Important Role of Thermal Inertia for Urban Heat Island Circulation Dynamics

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1. Introduction

To clarify of Urban Heat island circulation dynamics

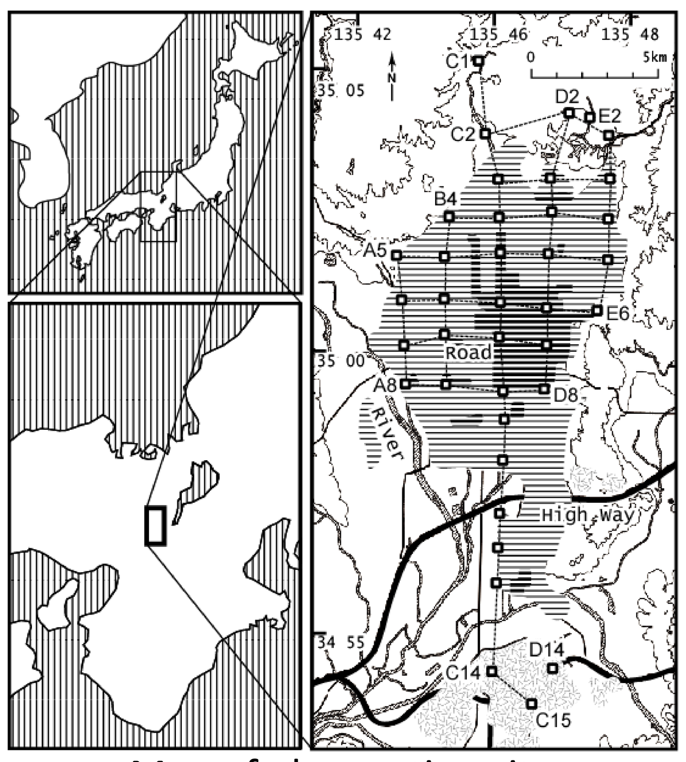
- How is the temperature distribution? :special and temporal high density observation is required.
- How is the thermal environment ? : thermal radiation observation is required.

We conduct a high density observation of temperature and thermal radiation.

2. Method

2.1 Study area

- A study area is Kyoto city, Japan. Kyoto has a population close to 1.5 million.
- A built-up area spreads in the center of Kyoto basin, which is surrounded on north, east and west sides by mountains. Southern area of the basin is covered in rice field.

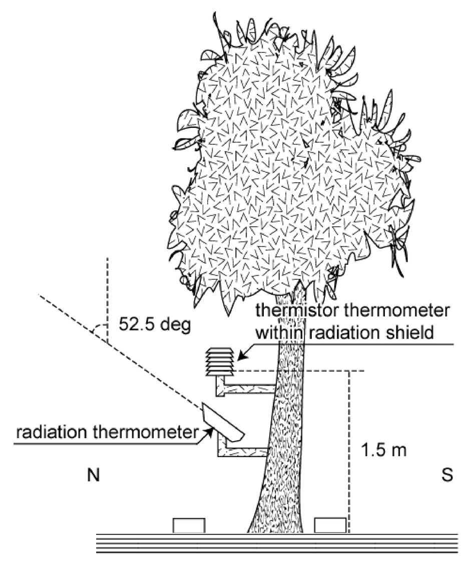


Map of observation sites.

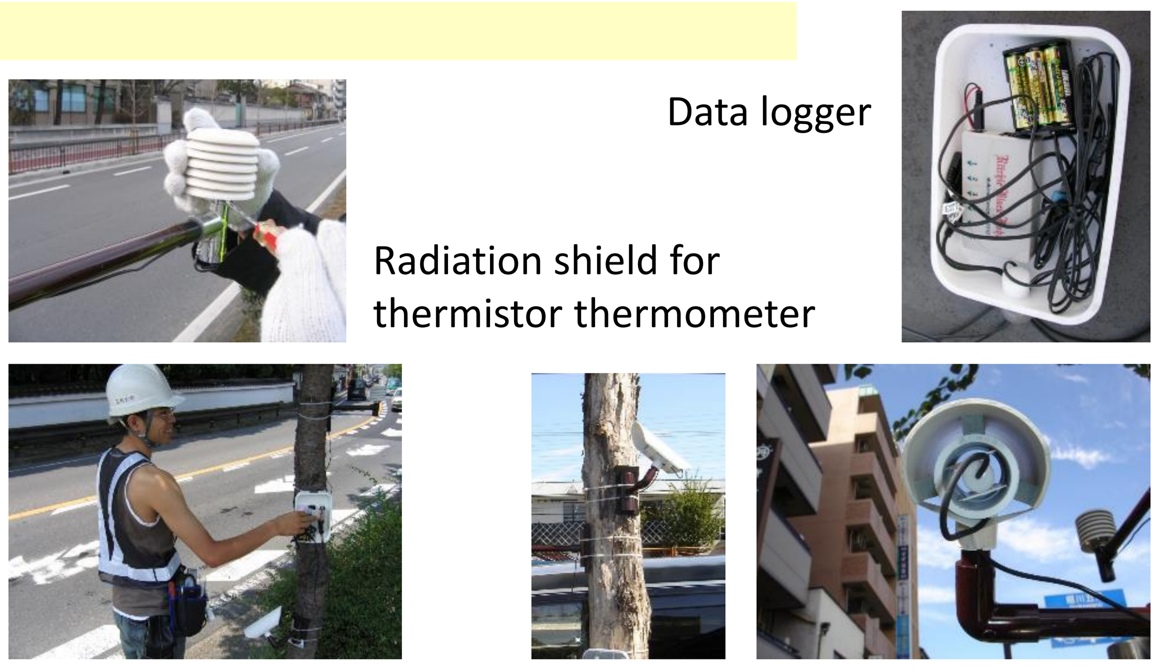
Rural area (D2)

Urban area (C7)

2.2 Instrumentation



Schematic of installation condition of instruments.



Radiation thermometer

- Observational instruments were installed on north-side of trees along a street for preventing as much of effect of direct sunlight as possible.
- The thermistor thermometers were set up at level of 1.5m height from the ground.
- The radiation thermometers were directed to a zenith angle of 52.5 degree.
- The loggers read the value each the second and recorded average value of each the second per 1 or 2 minute(s).

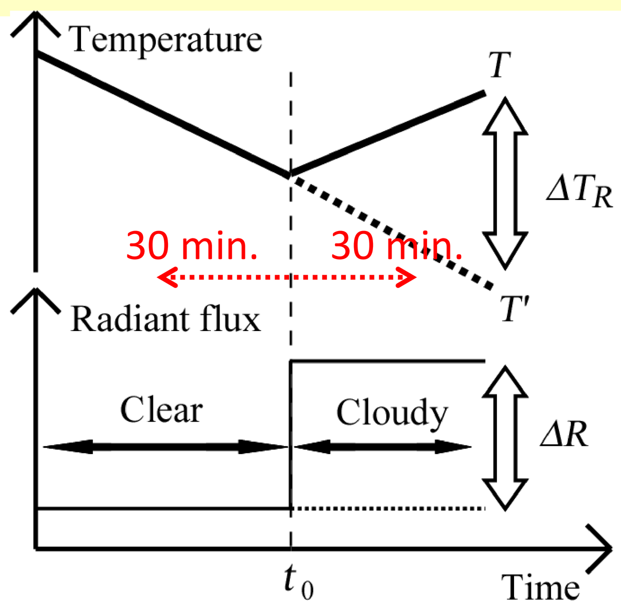
2.3 Observation

- We conducted observations of 8 periods, once every season during the 2004-2006.

Observation periods	Number of temperature sites	Number of radiation sites
3-7 Nov. 2004	24	0
28 Feb-12 Mar. 2005	35	8
13-24 May. 2005	36	12
10-26 Aug. 2005	36	16
10-23 Oct. 2005	36	17
19 Jan. – 12 Feb. 2006	19	19
24 Apr. – 7 May. 2006	19	19
24 Jul-6 Aug. 2006	19	19

2.4 Effective thermal inertia

When clouds appear, radiation balance will change. The change of radiation balance causes temperature change. We estimate local effective thermal inertia (LETI), which does not include the effect of thermal advection but the effect of sensible heat flux, from long-wave radiation and temperature change in cloud appearance in nighttime.

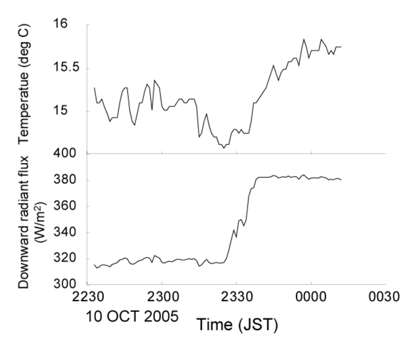


Temperature variation in NIGHTTIME.

A local effective thermal inertia I_{LETI} was derived from the temperature and long-wave radiation variation 30 min. before and 30 min. after cloud appearance.

$$I_{LETI} = \frac{2\Delta R}{\sqrt{\rho}\Delta T_R}\sqrt{t-t_0}$$

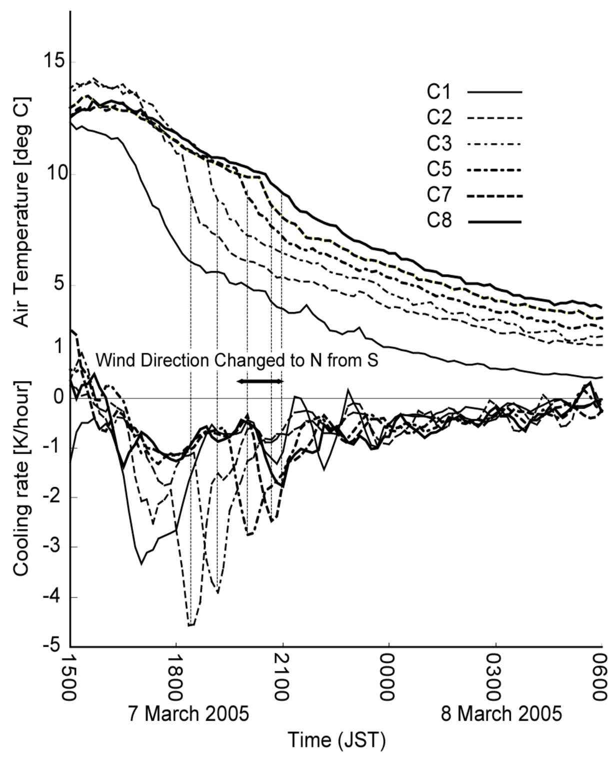
$$\Delta T_R = T - T_0 + k(t-t_0)$$



(see more detail derivation in extended abstract)

3. Results

3.1 Temperature variation



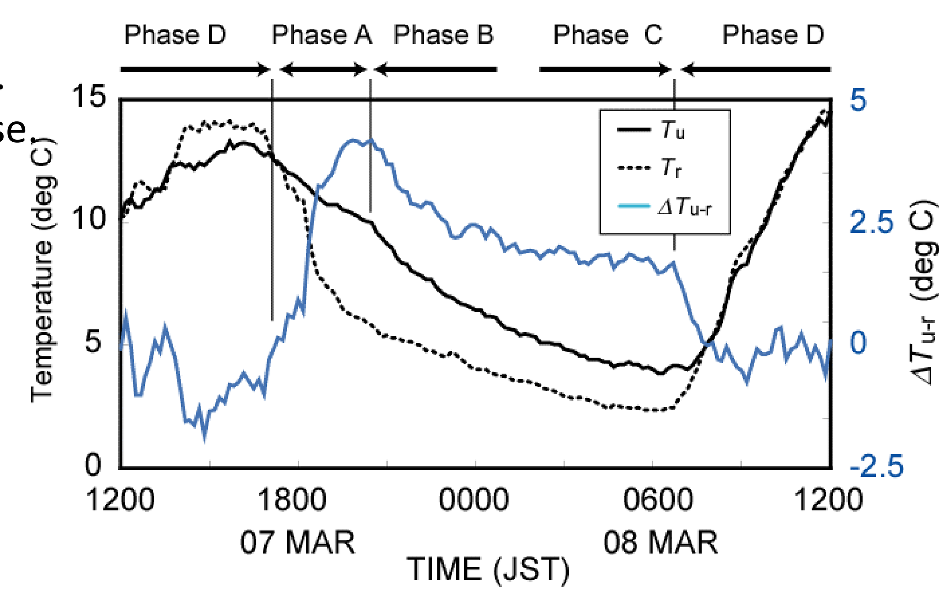
Time series of the air temperature and cooling rate.

- Temperatures in daytime are almost the same in different sites.
- There are two phases (Phase A and BC) of temperature decrease.
- The turning point of temperature decrease happens earlier in northern sites (rural area) than in southern sites (urban area).
- When the turning point happens, wind direction changes to north from south.

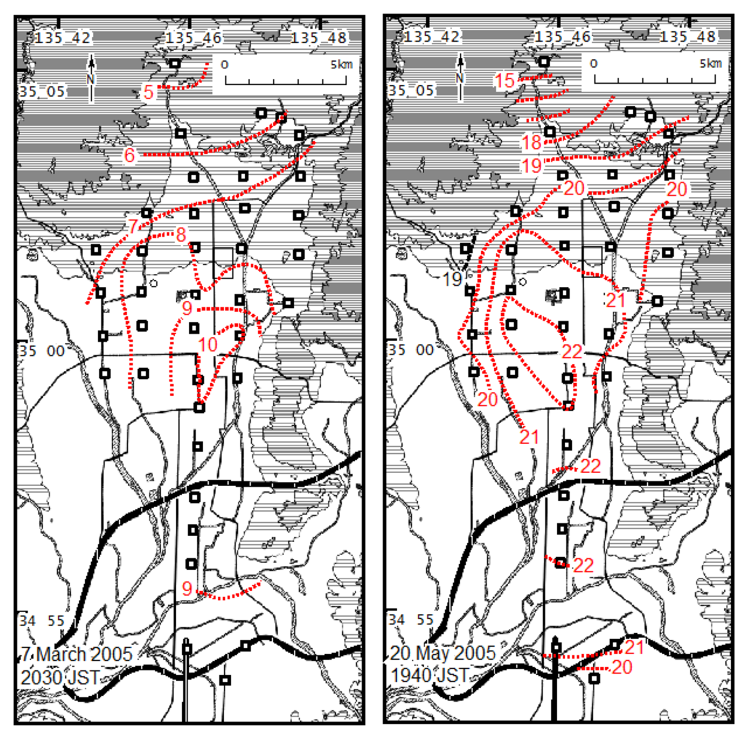
We think that different mechanisms may derive the temperature decreases in two different phases.

Phase A : *Thermal inertia*

Phase BC: *Thermal advection*



Time series of air temperature of urban (C7), rural (C2) and the temperature difference between those sites. in 7-8 March 2005.



The spatial distribution of air temperature.

3.2 Thermal inertia distribution

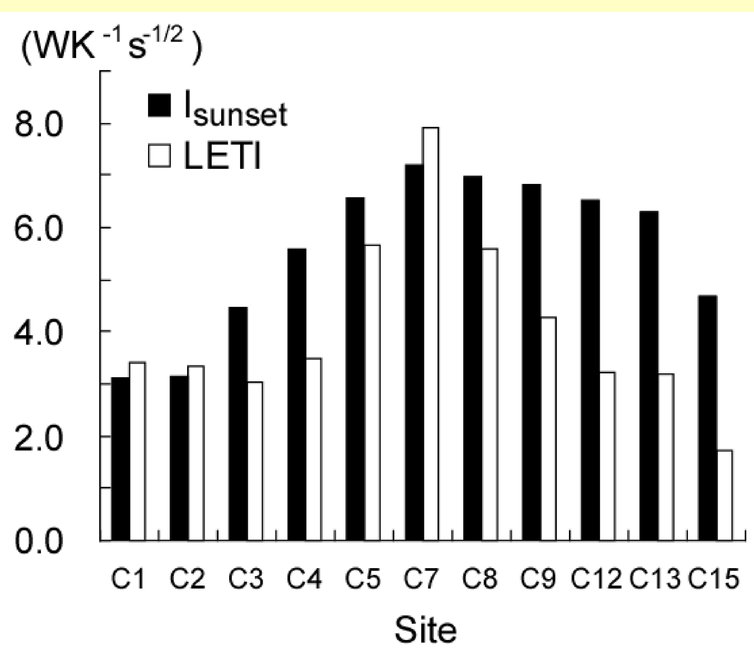
- LETI is derived from cloud appearances in nighttime.
- I_{sunset} is the thermal inertia derived from temperature and long-wave radiation changes from 30 min. before sunset to 2 hours after sunset.

(I_{sunset} corresponds to the ratio between temperature and radiation in Phase A.)

- I_{sunset} is good agreement with LETI.

The temperature decrease in Phase A is caused mainly because thermal inertia.

$$I_{sunset} = \frac{2\Delta R}{\sqrt{\rho}\Delta(T_{-30min} - T_{2hr})}\sqrt{9000s}$$



LETI and I_{sunset} in sites C1 to C15.

	Source	Thermal Inertia ×10³(W/Ks^1/2)	Temperature source	Time scale
Urban area	Carlson et al.(1981)	1.4	Satellite	Half a day
	Sugawara et al.(2001)	2.8	Surface	Half a day
	Takemoto and Moriyama(2002)	1.9-4.7	Air	Half a day
	LETI(Present work)	4.3-7.9	Air	30 minutes
Rural area	Oke and Maxwell (1975)	1.6	Air	Half a day
	Carlson et al.(1981)	1.0	Satellite	Half a day
	LETI(Present work)	1.7-3.4	Air	30 minutes

Thermal inertia estimated by previous studies.

- Thermal inertia derived from several ten minutes is important for understanding of the mechanism in Phase A.

4. Summary

- We conducted a high density observation of temperature and thermal radiation in Kyoto city, Japan.
- A local effective thermal inertia I_{LETI} was derived from the temperature and long-wave radiation variation 30 min. before and 30 min. after cloud appearance.
- There are two phases (Phase A and BC) of temperature decrease.
- The temperature decrease in Phase A is caused mainly because thermal inertia.