Monitoring of Radiant Temperature Distribution of Urban Vegetation Using High Resolution Multi-temporal Remote Sensing Data

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Abstract

In most studies concerning the basic analysis of spectral reflectance of vegetation surface, only visible, near infrared, and middle infrared images from satellite views, i.e., LANDSAT, SPOT, etc., are analyzed. Thermal infrared images, though, should also be used to indicate the characteristics of its radiant temperature distribution of urban vegetation, from the point of the deterioration of the urban thermal environment. This paper describes the results of the analysis using high resolution images of multi-temporal airborne multi-spectral scanner (MSS) data. The relationship between the radiant temperature distribution of urban vegetation and the area of each group of vegetation is investigated, considering weather parameters, i.e., incident solar radiation and air temperature. Furthermore, the relationship between the normalized vegetation index (NVI) and the temperature of urban vegetation is indicated.

1. INTRODUCTION

In recent years, the importance of urban vegetation have been re-recognized from the point of preventing to deteriorate the urban climate. The effect of declining the air temperature by a large land cover with vegetation is being proved by lots of investigations or measurements. However, there are a lot of small groups of trees in urban areas, i.e., the roadside trees or shrubbery, so the condition of vegetation distribution is different from that of either forest area or a green tract of land. It is very important to prove the effect of preventing the deterioration of the heat island phenomenon by the small groups of trees.

Satellite remote sensing is often informed for the investigation of surface temperature distribution of the vegetation or the activated degree of the vegetation. In the past, the basic studies of characteristics of spectral reflectance were mainly carried out with the range of visible or near infrared using satellite remote sensing data, i.e., LANDSAT or SPOT. Only the large-scale green tract of land can be handled because the spatial resolution is low. The characteristic of the radiant temperature distribution of a group of trees hasn't made clear.

A group of trees which exists in urban areas is focused on in this paper. The characteristic of the radiant temperature distribution of a group of trees which is projected on the multi-temporal airborne MSS data with 1.9 m of spatial resolution is clarified. And it is also made clear by image processing that the radiant temperature distribution of the tree crown surface is distinguished by the area, the shape, normalized vegetation index and the weather parameters.

2. OBSERVATION OUTLINE OF AIRBORNE MULTI-SPECTRAL SCANNER DATA AND AN ANALYSIS OF ACTUAL DISTRIBUTION OF VEGETATION

To analyze the diurnal or the annual change of the spectral characteristic of urban vegetation, we use airborne MSS data observed at noon and at the sunset on a clear sky day in summer and in winter. The specification and the observation outline of the airborne MSS sensor are shown in table 1. The characteristics of observation data are as follows.

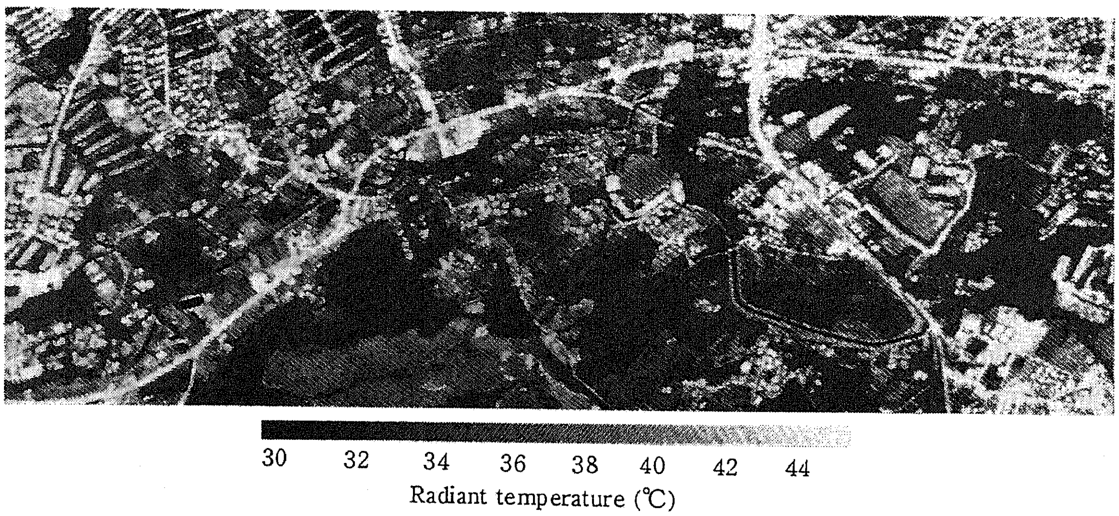

Fig. 1 An example of a thermal image obtained by airborne MSS
(August 9, 1987, 13:47–13:54)

(white: trees, gray: grass, black: other land cover)

Fig. 2 Training image of vegetation distribution

1) The small-scale vegetation, i.e., the roadside trees and the shrubbery could be observed, because of 1.9 m of spatial resolution.
2) The dynamic range of the radiant temperature of urban vegetation could be obtained dealing with daytime and nighttime of the summer and of the winter season.

In the analysis of the airborne MSS thermal images, the training image of the vegetation distribution was made on the MSS image to grasp the shape of a group of trees, based on the aerial color photograph and the ground research. An example of infrared thermal images observed by the airborne MSS is shown in the figure 1, and the training image is shown in figure 2. Three categories, i.e., trees, lawn and grass were deciphered by watching for making-up training image. In this paper, only trees are analyzed. Although mixels which contains both vegetation and other materials exist in the airborne MSS image, mixels are not described on this paper. The minimum unit of vegetation which was dealt with on the analysis is the 1 central pixel of the 3×3 pixels of vegetation.

Figure 3 shows the actual distribution of each group of trees in the target field. A cumulative histogram is also indicated. The frequency of the groups of trees with more than 80m^2 is very high. That means we cannot recognize urban vegetation distribution even if we use SPOT data.

Table 1 Outline of airborne MSS observation and weather data

Date: August 9, 1987	
13:47 – 13:54	S: 711W/m^2, A: 31.4℃ H: 58%, W: 3.0∼4.0m/s(SSW)
18:42 – 18:49	S: 0 W/m^2, A: 29.7℃ H: 71%, W: 3.0∼4.0m/s(SSW)
January 13, 1988	
12:57 – 13:04	S: 396 W/m^2, A: 12.4℃ H: 25%, W: 1.5m/s(ENE)
16:15 – 16:21	S: 0 W/m^2, A: 11.5℃ H: 30%, W: 1.6m/s(SE)

(S: solar radiation incident upon a horizontal surface, A: air temperature, H: relative humidity, W: wind velocity)

Place: Miyamae, Kawasaki, Japan
Resolution: 1.9 m
Band : Visible 0.60−0.65 μm
Near Infrared 0.92−1.00 μm
Thermal Infrared 8.00−12.0 μm

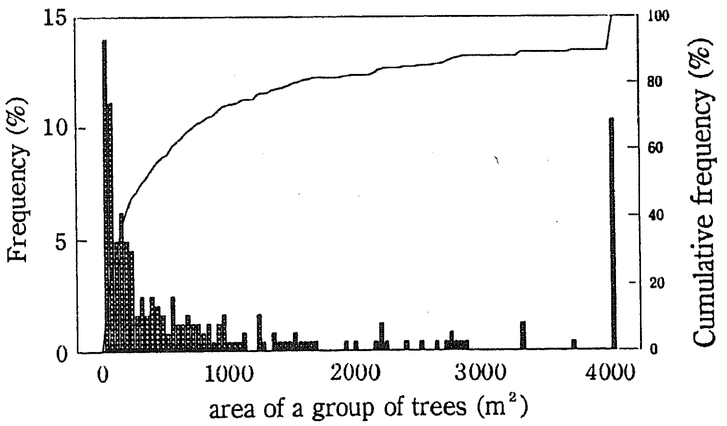

Fig. 3 Histogam of groups of trees from a point of the area

3. RELATIONSHIP BETWEEN NORMALIZED VEGETATION INDEX AND RADIANT TEMPERATURE OF A GROUP OF TREES

The activated degree and the leaf density of the tree crown have mainly influence on the normalized vegetation index (NVI) which is calculated from visible and the near infrared data, and it is expected that there is good correlation between NVI and the radiant temperature of the tree crowns. Figure 4 shows the relationship between the average of NVI and the average of radiant temperature of every group of trees.

Though the correlation coefficient with 0.7 is comparatively high of the daytime in summer, small groups of trees vary widely. At night, the radiant temperature of most groups of trees are about 1 degree lower than the air temperature for the reason of the sky radiation, so the radiant temperature is hardly related with NVI and the area of a group of trees. Also NVI in winter season is lower than that in summer season, and no relationship exists between NVI and the radiant temperature. NVI value and the area of a group of trees can be the parameters which distinguishes the radiant temperature of a group of trees.

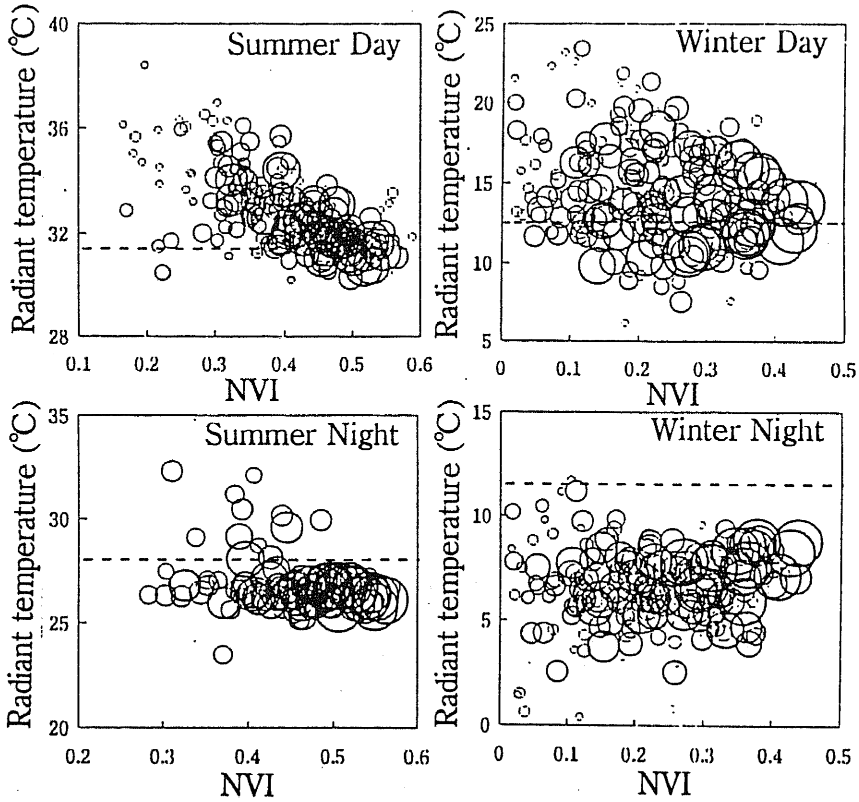

Fig. 4 Relationship between averaged NVI and averaged radiant temperature of a group of trees

4. CHARACTERISTICS OF RADIANT TEMPERATURE DISTRIBUTION IN A GROUP OF TREES

It is estimated that the distributions of NVI and the radiant temperature exist in one group of trees from the following points.

a) The surface of a group of trees is uneven, so both the shaded part and the sunlit part are shown in MSS thermal images.

b) The center part of a group of trees show lower temperature in MSS thermal images, because the larger the scale of a group of trees is, the lower the air temperature near the center of the trees is.

We verify a) and b) using the thermal infrared images observed by airborne MSS.

1) Relationship between the sun beam vector and the radiant temperature of the edge parts of trees

The relationship between the averaged NVI and the averaged radiant temperature at the edge of a group of trees using airborne MSS data observed at daytime in summer, is shown in figure 5, dividing into the sunlit side and the opposite side. The negative correlation exists, and the sunlit side is about 2°C higher than the shaded side even though NVI is same.

2) Radiant temperature distribution of a group of trees consisted of the shaded and sunlit pixels

Figure 6 shows a histogram of radiant temperature of a group of trees. Comparing the mode value, the radiant temperature of the first pixels facing to the sun at the edge of a group of trees shows 2°C higher than the air temperature. The difference is within 1℃ at two or three pixels inside, so the far from the edge of a group is, the smaller the temperature difference between the radiant temperature and the air temperature is.

Figure 7 shows the histogram of averaged radiant temperature difference between that of sunlit side and that of shaded side of a group of trees. The radiant temperature is higher than the air temperature at the pixels which are closer to the edge of a group of trees and the incident solar radiation is large.

5. CHARACTERISTICS OF RADIANT TEMPERATURE DISTRIBUTIONS OF URBAN VEGETATION AND ITS RELATIONSHIP TO WEATHER PARAMETERS

The sensible heat flux from a group of trees is investigated in this chapter. Figure 8 shows the relationship between the difference of the radiant temperature and the air temperature of a

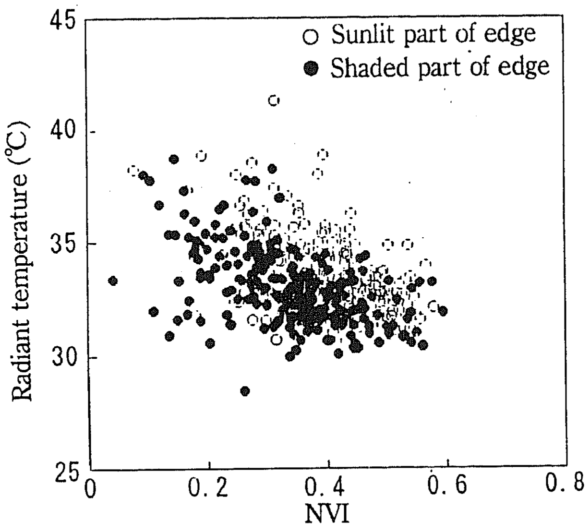

Fig. 5 Relationship between NVI and radiant temperature at the first pixel from the edge part of a group of trees

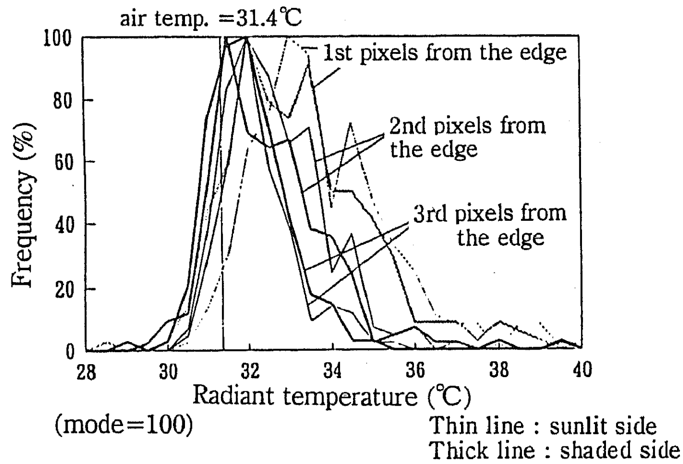

Fig. 6 Histogram of the radiant temperature at each pixels inside from the edge of a group of trees

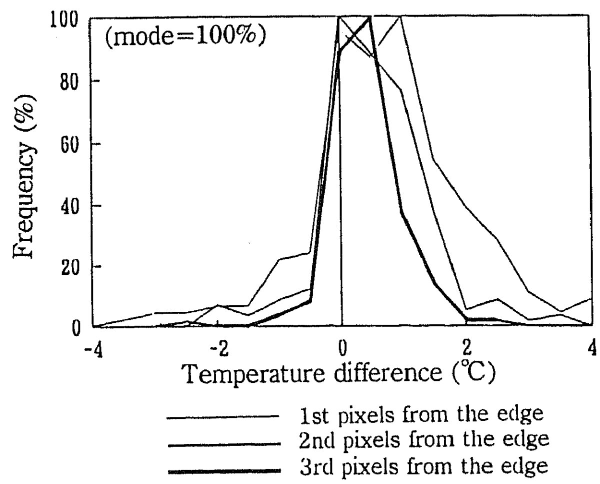

Fig. 7 Histogram of the difference between the radiant temperature of sunlit part and that of shaded part in a group of trees

group of trees, and the solar radiation incident upon a horizontal surface. Weather data was measured at the rooftop of the building in the center of Yurigaoka, Kawasaki City, Japan.

At noon, the difference between averaged radiant temperature at the sunlit edge of a group of trees and the air temperature is the largest value, i.e., the central value of about 3°C and maximum about 6°C. The average and the dispersion shows smaller at the shaded edge, and at the one pixel inside from the sunlit edge of group of trees. The averaged radiant temperature of pixels located at more than 4 pixels inside from the edge of a group of trees is equal to the air temperature. At night, the averaged radiant temperature of a group of trees is 2°C lower than the air temperature, because of the sky radiative cooling effect.

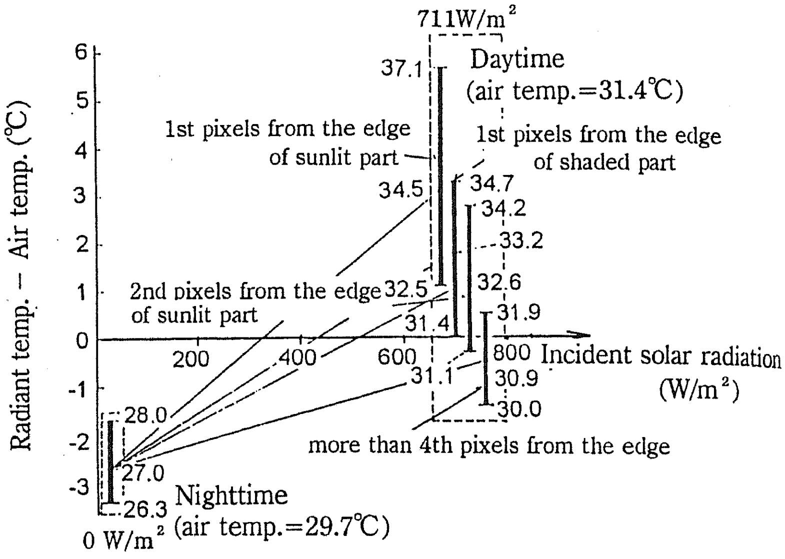

Fig. 8 Relationship between the radiant temperature of groups of trees and weather parameters

Time series observation using airborne MSS has limitation, therefore the method to presume the temperature difference between daytime and nighttime observation data is required. Penman-Monteith formula ([8], [9]) is proposed, as the method of formulating the trees heat and moisture budget using the weather parameters. This formula includes two resistance values, i.e. aerodynamic resistance *ra* at the crown surface and canopy resistance *rc*. The difference between the surface temperature of a group of trees and the air temperature is shown as below.

$$Ts - Ta = \frac{ra\ \gamma\ (1 + rc/ra)\ (Rn-G)}{\rho\ Cp\ \ (\Delta + \gamma\ (1+rc/ra))} + \frac{es(Ta) - ea}{\Delta + \gamma\ (1+rc/ra)} \qquad (1)$$

Ts: surface temperature of a group of tree (K), Ta: air temperature (K), ra: aerodynamic resistance (s/m), rc: canopy resistance (s/m), Rn: net sky radiation (W/m^2), G: heat conduction to the ground, ρ : density (kg/m^3), Cp: specific heat (J/kgK), Δ: the slope of the tangent of saturated vapor pressure curve, γ : constant of wet and dry bulb thermometer (Pa/K), es(Ta): saturated vapor pressure at Ta (Pa), ea: vapor pressure of the air (Pa)

Using weather data when the airborne MSS observation was performed in summer, the relationship between the incident solar radiation and the difference between the radiant temperature and the air temperature was calculated by the equation (1) (Figure 9). As the *rc* value, the measured data of keyaki [10] was used. Though both the air temperature term and relative humidity term are contained in the right side of the equation, the curve shown in figure 9 is assumed to be a straight line. We have already examined the heat and moisture budgets of lawn-planting are examined and showed that the difference between the surface temperature of lawn and the air temperature is linear to incident solar radiation [11]. The same results are shown in the case of tree crowns.

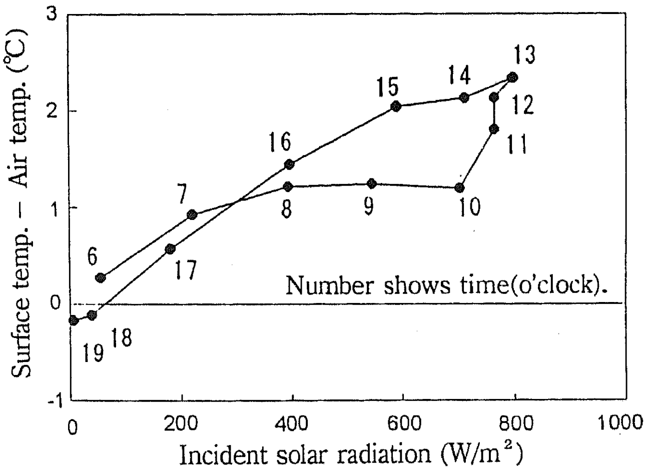

Fig. 9 Calculated results of the difference between the surface tempeature of a group of trees and the air temperature

Comparing the difference between the radiant temperature and the air temperature of a group of the trees of figure 8 to the computational result of figure 9, the observed radiant temperature is about 2°C lower than the calculated temperature. In the measurement of the radiant temperature of the ground surface, an infrared spot thermometer was used, so the calibration error of the infrared thermometer can not be ignored in the measurement result. Moreover, the air temperature in the daytime and nighttime is considered to be higher than the air temperature near the center of a group of trees, because the air temperature at the weather observatory was measured at the rooftop of a building in the city place. That is, the result of figure 9 shows a decline effect of the air temperature by a large group of trees, which has been pointed out as usual.

6. CONCLUSIONS

Using the airborne MSS data observed in the daytime and nighttime both in summer and the winter, the actual spatial distribution of the radiant temperature of every group of trees was investigated from the point of the relation with the weather condition. NVI value and the area of a group of trees could be the parameters which distinguishes the radiant temperature of a group of trees. Furthermore, a decline effect of the air temperature was clarified by a large group of trees.

7. REFERENCES

[1] Akira Hoyano, Sumio Yagi and Takehisa Kimura : Features of Thermal Environment Made by Plants in Outdoor Space, J. of Archit. Plann. Environ. Eng., AIJ, No.433, pp.1-10 (1992) (in Japanese).
[2] Mitsuo Kondo, Kazuyuki Manita, Yozo Yokoyama and Tomoo Ozawa : A Quantitative Study on the Effect of Micro-climate Control by an Existence of the Tree and the Lawn Area, J. of JILA, No46(3), pp. 161-175 (1983) (in Japanese).
[3] Tadahisa Katayama et al. : Cooling Effects on Thermal Environment in a Built-up Area

-Survey on Amount of Green and Air Temperature -, Engineering Science Reports. Kyushu University, Vol.12, No.2, pp. 215-220 (1990) (in Japanese).

[4] Akira Hoyano and Masunori Kato : Extraction of Urban Vegetation by Airborne Multi-spectral Scanner Data with High Spatial Resolution, J. of Archit. Plann. Environ. Eng., AIJ, No.407, pp. 37-45 (1990) (in Japanese).

[5] Kirk C. McDaniel : Assessing Mesquite-Grass Vegetation Condition from Landsat, Photogrammetric Engineering and Remote Sensing, Vol.48, No.3, pp. 441-450 (1982).

[6] John C. Price : Estimating Vegetation Amount from Visible and Near Infrared Reflectances, Remote Sensing Environ. 41, pp. 29-34 (1992).

[7] J.R. Dymond, P.R. Stephens, P.F. Newsome and R.H. Wilde : Percentage Vegetation Cover of a Degrading Rangeland from SPOT, INT. J. Remote Sensing, Vol.13, No.11, pp.1999-2007 (1992).

[8] Penman, H.L. : Natural Evaporation from Open Water, Bare Soil and Grass, Proc. Roy. Soc. London, A 193 (1948).

[9] Monteith, J.L. : Evapotranspiration and Environment. In 'The state and movement of water in living organs' (Fogg, G.E.,ed.), Soc. Exp. Biol. Symp., 19, Cambridge University Press (1965).

[10] Y. Tsukamoto : Forest Hydrology, Bun'eido (1992) (in Japanese).

[11] A. Hoyano, J. He, T. Horiguchi and G. Wang : Experimental Study on Heat Budget for Foliage Layer of Lawn-planting, J. of Archit. Plann. Environ. Eng., AIJ, No.462, pp.31-39 (1994) (in Japanese).