Relationship among Surface Temperature, Vegetation Index and Ground Cover in Osaka City Area Using Landsat TM Data

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Relationship among Surface Temperature, Vegetation Index and Ground Cover in Osaka City Area Using Landsat TM Data

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Abstract

Landsat-5 TM images for Osaka city area in different seasons are analyzed in this study. After the classification of ground covers, the surface temperature (T_s) and the normalized difference vegetation index (NDVI) are derived from satellite data. The distributions and seasonal variations of T_s and NDVI are obtained from various types of ground covers. There are higher surface temperatures in urban-residential areas and bare lands than in open water and vegetation areas. The NDVI appears to be an indicator of the difference in surface properties such as evapotranspiration and heat storage capacity. Higher NDVI values are observed in vegetated areas, while lower values are associated with unvegetated regions and open water. The relationships between T_s and NDVI in vegetated areas are analyzed for different seasons, there is a negative correlation between them in summer, whereas, in other seasons, this correlation becomes weaker due to the decreasing of surface temperature, which governs evapotranspirations and reduces latent heat from plants' surfaces.

1. Introduction

Many investigations have shown that different kinds of landuses produced different surface temperatures within a city[1]. The primary reason is that each of these surfaces has different heat capacity, albedo, and emissivity[2]. In daytime, the concrete and asphalt associated with urban, residential and industrial areas store the greater heat absorbed due to lower latent heat and higher heat capacity. Vegetated surfaces in urban park and other vegetated areas with adequate moisture availability during the growing season redistribute much of absorbed energy through evapotranspiration, thus the heat storage and availability are reduced.

There are a large number of surface temperature measurements available. In early years, most of the observations were surface based. Recently, many informations on surface temperatures can be obtained by infrared thermometry from satellites[3,4]. Vegetation indices computed from satellite remote sensing data have been demonstrated as useful estimators of the presence and density of plant vegetation, and have been successfully used in monitoring seasonal vegetation activity.

The objectives of this study are to obtain the distribution of surface temperature and vegetation index for Osaka city area in different seasons, using Landsat-5 TM data, and to analyze the relationship among the surface temperature, vegetation index and ground cover.

2. Data and method

Four Landsat-5 TM images including Osaka city area, observed on April 24, 1987, June 19, 1990, August 6, 1990, and September 28, 1986, were used in this study. The geometric distortions in original TM images are so significant that original images cannot be used for overlaying and referring to any maps. Before analyzing, geometric correction[5] as one of the preprocessing operations was carried out. Seven ground control points (GCPs) were selected from the maps based on Universal Transverse Mercator coordinate (1:25,000 scale) and from original TM images. These GCPs were used in the resampling by means of affine conversion, altering the orientation of pixel array in original image to be parallel with the Universal Transverse Mercator coordinate. The root mean square errors, which caused by the shifts of GCP locations in resampling of pixel arrays, fell within the range of 19.7−28.3m. In order to avoid altering the radiometric brightness in original image, the nearest neighbor resampling method was applied to geometric correction. The study area (Fig. 1) was selected about 120 ㎢ in rectangular. Each scene includes 349×355 pixels, and each pixel has the size of 31.8m×30.8m in latitudal and longitudal direction.

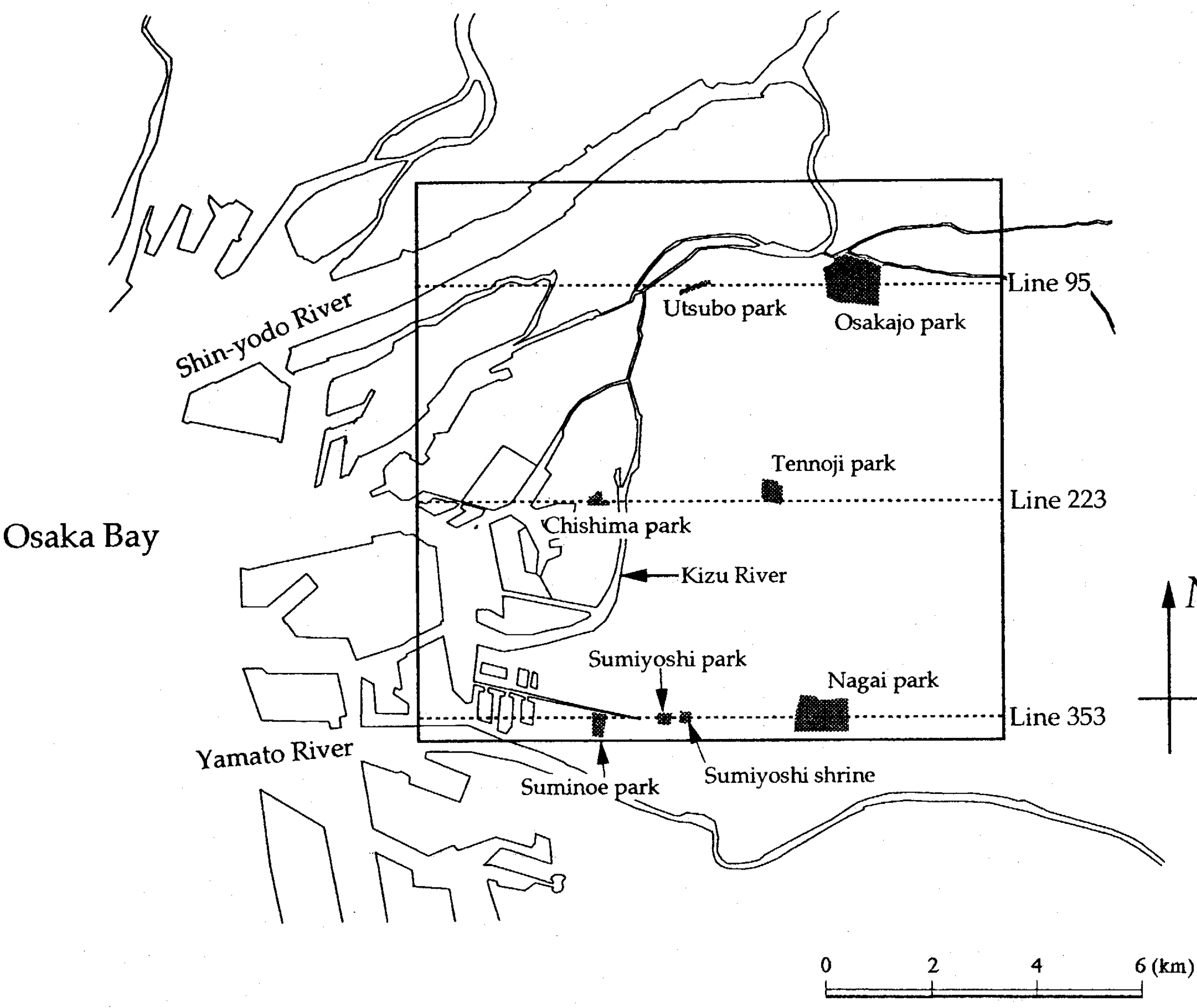

Figure 1 Location of study area. Dashed lines show image lines for examining NDVI in cross sections

The basic steps involved in ground cover classification procedure are summarized as follows. Primarily, seven categories for classification of ground covers were defined as: open water, high density urban, residential, mountain forest, park forest, cultivated and bare land. Five rectangular areas with uniform ground cover (5 pixels×4 lines for each rectangular) were selected for each kind of ground covers as representative training areas. Secondly, the Gaussian maximum likelihood classifier was used to self-classify the training set data under the assumption that the spectral response pattern of digital number (radiometric brightness) for each category shows normal distribution statistically. Digital numbers' response patterns from four bands for each category were used in classifying. The distribution of response pattern of digital member was evaluated for each band and each category. Then, each pixel should be classified into one ground cover category with its highest statistical probability of the pixel being a mumber. After some trials of classifications only for training data, the combination of band 1, 2, 3 and 4 was chosen as the suitable one with the highest accuracy in classifying ground cover (Table 1). After refinement process of training set, whole image in study area was classified into seven categories with the Gaussian maximum likelihood classifier. Finally, five kinds of classification categories (open water, urban and residential areas, cultivated area, forest area and bare land) were redefined. Therefore, two areas classified as dense urban and residential respectively were set as one category, and two forest categories were also put together.

Table 1 Classification accuracy of training set data using different combination of bands

Unit : %

Classification categories	Band 1.2.3.4	Band 1.3.4.7	Band 2.3.4.7	Band 2.3.4.5	Band 1.3.4.5
Open Water	100.0	100.0	100.0	100.0	100.0
Urban and residential area	92.5	92.5	92.5	91.5	91.0
Cultivated area	77.0	75.0	78.0	76.0	70.0
Forest area	93.0	93.5	86.5	88.5	92.5
Bare land	97.0	98.0	97.0	96.0	98.0
Average	91.9	91.8	90.8	90.4	90.3

In this study, we examined the changes in the surface temperature and a vegetation index NDVI, deduced from TM data, among the seasons and ground covers. Surface temperature for each pixel was derived from thermal infrared data of band 6 as follows:

$$\frac{1.40654}{255}V_6=5.1292\times10^{-5}\,T^2-0.01765T+1.47852 \quad (1)$$

where V_6 is the digital number (radiometric brightness) of band 6, and T is the surface temperature in absolute scale. The surface temperature in centigrade scale is expressed as T_s. We will discuss the distribution of surface temperatures and its seasonal change using the computations of surface temperatures for four images.

The normalized difference vegetation index (NDVI) is computed from digital number of visible red band 3 (V_3) and that of near infrared band 4 (V_4) as follows:

$$\mathrm{NDVI}=\frac{V_4-V_3}{V_4+V_3} \tag{2}$$

Vegetated area generally yields high value, because of its relative high near-infrared reflectance and low visible red reflectance. In contrast, clouds, water bodies and snow covers have larger visible red reflectance than near infrared one, thus these features yield negative index values. The NDVI value, especially in its range of 0−0.5, keeps close relation with the leaf area index[6], and associates with the activity or vigor of vegetation.

In order to examine the properties of distribution and seasonal change in NDVI value, we will show three types of figures of 1) the geographical distribution images of NDVI in Osaka city area; 2) the cross sections of NDVI values along three cross lines shown in Fig. 1; and 3) the frequency distribution of NDVI values for forest area. Finally, we will depict the relationships between surface temperatures and NDVI values for forest areas in different seasons, in order to understand the effect of vegetation on surface temperature.

3. Results and discussion

3.1 Ground cover classification

Since the change in ground cover for Osaka city area in the period of 1986−90 was relatively little, we assume that the differences of ground covers among images are negligible. In four images we analyzed, the image recorded on August 6, 1990 was the most clear one and was not cloud contaminated. Therefore, we classified ground cover using the image of August, and this result was applied to other three images after cloud contamination was excluded.

Photo. 1 shows the result of classification into five types of ground cover for Osaka city area. The accuracy of classification for each ground cover's training data fell within 77−100%, and its mean value was 92% (Table 1). In Photo. 1, the area classified as open water is recognized clearly. The park forest is successfully classified in the case of park area over 0.6 ha. Although there are pixels classified as cultivated in and around the central region of the city, it seems that most of them have appeared due to the failure of classifying the park forest into cultivated area.

3.2 Distribution and seasonal variation of surface temperature

Photo. 2 shows the result of surface temperature distribution derived from the data for April. The seasonal variation of mean value of T_S for each type of ground cover is shown in Table 2.

Table 2 Mean surface temperature for each type of ground cover

Unit : ℃

Type of ground cover	Apr.24,1987	Jun.19,1990	Aug.6,1990	Sep.28,1986
Open water	16.6	23.6	39.5	19.6
Urban and residential area	25.1	38.1	51.3	23.9
Cultivated area	22.4	34.1	46.3	21.8
Forest area	23.2	35.1	48.5	22.5
Bare land	24.7	36.6	50.8	23.7

Surface temperature varies associated with ground cover and season. For all of four images, the highest surface temperature was observed in urban and residential areas. In August, the mean value of T_S in urbanized area reached to 51.3℃. In this area, high heat capacity and low specific heat of materials of buildings and roads may cause such higher surface temperature than that in others. Surface temperatures in bare lands were also high, but were 0.2−1.5℃ lower than those in urban and residential areas. All images show that the surface temperature in central region of the city was somewhat lower than that in surrounding residential area. The reason of this decrement could not be cleared in this study, but it seems that large shadows of tall buildings in the central region of city influence the surface temperature and make it lower.

On the other hand, the park forest and cultivated (partly including park forests) areas, where much heat may be lost through evapotranspiration, show lower surface temperature than urbanized areas and bare lands. The differences between mean values of T_S in vegetated areas and those in urbanized areas ranged from 1.4℃ in September to 3.0℃ in June. Most of the pixels corresponding to park forest may partly include some areas of small building, bare land, grass land and other ground covers. Therefore, the surface temperatures in such areas may differ from those of forests in mountains. For example, mean value of T_S for the forest in Ikoma ridge was 31.7℃ on June 19, 1990[7], while that for the parks in Osaka city was 35.1℃ on the same date.

Excepting open water, other types of ground covers showed that there was the highest mean value of T_S in August and the lowest in September. It was higher in June than in April. The surface temperature for open water in September was higher than that in April, while those for other ground covers in both seasons were almost the same. Since the heat capacity of open water is larger than that of land, seasonal change in temperature is slow, so water body should be warmer in September than in April.

3.3 Distribution and seasonal variation of NDVI

NDVI is an indicator of the different surface properties. Parks, road trees, open water and bridges can be easily recognized in NDVI images (Photo. 3 and 4). In different seasons, vegetated areas (park areas) show more green color (more than 0.3 of NDVI value) in summer (August and June) than in spring (April) and autumn (September). Open water area shows black color with NDVI value less than -0.2.

Three cross lines were selected from four images to represent the variation in NDVI value among different ground covers and different seasons (Fig. 2). These cross sections were depicted using the moving averages over five pixels. Along the cross sections of Line 95 (top of Fig. 2), two peaks of NDVI appear at the locations corresponding to Utsubo park and Osaka-jo (Osaka Castle) park respectively. In such park areas, NDVI values ranged from -0.1 to 0.5, and fluctuated with small change of ground cover in parks. The dip at left edge of this cross section represents an open water area of Shin-yodo river. The cross sections of Line 223 (middle of Fig. 2) show two peaks associated with Chishima and Tennoji parks and four dips caused by cross line passage through the canals in harbor area and Kizu river. Along the Line 353 (bottom of Fig. 2), cross sections show some peaks associated with large parks. No dips are recognized in this cross section, however the cross line passes through some timber pools. This may be caused by the change of surface properties of pools by floating timbers. All cross sections show that

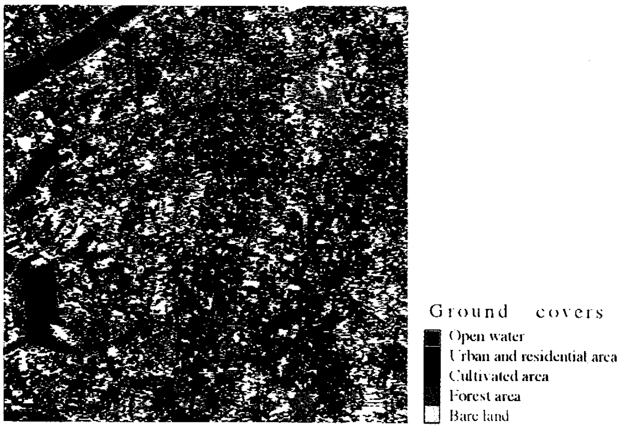

Photo. 1 Result of ground cover classification for August 6, 1990

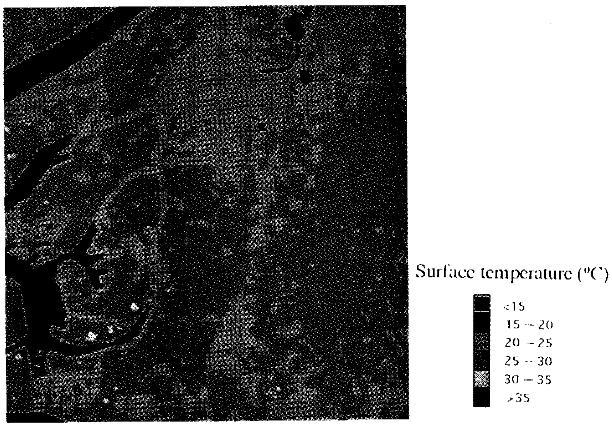

Photo. 2 Distribution of surface temperature on April 24, 1987

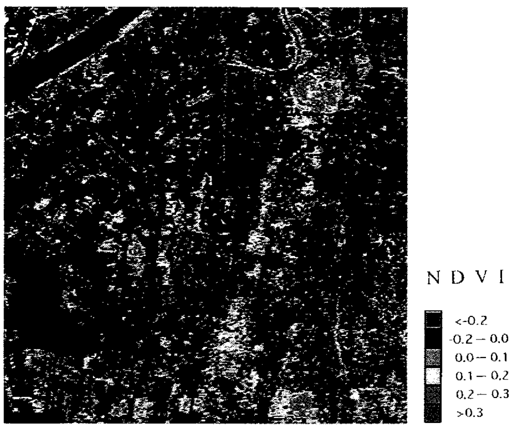

Photo. 3 Distribution of NDVI value on August 6, 1990

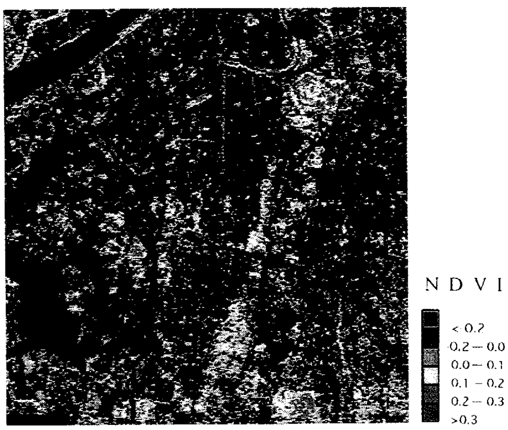

Photo. 4 Same as Photo 3, except for April 24, 1987

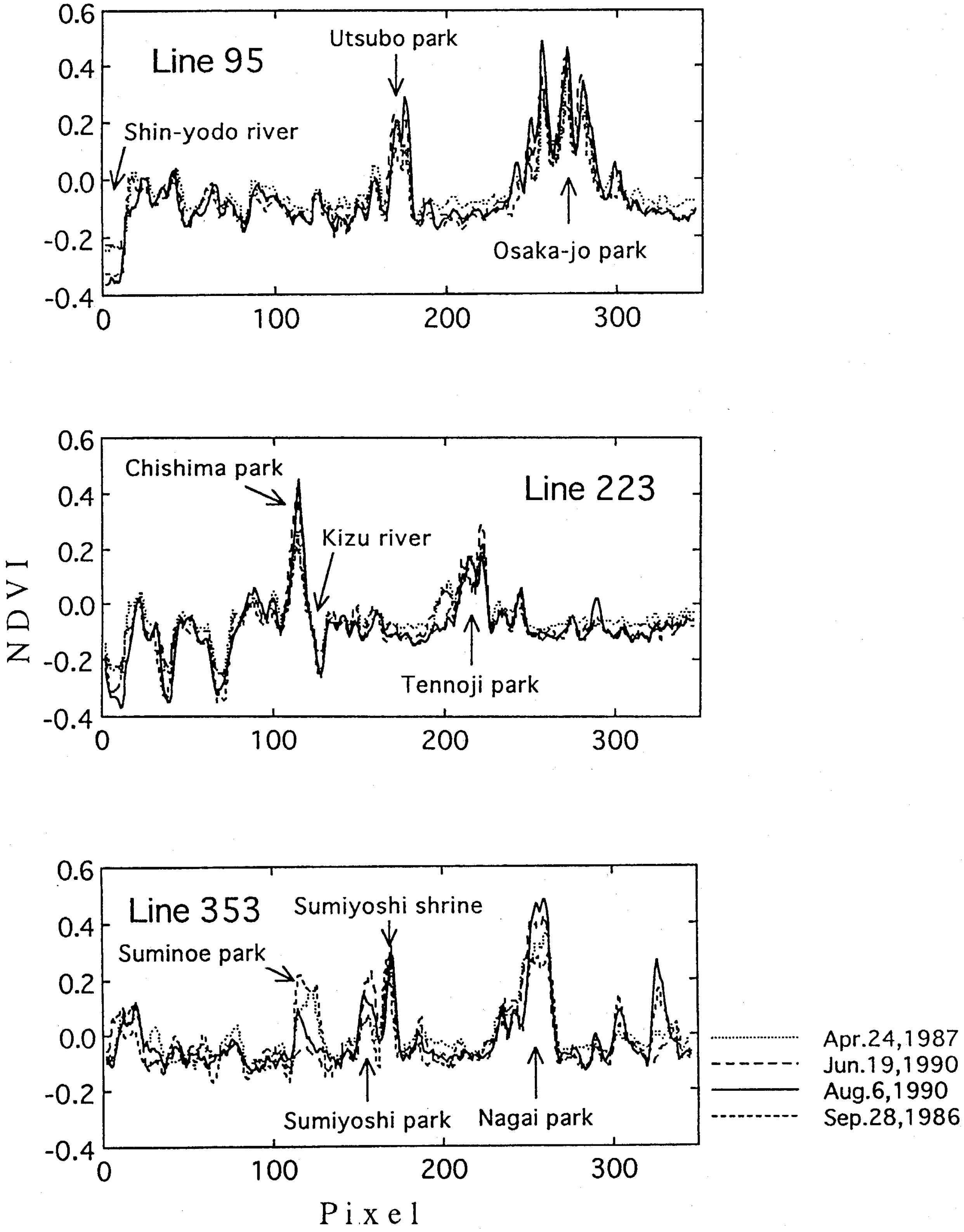

Figure 2 Cross section of NDVI value along the image line of No.95 (top), No.223 (middle) and No.353 (bottom)

there are negative NDVI values in urban and residential areas and bare land. NDVI values in August or June show the maximum (about 0.5) of these cross sections in four images.

Fig. 3 shows the frequency distribution of the number of pixels observed on each NDVI value only for the cover type of park forest area in different seasons. The total number of pixels for ground cover of park forest area is same for four images. These distributions show monomodal patterns with low skewness less than 0.1. The distribution curves for April and September were almost the same, and the modes of NDVI (about 0.08 in September and 0.12 in April) were lower than those for June and August. The distribution pattern for August shows narrow range with higher kurtosis of 3.65 than others, and pixels amass about from 0.0 to 0.5 of NDVI value. Its mode of 0.18 was the highest, because the vegetation activity is highest in midsummer. In June, NDVI value was distributed over the widest range with the lowest kurtosis of 2.52. It means that some of vegetation areas in June have the same property as that in August, while others have same properties as those in April or September. It seems that NDVI values for June show the transitive pattern in its seasonal succession from spring to midsummer. Its mode was about 0.14 that is higher than April and lower than August.

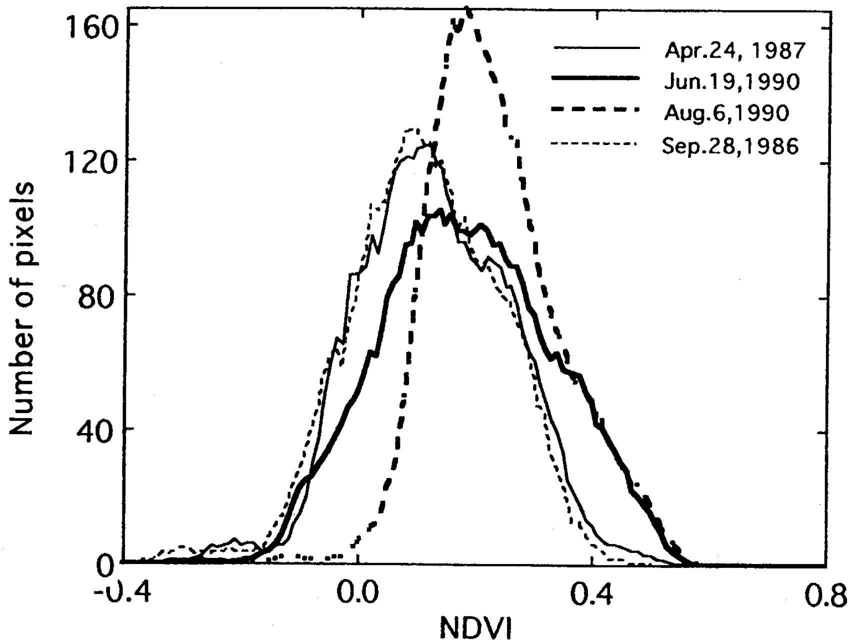

Figure 3 Frequency distribution patterns of the number of pixels observed to NDVI value for cover type of park forest.

3.4 Relationships of the surface temperature and NDVI in different seasons

The relationships between surface temperature and NDVI are examined for vegetation areas in four images (Fig. 4). NDVI values show negative correlation with surface temperature in summer. In this study, we assume that NDVI value represents biomass content including the information of leaf area index, and reflects the change in the amount of evapotranspiration attributed to leaf areas. It seems that more intense evapotranspirations in vegetated areas with higher NDVI values on growing season usually increase the latent heat flux, and then make surface temperature lower.

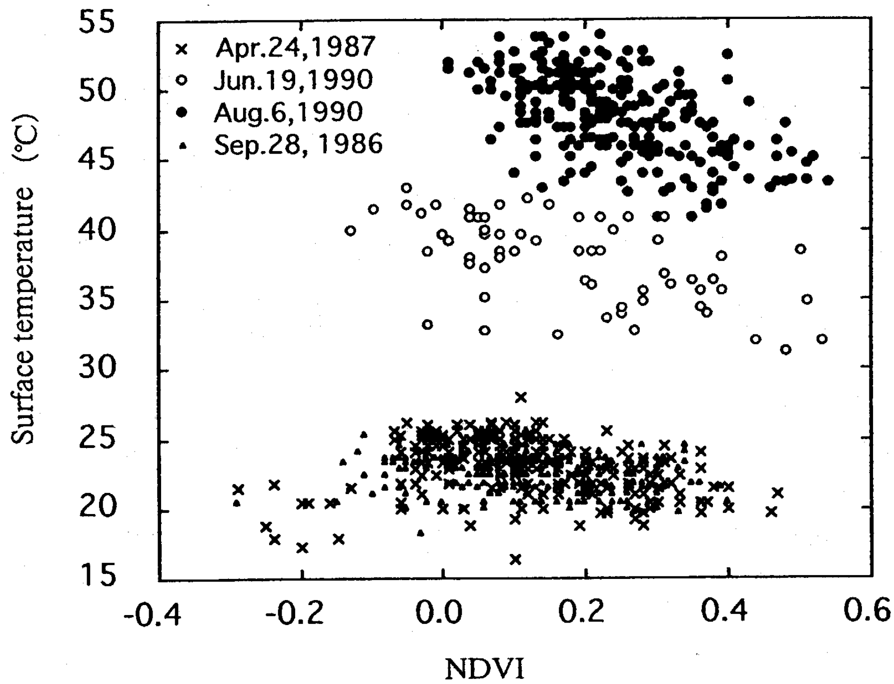

Figure 4 Relationship of the surface temperature and the NDVI for vegetated area in different seasons

This relationship almost disappeared in April and September. The slope of the relationship decreased from -15.1 in August to -10.0 in June, -3.0 in April and -2.5 in September with the decreasing surface temperature. KANEKO and HINO[8] defined this slope as an index expressing relative amount of evapotranspiration influenced by water vapor deficit at leaf surface, wind speed over vegetation and vegetation activities. When water vapor deficit at leaf surface becomes greater, attributed to higher surface temperature, evapotranspiration may have more sensitive response to the amount of vegetation or NDVI. Consequently, it seems that the slope varies with the seasonal change in the response mentioned above, and is influenced by surface temperature.

4. Conclusions

The satellite-derived surface temperature and normalized difference vegetation index (NDVI) data for Osaka city area were used to analyze their relationships with different ground covers and change in different seasons. The order of surface temperature from lower to higher for different types of ground covers in growing season is open water, vegetated area (forest and cultivated), bare land, and urban-residential areas. Higher NDVI value, of 0—0.5, were observed in vegetated area. In contrast, lower value of -0.2—0 was observed in urban and residential, and of less than -0.2 was observed in open water areas. In vegetation area, the relationship between surface temperature and NDVI shows negative correlation in summer, but this relationship becomes weaker due to the decreasing of surface temperature, which influences the amount of evapotranspiration from vegetation.

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