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Study on the Influence of Vegetation Cover on Urban Air Temperature in the Taipei Botanical Garden

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ABSTRACT The influence of vegetation cover on air temperatures was received more concerning recently. Air temperatures of above, under canopy and top of a concrete pavement building have been monitored for investigating the effects of tree canopy on air temperature. Results indicated that the yearly temperature difference between above and under canopy is about 0.42℃ and monthly highest temperature difference can be up to 0.93℃ during the summer season. The difference temperatures between above and under canopy showed no significant difference when temperature of above canopy below 27.2℃. The yearly difference temperatures between top of cement paved building and above canopy were 0.55℃ and showed no significant difference when the above canopy temperature below 24.3℃. This study also used the Landsat-8 thermal images to estimate air temperatures of the entire Taipei metropolitan area through converting infrared wavelength to radiation intensity and calculating brightness temperature (T_B). The obtained air temperature distribution map showed that the heat island effects can cause temperature of the urban area of Taipei city reaching up to 5.0 °C and temperature above vegetated zones showed a relatively lower temperature. These results also proved that vegetation coverages have a cooling effect to mitigate the effect of urban heat island (UHI) and provide a better understanding of the effects of vegetation cover on land surface temperature in the Taipei metropolitan area.

Key Words: air temperature, urban heat island effects, brightness temperature, thermal images

Introduction

Air temperature above ground surface for most places is mainly determined by the amount of received solar radiation which is related to latitude, weather conditions and cloudiness. However, air temperature is also significantly influenced by types and compositions of ground covers. Therefore, land uses can microscopically influence land surface temperature. Issues of global warming have received more attention in recent years due to the rising temperature and the frequently happened extreme temperatures. The urban heat island (UHI) effect is part of the discussion topics concerning of global warming and is increasingly recognized as a serious and worldwide problem (Oke 1982; Rizwan et al., 2008). The UHI effects refer to the phenomenon that the urban areas have a higher average temperature than the corresponding temperature in the nearby rural areas (Loughner et al., 2012). This kind of regional temperature difference phenomenon is widely known after the emergence of satellites, since then humans were able to photograph the earth surface from a high altitude and found that there is a significant difference in temperature between city and the surrounding areas. In the infrared image, the urban area looks like an island floating on the surrounding area and hence named heat island. Nowadays, the average surface temperature of many cities in the world are about 1~6℃ higher than the temperature in the adjacent rural areas (Rizwan et al., 2008). With the deterioration of global warming, the temperature difference between cities and its surrounding areas is also expended.

Coverage rate of plants is relatively high in rural areas and therefore the incident solar radiation energy during the day is mostly consumed by photosynthesis of plants. However, most of the solar radiation energy is absorbed by buildings, streets and pavements in city environment and stored in these ground covers thus will increase the ground and air temperature (Chou et al., 2019). There is no doubt that vegetation cover will lower the temperature below it and thereby affecting the microclimate. However, the degree of influence for vegetation cover in reducing air temperature and minute adjustment of microclimate are still uncertain. The purpose of this study is to investigate the effects of tree canopy on air temperature and to find how much will the temperature be reduced in the shade of plants and what period the influence is significant.

In addition, studies of temperature change were mostly based on the observed records from scattered weather stations. The spatial change of the regional surface temperature can only be obtained through the analysis of the meteorological point data. Point records generally have low resolution and will limit the accuracy of regional temperature estimation. However, with the advancement of telemetry technology and geographic information systems, large-scale and high-resolution data can be obtained

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through satellite telemetry technology to facilitate long-term monitoring ground surface temperature and analysis of its changes for large areas. This study also used the surface radiation received by the Landsat-8 satellite (resolution 30 m), combined with the remote sensing detection technologies to derive land surface temperatures in the Taipei city, and used the meteorological station records to explore and verify the relationship between vegetation cover and surface temperature. The distributed temperature records can be conveniently used to investigate the relationship between land use and UHI effect.

Meteorology

1. Study area and instruments

The instruments for monitoring of temperature were installed in the Taipei Botanical Garden (TBG) (Fig.1). The garden is located in the southwest of Taipei metropolitan area with an area about 8.2 hectares. Excepting of exhibition sites, visiting routes and lotus ponds, the other places of the garden are all covered with vegetation as the name suggested. Two sets of temperature monitoring instruments (MP101A Temp. /RH probe which can measure temperature from -40~60℃) were installed on the top and bottom (1.5 m above ground surface) of a 21.5 m iron tower for monitoring air temperature above and under the canopy of a small piece of forest. Degree of closeness around the tower is about 90% complete due to some branches were removed during construction the tower. Temperatures were monitored every 10 minutes and records of average of those quantities were stored in the CR1000 data logger. The temperature records have a resolution of 1 hour. In addition of those two sets of instruments, another set of monitoring system were installed on the top of the administration building of the Taiwan Forestry Research Institute (TFRI) which is concrete paved and is about 130 m straight-line distance from the tower. Temperature records of the top of the building were used as a baseline reference and for temperature conditions of urban building areas. In addition of the TBG, the whole Taipei metropolitan area was also selected as the study area for the surface temperature estimation of large area by using thermal images. Area of the Taipei city is about 271.8 km^2, the elevation of Taipei city ranges from 0 to 1120 m above sea level and there are about 2.70 million population in the Taipei city. Because of its basin topography and highly urbanized, the UHI effects of Taipei city are more serious than any other cities in Taiwan. Daytime temperature in the summer time is often the highest of Taiwan island.

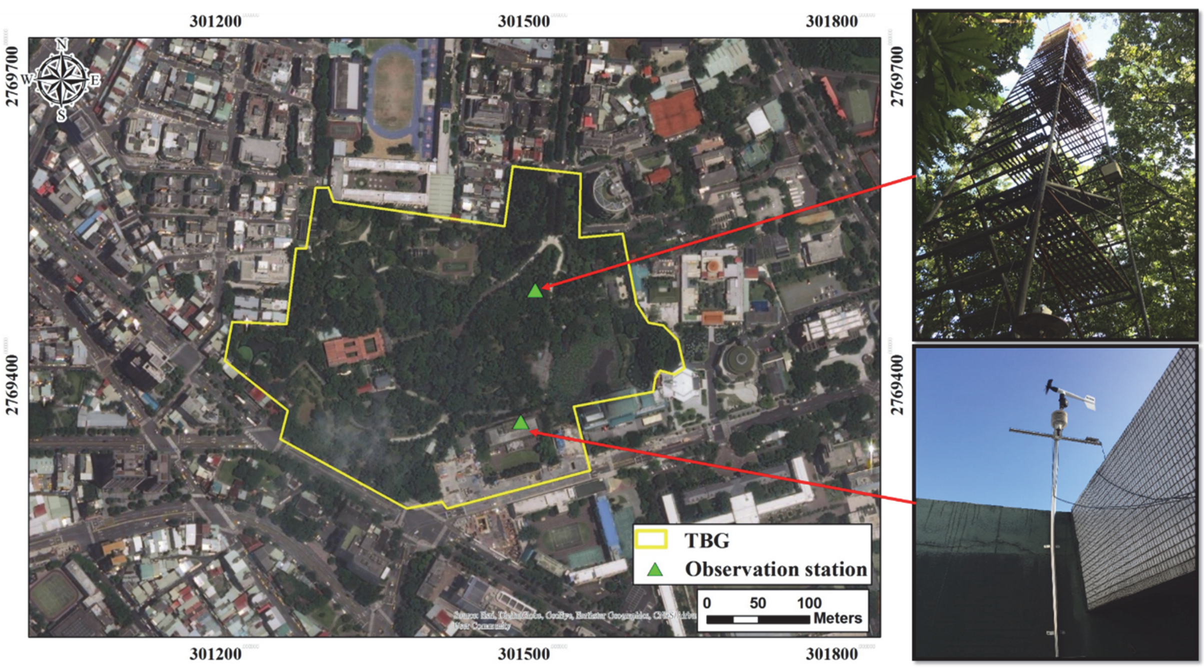

Fig.1 Location of the TBG observatory

2. Data usage

The hourly resolution records of air temperature from April 2020 to March 2021 monitored at the TBG were analyzed for the regimes and differences of temperature among monitored spots in this study. The whole year's records of air temperature at above canopy, under canopy and top of building are complete. Besides temperature records, this study also used the Landsat-8 thematic images (Landsat-8 TI) from the Center of the United States Geological Survey (http://earthexplorer.USGS.gov/) for surface temperature estimation of large areas. Landsat-8 TIs of Taiwan are taken every 16 days. The selected spectral bands were the 10th band (B10, wave length is 10.60 to 11.19 μm) and 11th band (B11, wave length is 11.50 to 12.51 μm) thermal infrared with spatial resolution 30x30 m and radiometric resolution up to 55,000 levels. Four thermal images (shot at10:30 AM of June 22, 2020, August 25, 2020, January 16, 2021, and February 1, 2021, respectively) combined with the observed air temperatures of 13 weather stations at each shooting time in the Taipei meteorological area which are administrated by the Central Weather Bureau of R.O.C. were used to estimate air temperature for the whole city.

3. Surface temperature inversion method

The surface temperature estimation was mainly conducted by converting the thermal infrared band to radiation intensity and calculated the brightness temperature (T_B) of each pixel. The methodology for estimation surface temperature generally has two ways. The first one is using T_B as surface temperature and the other one is extrapolating ground temperature from the influent factors such as ground cover, albedo of ground and atmospheric transmittance (Coutts et al., 1973; Giannini et al., 2015). Many researchers used the T_B directly as ground temperature (Coutts et al., 1973). This study explored the relationship between observed temperature and estimated surface temperature from T_B. Land surface temperature retrieval procedures were: selecting the thermal infrared band, estimating heat radiation intensity, calculating the T_B and verifying by the observed temperatures.

In order to avoid the cloud cover causing outliers in the analysis, the cloud cover should be excluded before the analysis. Then values of digital number (DN) of the thermal infrared bands 10 and 11 were converted into the thermal radiation intensity through a conversion equation. When the DN value is larger, the thermal radiation intensity is greater by the conversion. The conversion equation is:

$$L_\lambda = M_L \cdot Q_{cal} + A_L \quad (1)$$

Where L_λ is the intensity of heat radiation received by the detector in W×m^{-2}×sr^{-1}), M_L is the radiance multiplicative scaling factor, Q_{cal} is the DN value of pixel, and A_L is the radiance additive scaling factor (USGS, 2016, Chiu and Shiu, 2018).

The equation of converting heat radiation intensity received by the sensor into T_B is:

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)} - 273.15 \quad (2)$$

Where T_B is the temperature of the sensor at the satellite altitude in ℃, L_λ is the heat radiation intensity, K_1 is the thermal conversion constant of the selected band (B10 is 1321.0789, B11 is 1201.1441) (USGS, 2016). Although T_B can be used to represent the surface temperature, it is not the real surface temperature. The general method is to establish the relationship between T_B and the observed temperatures for estimating surface temperature of the target areas.

4. Statistics analysis

The two-sample *t*-test is used to determine if two population means are equal. The statistics t is:

$$t = \frac{(X_1 - X_2)}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \quad (3)$$

Where N_1 and N_2 are number of samples , X_1 and X_2 are the sample means and S_1^2 and S_2^2 are the sample variances. The significance level (α) 0.05 is selected for determining whether two population means are significant difference or not. Records of above canopy, under canopy and top of building at the same time of a day of each month were analyzed for determining whether the population mean is equal or not.

Results

1. Temperature regimes for the monitored spots in the TBG

The hourly average temperatures above canopy, under canopy and at the top of buildings for each month were shown in Fig.2 The monthly average, maximum and minimum temperatures were tabulated in Table 1.

Table 1 The average, maximum and minimum monthly temperatures of above canopy, under canopy and at the top of building of each month (℃) from April 2020 to March 2021

Month	Above canopy			Under canopy			Top of building		
	Avg.	Highest	Lowest	Avg.	Highest	Lowest	Avg.	Highest	Lowest
Apr	20.27	22.34	18.40	20.16	22.44	18.13	21.04	23.50	19.09
May	26.36	28.91	24.25	26.00	28.58	24.01	27.22	30.19	24.99
June	30.39	33.96	27.15	29.44	33.05	26.45	30.92	34.78	27.64
July	30.64	34.61	27.49	29.80	33.73	27.07	31.27	35.58	28.13
Aug	30.12	33.14	27.45	29.13	32.13	26.69	30.65	34.15	27.87
Sept	27.52	30.01	25.25	26.85	29.27	24.80	28.03	30.92	25.65
Oct	24.44	25.89	23.33	24.15	25.57	22.97	24.71	26.41	23.49
Nov	23.15	24.66	21.89	22.92	24.59	21.61	23.47	25.23	22.12
Dec	18.20	19.14	17.50	17.69	18.15	16.91	18.20	19.17	17.42
Jan	15.84	17.83	14.37	15.64	17.95	13.84	16.33	18.39	15.20
Feb	19.03	22.05	16.74	18.69	22.04	16.22	19.55	22.41	17.13
Mar	19.89	21.07	17.79	19.54	22.24	18.01	20.62	22.96	18.73
Avg.	23.82	26.19	21.81	23.33	25.84	21.39	24.33	26.97	22.28

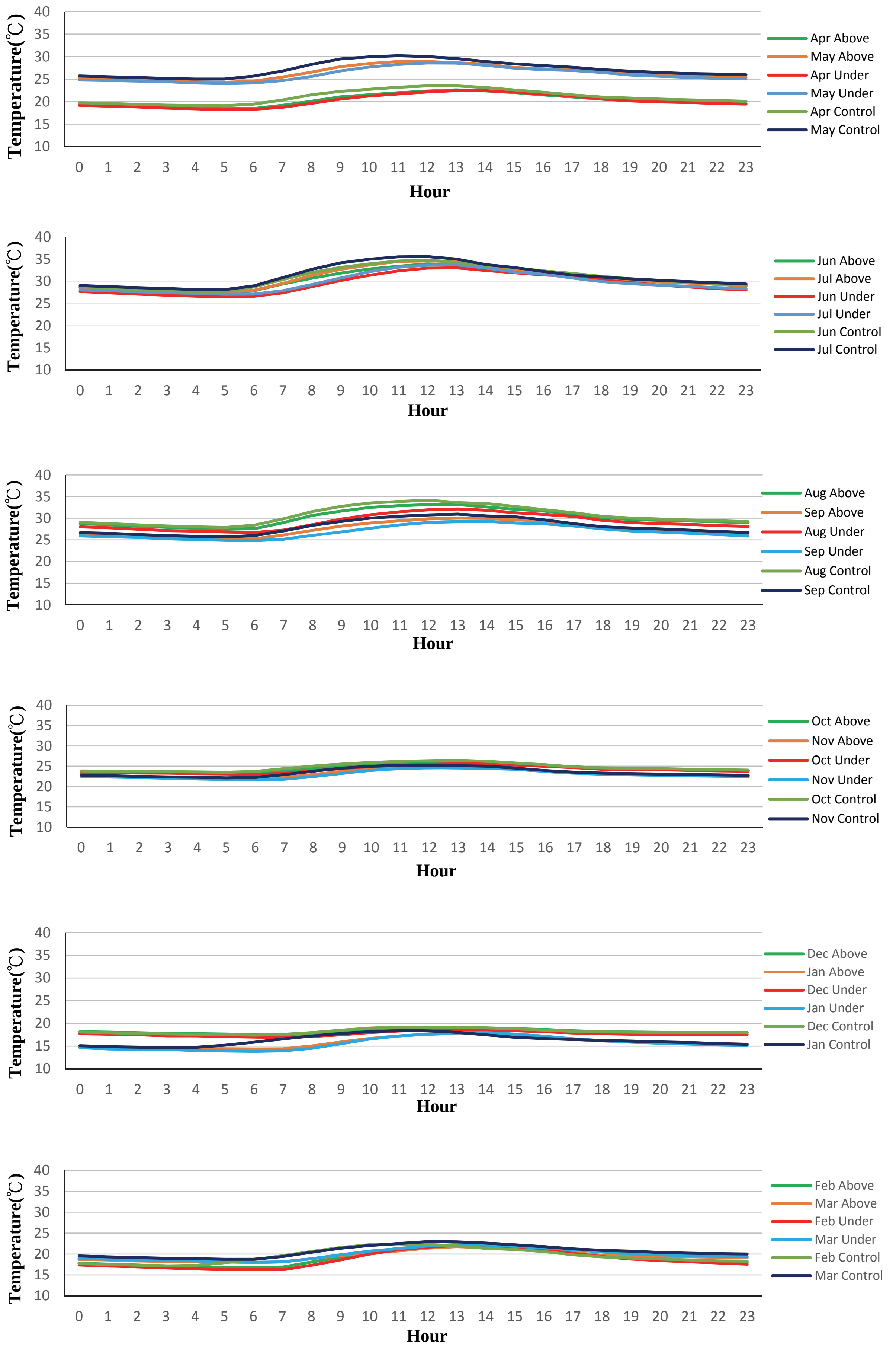

Fig.2 Hourly average temperature fluctuations of the above canopy, under canopy and top building (control)

From Table 1, the ranks of average, highest and lowest temperatures from high to low for all months mostly are at the top of buildings, above canopy and under canopy with a few exceptions. Those exceptions are: the average temperature on the top of building in December is equal to that of above canopy. The average of highest temperatures in January, March and April of under canopy are greater than those of above canopy and the average lowest temperatures in March of under canopy is higher than that of above canopy. The equal average temperature at top of the building and above canopy in December is probably caused by the frequent rain in that month. The higher average temperatures of under canopy are caused by the higher temperatures during night because canopy layer will prevent heat dissipation by radiation. The difference of average temperature between above and under canopy is about 0.42℃ and that of highest temperature can up to 0.99℃ during the summer months from June to August. The lower air temperatures of under canopy proved that canopy has the effect of reducing air temperature especially during the sunny time.

The highest temperature generally occurred at 11am to 14pm for those three observation spots with the chronological order of occurrence as top of the building, above canopy and under canopy. There was about 1 hour delay for the occurrence of the highest temperature. The lowest temperatures occurred at 5am to 7am with the same chronological order of occurrence as that of the highest temperature. Due to the resolution of records is one hour, it is difficult to examine time lag accurately for those three conditions.

2. The effects of vegetation on temperatures

It is generally assumed that the two population variances are equal before conducting the two-sample *t*-test. However, if the analysis of variance (ANOVA) is used to examine whether the population variance of data sets are equal, it will give more precise estimates and reduce the probability of discarding a good null hypothesis. The statistic F values (value of F-test statistic) of all temperature data sets which are the temperatures of above canopy, under canopy and top of building for the same time of a day of each month are all smaller than the critical value (about 1.61 for 30 and 30 degree of freedoms) at 95% significant level. The results of ANOVA indicated that all temperature data sets having equal population variance.

Results of the statistic *t* values between temperature records sets of above canopy and under canopy for the same time period of months having *t* values exceeding the critical value (which is 1.69 for 30 degree of freedom of the *t* distribution with 95% confidence level) were tabulated in Table 2. From Table 2, it can be found that the significant temperature difference time periods were all belong to summer hotter times. In fact, those significant temperature difference periods were all happened in the period when the average temperature of above canopy exceeding 27.15 ℃. The range of above canopy temperature which have significant difference with that of under canopy was 27.15 to 34.62℃. However, it is not always that the temperature of above canopy exceeding 27.15 ℃ will certainly show a significant difference between temperatures of above and below canopy. Many time periods during the afternoon and night of summer season showed no significant difference between those two temperature quantities even though temperature of above canopy were higher than 30.0℃.

Table 2 The significant *t* values for temperature data sets of above canopy and under canopy at the same time period of months having significant difference

Time (h)	June	July	Aug	Sep
0~1	2.64*	1.69*	1.88*	0.72
1~2	2.47*	1.55*	1.82*	0.91
2~3	2.29*	1.60*	1.95*	0.78
3~4	2.51*	1.56*	2.21*	0.80
4~5	2.71*	1.40*	2.09*	0.74
5~6	2.73*	1.40*	1.94*	0.82
6~7	4.62*	3.15*	3.16*	0.84
7~8	6.00*	6.33*	5.59*	1.71*
8~9	5.19*	7.84*	6.45*	1.61
9~10	4.24*	9.34*	5.12*	1.67
10~11	2.39*	6.86*	3.81*	1.31
11~12	2.09*	5.01*	2.85*	0.94
12~13	1.74*	2.84*	2.29*	0.81
13~14	1.00	1.80*	1.60	0.83
14~15	0.79	0.80	1.11	0.69
15~16	0.84	0.53	1.06	0.74
16~17	0.84	0.67	1.06	0.77
17~18	0.52	.043	0.80	0.51
18~19	1.11	1.05	1.13	0.61
19~20	1.38	1.19	1.33	0.61
20~21	1.69*	1.37	1.75	0.70
21~22	1.92*	1.44	1.90*	0.74
22~23	2.43*	1.70*	2.04*	0.76
23~0	2.45*	1.70*	2.22*	0.84

The *t*-statistic values in rejection region between data sets of above canopy and top building for each time period of each month were listed in Table 3. The significant difference time periods were concentrated from May to August and all of those time periods were occurred from early morning to noon. Temperatures of above canopy during these significant difference periods ranged from 24.30 to 34.62℃. It also shown that there is no significant difference between temperatures of above canopy and that of top building when temperature of above canopy below 24.30℃. However, it is not certainly showing significant difference between temperatures of those two monitored spots when temperature of above canopy exceeding 24.30℃.

Table 3 The statistic-t values for temperature data sets of above canopy and top building at the same time period of months having significant difference

Time (h)	May	Jun	July	Aug
0~1	1.45	0.16	1.12	0.81
1~2	1.47	0.83	1.31	0.82
2~3	1.56	1.05	1.38	0.91
3~4	1.50	1.06	1.52	1.06
4~5	1.77*	1.18	2.38*	1.19
5~6	2.14*	2.45*	4.08*	3.18*
6~7	2.95*	3.38*	5.96*	2.82*

Time (h)	May	Jun	July	Aug
7~8	2.51*	2.77*	6.63*	2.54*
8~9	2.51*	3.55*	9.00*	2.96*
9~10	2.12*	3.37*	6.03*	2.19*
10~11	1.64	2.79*	3.59*	1.79*
11~12	1.31	2.33*	2.68*	2.00*
12~13	1.67	1.50	1.20	0.72
13~14	1.05	0.97	0.57	1.06
14~15	0.71	0.84	0.76	0.89
15~16	0.96	0.69	0.43	0.45
16~17	0.92	0.40	0.41	0.62
18~19	0.79	0.32	0.54	0.53
19~20	0.68	0.14	0.62	0.74
20~21	0.89	0.09	0.77	0.66
21~22	0.99	0.26	0.76	0.56
22~23	1.23	0.46.	0.84	0.73
20~0	1.34	0.43	0.99	0.55

3. Land surface temperature estimation by thermal images

In this study, the T_B values obtained from DN of B10 and B11 were used to estimate surface temperature. The DNs were converted into the intensity of radiation through equation (1) and the T_B values were calculated from equation (2). The distribution of T_B for the Taipei City was shown in Fig.3 It can be seen from Fig.3 that the distribution of higher T_B are mostly belong to construction areas and the distribution of significant lower T_B are mostly belong to rivers, vegetation cover areas and green corridor along roads for both images taken in summer and winter.

The linear relationship between T_B obtained from B10 and B11 and observed temperatures from meteorological stations were shown in Fig.4 Both of the two relationships have highly correlation (R^2=0.91, n=51 and p<0.001 for B10; R^2=0.78, n=51 and p<0.001 for B11). This high relationship indicated that T_B can reflect air temperature. Therefore, many researchers directly use T_B as the ground temperature (Coutts et al., 1973; Rozenstein et al., 2014). In addition, estimation of T_B from wave of B10 was more coincident with the real temperature than that of estimated from B11. It is suggested that the surface temperature can be estimated from B10 to obtain a better result.

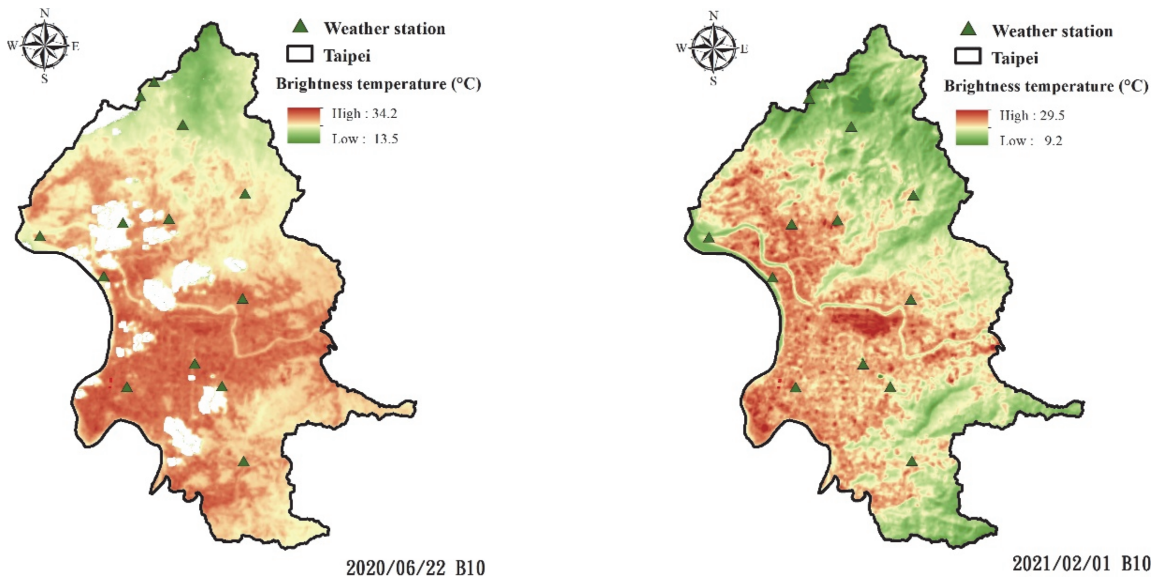

Fig.3 Distribution of T_B in Taipei City (excluding cloud cover)

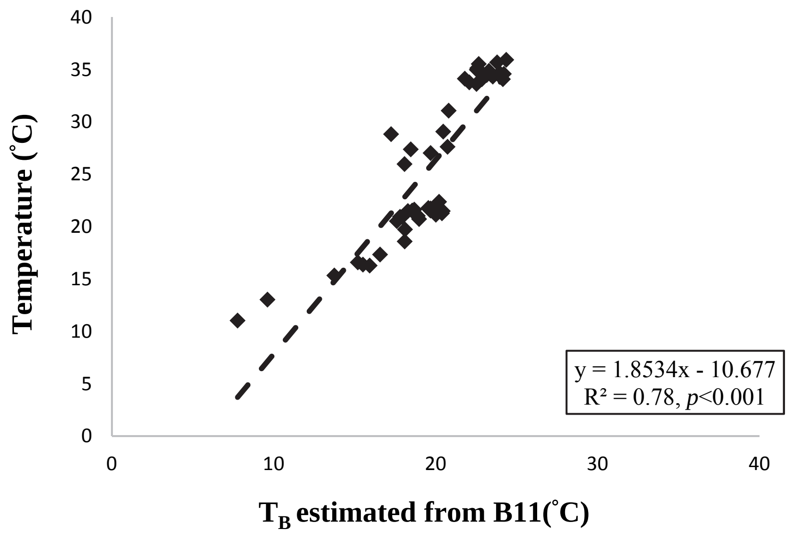

Fig.4 The relationship between T_B and observed temperatures

The T_B can be converted into air temperature through the established regression equations, and the spatial distribution map of temperature in Taipei City was shown in Fig.5 The average temperatures of those 13 weather stations in the metropolitan area of Taipei city at the images taken on June 22, 2020, August 25, 2020, January 16, 2021, and February 1, 2021 were 32.6, 32.3, 19.0 and 20.1℃, respectively. The temperature distribution map showed that the heat island effect caused temperature of the urban area of Taipei City (excluding mountainous areas such as Yangmingshan) reaching up to 5.0 °C, especially in dense buildings and concrete-paved areas. The distribution of temperature of street trees and green corridors showed a relatively lower temperature and the minimum temperature of the green belt is about 1.0~2.0 ℃ lower than that of the nearby building areas. This phenomenon indicated that vegetation have a cooling effect to mitigate the effect of UHI.

4. Verification of the estimated air temperature

The estimated temperatures from the established liner regression equations were verified by the observed temperatures in the TBG. Accuracy of verification was based on the difference of temperature between estimated from T_B and observed temperatures. Table 4 showed the observed and estimated temperatures for the top building and above canopy of the TBG at the time of the thermal images taken. Except two estimations having the difference between estimated and observed temperatures exceeded 0.5℃, the other estimations gave more accurate estimations. This result indicated that the temperature estimated by conversion through T_B has the acceptable accuracy and can be used to estimate temperature for large area. The estimated temperature of buildings and tree canopies in the TBG showed that the temperature of the top of buildings was significantly higher than that of the tree canopy no matter in summer or winter. It proved that the canopy has the effect of lowering temperature, especially in the Taipei area where UHI is severe.

Table 4 Estimated and measured temperature of the TBG (℃)

Date	Top building	Diff.	Above canopy	Diff.
2020/06/22_B10	34.3	-0.6	32.7	-0.1
2020/06/22_Obs.	34.9		32.6	
2020/08/25_B10	34.2	-0.3	32.4	-0.2
2020/08/25_Obs.	34.5		32.2	
2021/01/16_B10	20.7	-0.5	20.3	-0.2
2021/01/16_Obs.	20.2		20.5	
2021/02/01_B10	20.9	-0.5	20.3	0.6
2021/02/01_Obs.	21.4		19.7	

Diff.: Difference, B10: Estimated from B10, Obs.: Observed temperature

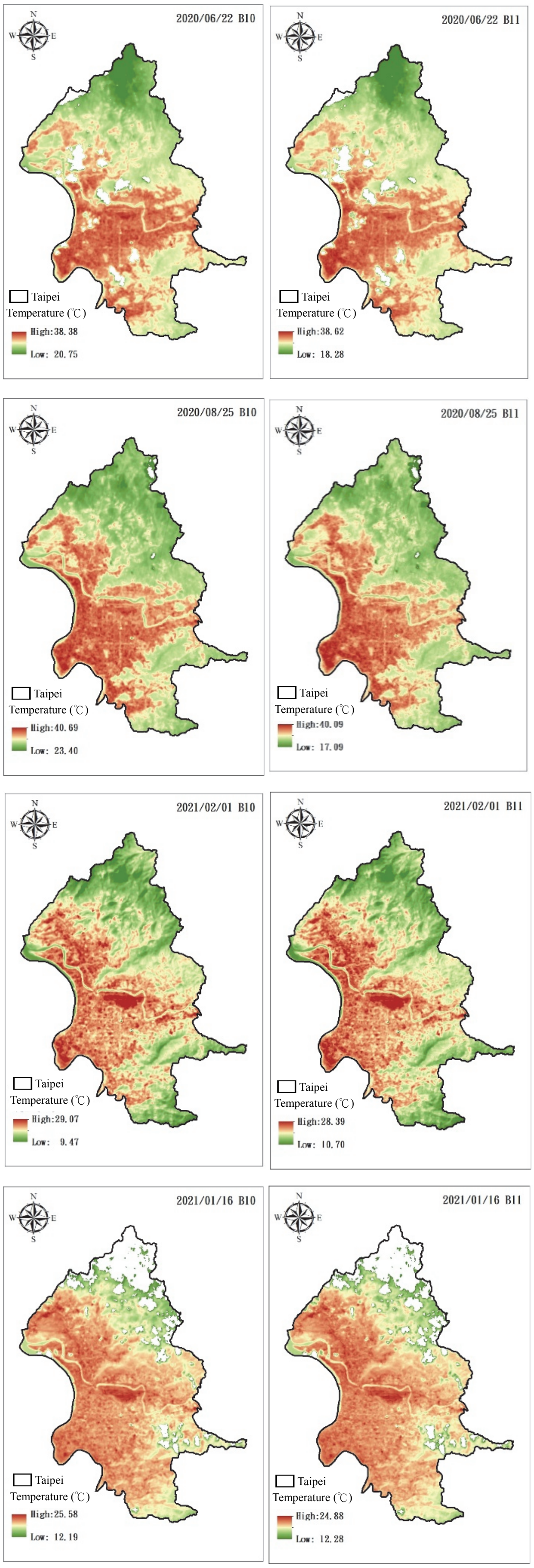

Fig.5 Temperature distribution converted from T_B in Taipei City (excluding cloud cover)

Discussions

1. Sources of heat and its influence on temperature

Sources of heat of earth's surface are major solar radiation, geothermal heat conducting to the ground, artificial heat emissions, and heat carried by air current. However, the main source is solar radiation for most areas. After the incident solar radiation reaches the surface, the energy balance relationship is (Cellier et al., 1996; Ogee et al., 2001):

$$Rn = H + \lambda E + G \quad (4)$$

where Rn is net radiation (cal/cm^2), H is atmospheric sensible heat flux (cal/cm^2), λ E is latent heat or evaporation flux (cal/cm^2) and G is net energy storage within ground (cal/cm^2).

It is necessary to reduce the net radiation and increase the potential of latent heat divergence and the energy stored on the ground for reducing the sensible heat flux. During the growing season of vegetation, evapotranspiration and photosynthesis will consume about two-thirds of the incident energy (Cellier et al., 1996). Therefore, the simplest and most effective way to increase solar energy consumption is to plant as many trees as possible and cover ground or top of buildings with vegetation. Our observations in the TBG showed that the yearly average temperature under the tree canopy during the monitoring period can be 1.0℃ lower than that at the top of building. Although the difference of yearly average temperature among those three observation locations is in a small amount, the differences of day time (07:00 to 17:00) average temperatures among them were significant. The difference of day time average temperature between top of the building and under canopy can reach as higher as 2.25℃, and that between above canopy and under canopy was 1.45℃. This indicated that daily temperature difference mainly came from the cooling effect of plants.

Canopy of trees will also prevent heat conduction into atmosphere from ground surface and block air current movement. Therefore, it is possible that temperature below the canopy may higher than that of above canopy. Records in this study showed that these situations occurred at a few night hours from January to April and mostly in January. This phenomenon is generally because locations under tree canopy are generally the shelter from wind and receiving more heat from soil layers.

Many factors that influence ground temperature include latitude, elevation, topography, costal or interior location, surface type and atmospheric, oceanic circulations and meteorological conditions (Yang et al., 2016). Only surface types were considered in this study. Surface materials in the building areas of city generally are composed by asphalt, cement, rock, brick and shingle. Those materials hold little water in comparison with the moist soil surface of rural area and forests. In addition, urban materials absorb a greater portion of incident heat energy and quickly cause its temperature rising. This study verified that air temperature of top building showed rapid rising and rapid falling because of the lower specific heat of concrete pavement. In fact, the surface temperature of the concrete pavement is much higher than that of the air temperature above it. Heat absorbed in the pavement affects air temperature above it through radiation and convection and results in higher air temperature.

In cool seasons or during the nights, the major source of heat is coming from air current especially in high latitudes areas. Air current dominates the land surface temperature variations and in cool or cold seasons for subtropical, temperate and frigid regions. Heat energy from solar radiation in cold seasons has no or little effects to increasing air temperature because its amount is negligible in comparison with the extreme low thermal content of cold current in those regions. In this situation, vegetation has little or no effects for mitigating surrounding microclimate. Our observations showed that temperatures of above and under canopy only in the hottest months had statistically significant difference. In those significant difference time periods, the cooling effects of vegetation cover are relatively strong. Although most time periods showed no statistical difference for temperatures between above and under canopy, people can obviously feel the body temperature significantly reduced in shades of trees.

2. The roles of canopy structures in mitigating air temperature

Composition of vegetation cover not only affects energy flow but also influences the efficiency of evapotranspiration (Song et al., 2014). Composition refers to the variety and abundance of land cover types. It is consistently acknowledged that canopies of large amplitude and volume, multiple layers, and higher crown density will more effectively lower land surface temperature below it (Chen et al., 2020). Characteristic of canopy of the study area in the TBG are single layer, small amplitude, not complete closeness and about 18 m above ground surface. The ability of lowering land surface temperature below the canopy may not as effectiveness as that of forest in the wild. In addition, the woods of observation spot are isolated by concrete paved visiting routes on both sides. The configuration of the studied woods is not beneficial to mitigate UHI effects. However, those characteristics of the studied canopy are just the characteristics of urban forests. This study showed that a small piece of woodland in the TBG can significantly and effectively reduce daytime air temperature in summer time and its accumulated cooling functions may further mitigate UHI effects.

3. The effects of vegetation cover for reducing urban temperature

In order to study the effect of vegetation cover on lowering air temperature, we drew a virtual line through two temperature observation spots of the TBG and studied the relationship between vegetation cover and air temperature (Fig.6). Vegetation cover is represented by the Normalized Difference Vegetation Index (NDVI), which is usually used to quantify the surface vegetation cover by measuring the difference between near infrared (strong reflection from healthy vegetation) and red light (vegetation absorption) (Cai et al., 2014; Rouse et al., 1973).

Temperature distribution and NDVI values of the TBG and nearby on June 22, 2020 were shown in Figure 7. It can be seen that the lowest temperature is located at the center of the TBG, and the temperature difference between inside and outside the park is about 2.5°C. Under the same geographical location, there is a significant difference in temperature between buildings and green spaces in the urban area, which can result an air temperature difference of as high as 1~7°C. This phenomenon is sometimes called "park cool island" (Oke et al., 1989; Hamada et al., 2010). Trees can eliminate large amounts of incident short-wave solar radiation through reflection and absorption (Khare et al., 2021). The evapotranspiration and photosynthesis of vegetation will consume radiant energy or convert light energy into chemical energy, leading to a drop of temperature. The temperature distribution in Fig.7 showed that with the increase of vegetation coverage, the "cool island in the park" at the center areas is more obvious, and it also has a cooling effect at the TBG boundary. This effectiveness depends on the characteristics of the park, such as park size and park coverage composition (Chang et al., 2007; Cao et al., 2010). In terms of improving the thermal environment, trees are generally more effective than grass (Khare et al., 2021).

Fig.6 Profile line through two temperature observation spots of the TBG

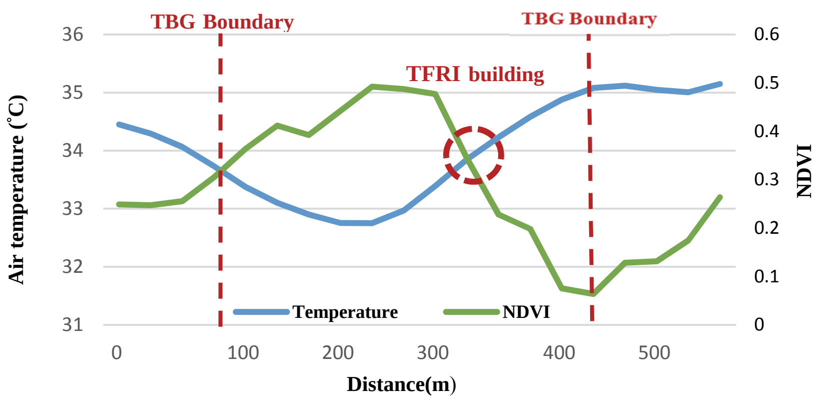

Fig.7 The relationship between NDVI and air temperature in the TBG

Conclusion

The observed temperature records in this study indicated that canopy of a small piece woods in the TBG can significantly reduce air temperature in warmer time. The difference temperatures between above and below canopy and that between above canopy and top of building showed significant difference only when above canopy temperature exceeding 27.2 and 24.3℃, respectively. Tree canopy influences land surface temperature more strongly during daytime than nighttime, and summer seasons than winter seasons. This study also proved that it is feasible to use Landsat satellite thermal images to estimate air temperature in a large area. The spatial distribution of temperature of Taipei city showed that the temperature difference of the urban area of Taipei city can reach up to 5.0°C due to the UHI effects. In addition, it also confirmed that vegetation has a cooling effect, which is indeed beneficial to improving the overall urban environment. Although this study is an example of Taipei metropolitan area and TBG, hopefully these results can provide a basic reference for mitigating the impact of UHI through better understanding the influence of vegetation cover on air temperature.

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References

[1] Cai, D.L., Fracdrich, K. Sielmann, Y.N., Guan, S., Guo, S., Zhang, L., and Zhu, X.H. (2014). *Climate and vegetation: an ERA-Inter and GIMMS NDVI analysis. Journal of Climate*, 27, 5111-5118.

[2] Cao, X., Onishi, A., Chen, J., and Imura, H. (2010). Quan tifying the cool island intensity of urban parks using ASTER and IKONOS data. Landscape Urban Plan, 96(4), 224-231.

[3] Cellier, P., Richard, G., and Robin, P. (1996). Partition of sensible heat fluxes into bare soil and atmosphere. Agricultural and Forest Meteorology, 82, 245-265.

[4] Chang, C.R., Li, M.H., and Chang, S.D. (2007). A preliminary study on the local cool-island intensity of Taipei city parks. Landscape Urban Plan, 80(4), 386-395.

[5] Chen, J., Jin, S., and ZDu, P. (2020). Roles of horizontal and vertical tree canopy structure in mitigating daytime and night urban heat island effects. International Journal of Applied Earth Observation and Geoinformation. http://doi.org/10.1016/j.jag.2020.102060.

[6] Chiu, J.T., and Shiu, Y.S. (2018). Using Landsat-8 Images for the impact of flowery field on the land surface temperature change. Journal of Photogramm Remote Sensing, 23(1), 25-42. [in Chinese with English summary].

[7] Chou, T.H., Lin, Y.Q., and Wang, S.D. (2019). Applying MODIS and Landsat-8 Images for Evaluating Urban Cool Island Effect. Journal of Photogramm Remote Sensing, 24(4), 223-33. [in Chinese with English summary].

[8] Coutts, A.M., Harris, R.J., Phan, T., Livesley, S.J.,Williams, N.S.G., and Tapper, N.J. (2016). Thermal infrared remote sensing of urban heat in Tempe, Arizona: Introduction the MaRTy observational platform. The Science of the total environment, 687, 137-151.

[9] Giannini, M.B., Belfiore, O.R., Parente, C., and Santamaria, R. (2015). Land surface temperature from Landsat-5 TM images: Comparison of different methods using airborne thermal data. Journal of Engineering Science Technological Review, 8(3), 83-90.

[10] Hamada, S., Ohta, T. (2010). Seasonal variations in the cooling effect of urban green area on surrounding urban areas. Urban For Urban Gree, 9(1), 15-24.

[11] Loughner, C.P., Allen, D.J., Zhang, D.L., Pickering, K.E., Dickerson, R.R., and Landry, L. (2012). Roles of urban tree canopy and building in urban heat island effects: parameterization and preliminary results. Journal of Applied Meteorology and Climatology. 51, 1775-1793.

[12] Ogee, J., Lamaud, E., Brunet, Y., Berbigier, P., and Bonnefond, J.M. (2001). *A long-term study of soil heat flux under forest canopy. Agricultural and Forest Meteorology*. 106, 173-186.

[13] Oke, T.R. (1982). The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society. 108 1-24.

[14] Oke, T.R., Crowther, J.M., McNaughton, K.G., Monteith, J.L., and Gardiner, B. (1989). *The micrometeorology of the urban forest [and discussion]. Philosophical Transactions of the Royal Society B*, 324(1223), 335-349.

[15] [15] Rizwan, A.M., Dennis, L.Y., and Liu, C. (2008). A review on the generation, determination and mitigation of urban heat island. Journal of Environmental Science, 20,120-128.

[16] Rouse, J.W., Haas, R.H., Schell, J.A., and Deering, D.W. (1973). *Monitoring vegetation systems in the Great Plains with ERTS*. Third ERTS Symposium, NASA SP-351, Washington DC, USA, 309-317.

[17] Rozenstein, O., Qin, Z., Dermian, Y., and Karnieli, A. (2014). Derivation of land surface temperature for Landsat-8 TIRS using a split window alogrithm. Sensors, 14(4), 5768-5780.

[18] Song, J., Du, S., Feng, X., and Guo, L. (2014). The relationship between landscape compositions and surface temperature quantifying their resolution sensitive with spatial regression models. Landscape and Urban Planning, 123, 145-157.

[19] U.S.G.S. (2016). *Landsat-8 (L8) data users handbook*. Version2.0. USGS, http://landsat.usgs.gov.

[20] Yang, L.S., Yang, P.H., Ho, C.W., Yeh, M.L., and Chou, T.Y. (2016). The study of urban heat island effect change and contribution factors in Taichung City. Journal of Photogramm Remote Sensing, 20(1), 29-42. [in Chinese with English summary].

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