RADIATIVE COOLING ESTIMATE BY CLOUDINESS, TEMPERATURE, AND DEWPOINT TEMPERATURE

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Abstract

We estimate the empirical formula which shows the relationship between radiavitve cooling, cloudiness, temperature, and dewpoint temperature. In this formula the radiavite cooling is upward radiation from the atmosphere minus downward radiation from the sky and cloud. The radiative cooling is dominated by 3 parameters, air temperature, cloudiness, and cloud base temperature. In order to reduce the number of parameters, 15 JST reduced radiative cooling R_{15} is introduced. The empirical formula which shows the relationship between 15 JST reduced radiative cooling R_{15}, cloudiness N, and 15 JST dewpoint depression (difference between temperature and dewpoint temperature on 15 JST) TTD_{15} is derived from least-square method: $R_{15} = -10.14N + 4.586\ TTD_{15} + 72.12$.

Key words: radiative cooling, cloudiness, dewpoint temperature

1. INTRODUCTION

For urban climate, radiative cooling is one of the important meteorological elements, as well as temperature, wind velocity, and so on. But there are far fewer observation points which observe radiative cooling than those observe temperature, wind velocity, and so on. Radiative cooling (in this study, net radiation between atmosphere and outer space) is determined by the radiations from land surface, cloud, and outer space, as shown in Figure 1. Scince the radiation from outer space is constant and very low, the radiative cooling depends mainly on land surface temperature, cloudiness, and cloud temperature. The cloud temperature is the function of the altitude of clouds because clouds and the air surrounding the clouds have the same temperature. Since clouds are formed at the altitude where the dewpoint temperature of rising air reaches at the temperature of surrounding atmosphere, the cloud temperature depends on dewpoint depression, which is the difference between temperature and dewpoint temperature. In this study we estimate the empirical formula which shows the relationship between radiavitve cooling, cloudiness, temperature, and dewpoint temperature.

2. OBSERVATION AND DATA

The amount of radiative cooling was observed by a pyrgeometer (Figure 2, Sakai et al. 2009) in Kyoto from April 2007 to July 2007. Hourly-averaged data was used for analysis. The data of temperature, dewpoint temperature, and cloudiness (SYNOP) was obtained from Kyoto Local Meteorological Observatory. The data of 3:00, 9:00, 15:00, and 21:00 JST was used for analysis.

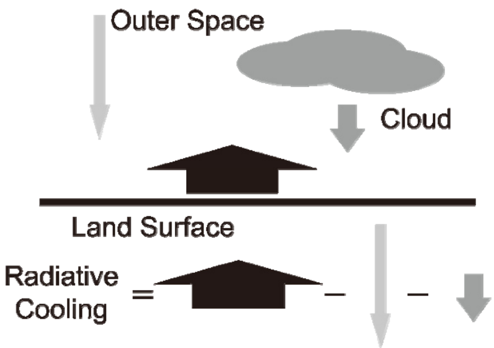

Fig. 1. Schematic diagram of radiative cooling.

Fig. 2. A pyrgeometer.

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3. ANALYSIS AND RESULTS

3.1. Cloudiness and radiative cooling

Figure 3 shows the relationship between cloudiness N and radiative cooling R_0 on 3:00, 9:00, 15:00, and 21:00 JST. Solid lines in figure 3 are obtained by least-square method. The gradients and intercepts of the lines are shown in table 1. Although the gradients (ratio of radiative cooling to cloudiness) are relatively-equal value on each time, the intercepts are different. This difference depends on the difference of land surface temperature. In order to reduce the parameter, land surface temperature, 15 JST reduced radiative cooling R_{15} is introduced. 15 JST reduced radiative cooling R_{15} is defined by

$$R_{15} = R_{0i} + R_{di},$$

where R_{0i} is observed radiative cooling at time i, and R_{di} is the radiation which corresponds to the temperature difference between time i and 15 JST after time i. Figure 4 shows the relationship between cloudiness N and 15 JST reduced radiative cooling R_{15} on 3:00, 9:00, 15:00, and 21:00 JST. Solid lines in figure 4 are obtained by least-square method. The gradients and intercepts of the lines are shown in table 1. The gradients and intercepts of the lines are relatively-equal value on each time. This indicates that R_{15} can reduce one parameter, land surface temperature.

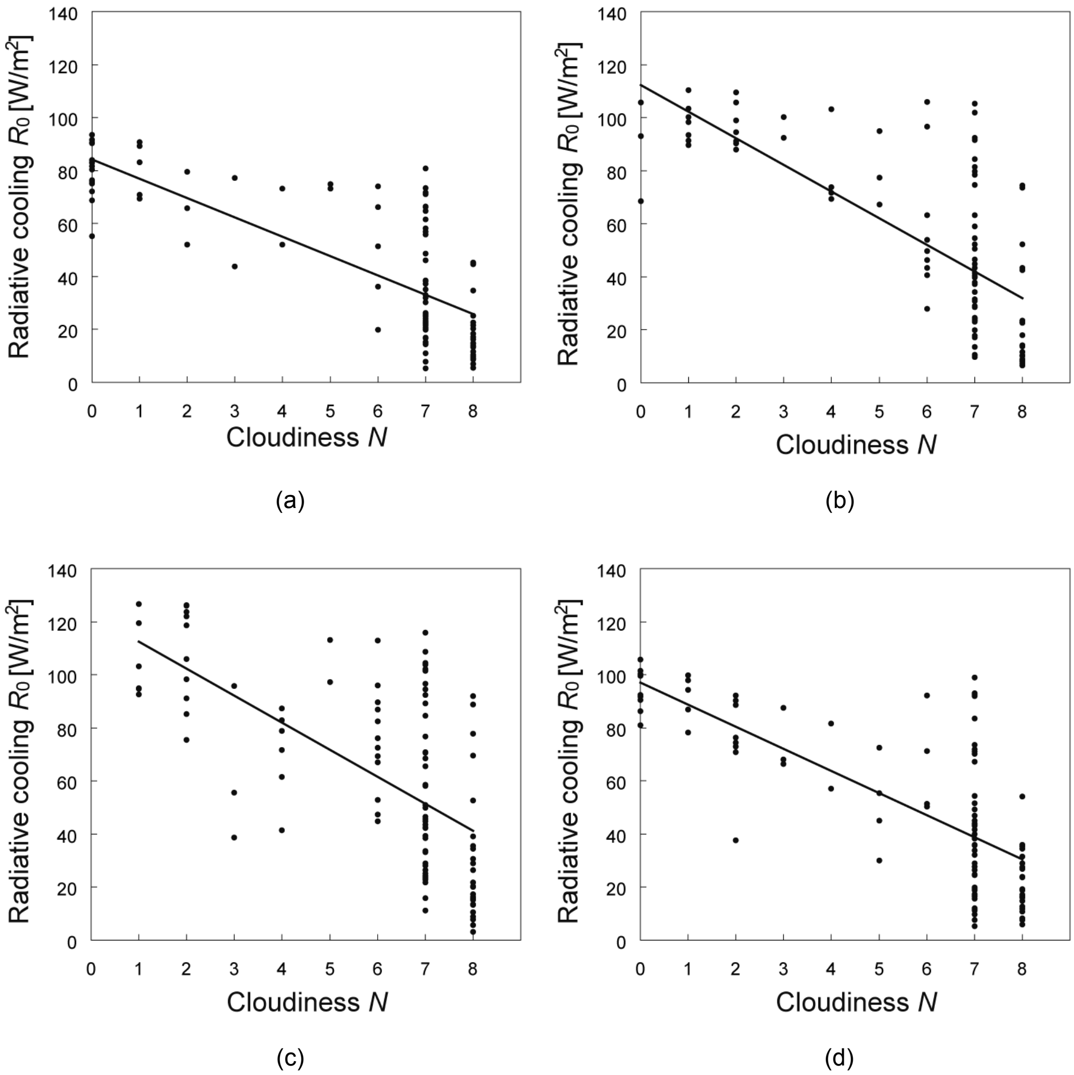

Fig. 3. Relationship between cloudiness N and radiative cooling R_0 on (a) 3:00, (b) 9:00, (c) 15:00, and (d) 21:00 JST.

	3:00	9:00	15:00	21:00
R_0 vs. N (gradient, intercept)	-7.30, 84.2	-10.1, 112	-10.2, 123	-8.33, 97.1
R_{15} vs. N (gradient, intercept)	-9.92, 138	-9.16, 129	-10.2, 123	-10.7, 135

Table 1. The values of the gradients [W/m^2/N] and intercepts [W/m^2] of the lines in figures 3 and 4.

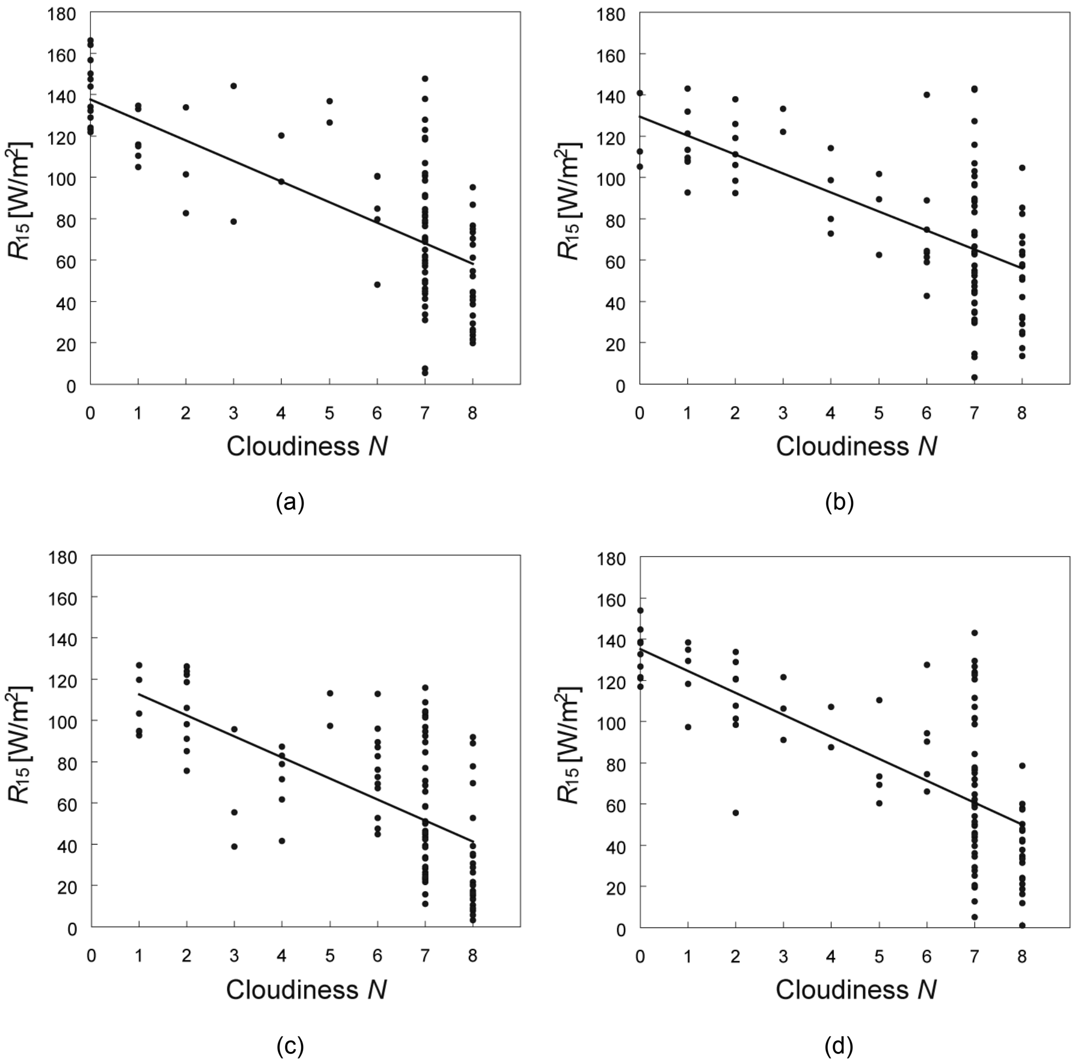

Fig. 4. Relationship between cloudiness N and 15 JST reduced radiative cooling R_{15} on (a) 3:00, (b) 9:00, (c) 15:00, and (d) 21:00 JST.

3.2. Altitude of cloud and radiative cooling

In the daytime atmosphere is well mixed and clouds are formed at the altitude where the dewpoint temperature of rising air reaches at the temperature of surrounding atmosphere. Therefore cloud temperature depends on dewpoint depression *TTD*, which is the difference between temperature and dewpoint temperature. In the nighttime, however, atmosphere is not well mixed. Assuming that the altitude of clouds in the nighttime is the same altitude in cloud formation, the cloud temperature in the night time depends on the dewpoint depression in the daytime. This indicates that radiative cooling depends on the dewpoint depression in the daytime. Figure 5 shows the relationship between dewpoint depression on 15 JST TTD_{15} and 15 JST reduced radiative cooling R_{15} on 3:00, 9:00, 15:00, and 21:00 JST. Solid lines in figure 5 are obtained by least-square method. In figure 5, 15 JST reduced radiative cooling R_{15} bears a direct relation to dewpoint depression on 15 JST TTD_{15}.

3.3. Empirical formula

Sections 3.1. and 3.2. shows that cloudiness N and dewpoint depression on 15 JST TTD_{15} are adequate parameters to 15 JST reduced radiative cooling R_{15}. The empirical formula indicating the relationship between R_{15}, N, and TTD_{15} is estimated by least-square method. The formula is

$$R_{15} = -10.14N + 4.586\ TTD_{15} + 72.12.$$

A standard deviation is 22.46 [W/m^2].

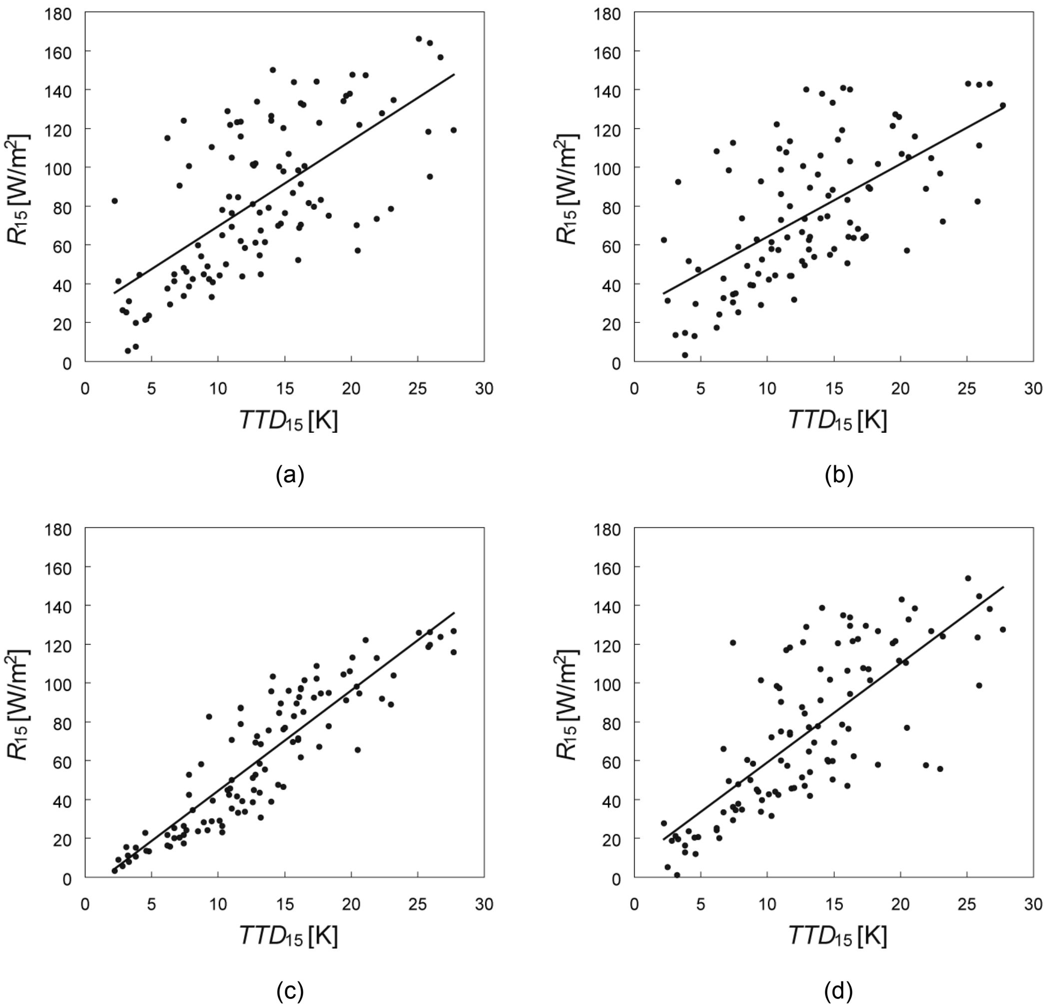

Fig. 5. Relationship between dewpoint depression on 15 JST TTD_{15} and 15 JST reduced radiative cooling R_{15} on (a) 3:00, (b) 9:00, (c) 15:00, and (d) 21:00 JST.

References

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