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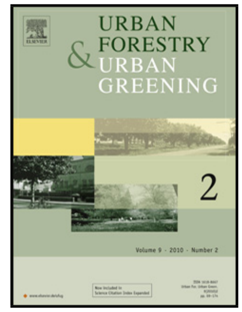

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Quantifying the cool island effects of urban green spaces using remote sensing Data

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Abstract

Urban Heat Island (UHI) leads to increased energy consumption, aggravated pollution and threatened health of citizens. Urban green spaces mitigate UHI effects, however, it is still unclear how the green space characteristics and its surrounding environment affects the green space cool island (GCI). In this study, land surface temperature (LST) and land cover types within the outmost ring road of Shanghai, China were obtained from Landsat 8 data and high-resolution Google Earth data. The GCI effects were defined in three aspects: GCI range (GR), amplitude of temperature drop (TA) and temperature gradient (TG). Pearson correlation analysis was processed to get the relationship between the aspects and impact factors. The results indicated that the GCI principle could be explained by the thermal conduct theory. The efficient methods to decrease LST of green spaces include increasing green space area while staying below the threshold, adding complexity of green space shape, decreasing impervious surfaces and enlarging the area of water bodies. For the surrounding environment of the green spaces, increasing vegetation and water body fractions or decreasing impervious surfaces will help to strengthen GCI effects. The findings can help urban planners to understand GCI formation and design cool green spaces to mitigate UHI effects.

Keywords: Urban heat island, Green space Cool Island, Land surface temperature, Land cover types, Landsat 8

1 Introduction

Rapid urbanization process enlarges the range of urban areas, increases the density of buildings and changes the features of underlying surfaces. The temperature in urban areas is higher than suburban areas because the artificial surfaces have smaller thermal capacity than the natural ones. Thus, the ecological environment problem of Urban Heat Island (UHI) arises.

The UHI effect means a higher temperature in the urban than its surrounding areas (Oke, 1973). It is one of the most obvious features of urban climate. The UHI effect leads to increased energy consumption, aggravated pollution and threatened health of citizens (Alghannam and Al-Qahtnai, 2012; Ng et al., 2012). Along with the UHI research, the Urban Cool Island (UCI) which stresses UHI mitigation by effective landscape planning is developed and attracts the attention of scholars and urban planning authorities.

So far, the two efficient research methods for UHI and UCI are most applied: meteorological observation (Magee et al., 1999; Unger et al., 2001) and remote sensing retrieval (Chudnovsky et al., 2004; Du et al., 2016; Jin et al., 2011). Meteorological observation is the traditional method. It measures the air temperature at the meteorological stations in urban and suburban areas. The advantage is the accuracy of data. However, the density of meteorological station distribution is limited, which leads to poor coverage of the concerned areas. So it is difficult to reveal the UHI spatial distribution of the whole area. Recently, the high-resolution remote sensing technology is widely applied in the UHI study. The principle is to retrieve the land surface temperature (LST) from the remote sensing images. The method achieves excellent synchronicity and spatial coverage, which overcomes the weakness of the traditional method.

Plenty of research prove that urban green spaces can form UCI effects called Green Space Cool Island (GCI) (Oliveira et al., 2011; Yu and Hien, 2006; Zhang et al., 2009). Urban green space is defined as green infrastructure that uses vegetated spaces, including urban parks, road, residence and workplace greenspace (Benedict and McMahon, 2006; Kantzioura et al., 2012). The vegetation in green space shade and absorb the radiation energy by photosynthesis and transpiration, thus cool down the LST (Bonan, 1997; Bowler et al., 2010; Wong and Yu, 2005). The GCI shows good effects on UHI mitigation and is quite applicable by effective landscape planning, so the research on GCI impact factors and evaluation indexes is valuable. (Chen et al., 2014; Hamada and Ohta, 2010).

As concluded by previous research, the impact factors of GCI include size, shape, type and landscape pattern of the green space (Cao et al., 2010; Li et al., 2011; Li et al., 2012; Oliveira et al., 2011). Jauregui (1990) finds that the influence radius on the surrounding air temperature by Chapultepec Park in Mexico is 2 km and the relationship between size and GCI range (GR) of green space is nonlinear. It is also proved that there is a threshold of the green space area (Cao et al., 2010; Chang et al., 2007; Lu et al., 2012; Mikami and Sekita, 2009). If the green space area exceeds the threshold, the cooling effect will drop sharply. As to the shape, Chang et al. (2007) research on GCI of the urban parks in Taipei and conclude that complex shape of the green space leads to strong GCI. The research of Jonsson (2004) and Wong et al. (2007) prove that the GCI of different types of green space differs obviously, trees provide the highest GCI, while the shrubs and the grass provide the lowest. There are also research indicate that the spatial arrangement and configuration of the green space are significantly correlated with its GCI. For example, Li et al. (2012) indicate the percent cover of green space has a significant negative impact on LST.

Except for GR, the amplitude and gradient of temperature drop of the green space could also indicate the GCI features of green spaces comprehensively. However, this is conducted in very few research. Moreover, shape, size, type and landscape pattern are only factors inside the green space, the information around the green spaces are seldom noticed. Also, there are some different conclusions on the same topics, which is caused by different backgrounds and research methods. So, it is necessary to research on the relation between the impact factors of GCI and GCI indicators in more cases. The impact factors should include multiple variables from both inside and around the green spaces and the GCI indicators should include not only GR, but the amplitude and gradient of the temperature drop as well.

In this paper, based on the high-resolution Google Earth and Landsat-8 satellite imagery data of the 68 green space samples within the outer ring road of Shanghai, China. We aim to: (1) Use GR, amplitude and gradient of temperature drop to indicate GCI. (2) Reveal the relationship between GCI and the impact factors derived from the both inside and around the green spaces. (3) Synthesis all internal and external impact factors of GCI and build up the regression model for the relationship.

The second section includes a brief introduction of the research case, explanation of the research methods. The third section is the result of LST retrieval and data calculation. The fourth section is the analysis and discussion based on the calculated results and the last section is the conclusion

2 Materials and methods

2.1 Study area

Shanghai is one of the most urbanized cities in China and locates on the coast of East China Sea, ranging from 31°40′N to 31°53′N and 120°51′E to 121°12′E (Fig. 1). By the end of 2014, the permanent resident population is 24.2568 million. Within the total area of 6340.5 km^2,green space covers 1242.95 km^2 (Shanghai Municipal Statistics Bureau, 2011). Based on the high-resolution Google Earth 2013, 68 green spaces larger than one hectare (ha, 1ha=0.01km^2) are selected as research samples of this paper (Fig. 2).

2.2 LST retrieval and land cover identification

According to the result of Sobrino et al. (2004), by radiative transfer equation (RTE), the retrieved LST based on atmospheric profile measurement can reach an accuracy of 0.6 ℃. Therefore, this method is introduced to retrieve the LST of Shanghai in August 29, 2013. The data come from the thermal infrared sensor (TIRS) on satellite Landsat-8 which is launched in February, 2013. The LST retrieval process is the same as Du et al. (2016).

The land cover types are identified based on high-resolution Google Earth 2013 (Fig. 3). The following four types of land cover are visually mapped:

- Green land: basically covered by trees and shrubs, other covers are less than 10%.

- Grass land: basically covered by lawn, other covers are less than 10%.
- Impervious surface: residential, commercial center, industrial zones, transportation and roads.
- Water body: rivers and lakes.

2.3 Definition of GCI indicators

GCI effect is evaluated by the LST difference between green spaces and their surroundings. In this research, from the edge of a green space, its surrounding buffer is sliced into annulus-shaped areas with a fixed width. The average LST within each annulus is calculated respectively, then considering the corresponding distance, a temperature curve is formed by connecting the discrete points.

Referring to the previous research in Du et al. (2016), the GCI effect includes the following three aspects:

- GCI Range (GR): The distance between the first turning point of temperature curve and the edge of green space. The unit is km.
- Temperature Drop Amplitude (TA): The LST drop between turning point and green space interior. The unit is ℃.
- Temperature Gradient (TG): The gradient (temperature drop with unit distance) of surrounding LST. The unit is ℃/km.

2.4 Descriptors of green space and the surrounding areas

In this research, the following concerned impact factors are selected:

- Green Space Area (GSA)
- Landscape Shape Index of the green space (LSI)
- Percentage of Vegetation inside the green space (PV_in)
- Percentage of Water Body inside the green space (PW_in)
- Percentage of Impervious Surfaces inside the green space (PI_in)
- Percentage of Vegetation outside the green space (PV_out)
- Percentage of Water Body outside the green space (PW_out)
- Percentage of Impervious Surfaces outside the green space (PI_out)

By applying the ArcGIS 10.1 software, the GSA and percentage variables are calculated. The LSI of each green space is calculated as equation 1.

$$LSI = (\pi \times GSA)^{-0.5} \times D/2 \qquad (1)$$

Where D is the perimeter of green space, and is also calculated by ArcGIS 10.1. The larger LSI indicates a more complex shape of green space. For example, LSI for circle is 1 while for square is 1.13 (McGarigal and Marks 1995).

2.5 Analytical methods

First, a 2000 m buffer is built by ArcGIS 10.1 for each of the green space. By superposing the buffer with the results of LST retrieval, the LST distribution around each green space is acquired. Then applying MATLAB 2014, the buffer is equally sliced into 200 small annuluses (10 m wide for each) and the average LST within each annulus is calculated. The calculated results are collected, and plotted on a temperature versus distance figure, thus forming the temperature curve for each green space buffer. Finally, according to the definitions in Section 2.3, the GCI aspects for each green space are manually extracted for statistical analysis.

The statistical analysis is performed by SPSS 19.0. The relationship between GCI aspects and impact factors are analyzed by curve fitting and Pearson Correlation Coefficient.

3 Results

3.1 Green space characteristics and GCI effects

Combining the data of land cover types in 2013 with the retrieved LST, it can be calculated that the average LST inside the selected 68 green spaces is 38.63 ℃. This is obviously lower than the total average LST (40.7 ℃) of the areas within the Shanghai outermost ring-road. The result proves that urban green spaces have cool island effects. According to the results listed in Table 1, for the 68 green spaces, the GSA is between 1.12 ha and 205.32 ha, the LSI is between 1.11 and 3.68 and the average inside LST is between 36.52 ℃ and 41.29 ℃.

Figure 4 shows the LST curves of the first 6 green spaces as examples. It can be observed that the LST around green space rises as the distance from green space increases. As the distance further increases, the temperature increase slows down or even decrease. This indicates that GR is reached.

For the 68 green spaces, the general results are shown in Table 1. GRs are between 0.09 km-1.61 km with an average value of 0.57 km, the TAs lie between 0.78 ℃-5.20 ℃ with an average value of 3.02 ℃ and the TGs lie between 1.44 ℃/km-18.71 ℃/km with an average value of 6.31 ℃/km. Detailed results for each green space are listed in the Appendix A.

Temperature drop amplitude; TG: temperature gradient

3.2 Relation between green space LST and impact factors

Fig. 7 is the fitting curve corresponding to the scatter diagrams of the LSTs versus GSA. The curves indicate that GSA is significantly negatively correlated with its LST ($P<0.01$). This means the GSA is one of the major impact factors of LST.

When GSA is smaller than 40 ha, the green space temperature decreases significantly with the increasing GSA. If the GSA exceeds 40 ha, the LST decrease slows down and meets the limits (Fig. 5). Accordingly, there is an obvious threshold of the LST values. For this case in Shanghai, the threshold is 40 ha.

The LST of green space is significantly negatively correlated with LSI (Fig. 6). For green spaces with LSI greater than 2, the average LST is 37.66 ℃ which is lower than 39.02 ℃ for LSI smaller than 2. So the green space with more complicated shape leads to lower inside LST .

19 of the selected 68 green spaces contain impervious surfaces. Thus the 19 samples are extracted for further analysis. According to the fitting curves in Fig. 7, PI_in is positively significantly correlated with green space LST. So higher PI_in leads to higher LST.

According to Fig.8, the PV_in of green space is not significantly correlated with green space LST.

16 of the selected 68 green space contain water bodies. So they are extracted to analyze the connections between PW_in and green space LST (Fig. 9). The average LST of green space with PW_in >20 % is 36.94 ℃, for green space with PW_in between 0 and 20 %, the value is 37.74 ℃, and 38.94 ℃ for no-waterbody green spaces. This indicates that the greater PW_in of the green space is, the lower LST could be achieved.

3.3 Relation between GCI and impact factors

According to Table 2, GR is positively correlated with GSA, PV_out and LSI (P<0.01), negatively correlated with PI_out (P<0.01) and not significantly correlated with PI_in, PV_in PW_in and PW_out (P>0.05). This indicates that GR could be improved by enlarging GSA, complicating the shape, increasing PV_out and decreasing the PI_out. TA is only positively correlated with GSA and LSI (P<0.01). This indicates TA is most impacted by GSA and LSI. TG reflects the efficiency of GCI effects, it is significantly positively correlated with PW_in and PW_out. This indicates higher PW_in and PW_out will increase the GCI efficiency.

GCI: green space island; GR: green space island range; TA: Temperature drop amplitude; TG: temperature gradient; GSA: green space area; LSI: landscape shape index; PI_in: Percentage of Impervious Surfaces inside the green space; PV_in: Percentage of Vegetation inside the green space; PW_in: Percentage of Water Body inside the green space; PI_out: Percentage of Impervious Surfaces outside the green space; PV_out: Percentage of Vegetation outside the green space; PW_out: Percentage of Water Body outside the green space

4 Discussion

4.1 Green space LST impact factors

The result of Section 3.2 indicates that large GSA, high LSI, high PW_in and low PI_in will bring low LST of the green spaces. The result coincides with the conclusions of Cao et al. (2010) and Chang et al. (2007). The reason is that larger GSA contains more vegetation, then the photosynthesis and transpiration consumes more energy, thus leads to a lower LST (Jauregui, 1990; Lu et al., 2012; Saito et al., 1990), the low thermal capacity and high thermal conductivity of impervious surfaces leads to higher LST with the same amount of energy (Jin et al., 2011b), water body has high thermal capacity and inertia, which leads to lower LST (Chang et al., 2007). However, PV_in is not correlated with green space LST, this is different from the conclusion of Kong et al. (2014) and Weng et al. (2004), which found a negative correlation between PV_in and LST. In this research, the samples are mostly consisted of three types of cover: vegetation, water and impervious surfaces. Both water and vegetation have high thermal capacities, however the percentage of water and vegetation varies a lot and the number of samples are limited. This causes the result that both water and vegetation are not correlated with LST. However, if the total percentage of vegetation and water is treated as one variable, it is obvious that this variable is negatively correlated with LST because its complementary variable: PI_in is correlated to LST. So the green space LST can be decreased by increasing the ratio of vegetation or water body or removing some of the impervious surfaces. Also synthetic methods like optimizing structure and type of the vegetation groups, proper distribution of impervious surfaces are sufficient (Lu et al., 2012; Weng et al., 2007; Zhou et al., 2011).

4.2 GCI impact factors

The results of Section 3.3 indicate that, large GSA, high LSI will lead to long GR, this is similar to the conclusions of Jauregui (1990), Chang et al. (2007) and Kong et al. (2014). Besides, PI_out and PV_out are also significant impact factors for GR. High PI_out or Low PV_out leads to short GR. TA is only effected by GSA and LSI. Large GSA and high LSI contribute to large TA. TG is only effected by PW_in and PW_out. High PW_in and PW_out correspond to large TG of the green space.

With the same intensity of radiation, the green space has a lower LST increase compared to its surrounding areas due to its high thermal capacity, photosynthesis and transpiration. Then the temperature difference from the surrounding area is generated. The hot air in the urban tends to flow towards the green spaces. However, the dense air near the green spaces could not flow out, thus forms a high pressure area which leads to a maintained cooler micro climate. So the heat exchange between green space and its surrounding area depends mostly on heat conduction.

We can use the thermal conduct theory as analogy for the explanation of these results. When there is a temperature difference between heat source and the surrounding environment, the relation between the total conducted thermal power P_th and the temperature difference ΔT is calculated as equation 2.

$$\Delta T / P\_th = R\_th \qquad (2)$$

R_th is the thermal resistance of the heat conduct medium, it represents the heat conductivity of the material and structure. Total conducted thermal power P_th represents the heat flux.

The Shanghai urban area could be treated as an ideal heat source because its thermal volume is significantly larger than the urban green spaces. The green spaces are distributed in the ideal heat source and exchange energy with the source through the buffers. The shape and consistence of the buffer effects the thermal resistance. ΔT is actually TA in this paper.

Due to energy conservation, the heat power that the green space absorbs from the Shanghai urban area should equal to the extra energy that it dissipates by photosynthesis and transpiration when the heat conduction reaches a balanced state. The larger area of green space means more energy dissipation, which leads to more conducted thermal power. Due to equation (2), if the P_th is large, with the same buffer (R_th), the temperature drop ΔT will be high. Or with the same temperature drop, the R_th should be smaller, then the buffer has to be larger to increase the heat exchange volume. In practice, both happens, then the larger GSA will lead to higher GR and TA. High green space LSI will also lead to high LSI of the buffer, then the volume of the buffer would be decreased compared to circle buffers, thus larger GR will be led to with the same exchange heat power. If the GR is not increased, higher temperature drop ΔT would be observed due to the high thermal resistance. In practice, both happens, then the larger LSI will also lead to higher GR and TA.

PV_out and PI_out contribute extra energies to the micro climate around the green spaces. PV_out adds to the total energy consumption thus increases GR. However, it does not impact TA as the TA calculation uses the temperature inside the main green space rather than the PV_out around it. For PI_out, the process is the opposite.

The water body itself has strong UCI, so water body becomes the extra cold source in the green space buffer, thus changes the GCI efficiency.

4.3 Implications for urban landscape design

According to Sections 4.1 and 4.2, to better mitigate UHI effects by introducing GCI in landscape design, the designer should: (1) increase the GSA, however, a threshold should be considered because the UHI mitigation efficiency decreases significantly if GSA exceeds this threshold; (2) make the shape and boundary of the green spaces complicated with limited GSA, increase the percentage of vegetation groups, and decrease the percentage of impervious surfaces; (3) increase the percentage of water bodies both inside and outside the green spaces to strengthen GCI effects and efficiency.

5 Conclusion

Urban Heat Island (UHI) leads to increased energy consumption, aggravated pollution and threatened health of citizens. This study investigated the relationship between GCI effects and its impact factors of rapid urbanizing Shanghai. Linking the methods of the geophysical information, landscape ecology and remote sensing, the results show as the following:

1) There is a significant cooling island effect of green space. The average GR, TA and TG of the 68 green spaces is 0.57 km, 2.63 ℃ and 5.86 ℃ /km respectively.
2) There is an 40ha upper threshold of GSA to decrease the LST There is a positively significantly relationship between the LST inside green spaces and their PI_in. Also, a significant negative correlation between green spaces LST and LSI is found. Efficient methods to decrease LST of green spaces include enlarging GSA within the threshold, adding complexity of green space shape and outline, decreasing impervious surfaces and enlarging the area of vegetation and water bodies.
3) The GCI effects depends on green space itself and its surrounding characteristics. There is a positive correlation between GSA, PV_out LSI and GR, a negative correlation between GR and PI_out. No significant correlation between GR and PI_in, PV_in PW_in and PW_out is found. TA is only positively correlated with GSA and LSI. TG is only significantly correlated with PW_in and PW_out. Therefore, increasing vegetation and water body fractions or decreasing impervious surfaces will help to strengthen GCI effects.

This study improves our understanding on how the impact factors inside and outside the green spaces influences the GCI indexes including GR, TA and TG. The conclusions can be referred by the landscape designers to improve the urban micro climates, then a comfort and healthy resident environment could be achieved.

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Appendix B

List of abbreviations:

- Urban heat island (UHI)
- Urban cool island (UCI)
- Green space cool island (GCI)
- Green space cool island range (GR)
- Temperature Drop Amplitude (TA)
- Temperature Gradient (TG)
- Green Space Area (GSA)
- Landscape Shape Index of the green space (LSI)
- Percentage of Vegetation inside the green space (PV_in)
- Percentage of Water Body inside the green space (PW_in)
- Percentage of Impervious Surfaces inside the green space (PI_in)
- Percentage of Vegetation outside the green space (PV_out)
- Percentage of Water Body outside the green space (PW_out)
- Percentage of Impervious Surfaces outside the green space (PI_out)

References

Alghannam, A.R.O., Al-Qahtnai, M.R., 2012. Impact of vegetation cover on urban and rural areas of arid climates. Australian Journal of Agricultural Engineering 3, 1-5.

Bonan, G.B., 1997. Effects of land use on the climate of the United States. CLIMATIC CHANGE 37, 449-486.

Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. LANDSCAPE URBAN PLAN 147-155.

Cao, X., Onishi, A., Chen, J., Imura, H., 2010. Quantifying the cool island intensity of urban parks using ASTER and IKONOS data. LANDSCAPE URBAN PLAN 224-231.

Chang, C.R., Li, M.H., Chang, S.D., 2007. A preliminary study on the local cool-island intensity of Taipei city parks. LANDSCAPE URBAN PLAN 80, 386-395.

Chen, A., Yao, X.A., Sun, R., Chen, L., 2014. Effect of urban green patterns on surface urban cool islands and its seasonal variations. URBAN FOR URBAN GREE 13, 646-654.

Chudnovsky, A., Ben-Dor, E., Saaroni, H., 2004. Diurnal thermal behavior of selected urban objects using remote sensing measurements. Energy & Buildings 36, 1063-1074.

Du, H., Song, X., Jiang, H., Kan, Z., Wang, Z., Cai, Y., 2016. Research on the cooling island effects of water body: A case study of Shanghai, China. ECOL INDIC 67, 31-38.

Du, H., Wang, D., Wang, Y., Zhao, X., Qin, F., Jiang, H., Cai, Y., 2016. Influences of land cover types, meteorological conditions, anthropogenic heat and urban area on surface urban heat island in the Yangtze River Delta Urban Agglomeration. SCI TOTAL ENVIRON 571, 461-470.

Hamada, S., Ohta, T., 2010. Seasonal variations in the cooling effect of urban green areas on surrounding urban areas . URBAN FOR URBAN GREE 9, 15-24.

Hillevi, U., Ingegärd, E., Sven, L., 1998. The influence of green areas on nocturnal temperatures in a high latitude city (Göteborg, Sweden). INT J CLIMATOL 18, 681-700.

Jauregui, E., 1990. Influence of a large urban park on temperature and convective precipitation in a tropical city. Journal of Energy and Buildings 15/16, 457-463.

Jin, M.S., Kessomkiat, W., Pereira, G., 2011a. Satellite-observed urbanization characters in Shanghai, China: aerosols, urban heat island effect, and land－atmosphere interactions. REMOTE SENS-BASEL 3, 83-99.

Jin, M.S., Kessomkiat, W., Pereira, G., 2011b. Satellite-Observed urbanization characters in Shanghai, China: Aerosols, urban heat island effect, and land-Atmosphere interactions. REMOTE SENS-BASEL 3, 83-99.

Jonsson, P., 2004. Vegetation as an urban climate control in the subtropical city of Gaborone, Botswana. INT J CLIMATOL 24, 1307-1322.

Kantzioura, A., Kosmopoulos, P., Zoras, S., 2012. Urban surface temperature and microclimate measurements in Thessaloniki. ENERG BUILDINGS 44, 63-72.

Kong, F., Yin, H., James, P., Hutyra, L.R., He, H.S., 2014. Effects of spatial pattern of greenspace on urban cooling in a large metropolitan area of eastern China. LANDSCAPE URBAN PLAN 128, 35-47.

Li, J., Song, C., Cao, L., 2011. Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. Remote Sensing of Environment 115, 3249-3263.

Li, X., Zhou, W., Ouyang, Z., Xu, W., Zheng, H., 2012. Spatial pattern of greenspace affects land surface. LANDSCAPE ECOL 27, 887-898.

Lu, J., Li, C., Yang, Y., Zhang, X., Jin, M., 2012. Quantitative evaluation of urban park cool island factors in mountain city. J CENT SOUTH UNIV 19, 1657-1662.
Magee, N., Curtis, J., Wendler, G., 1999. The Urban Heat Island Effect at Fairbanks, Alaska. Theroretical & Applied Climatology 64, 39-47.
McGarigal, K., Marks, B.J., 1995. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure.
Mikami, T., Sekita, Y., 2009. Quantitative evaluation of cool island effects in urban green parks. Japan:The Seventh International Conference on Urban Climate 56-63.
Ng, E., Chen, L., Wang, Y., Yuan, C., 2012. A study on the cooling effects of greening in a high-density city: An experience. BUILD ENVIRON 47, 256-271.
Oke, T.R., 1973. City size and the urban heat island. ATMOS ENVIRON 7, 769-779.
Oliveira, S., Andrade, H., Vaz, T., 2011. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. . BUILD ENVIRON 46, 2186-2194.
Saito, I., Ishihara, O., Katayama, T., 1990. Study of the effect of green areas on the thermal environment in an urban area. Energy & Building 15, 493-498.
Shanghai Municipal Statistics Bureau, 2011. Statistical Yearbook of Shanghai 2000–2011. China Statistics Press, Beijing.
Sobrino, J.A., Jiménez-Munoz, J.C., Paolini, L., 2004. Land surface temperature retrieval from LANDSAT TM 5. REMOTE SENS ENVIRON 90, 434-440.
Spronkensmith, R.A., Oke, T.R., 1998. The thermal regime of urban parks in two cities with different summer climates. Internationla Journal of Remote Sensing 19, 2085-2104.
Unger, J., Sümeghy, Z., Zoboki, J., 2001. Temperature cross-section features in an urban area. ATMOS RES 58, 117-127.
Weng, Q., Liu, H., Lu, D., 2007. Assessing the effects of land useand land cover patterns on thermal conditions using landscape metrics in city of Indianapolis, United States. URBAN ECOSYST 10, 203-219.
Weng, Q., Lu, D., Schubring, J., 2004. Estimation of land surface temperature – vegetation abundance relationship for urban heat island studies. REMOTE SENS ENVIRON 89, 467-483.
Wong, N.H., Jusuf, S.K., Win, A.A.L., Thu, H.K., Negara, T.S., 2007. Environmental study of the impact of greenery in an institutional campus in the tropics. Building and Environment 42, 2949-2970.
Wong, N.H., Yu, C., 2005. Study of green areas and urban heat island in a tropical city. Habitat International 29, 547-558.
Yu, C., Hien, W.N., 2006. Thermal benefits of city parks. ENERG BUILDINGS 38, 105-120.
Zhang, X., Zhong, T., Feng, X., Wang, K., 2009. Estimation of the relationship between vegetation patches and urban land surface temperature with remote sensing. INT J REMOTE SENS 30, 2105-2118.
Zhou, W., Huang, G., Cadenasso, M.L., 2011. Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. LANDSCAPE URBAN PLAN 102, 54-63.

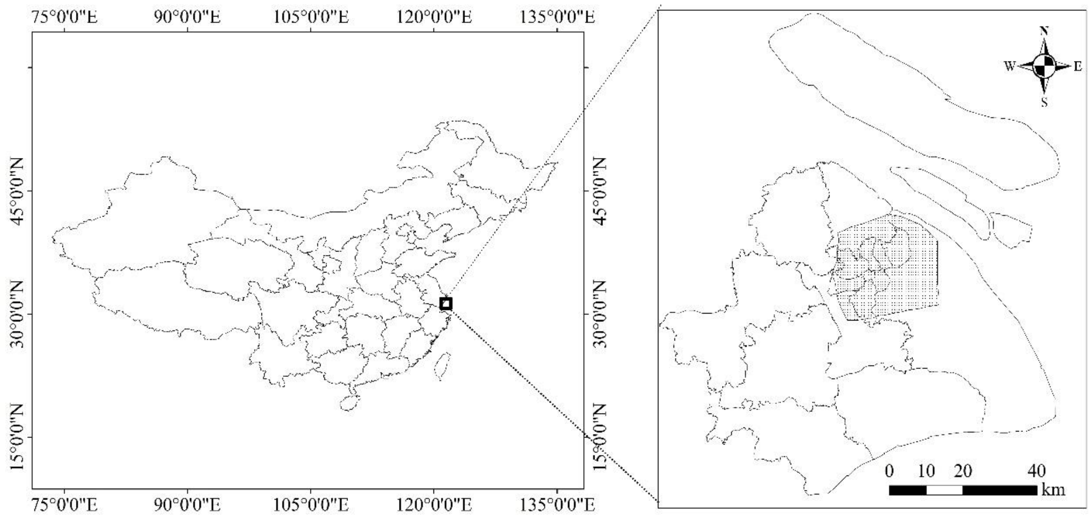


Fig. 1 Location map of Shanghai and the outmost ring road.

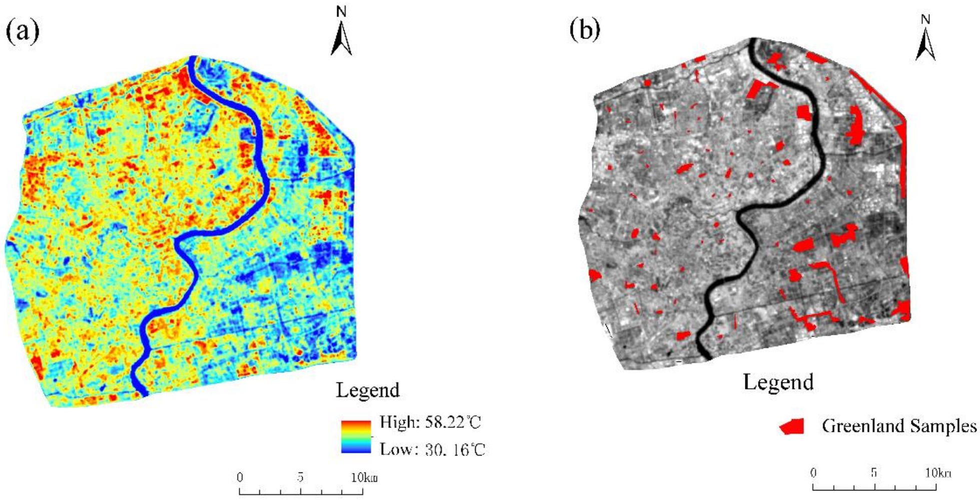


Fig. 2 Land surface temperature (a) and location of green lands (b) inside the outmost ring road of Shanghai

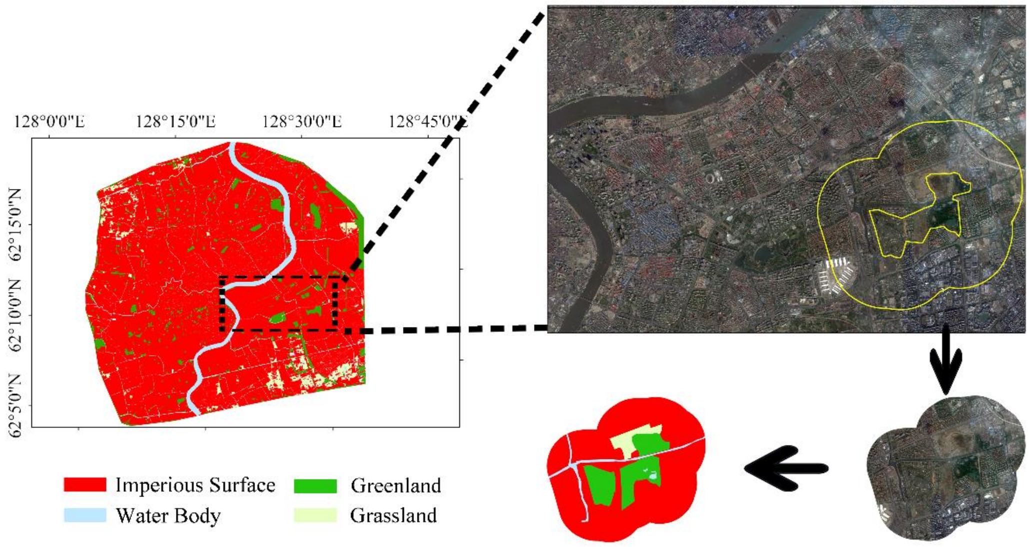
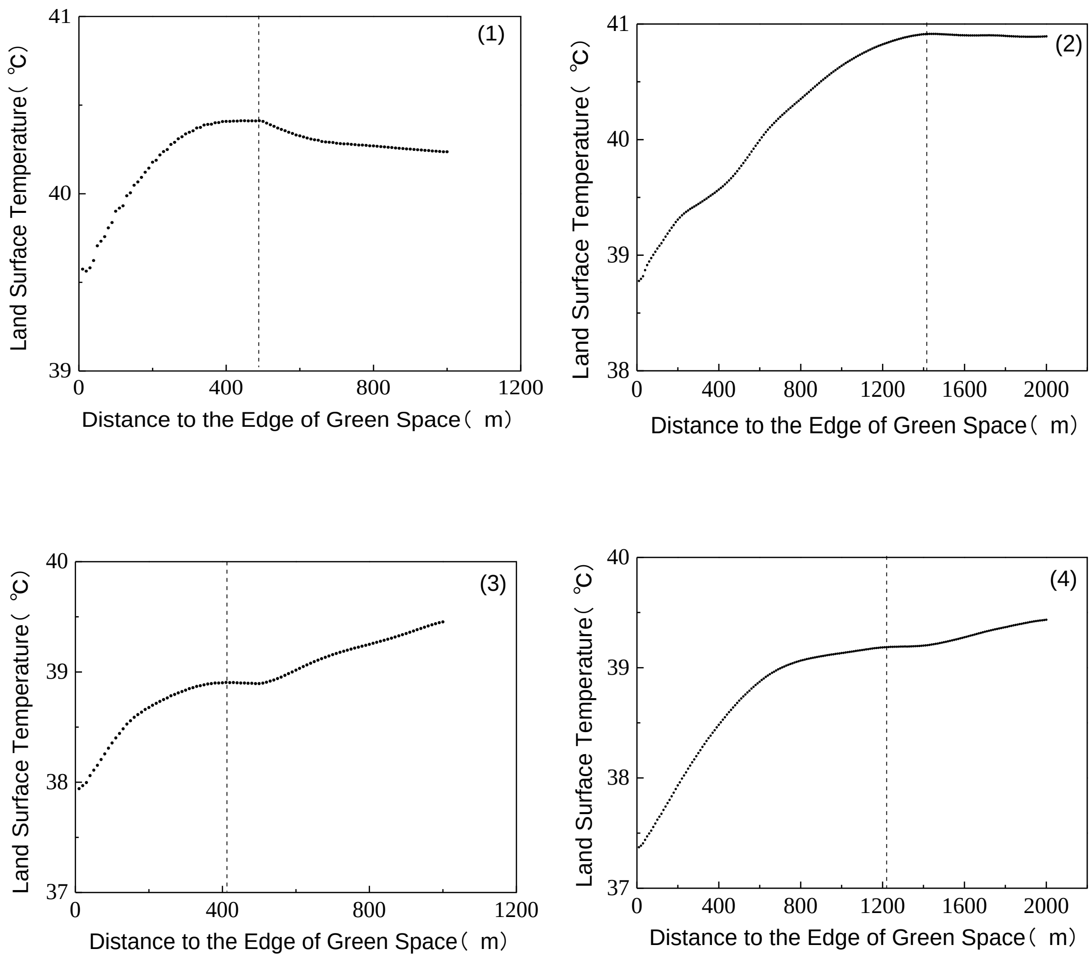


Fig. 3 The sketch map of land cover types and buffer



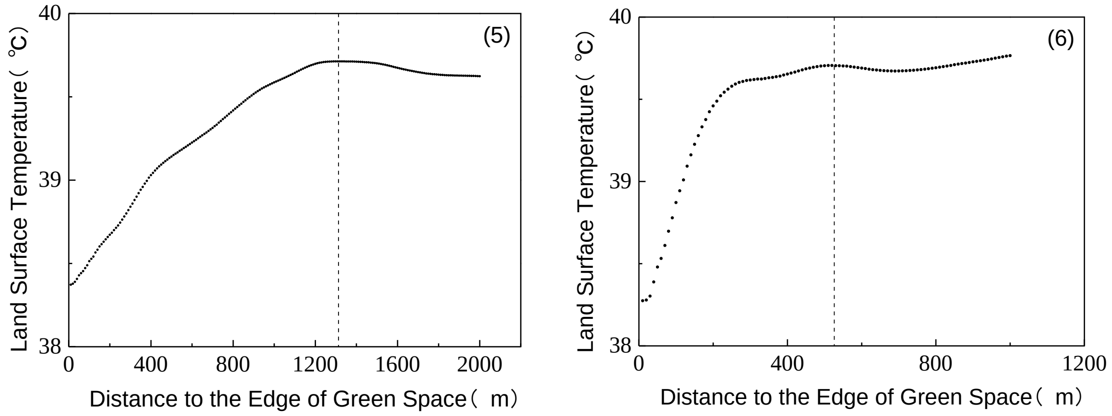


Fig.4 Land Surface Temperature (LST) curves of the green space buffers

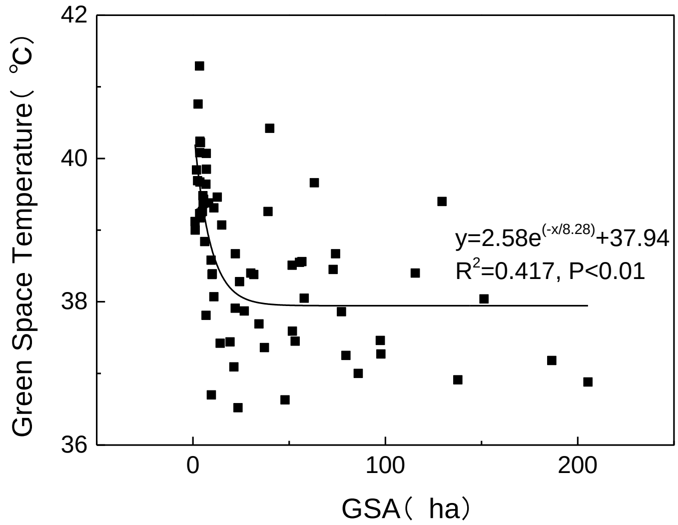


Fig. 5 Relationship between green space area (GSA)and its temperature

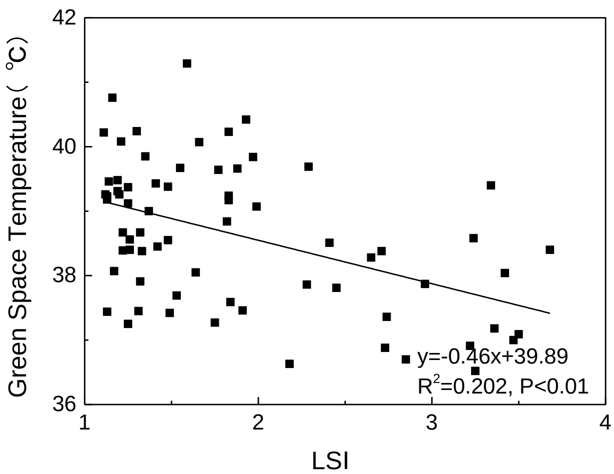


Fig. 6 Relationship between landscape shape index (LSI) of green space and its LST

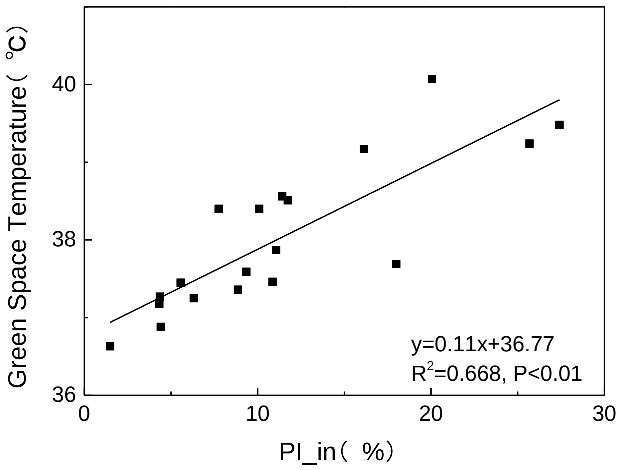


Fig. 7 Relationship between percentage of impervious surfaces inside (PI_in) the green space and its LST

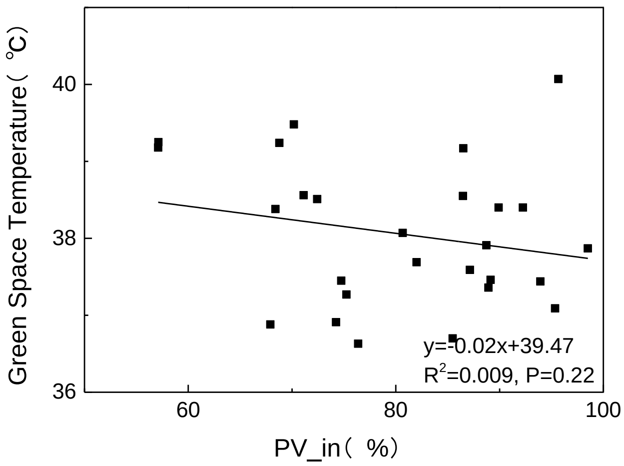


Fig. 8 Relationship between percentage of vegetation inside (PV_in) the green space and its LST

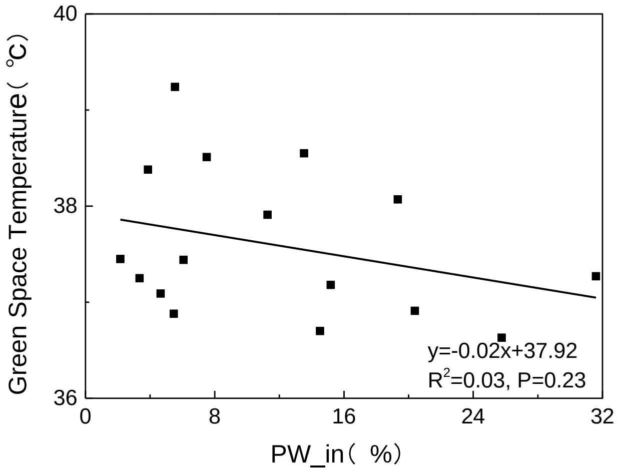


Fig. 9 Relationship between percentage of water bodies inside (PW_in) the green space and its LST

Table 1 Statistic of green space characteristics and green space island effects inside the outmost ring road of Shanghai

	GSA(ha)	LSI	Temperature(℃)	GR (m)	TA (℃)	TG (℃/km)
minimum value	1.12	1.11	36.51	0.09	0.78	1.44
maximum value	20.52	3.68	41.29	1.61	5.2	18.71
average value	37.24	1.89	38.63	0.57	3.02	6.31

GSA: **green space area; LSI: landscape shape index; GR: green space island range; TA:**

Table 2 Pearson correlations between GCI and impact factors

GCI	GSA	LSI	PI_in	PV_in	PW_in	PI_out	PV_out	PW_out
GR	0.734**	0.539**	-0.076	0.151	0.177	-0.444**	0.432**	-0.027
TA	0.588**	0.544**	-0.102	0.173	0.272	-0.378	0.268	0.255
TG	-0.212	0.024	0.032	0.063	0.294*	0.029	-0.180	0.408**

*P<0.05, **P<0.01

Appendix A

Table 3 Statistic of green space characteristics and GCI effects inside the outmost ring-road of Shanghai

Sample Number	S(ha)	LSI	Temperature(℃)	GR (m)	TA (℃)	TG (℃/km)
1	53.17	1.31	37.45	490	3.29	6.71
2	186.52	3.36	37.18	1440	8.73	6.06
3	47.87	2.18	36.63	410	2.93	7.14
4	205.32	2.73	36.88	1230	2.31	1.88
5	137.7	3.22	36.91	1310	2.8	2.14
6	79.56	1.25	37.25	520	2.46	4.72
7	3.71	1.83	39.17	630	1.32	2.09
8	56.69	1.26	38.56	480	3.15	6.56
9	5.19	1.19	39.48	410	0.80	1.96
10	51.59	2.41	38.51	630	2.98	4.73
11	3.60	1.21	40.08	550	1.33	2.41
12	23.46	3.25	36.52	1110	4.52	4.07
13	4.26	1.83	39.24	260	1.99	7.66
14	21.33	3.50	37.09	220	4.12	18.71
15	97.43	1.91	37.46	430	3.91	9.09
16	30.10	1.26	38.40	430	3.77	8.77
17	8.13	1.48	39.38	220	2.48	11.29
18	97.71	1.75	37.27	840	4.18	4.98
19	19.33	1.13	37.44	370	4.58	12.38
20	10.94	1.17	38.07	620	4.22	6.80
21	9.99	1.33	38.38	510	3.25	6.37
22	55.41	1.48	38.55	810	2.02	2.49
23	1.87	1.97	39.84	140	1.54	10.99
24	39.06	1.12	39.26	690	2.45	3.55
25	31.64	2.71	38.38	240	2.43	10.13
26	1.12	1.25	39.12	90	0.78	8.70
27	10.08	1.22	38.39	170	2.83	16.67
28	4.10	1.13	39.18	350	2.9	8.29
29	63.14	1.88	39.66	800	3.65	4.56
30	6.95	1.66	40.07	490	1.41	2.88
31	10.89	1.19	39.31	200	1.80	9.02
32	129.46	3.34	39.40	1610	9.35	5.8
33	9.46	3.24	38.58	920	3.35	3.64
34	77.20	2.28	37.86	820	5.56	6.78
35	72.87	1.42	38.45	580	3.02	5.20
36	2.72	1.16	40.76	380	0.98	2.59
37	12.69	1.14	39.46	610	2.34	3.84

38	3.66	1.55	39.67	550	1.79	3.26
39	3.96	1.11	40.22	560	3.03	5.41
40	21.99	1.32	37.91	810	4.06	5.01
41	3.64	1.30	40.24	140	1.47	10.51
42	14.16	1.49	37.42	550	3.82	6.94
43	37.19	2.74	37.36	520	2.65	5.09
44	51.74	1.84	37.59	470	2.72	5.78
45	26.72	2.96	37.87	440	3.81	8.65
46	24.24	2.65	38.28	140	0.89	3.35
47	39.92	1.93	40.42	260	2.14	8.23
48	74.14	1.22	38.67	620	2.80	4.52
49	57.85	1.64	38.05	450	2.93	6.51
50	6.85	2.45	37.81	200	1.99	9.94
51	15.00	1.99	39.07	490	4.29	8.76
52	6.18	1.82	38.84	480	2.07	4.31
53	3.50	1.13	39.23	440	2.42	5.50
54	2.47	2.29	39.69	710	3.01	4.24
55	3.71	1.83	40.23	210	2.15	10.23
56	3.44	1.59	41.29	330	1.45	4.38
57	5.32	1.25	39.37	820	2.83	3.46
58	9.59	2.85	36.70	460	4.28	9.31
59	6.75	1.77	39.64	700	2.51	3.58
60	7.00	1.35	39.85	290	1.89	6.53
61	4.95	1.20	39.26	430	2.64	6.13
62	5.57	1.41	39.43	500	2.53	5.05
63	115.59	3.68	38.40	1230	5.66	4.60
64	34.36	1.53	37.69	260	1.57	6.03
65	22.06	1.32	38.67	360	1.86	5.18
66	1.18	1.37	39.00	410	2.96	7.23
67	151.32	3.42	38.04	1450	6.09	4.20
68	85.93	3.47	37.00	850	5.20	6.11