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HOW MUCH COOL AIR DOES AN URBAN GREEN PARK PRODUCE?

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Abstract Synchronized kite balloon (kytoon) measurements in an urban park revealed the development of a nocturnal stable layer, which could mitigate urban heat island effects. A stable layer developed from the surface to 71 m above ground level in the park, although neutral stratification lasted throughout the night in the surrounding urban area. Calm, clear sky conditions triggered the development of the stable layer and a significant cool island. The cooling energy of the cool island formation was estimated to be approximately 5 Wm^{-2}.

Key words: cool island, urban climate, urban heat island

1. Introduction

The urban heat island effect, by which the temperature in an urban area exceeds that in surrounding rural areas, can be considered a climate hazard. In addition to stresses on human health, warmer urban temperatures in summer result in more anthropogenic energy consumption for air conditioning, while warmer temperatures in winter may allow pests to overwinter. One of the approaches to mitigating these and other problems associated with urban heat islands is urban "greening." A number of previous studies have revealed that cool islands form over parks and have examined the air temperature distribution in and around urban parks (Hamada and Mikami 1994), the cool-island formation process (Sproken-Smith and Oke 1999), and park-breeze characteristics (Narita *et al.* 2004). However, the amount of cool air in a park has not been evaluated quantitatively, possibly because of the technical difficulties in vertical profile measurement. The amount of cooler air would indicate the potential energy for cooling the surrounding urban area and thus is essential information for urban planners.

In this study, we measured the vertical and horizontal distributions of air temperature in and around an urban green park. We discuss the formation process of the cool air, especially its vertical development, and evaluate the amount of cool air produced over the park.

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2. Observation

Measurements were taken in a large urban park in Tokyo (Shinjyuku-gyoen). The park, located in central Tokyo, covers 0.58 km^2 and includes open lawn areas and a forest whose canopy is roughly 10 m in height. The terrain is almost flat, except for a small valley at the eastern edge of the park and some ponds. Surrounding the park are areas of taller buildings to the north and west (average height 40 m) and relatively low-rise residential houses to the east and south. We conducted measurements at the park for nearly 2 months from July to August 2005 to obtain the vertical profile and horizontal distribution of air temperature.

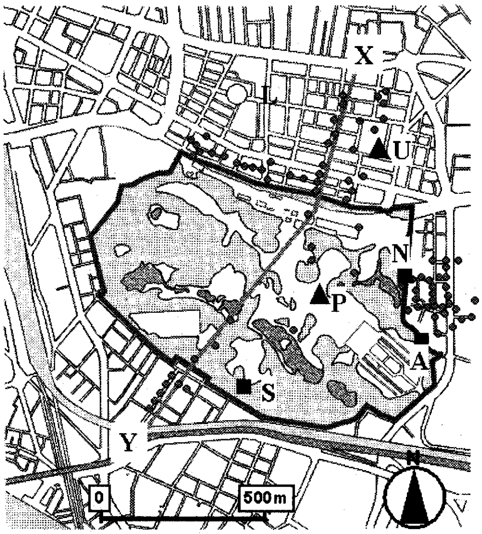

Fig. 1 Observation area. The shaded area shows the park (Shinjyuku-gyoen). Filled circles indicate the locations of the air temperature measurements at 2.5 m AGL. Filled triangles represent the kytoon measurement points (P and U). Filled squares mark the locations of the temperature profile measurements inside the tree canopy.

Vertical profile measurement

The vertical profile of air temperature was observed during the night of 14 to 15 August. Two sets of kite balloons (kytoons) were deployed for simultaneous measurements at the center of the park (point P in Fig. 1) and at a schoolyard outside the park (point U in Fig. 1; referred to as the "town" site). Tethers allowed the kytoons to rise up to 100 m; thermometers (HIOKI 3632) were attached to the tethers at 18 levels for the park measurement and 16 levels for the town measurement. Measurements were taken every 10 s, and data were averaged at 10-min intervals. The vertical interval of measurement averaged a few meters and was smaller at lower levels. The thermometers were calibrated before the observation, and fluctuation of kytoon height was periodically corrected by the pressure sensor.

Horizontal distribution measurement

Air temperature at 2.5 m above ground level (AGL) was measured at 90 points in and around the park for almost 2 months in July and August at measurement intervals of 2 min. The thermometers were placed in forced ventilation radiation shields and mounted on street lamp poles. Data were corrected for the instrumental error and averaged for 10-min intervals.

Other measurements

Four components of radiation flux (upward and downward, shortwave and longwave) were measured on the lawn surface in the park. Wind at the rooftop level (28 m AGL) was measured at point L in Fig. 1 by Life and Business Weather, Inc. (Tokyo). Using thermocouples, temperature profiles were also measured below the tree crowns in the forest of the park (points S, A, and N in Fig. 1).

3. Results

Figure 2 shows the measured profile of potential temperature. At 03:00 Japan Standard Time (JST), a stable layer developed and remained near the ground surface of the park, with a neutral layer occurring above it. The large sky view factor and relatively low heat capacity of the lawn surface would have led to more radiative cooling followed by the formation of the stable layer. In the forest area, a stable layer also developed below the tree crowns (Fig. 3). This stable layer can be explained by horizontal advection from the lawn area (Narita *et al.* 2004). Additionally, radiative cooling at the tree crown would have created colder air, which would have moved

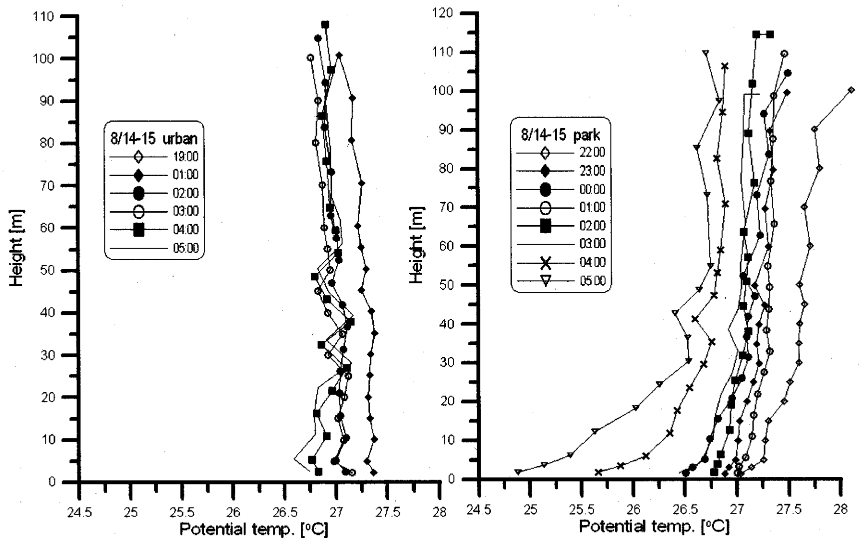

Fig. 2 Potential temperature profile measured by the kytoon systems at points P (park) and U (town).

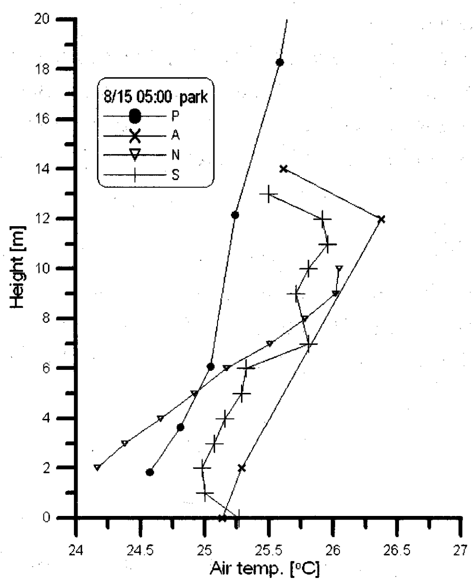

Fig. 3 Air temperature profiles in the park at 05:00 JST. P: above the lawn surface measured by the kytoon system. A, N, and S: below the tree crown in the forest area measured by thermocouples.

downward and accumulated on the forest floor. The stable layer at point N was more significant than others, maybe because point N was located in the pathway of cold airflow into the small valley at the eastern edge of the park.

On the other hand, at the town site, nearly neutral stratification formed below ~40 m AGL, with an unstable layer above (Fig. 2). The average height of buildings around point U was about 43 m. Mixing occurs as circulation flows in the urban canopy (Baik and Kim 2002), causing a neutral layer. The large deviation in the neutral layer at 03:00 JST and later reflects weaker circulation because the wind speed above the roof level decreased in this period (Fig. 5C). Local anthropogenic heat sources are attributed to the "kinks" in the profiles. A stable layer also occurred at the town site after 04:00 JST and can be explained by radiative cooling at the schoolyard observation site, which is a small open space (~5000 m^2). A key question is whether the urban stable layer formed by horizontal advection from the park. To explore this issue, the horizontal temperature distribution is shown in Fig. 4. A small but isolated cool island occurred around point U. The advection-like contours at the right side of Fig. 4 were probably caused by the lack of observation points around this area and cannot be considered real features. The cool island formed even in the small open space.

The accumulation of cooler air in the park started at 03:00 JST (Fig. 5A), triggered by the decrease in wind speed (Fig. 5C) and the decrease in cloudiness, as seen in the large negative value of net longwave radiation (Fig. 5D). The accumulation of cooler air resulted in a cool island (Fig. 5B), which became more distinct at 04:00 and later. After sunrise (05:00), the park stable layer vanished until 06:00. The profile shape at the town site was almost unchanged from 05:00 to 06:00, a result that is attributable to the large heat capacity of the buildings and vertical transport of heat more than 100 m.

When we compared the profiles of the town and park sites (Fig. 5A), the stable layer depth was normally 35 m (01:00 to 03:00) but ranged up to 71 m (04:00). Relative cooling energy Q_g (Jm^{-2}) stored over the park was estimated by the difference from that at the town site (Fig. 5A):

$$Q_g = \int_0^{Z_t} c_p \rho \left(T_{park} - T_{town}\right) dz \quad , \qquad (1)$$

where C_p is the specific heat, ρ is the air density, and T_{town} and T_{park} are the temperature profiles for the town and park sites, respectively. The top of the stable layer is represented by Z_t, which was determined as the cross point of the two profiles. Table 1 lists the Z_t and Q_g values at 1-hr intervals. The maximum value of $\partial Q_g/\partial t$ was approximately 5 Wm^{-2}, which is roughly the same magnitude as the measurement error of radiation flux and turbulent flux; thus, direct measurement of this cooling flux is almost impossible. Note that Q_g represents the difference between the park and the town. Therefore, Q_g includes the anthropogenic heat in the urban area as well as the negative sensible heat flux at the park surface.

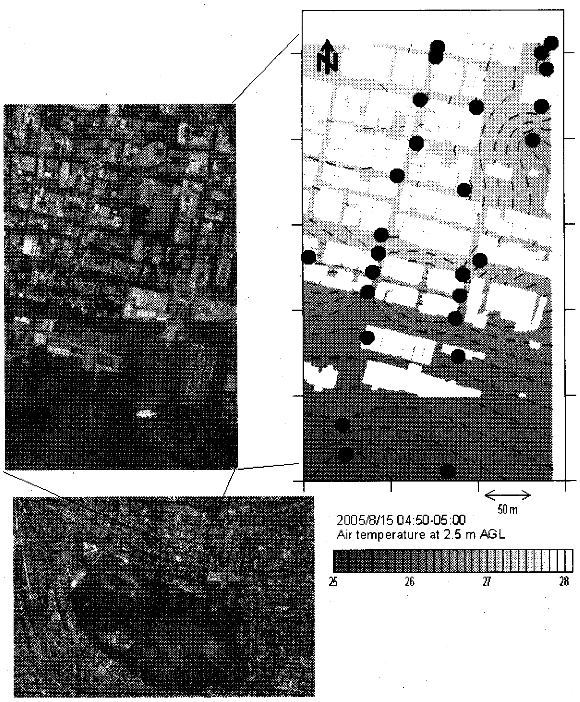

Fig. 4 Horizontal distribution of air temperature at 2.5 m AGL. Filled circles indicate the measurement points. The aerial photo was taken by the Geographical Survey Institute of Japan.

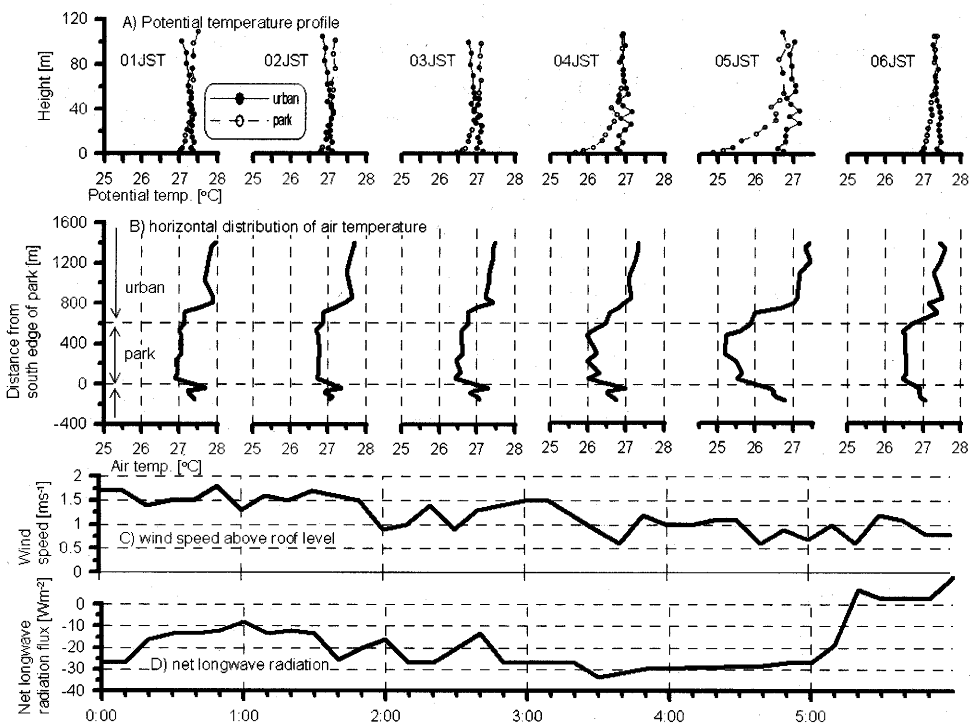

Fig. 5 Time series of potential temperature profiles (A), horizontal distribution of air temperature along the line X–Y in Fig. 1 (B), roof-level wind speed (C), and net longwave radiation flux at a lawn surface in the park (D).

Table 1 Time series of the stable layer height and cooling energy

LST	1	2	3	4	5
Stable layer height Z_t, m	35	35	35	71	55
Cooling energy Q_g, Jm^{-2}	6893	5099	10207	29682	49903
$\partial Q_g/\partial t$, Wm^{-2}		-0.5	1.4	5.4	5.6

If we assume a horizontally homogeneous temperature field over the park, as suggested by Fig. 3, then Q_gS is the total cooling energy of the park where S is the surface area of the park. Thus $\partial Q_gS/\partial t$, which was estimated as approximately 3.2×10^6 W, indicates the ability of the park to cool the surrounding warm town. The typical room-scale air conditioner has a cooling ability of 2.8×10^3 W. Therefore, the cooling ability of the park is equivalent to roughly 1000 air conditioner units.

4. Conclusion

The vertical profile and horizontal distributions of air temperature were observed in an urban park and the nearby urban area, and the accumulation process of relatively cooler air in the park was examined. A surface stable layer developed up to 71 m above the lawn surface of the park. The stable layer also formed inside the forest of the park. Calm, clear sky conditions triggered the development of the stable layer and the significant cool island. At the town site, neutral stratification lasted throughout the night inside the urban canopy, although an unstable layer continued to exist above the urban canopy.

The maximum cooling energy of the cool island formation was estimated to be 5 Wm^{-2}. Given the horizontally homogeneous temperature field in the park, the park cooling energy corresponded to 1000 units of room-scale air conditioners.

Acknowledgments

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Reference

Baik, J. J. and Kim, J. J. 2002. On the escape of pollutants from urban street canyons. *Atmospheric Environment* **36**: 527-536.

Hamada, T. and Mikami, T. 1994. Cool island phenomena in urban green spaces: A case study of Meiji Shrine and Yoyogi park. *Geographical Review of Japan* **67A**: 518-529.*

Narita, K., Mikami, T., Sugawara, H., Honjo, T., Kimura, K., and Kuwata, N. 2004. Cool-island and cold air-seeping phenomena in an urban park, Shinjyuku Gyoen, Tokyo. *Geographical Review of Japan* **77**: 403-420.*

Sproken-Smith, R. A. and Oke, T. R. 1999. Scale modeling of nocturnal cooling in urban parks. *Boundary-Layer Meteorology* **93**: 287-312.

(* : in Japanese with English abstract)