates from the Tokyo Bay

5. Summary

Using high density temperature data (Extended METROS), interactions between the urban heat island and the local circulation in Tokyo metropolis in warm season are analyzed. The results are summarized as follows:

- The temperature distribution shows typical urban heat island patterns in nighttime and the heart of high temperature area moves to northern Kanto plain as the sea breeze front penetrates to inland. The heart of high temperature area existed around Kawagoe City and northern Kanto plain at 14 o'clock and 16 to 18 o'clock, respectively. These regions are located approximately anterior the sea breeze front. When southerly wind is blowing over the whole Kanto plain, a high temperature belt from Kumagaya city to central Tokyo is formed.
- In the afternoon, as the sea breeze penetrates into inland area, temperature becomes decrease in order of the distance from coast. However, after the sea breeze has passed through, temperature doesn't decrease in Tokyo wards area. For this reason, cooling effect of the sea breeze on the leeward of highly urbanized Tokyo area becomes small.

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