Urban Green Space Remote Sensing

-----Multi-dimension and Multi-angle Perception of Urban Vegetation

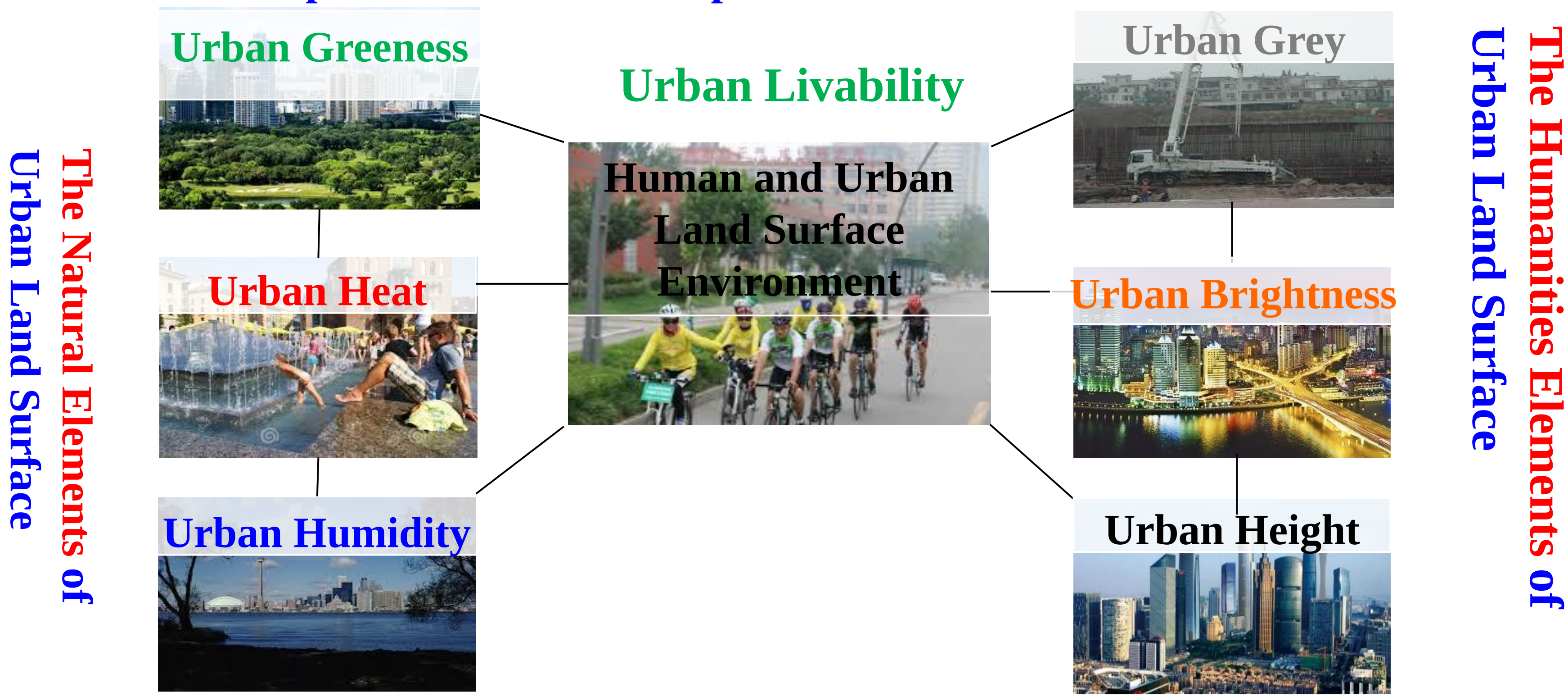
Prof. Dr. Qing-yan Meng

Aerospace Information Research Institute,

Chinese Academy of Sciences

Construction of the Remote Sensing Technology System of Urban Land Surface Environment

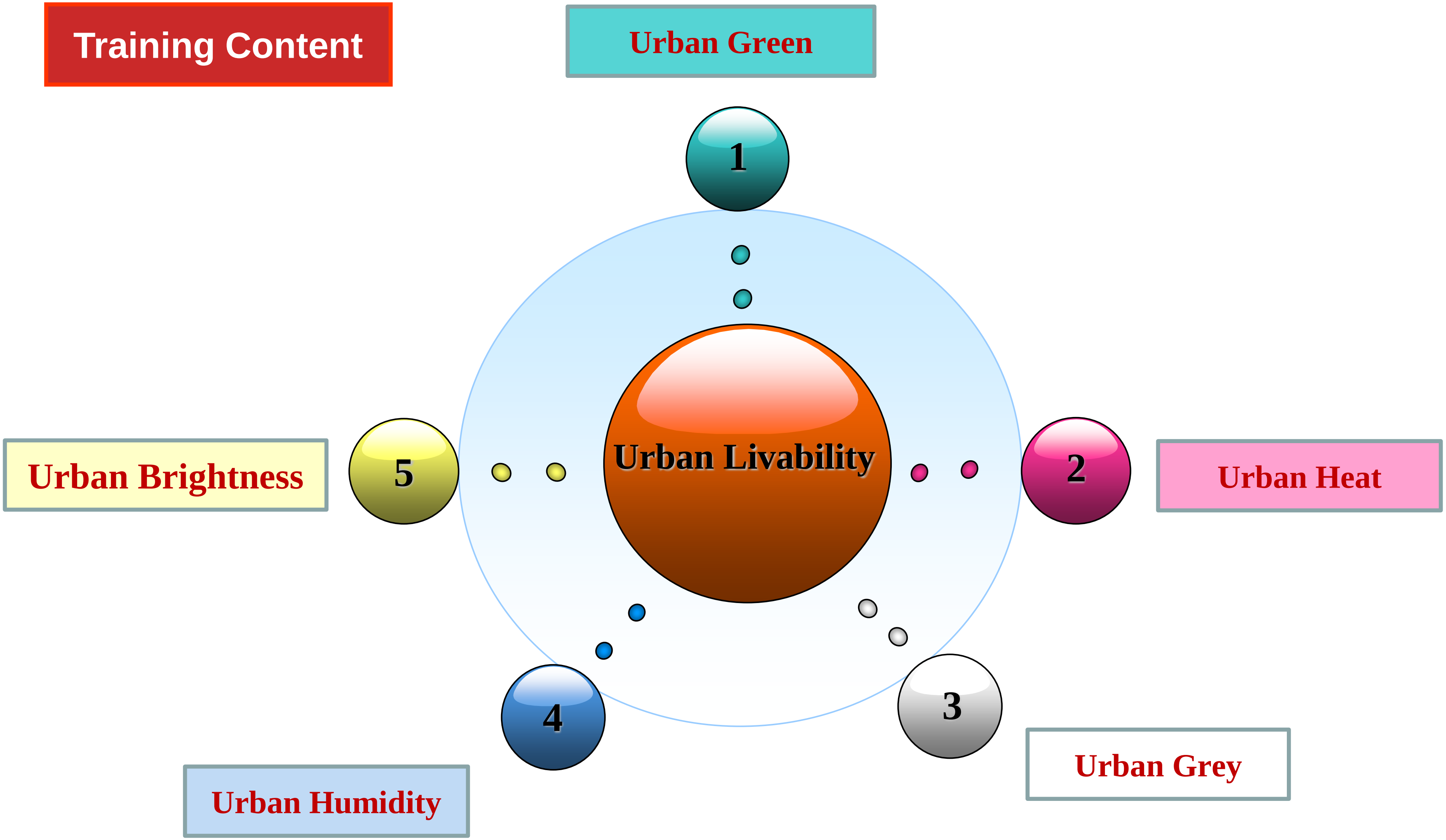
Urban land surface environment has great influence on urban environment and its livability, closely related to people's daily life. Its internal mechanism is complex and has become an important research hot spot.



Based on the multi-source data of Space-plane-earth, study the urban social-economic-natural composite system from multi-dimensions and multi-perspectives such as greenness, heat, gray, humidity and brightness, and explore its temporal and spatial evolution law and interaction mechanism, providing support for urban studies!

4. Thematic Content of The Course

Training Content



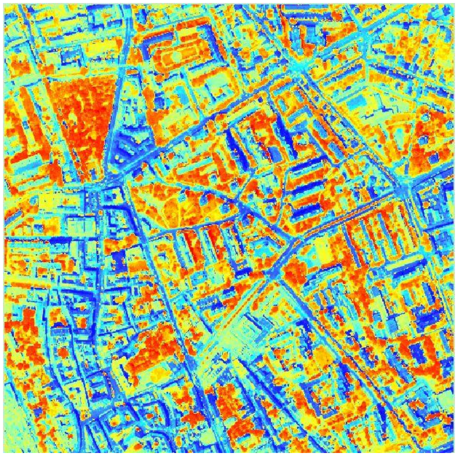
Urban Green

- Vegetation information extraction
- Multi-method urban green measurement
- Multi-scale perception model
- Accessibility and fairness

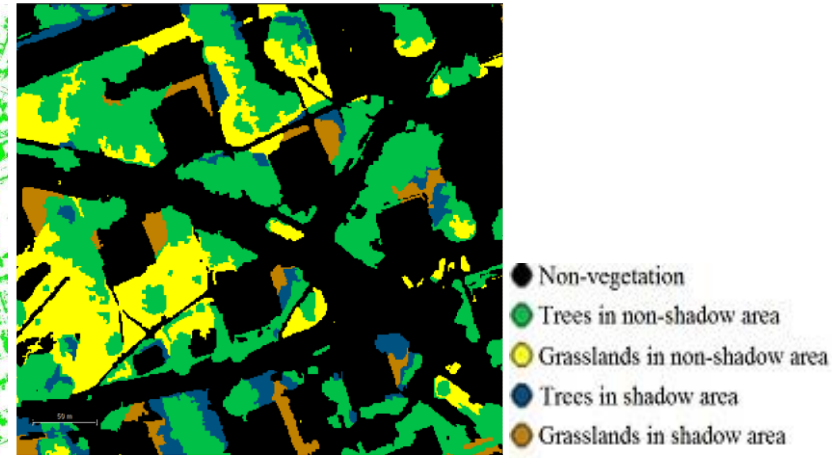
Urban Green Space

——Vegetation 2D/3D information extraction

2D

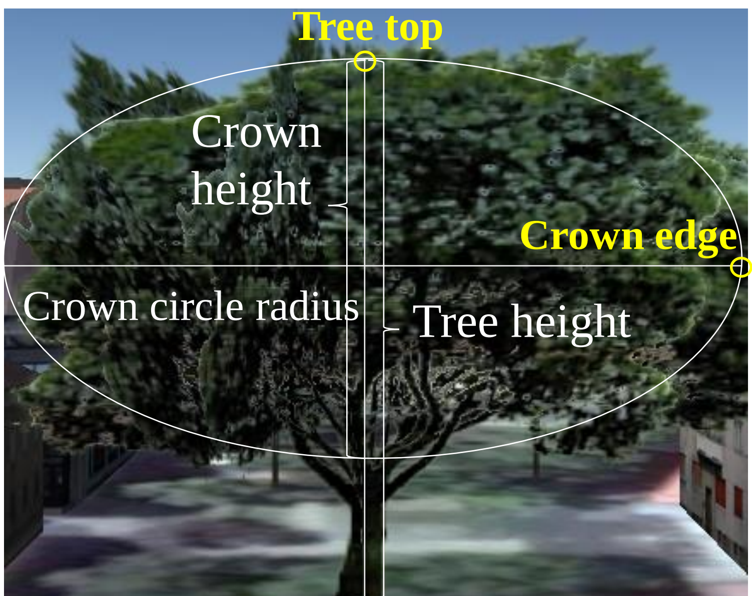


NDVI image

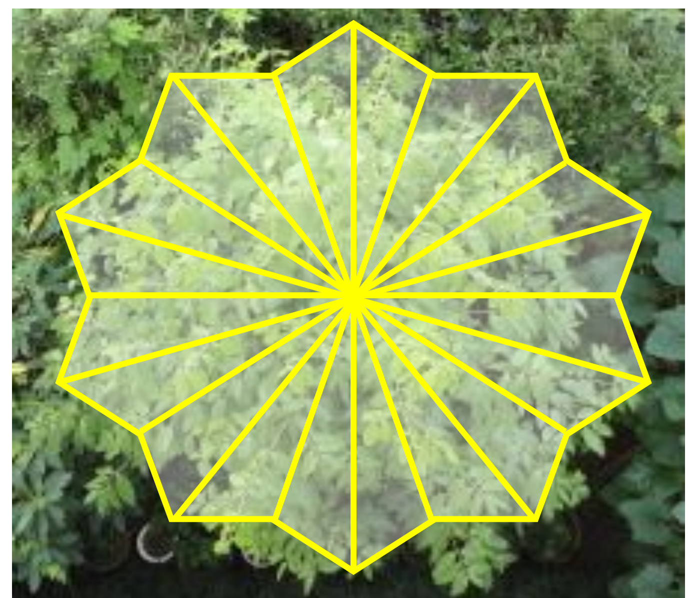


Vegetation extraction results

3D



3D structure of tree crown



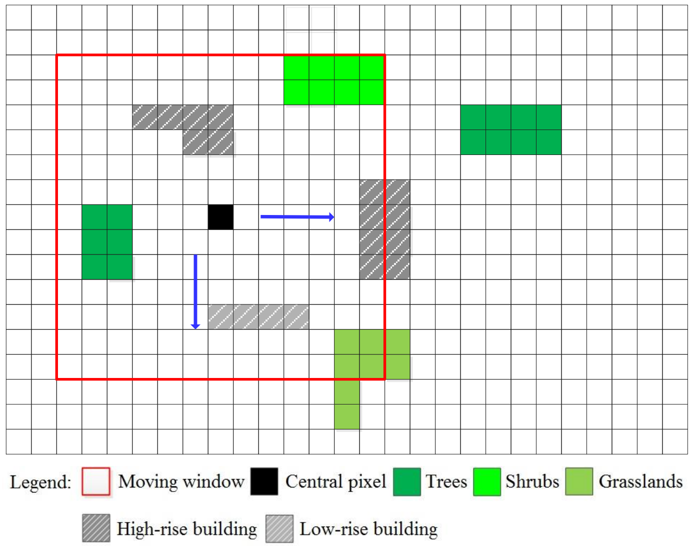
Tree crown delineation

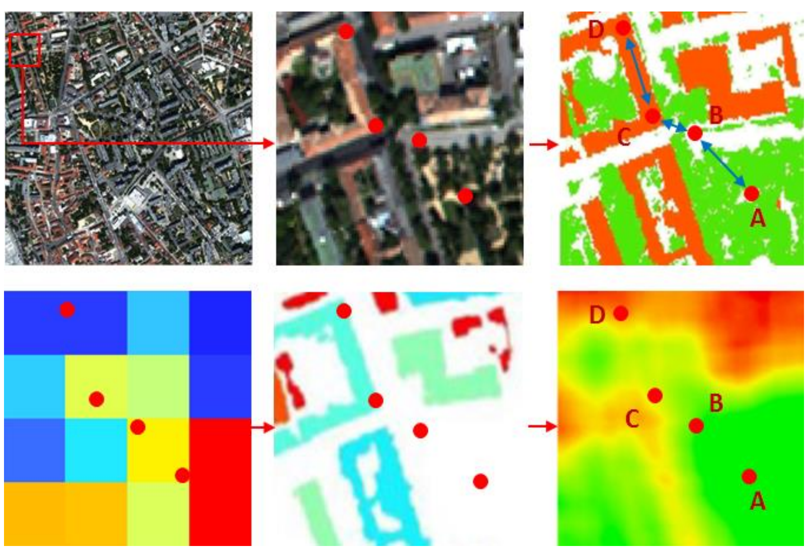
Urban Green Space

——Multi-method urban green measurement

Moving window method

——a continuous and accurate measurement method
——avoids edge effects
——improves the operation efficiency

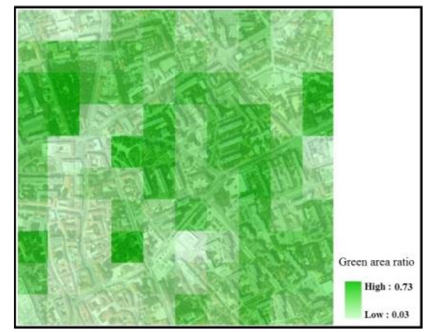




Comparison of various methods

Grid method

——Describes the spatial distribution characteristics of urban green space in different scales



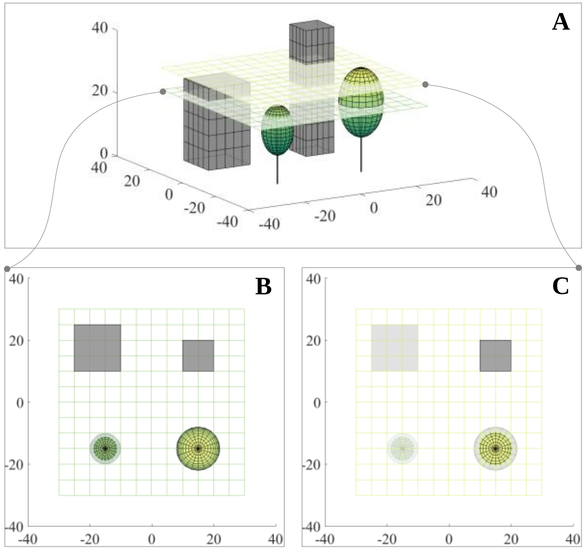
Grid size 100m×100m

Grid size 50m×50m

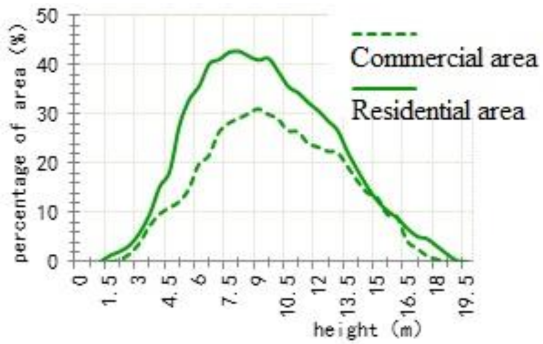
Grid size 25m×25m

Urban Green Space

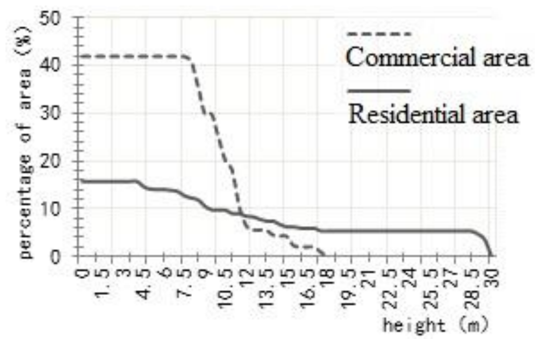
——Multi-scale perception model



Vertical distribution curves——An objective description of the vertical distribution of urban green space. It serves for the evaluation and allocation of urban green space.

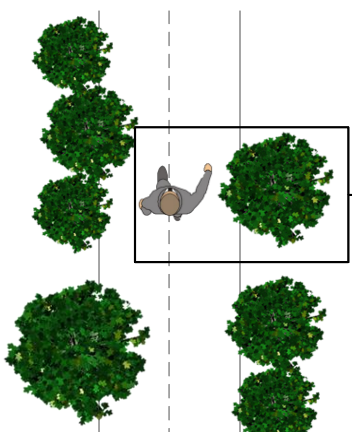


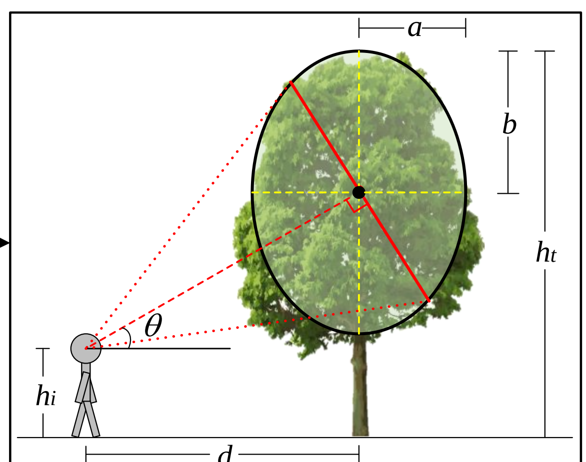
Green space

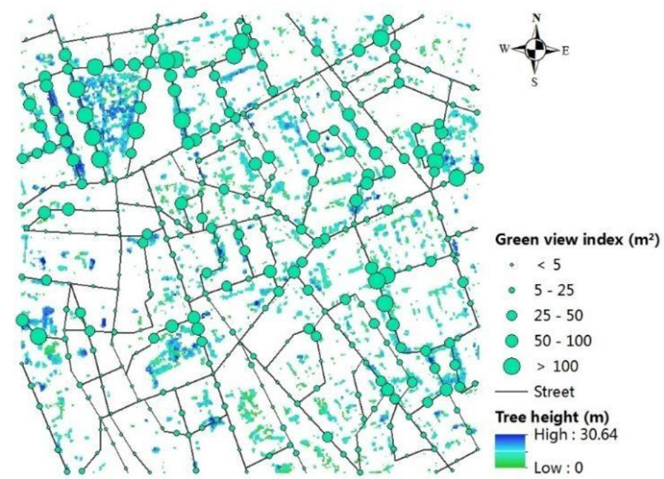


Building space

Green view index of street——analyzes the real physical scene from the perspective of spatial structure quantification, and quantifies the visual quality of urban green space.





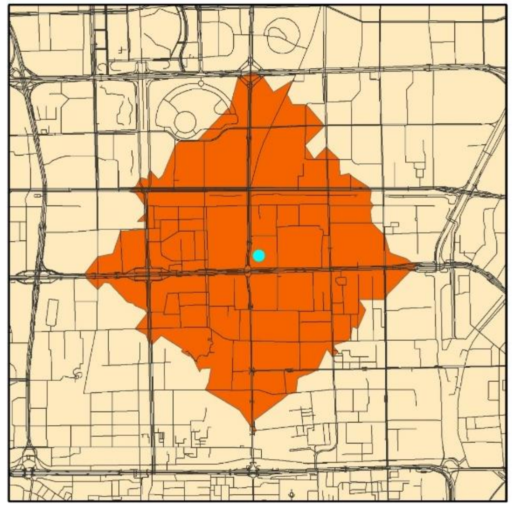


Urban Green Space

——Accessibility and fairness

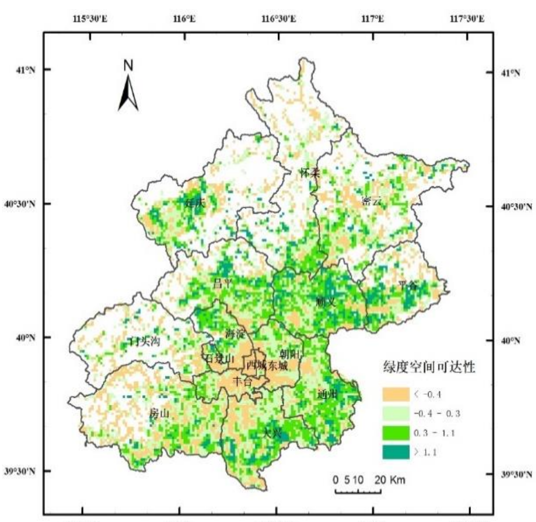
Accessibility

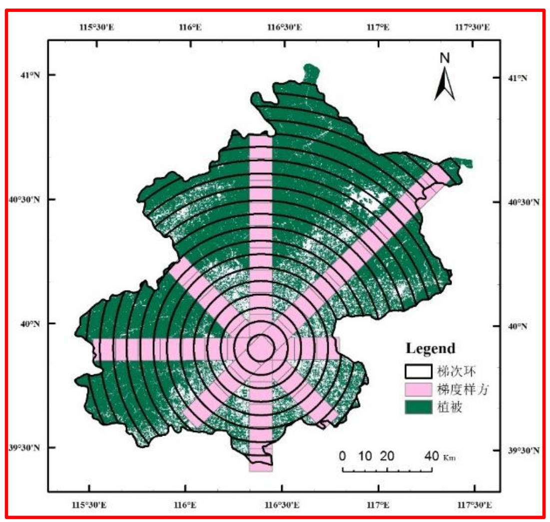
Accessible range calculation based on road distance



Accessibility measurement model

Gradient analysis of accessibility





Fairness——The accessibility level of green space showed significant unfairness to social population factors.

district / Factor	Beijing	Urban functional area	Urban development area
External population	-0.004 (-1.75)	0.003 (0.84)	-0.003 (-1.31)
Agriculture population	**0.004 (5.57)****	**0.005 (4.54)****	**0.004 (3.5)****
female	-0.001 (-1.36)	**-0.030 (-3.27)****	0.014 (1.14)
0 to 14 years old	0.011 (1.277)	-0.006 (-0.34)	**-0.040 (-2.56)***
Over 60 years old	0.003 (0.556)	-0.008 (-1.3)	0.004 (0.005)
College degree	**-0.005 (-4.63)****	-0.0002 (-0.10)	**-0.008 (-3.4)****
illiteracy	**0.010 (-2.179)***	0.025 (0.686)	0.003 (0.47)
Ethnic minorities	**-0.015 (-2.85)****	0.003 (0.84)	-0.008 (-1.04)
family size	**0.247 (4.06)****	0.072 (0.589)	**0.398 (4.9)****

Urban Heat

Space-time characteristics of heat island effect

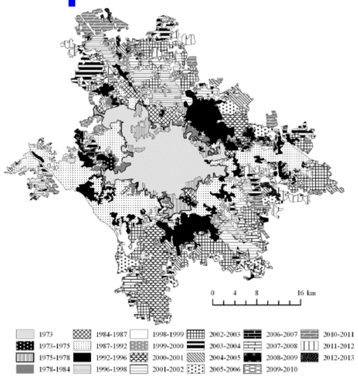
Surface temperature driving law

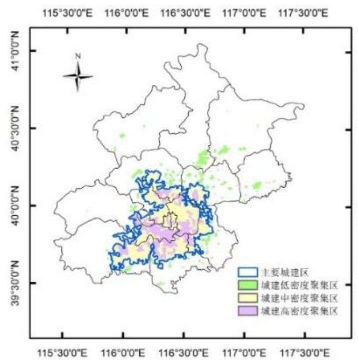
Thermal infrared remote sensing monitoring of industrial capacity reduction

Urban Heat Space

——Temporal and spatial characteristics

Extraction of built-up area based on impervious surface distribution density





Heat island intensity definition

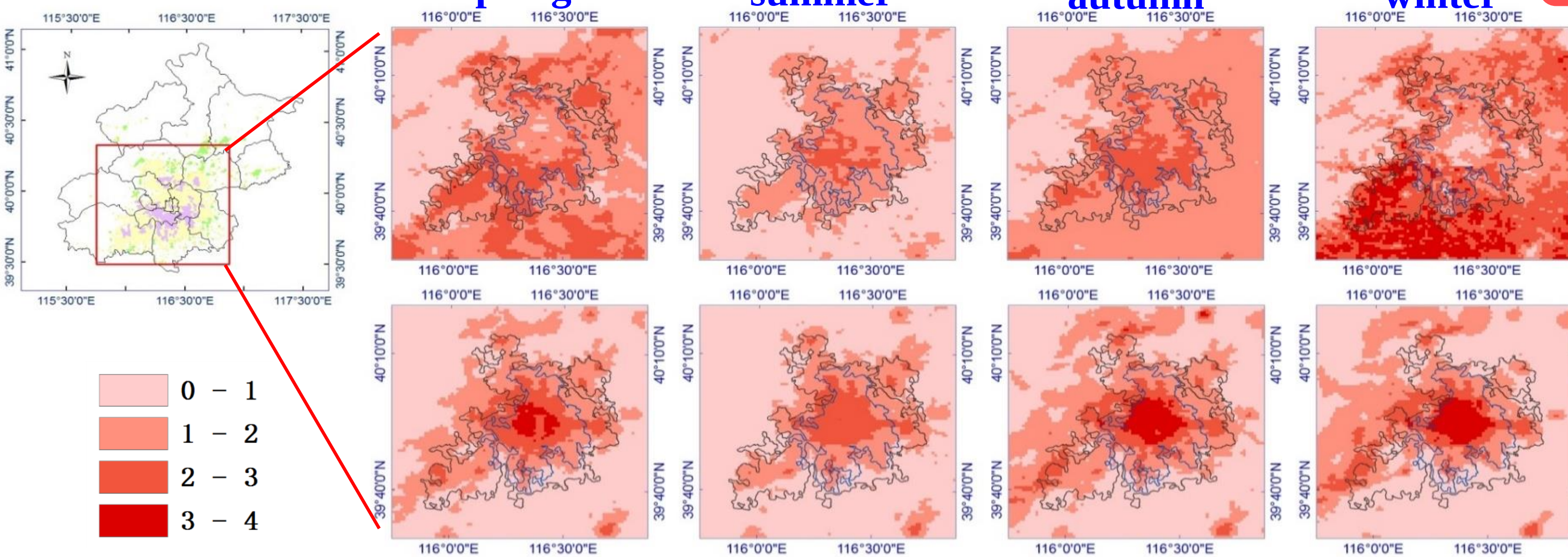
热岛强度等级	定义
一级强度	$T_{B\_ij} \le T_{ij}(k,x,y) < T_{B\_ij} + \Delta T_{ij}$
二级强度	$T_{B\_ij} + \Delta T_{ij} \le T_{ij}(k,x,y) < T_{B\_ij} + 2\Delta T_{ij}$
三级强度	$T_{B\_ij} + 2\Delta T_{ij} \le T_{ij}(k,x,y) < T_{B\_ij} + 3\Delta T_{ij}$
四级强度	$T_{B\_ij} + 3\Delta T_{ij} \le T_{ij}(k,x,y) < T_{B\_ij} + 4\Delta T_{ij}$
五级强度	$T_{ij}(k,x,y) \ge T_{B\_ij} + 5\Delta T_{ij}$

Calculation method

Spatiotemporal features

Day and night intensity of heat island intensity in Beijing in different seasons

spring summer autumn winter



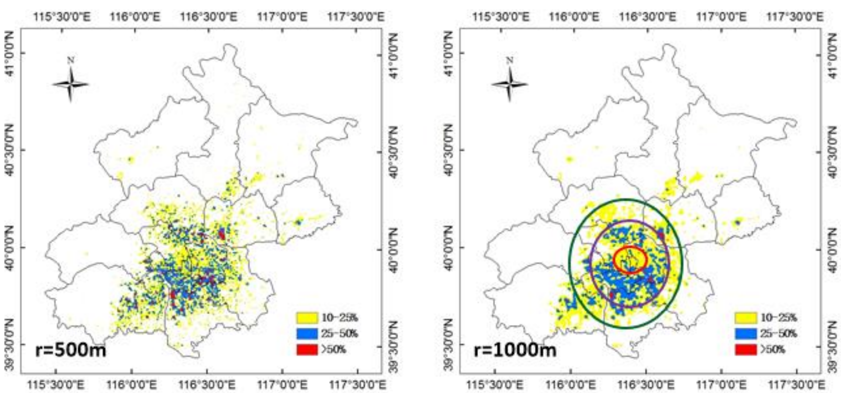
day

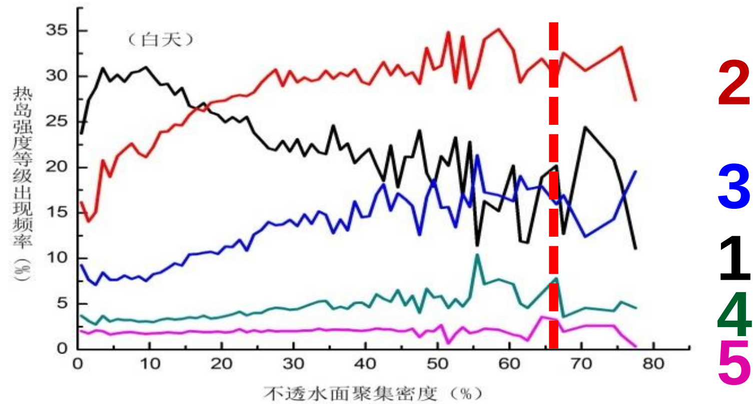
night

Urban Heat Space

——Driving law of surface temperature

The law of action between impervious surface distribution density and urban heat island intensity

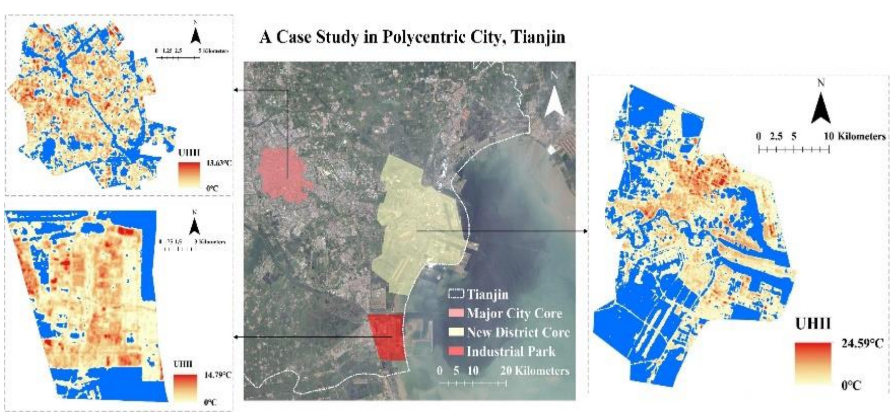


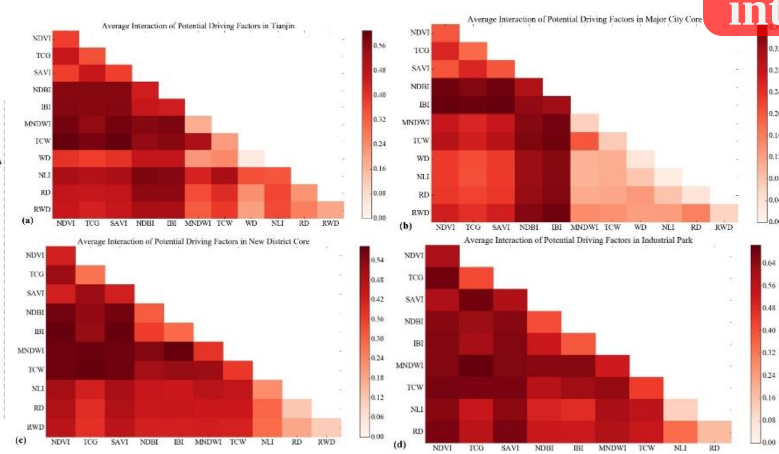


Critical point of action

Multi-factor interaction

Spatial quantification of potential driving factors of surface temperature



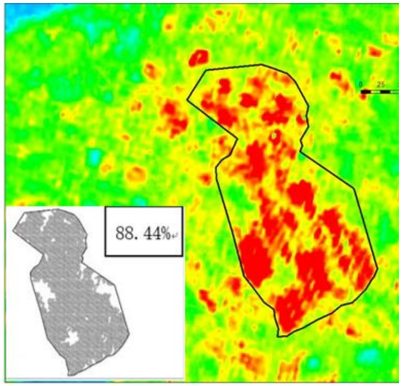


LST potential drivers show bilinear or nonlinear enhancement in interaction

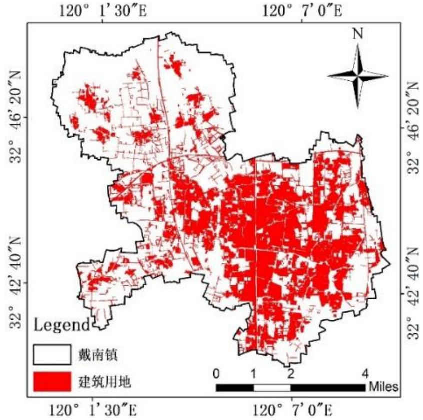
Urban Heat Space

——Industrial capacity reduction

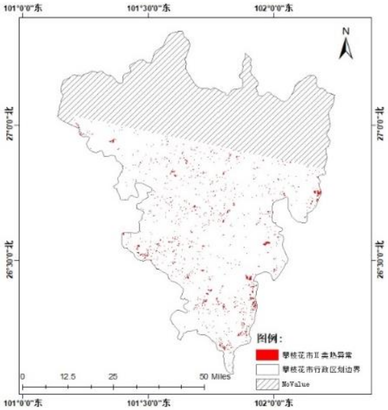
Definition of industrial thermal anomalies → **Extraction of industrial thermal pollution** → **Industrial thermal anomaly inspection**



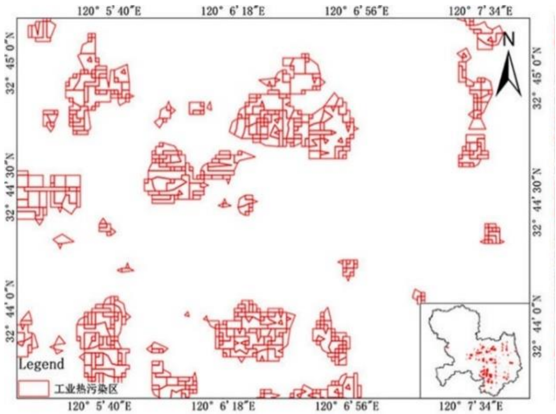
Class I thermal anomalies based on high temperature characteristics



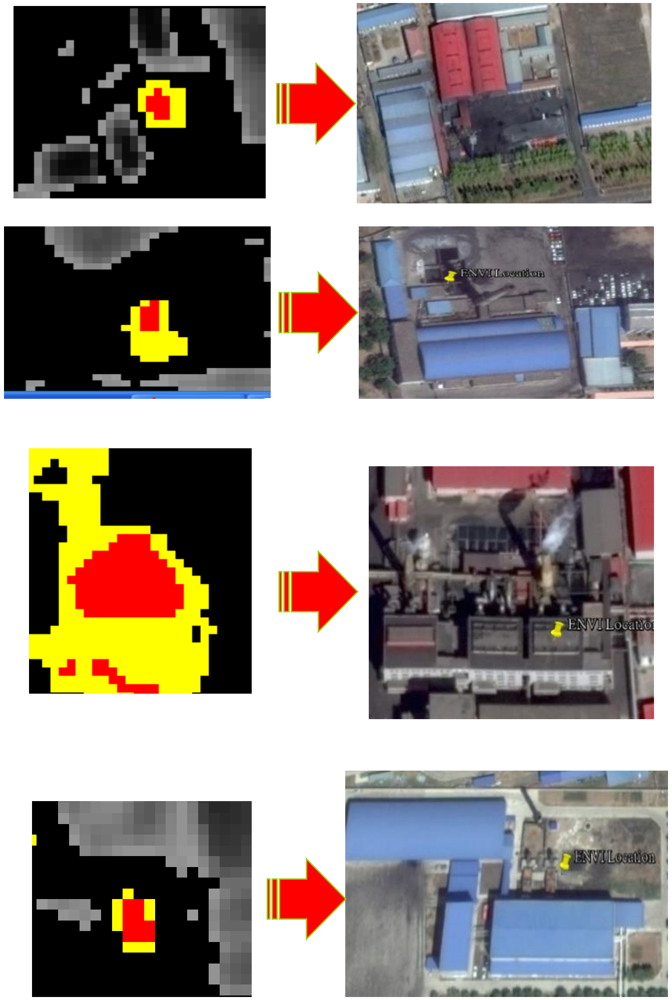
Building extraction based on OBIA



Class II thermal anomalies based on temperature change characteristics



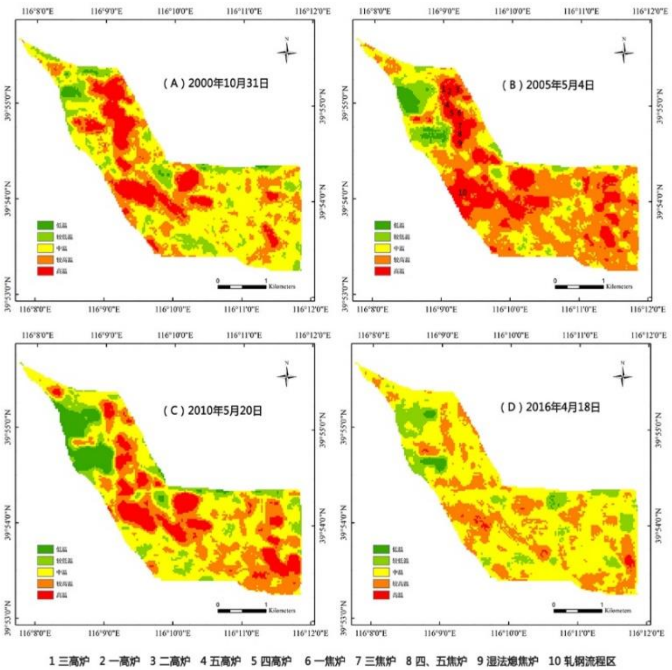
Industrial thermal pollution extraction



Urban Heat Space

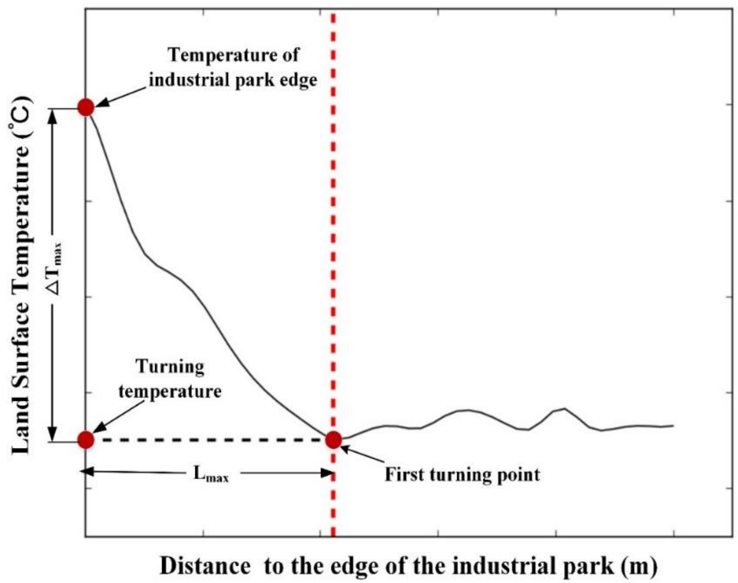
——Industrial capacity reduction

Mitigation of the relocation of industrial zones to the local heat island effect



- **The proportion of high-temperature areas drops**
- **Urban heat island ratio index URI decreases**
- **Relocation of industrial zone eases local heat island effect**

Paradigm of Quantitative Evaluation Method of Heat Island Effect in Industrial Zone



- **Profile of surface temperature changes in industrial areas**
- **Quantitative measurement index of industrial heat island effect**
- **Provide key parameters for optimizing land use allocation**

Comprehensive evaluation of local thermal environment impact → **Quantitative method of industrial heat island effect**

Urban Grey

impervious surface extraction

Road extraction

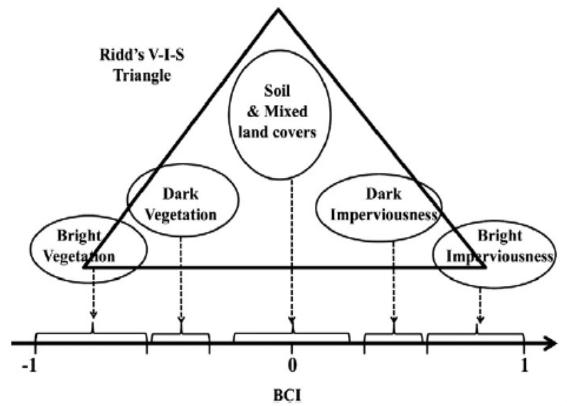
Built-up area extraction

Urban Grey Space

——Classic methods of impervious surface extraction

Pixel

BCI



Soil: BCI = 0

Vegetation: BCI < 0

Impervious surface: BCI > 0

Mask water Remove water area by NDWI index

↓

TCP Brightness、Greennes、Wetness

↓

BCI $BCI = \frac{(B+W)/2-G}{(B+W)/2+G}$

↓

Threshold Identify impervious surfaces by threshold

↓

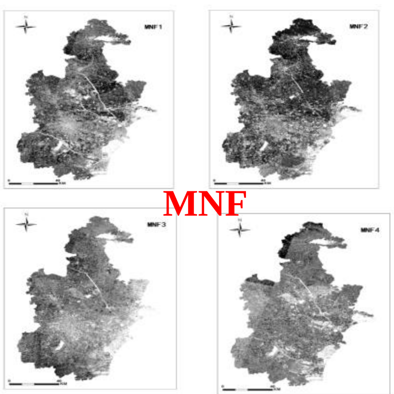
Impervious surface Impervious surface map

Sub-pixel

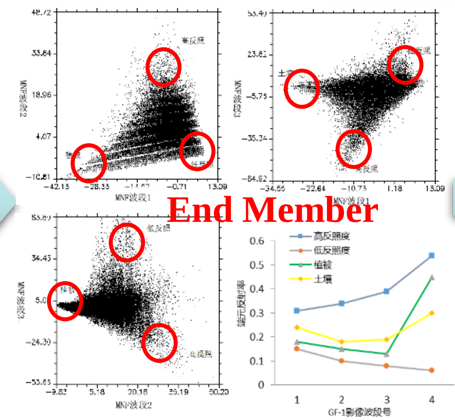
LSMA

$$\rho_b = \sum_{i=1}^{N} f_i \rho_{(i,b)} + e_b \text{ ,and } \sum_{i=1}^{N} f_i = 1$$

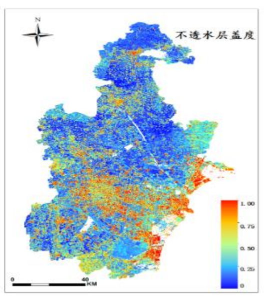
Where ρ_b is the b band reflectivity of the remote sensing image, N is the number of endmembers, f_i is the weight of the endmember i, which is determined by the ratio of the endmember i to the pixel, and $\rho_{(i,b)}$ is the endmember i in the b band. Reflectivity, e_b is the residual.



MNF



End Member



Tianjin ISP map

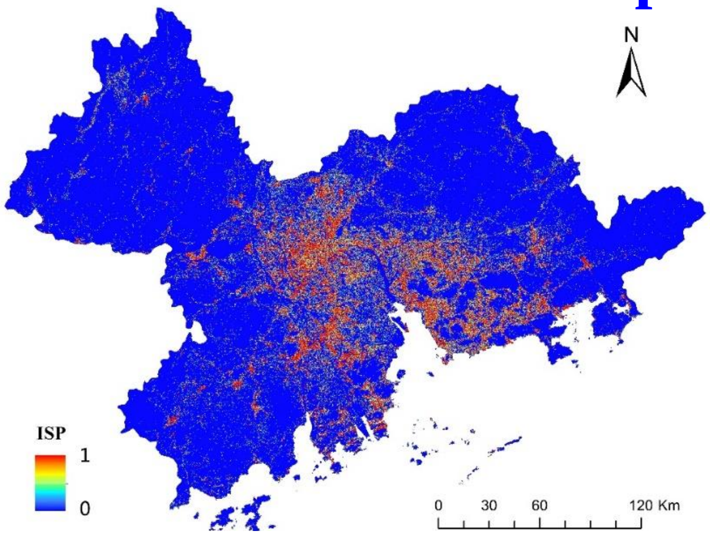
$$R_{\text{imp-b}} = f_{low} R_{low-b} + f_{high} R_{high-b} + e_b$$

and $f_{low} + f_{high} = 1$, $f_{low} > 0$, $f_{high} > 0$

Urban Grey Space

——impervious surface extraction

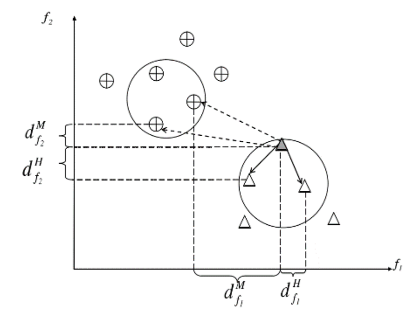
Sub-pixel : based on feature optimization and SVM



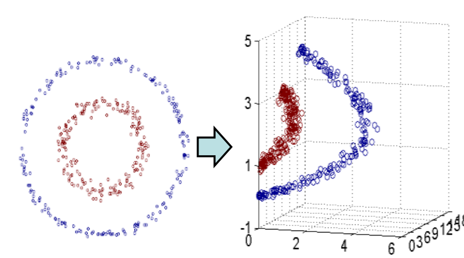
Obtain ISP reference values for training samples and verification samples

Extract feature variables

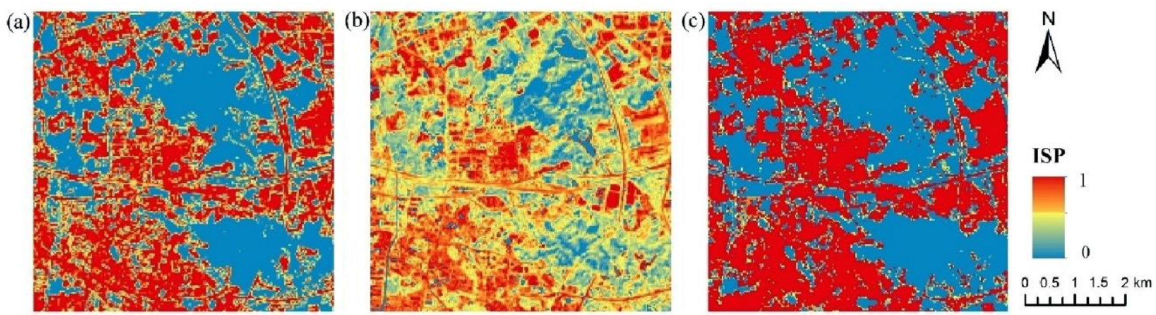
Optimization of feature variables based on Relief-F



Inversion of ISP based on SVM model



Evaluation



ISP reference value LSMA ReliefF-SVM

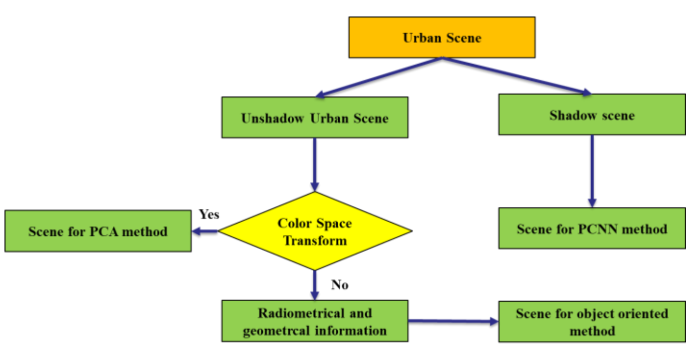
Method	MAE/%	RMSE/%	Kappa
LSMA	19.06	26.15	0. 6011
ReliefF-SVM	11.92	12.08	0.8362

Urban Grey Space

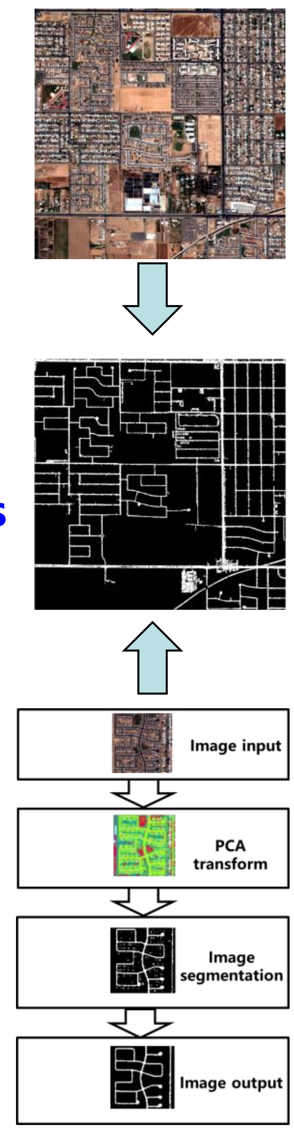
——Road extraction

Extraction difficulties

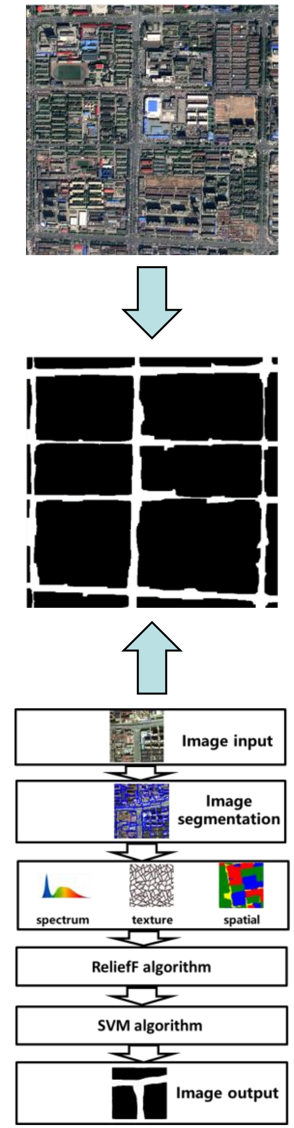
Results



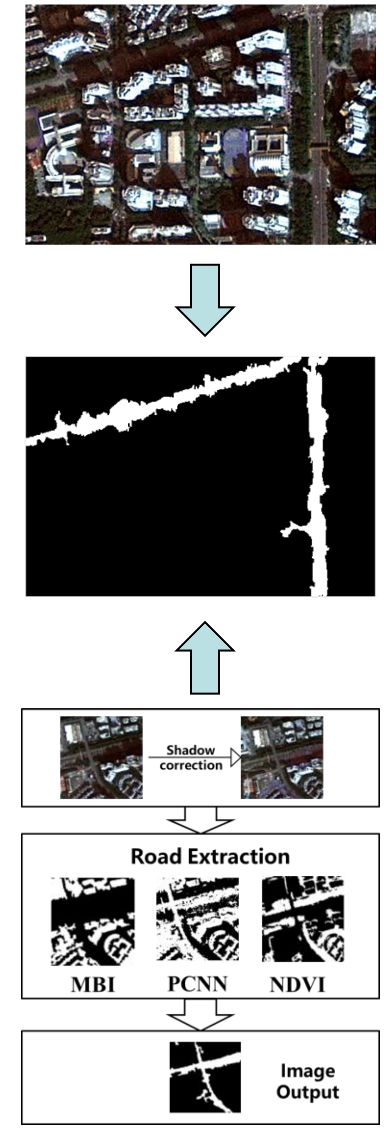
Flowchart



PCA



Object oriented

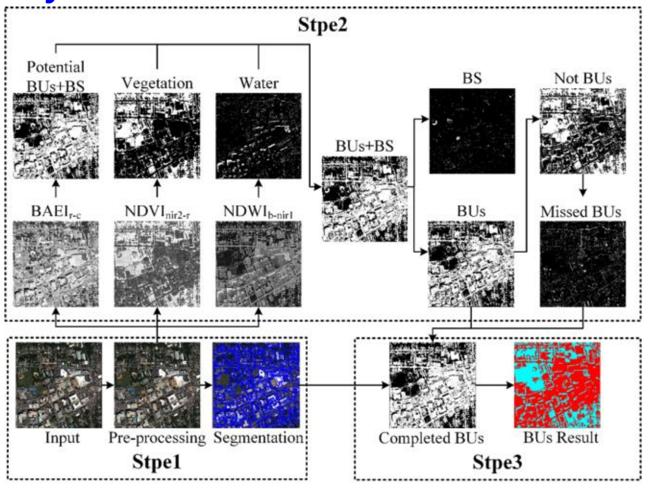


PCNN

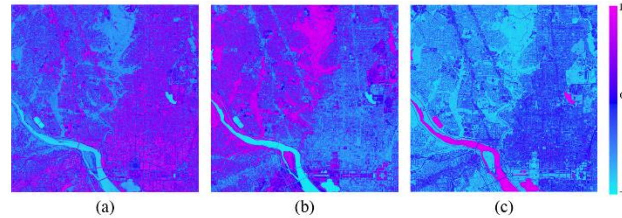
Urban Grey Space

——Built-up area extraction

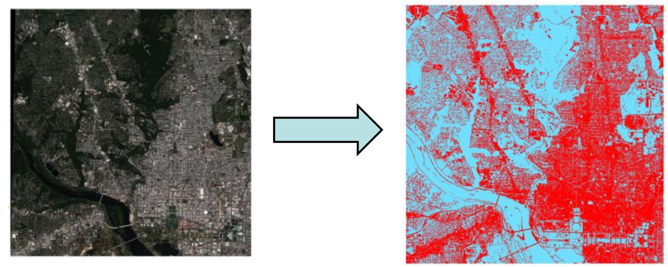
Object-based Automatic Multi-index Method



Flowchart



$BAEI_{r-c} = \frac{red - coastal}{red + coastal}$ $NDVI_{nir2-r} = \frac{NIR2 - red}{NIR2 + red}$ $NDWI_{b-nir1} = \frac{blue - NIR1}{blue + NIR1}$



Results

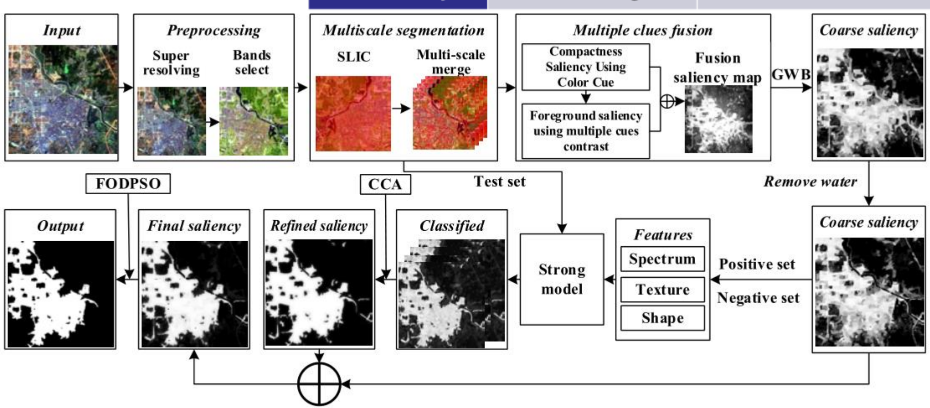
Improved Boosting Learning Saliency Method

OIF

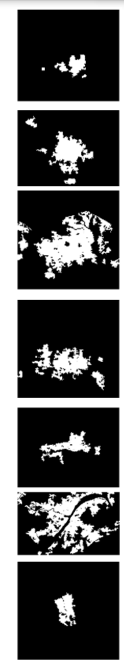
J-M distance

City type	Representative city	Best band combination
Desert city	Yulin	band 12,11,7
Coastal city	Haikou	band 12,11,7
River-side city	Wuhan	band 12,11,7
Valley city	Lanzhou	band12,11,5
Plain city	Baoding	band12,11,7

Best band combination



Flowchart



Results

Urban Humidity

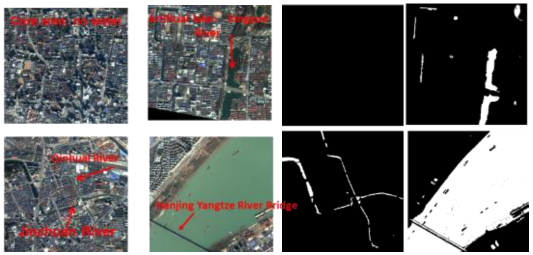
Accurate extraction of water resources

Identification of urban black odor water

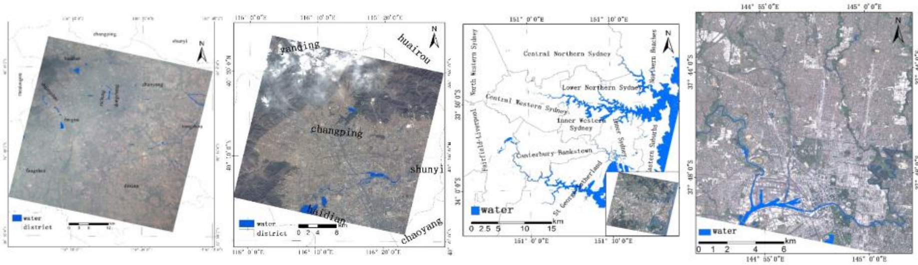
Urban humidity

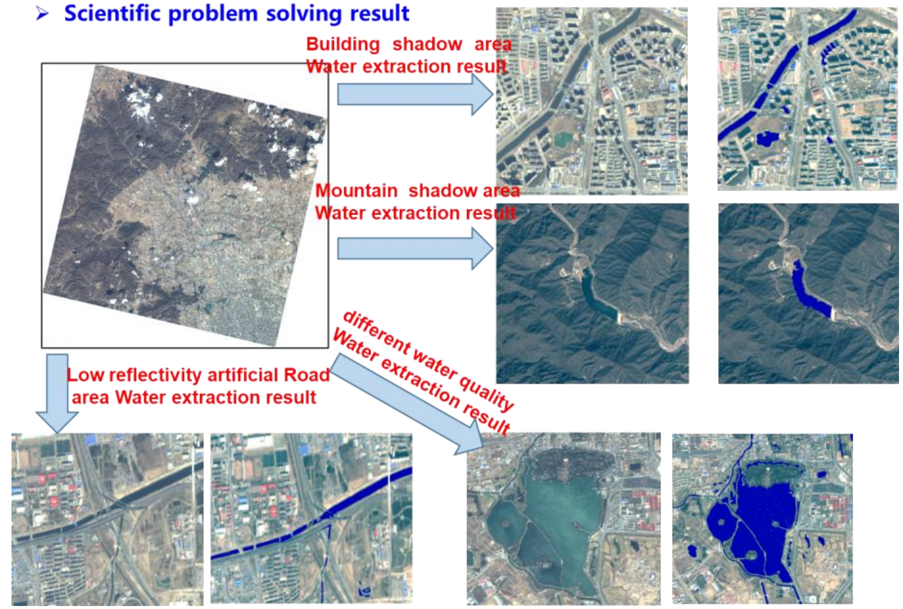
——Accurate extraction of water resources

Automatic extraction of Urban Fine Water



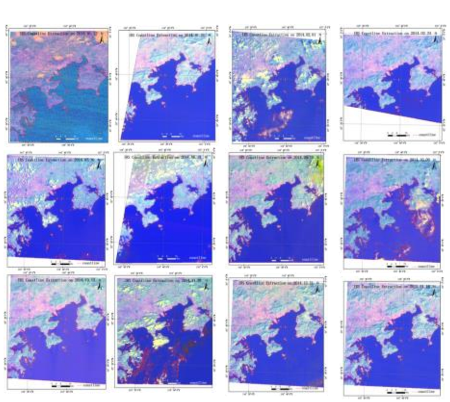
The results of BRAT model

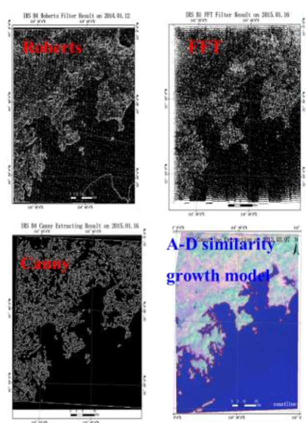




BRAT model obtains very good water extraction results in different types of waters.

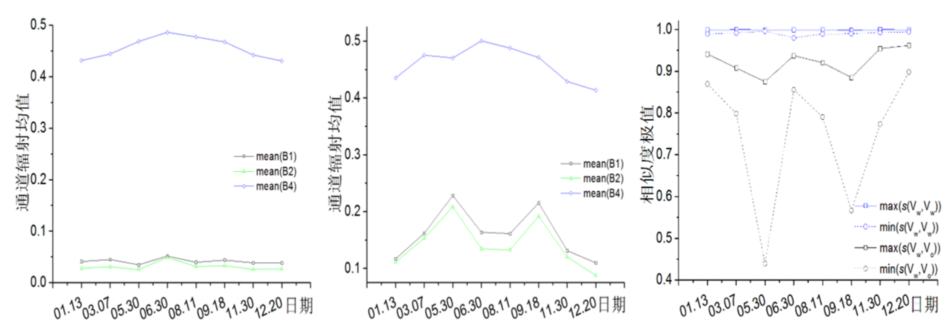
Coastline Extraction Automatically with RS





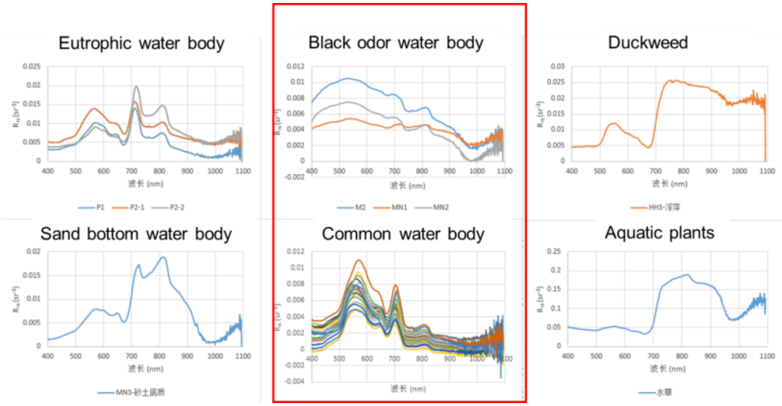
$$s(V_i,V_j)=\frac{\cos ine\ angle}{normalized\ distance}=\frac{\cos(\theta)}{|\vec{d}|/D+1}=\frac{V_i\cdot V_j/(|V_i||V_j|)}{|V_i-V_j|/D+1}$$

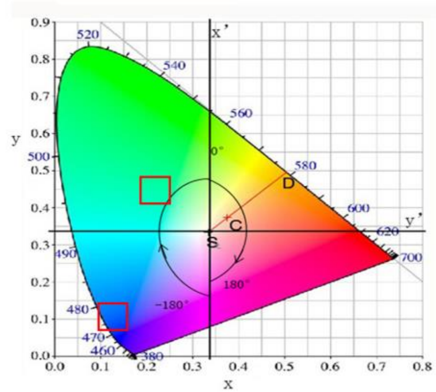
A-D similarity growth model



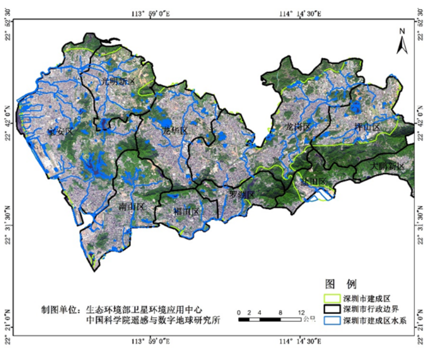
Urban humidity

——Identification of urban black odor water



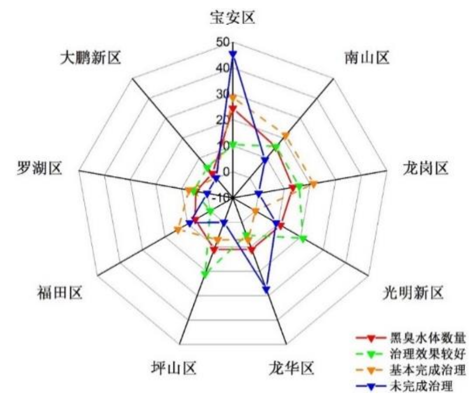


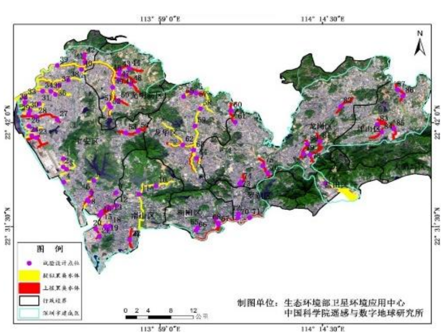
The recognition characteristics of different types of water saturation.



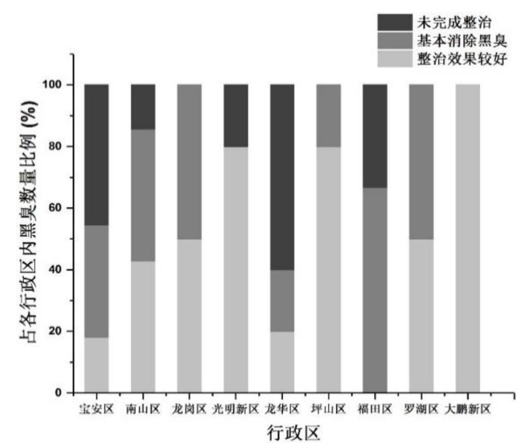
City Name	Administrative District	River Area(km^2)
Shenzhen	Baoan	13.78
Shenzhen	Longgang	4.17
Shenzhen	Nanshan	4.23
Shenzhen	Yantian	0.32
Shenzhen	Futian	1.07
Shenzhen	Guangming	4.18
Shenzhen	Luohu	0.76

Evaluation of governance effect





Administrative district	Good rectification effect(%)	Basic elimination of black odor(%)	Proportion of unfinished remediation(%)
Baoan	18.18	27.27	45.45
Nanshan	42.86	42.86	14.29
Longgang	50.00	50.00	0
Guangming	80.00	0	20.00
Longhua	20.00	20.00	60.00
Pingshan	80.00	20.00	0
Fuluo	0	66.67	33.33
Luohu	50.00	50.00	0
Dapeng	100	0	0



Non-point source pollution risk identification and assessment of drinking water sources

Non-point source pollution risk identification

Non-point source pollution risk index:

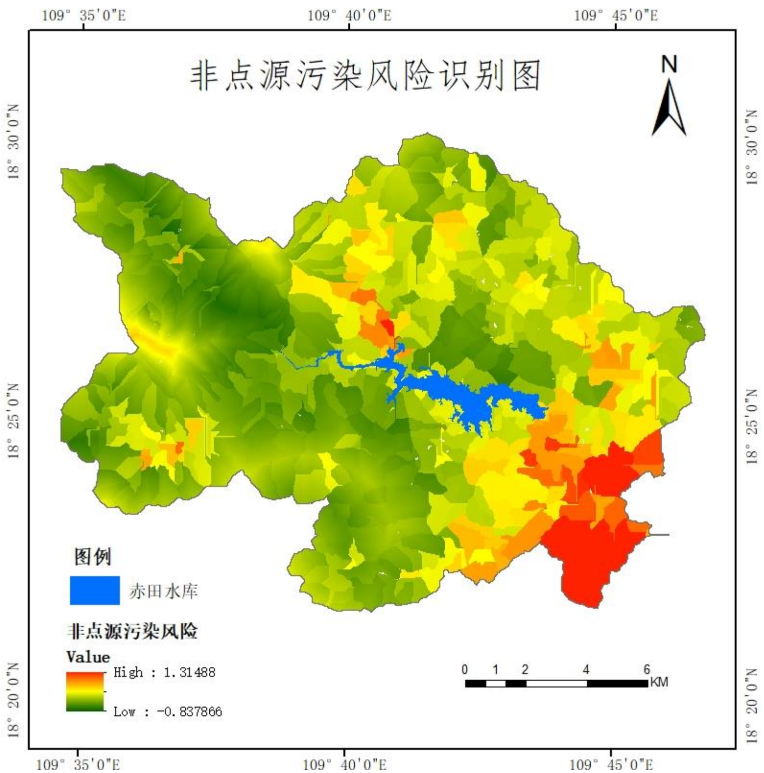
The pollution risk of each sub-basin is calculated with the "source-sink" pollution load risk index of the landscape space. Topographic factors and the distances from the river are included in the calculation of the non-point source pollution risk index. Then based on the non-point source pollution risk evaluation index to evaluate the non-point source pollution risk of each sub-basin unit, the formula is as follows:

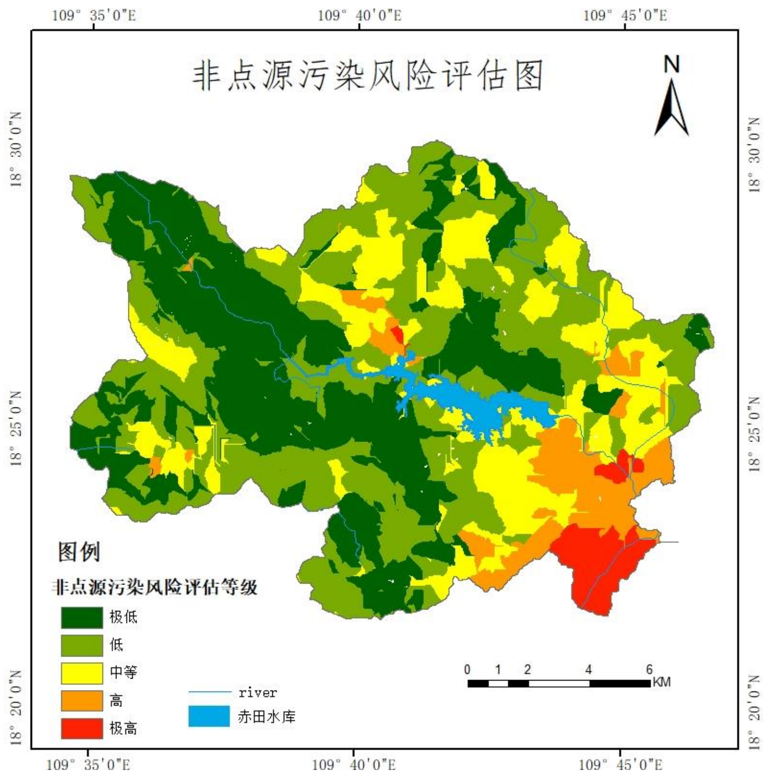
$$\mathrm{NPPRI}_m = LCI_{mNP} \times \left(1 + \frac{Slope_m}{Slope_{max}}\right) \times \left(1 - \frac{\mathrm{Distance}_m}{\mathrm{Distance}_{max}}\right)$$

LCImNP is the total nitrogen and phosphorus pollution load of sub-basin m, Slopem is the slope of sub-basin m, Distancem is the channel cost distance of sub-basin m; NPPRIm is the non-point source pollution risk index of the m-th sub-basin.

Non-point source pollution risk identification and assessment of drinking water sources

Monitoring results of risk sources in water sources





Urban Brightness

Housing Vacancy

Poverty Measurement

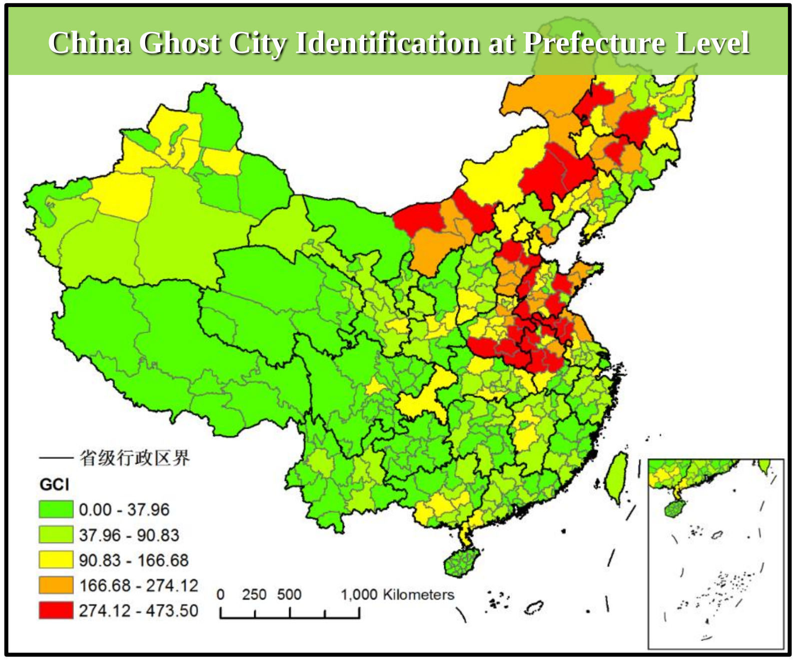
Urban Brightness Space

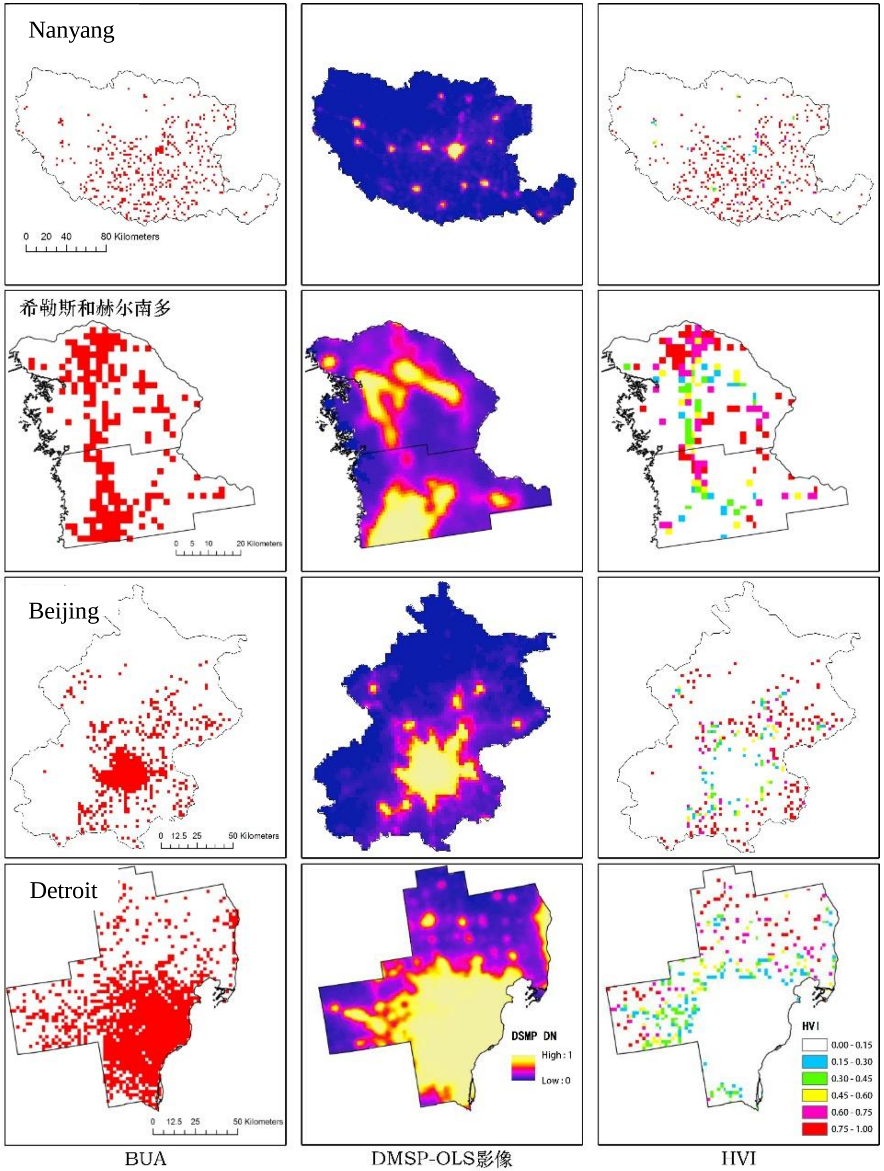
——Housing Vacancy

- **Based on the characteristics of vacancy houses, Housing Vacancy Index (HVI) was designed. The formula is as follows:**

$$HVI=BUA*(1-OLS_{nor})$$

Where BUA is the pixel value of binary image of built-up area, in which 0 means non-built area, 1 means built-up area. OLSnor is the pixel value of DMSP-OLS image which has been normalized to 0-1.





Urban Brightness Space

——Poverty Measurement

Global Spatial Autocorrelation

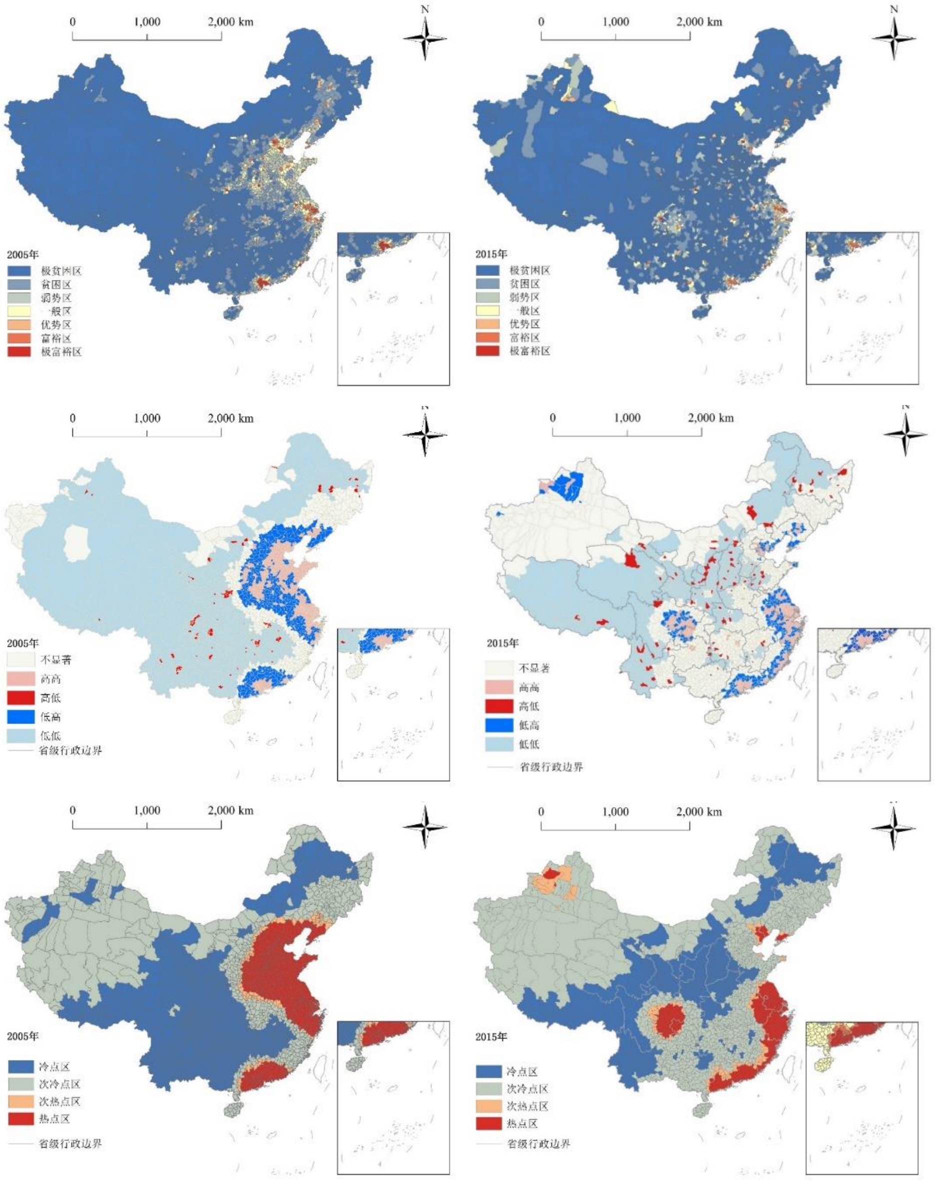
$$I = \frac{n\sum_i \sum_j w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_i \sum_j w_{ij}}$$

Local Spatial Autocorrelation

$$LISA_i = \frac{\left(x - \bar{x}\right)}{\left(x_i - \bar{x_i}\right)^2 / n} \sum_j w_{ij}\left(x_i - \bar{x}\right)$$

Hot Spot Analysis

$$G_i = \frac{\sum_j w_{ij} x_j}{\sum_j x_j}$$



The distribution of poverty and affluence in my country has obvious spatial agglomeration, and the difference is obvious on both sides of the Hu-Huanyong line.

Urban Livability

Evaluation factor

Spatial analysis of livability

Urban Livability

——Urban livability evaluation

Landsat8

- Spectral Range：0.450-2.350μm
- Spatial Resolution ： 30m
- Operation Cycle ： 16 days

MODIS

- Spectral Range ： 10.4-12.5μm
- Spatial Resolution ： 1km
- Operation Cycle ： 4 times per day

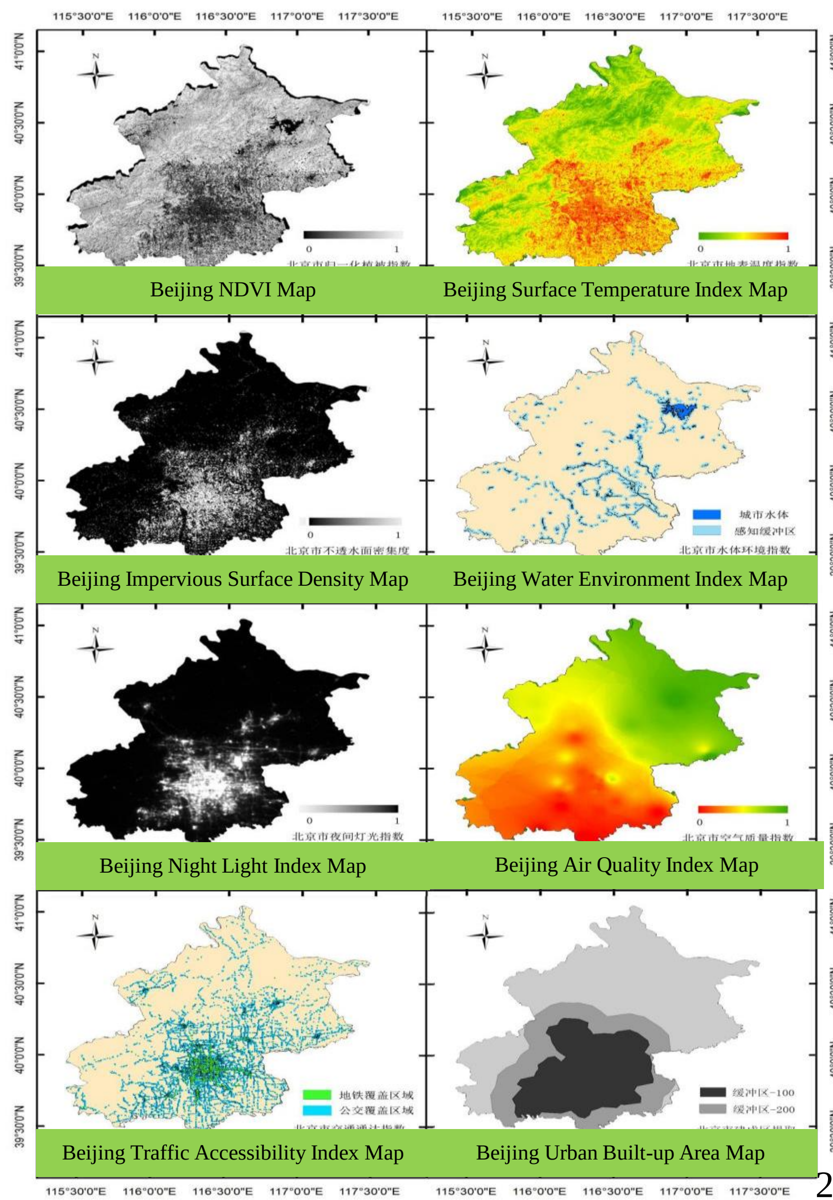
Landsat8

- Spectral Range： 0.4-1.1μm 10.0-13.4μm
- Spatial Resolution： 0.5km
- Operation Cycle： 101 min

Explore the spatial distribution characteristics of Beijing urban impervious surface, vegetation index, water body index

Study on the distribution of urban thermal environment and the intensity of heat islands in Beijing

Extract long-term night light data in Beijing area, and use the night light index as the evaluation index in humanities.


Beijing NDVI Map
Beijing Surface Temperature Index Map
Beijing Impervious Surface Density Map
Beijing Water Environment Index Map
Beijing Night Light Index Map
Beijing Air Quality Index Map
Beijing Traffic Accessibility Index Map
Beijing Urban Built-up Area Map

Urban Livability

——Spatial analysis of livability

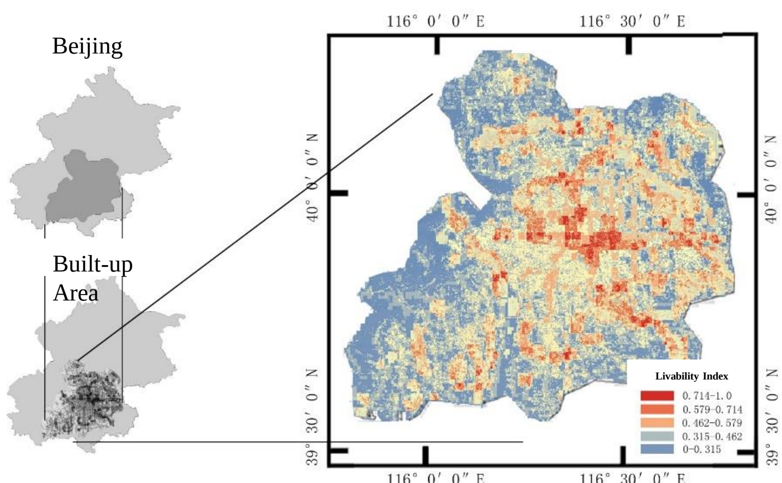
Principal Component Conversion

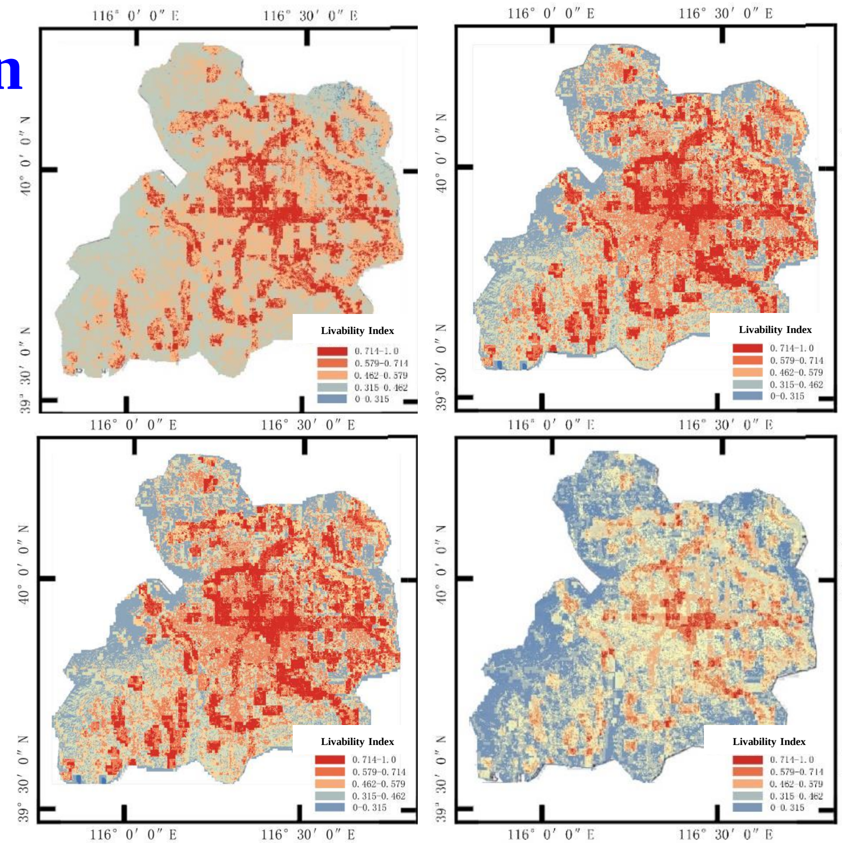
The PRINCOMP function in the GRID module is used to convert the principal components of the comprehensive graph, to find the eigenvectors, eigenvalues of the correlation matrix, the variance contribution rate, cumulative contribution rate, factor load matrix of the principal components, etc. for the next calculation.

Weight calculation

$$H_j = \sum_{j=1}^{m} \lambda_{jk}^2 \quad (j = 1,2,\cdots,17;\ k = 1,2,\cdots m)$$

Calculation result of livability in Beijing:





2003-2018 Temporal and Spatial Graphs of Beijing's Land Surface Environmental Livability

2018 Beijing Livability Index Rank Proportion

	Level 5	Level 4	Level 3	Level 2	Level 1
Evaluation Rank Index	0.714-1.0	0.579-0.714	0.462-0.579	0.315-0.462	0-0.315
Proportion	6.8%	9.4%	20.1%	43.4%	20.3%

Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

1. Research Background and Necessity

Application Background

Urban green space is called the 'kidney of city', which plays an important role.

- **Beautify The Environment**

  ——Maintain ecological balance and improve human settlements

- **Purify The Air**

  ——Absorb the suspended particles in the air and purify the air

- **Regulating Temperature**

  ——Influence the evaporation runoff of urban surface and weaken the heat island effect

- **Aesthetic Value**

  ——is pleasing to the citizens

1. Research Background and Necessity

Unbalanced Distribution of Green Per Capita

Figure 1. *Urban heterogeneity. False color infrared aerial photo of Baltimore City, MD, taken in 1999 at submeter resolution.*

1. Research Background and Necessity

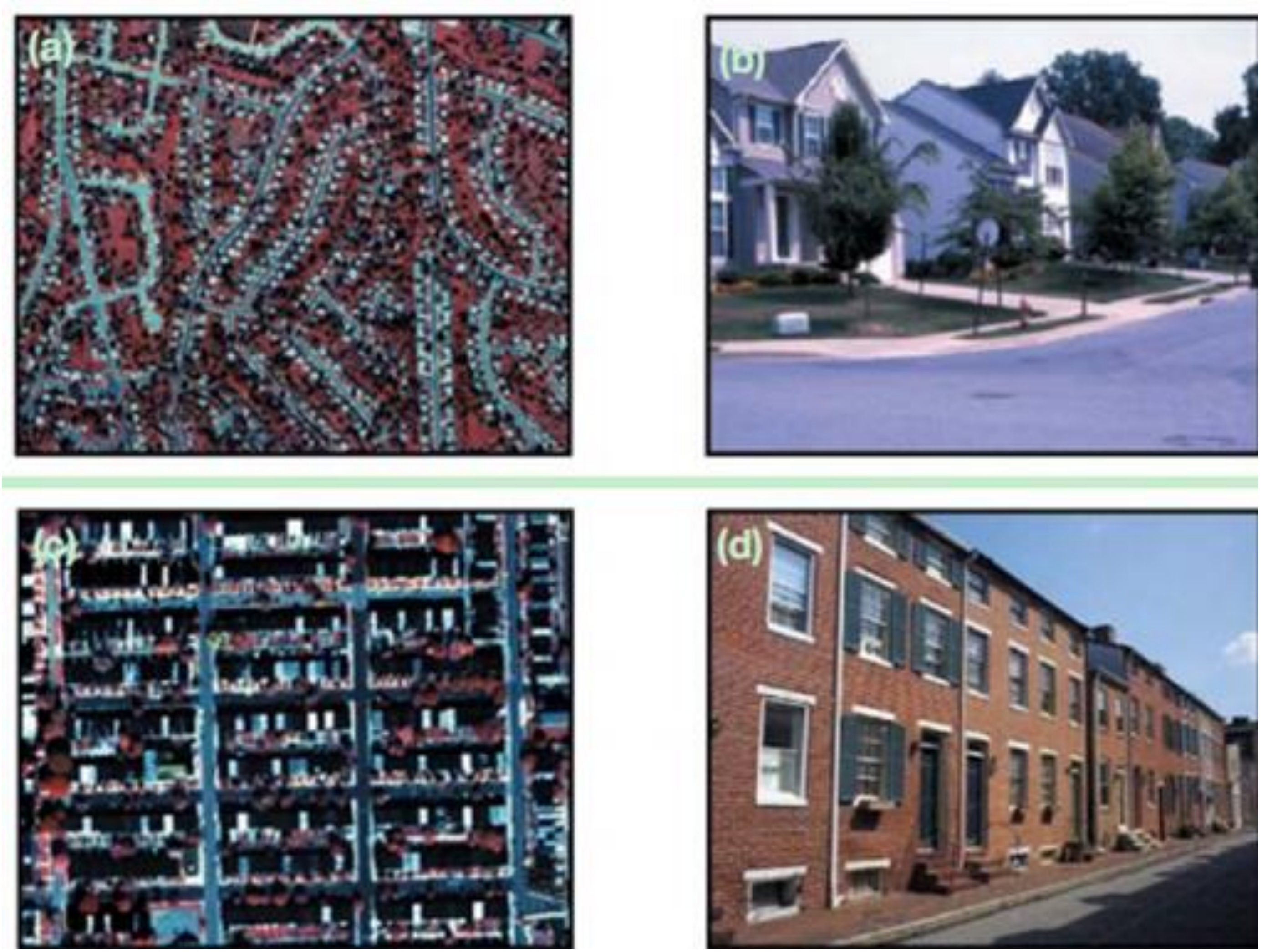
Unbalanced Distribution of Green Per Capita

New York

Beijing

1. Research Background and Necessity

Unbalanced Distribution of Green Per Capita



1. Research Background and Necessity

Facing A Lot of Urban Environment Problems and National Urgent Needs

- **How to extract urban vegetation information from multiple dimensions?**
- **How to measure the distribution of urban green space scientifically?**
- **How to estimate the probability of resident contacting green space and the level of enjoying green space?**
- **How to combine remote sensing, evaluation and planning?**

1. Research Background and Necessity

What is Urban Green Space Remote Sensing?

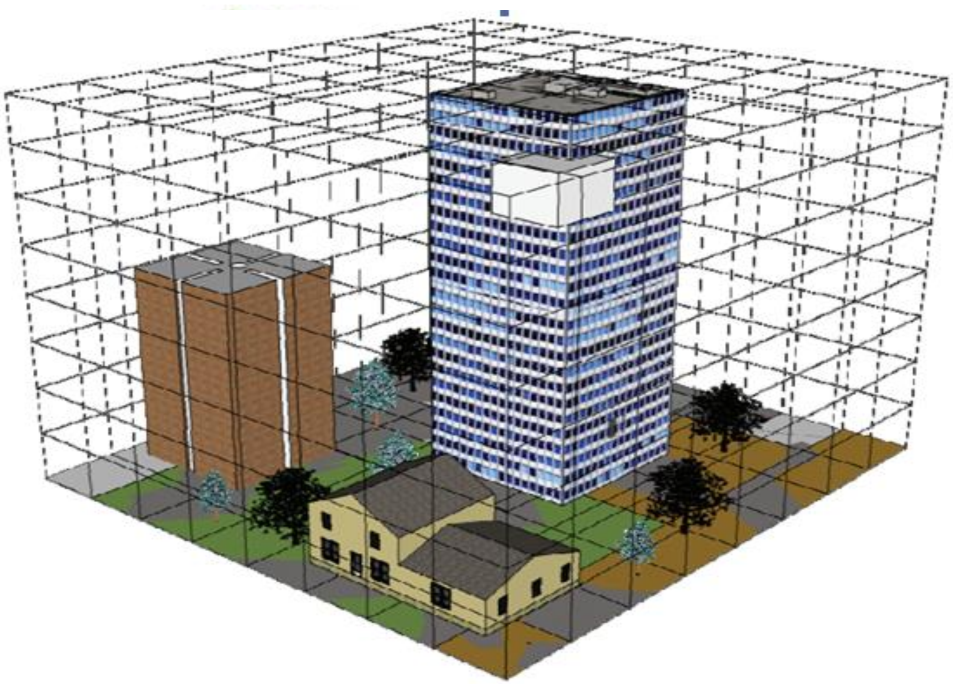
- Urban Area covered by Vegetation

Urban green space remote sensing measures the quantity, quality and human perception of urban green space quantitatively from **multi-dimension, multi-angle and multi-scale** based on multi-source remote sensing data and GIS technology, aiming at realizing the comprehensive evaluation of green space structure, ecological function and ecological services.

Research Content

- Evaluation of green structure
- Evaluation of ecological function of green
- Evaluation of ecological service of green

1. Research Background and Necessity



Three Dimensional Analysis Of Urban Green Space

- Considering the configuration relationship between urban buildings and urban green land comprehensively;
- Developing the green space index on building scales;
- Highlighting the spatial distribution of urban vegetation from both vertical and horizon dimensions.

Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

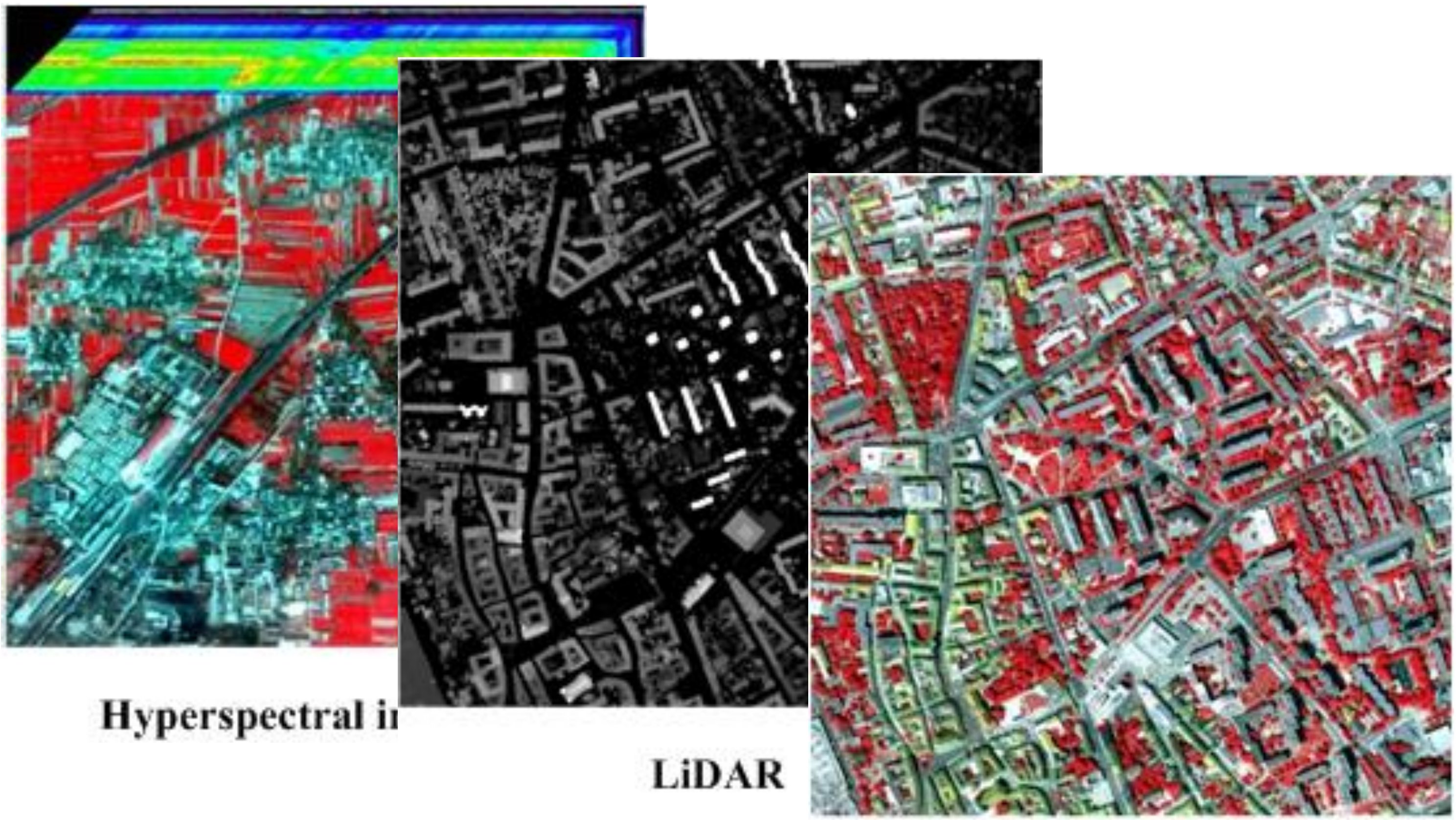
Introduction of Study Area

Study Area

Székesehérvár

Data Sources and Preprocessing

Data Sources



Hyperspectral i

LiDAR

Multi-spectral imagery

Remote Sensing Extraction of Urban features

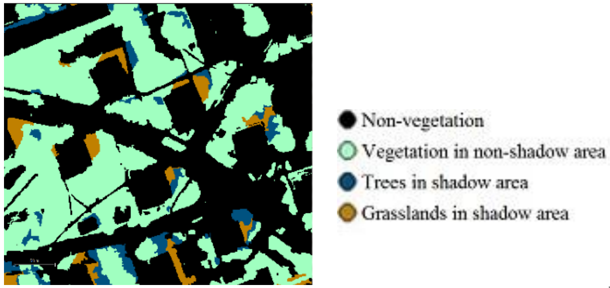
Vegetation 2D information extraction

- **Shadow area**

Distinguish trees and grasslands through NDVI and brightness characteristics.

The color of grassland is dark and the brightness is low; NDVI value of trees is high.

By setting the appropriate threshold value for (brightness * NDVI), we can distinguish the information of trees and grasslands in the shadow area.

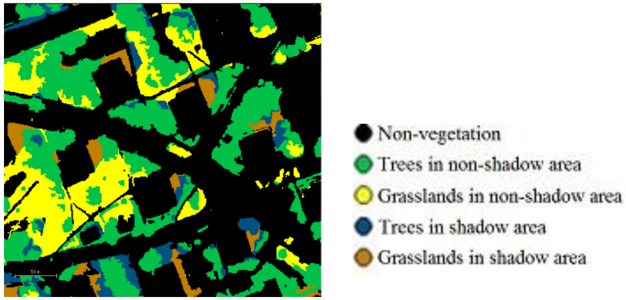


- **Non-shadow area**

Trees and grasslands are distinguished by intensity and GLDVA.

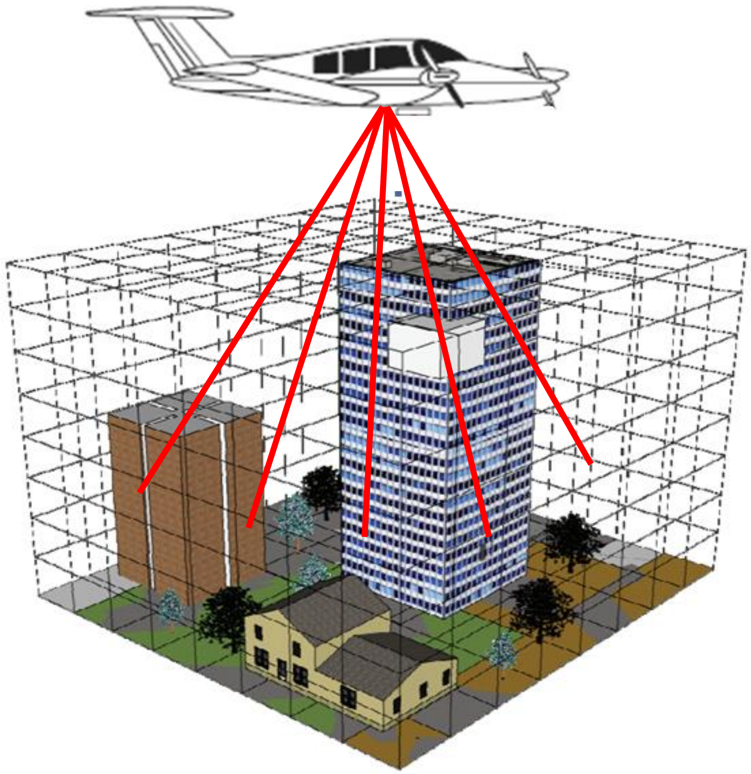
The intensity and gldva values of grassland were higher.

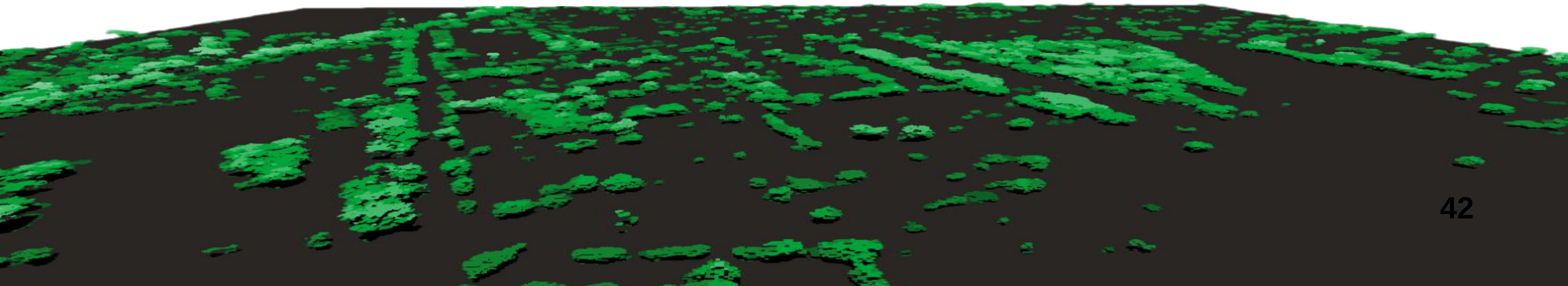
By setting an appropriate threshold value for (intensity * gldva), we can distinguish the information of trees and grasslands in the non shadow area.



Methods for extracting vegetation information		Overall accuracy	Kappa Coefficient
Pixel-based	Traditional Maximum likelihood Method (not separate shadow area)	0.863	0.759
Object oriented	Thresholds Method(not separate shadow area)	0.890	0.804
	Thresholds Method(separate shadow area)	0.904	0.832
	Thresholds Method + SVM classifier(separate shadow area)	0.894	0.817
	Thresholds Method +RF classifier(separate shadow area)	0.922	0.866

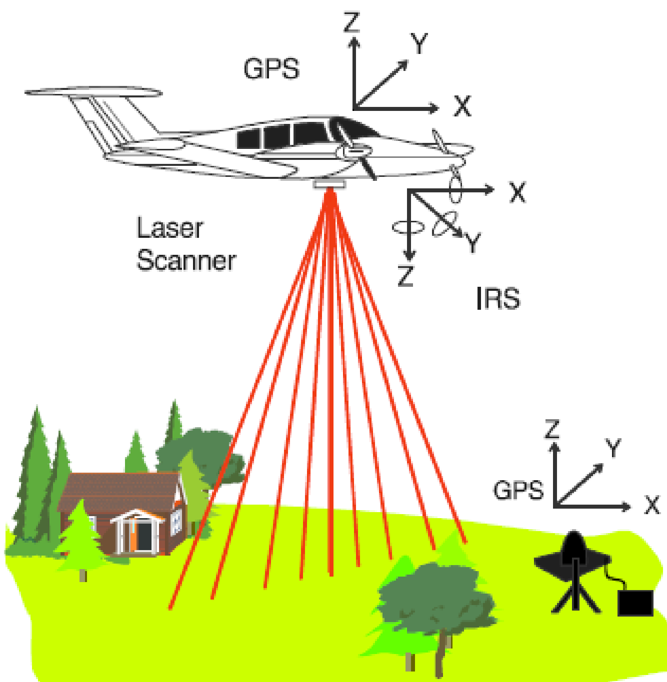
3-Dimension Canopy Parameters Retrieval





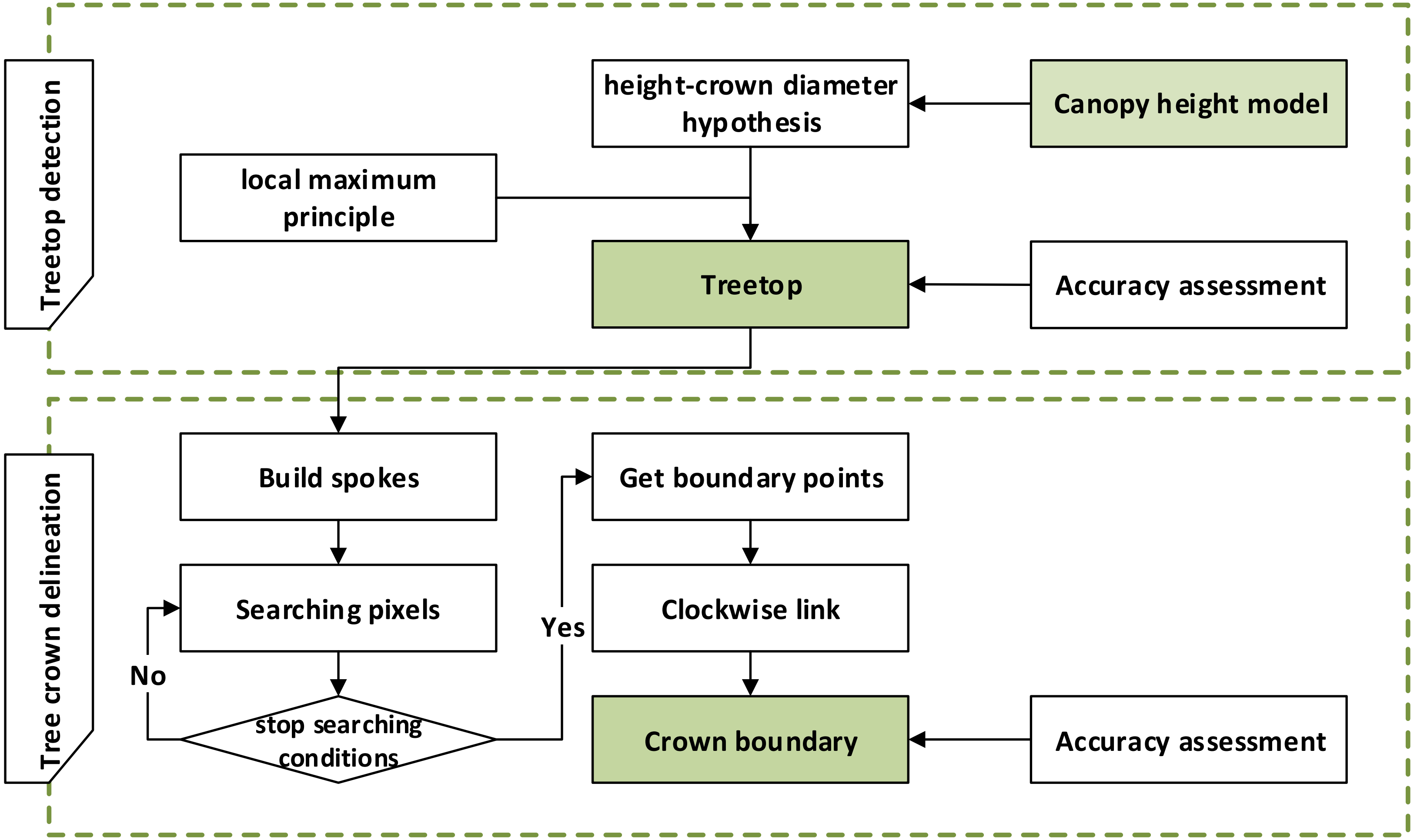
3-Dimension Canopy Parameters Retrieval

- **We propose a set of technical processes for crown delineation, crown volume estimation and canopy structure information extraction of different individual tree species based on airborne LiDAR and high resolution remote sensing data.**
- **And solved the error of crown volume measurement caused by canopy porosity.**

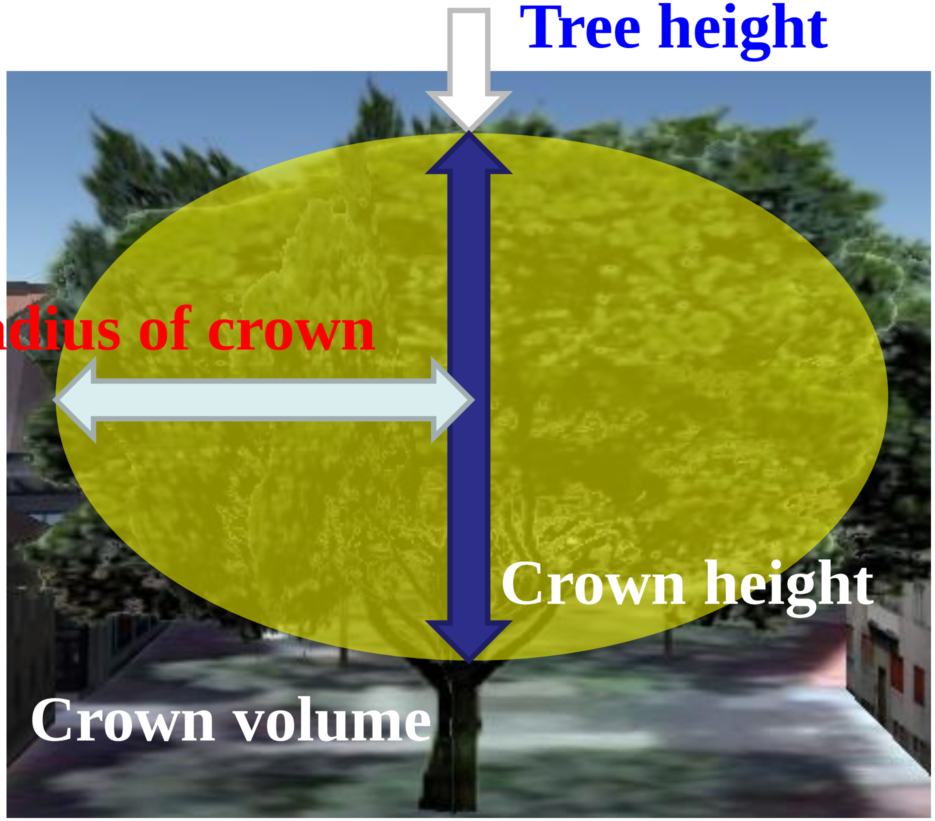


3-Dimension Canopy Parameters Retrieval

Tree Top Detection Based on Local Maximum Search Algorithm



3-Dimension Canopy Parameters Retrieval



front view

top view

- ➢ Only the tree crown with ellipsoid shape will be considered for the sake of simplicity.

3-Dimension Canopy Parameters Retrieval

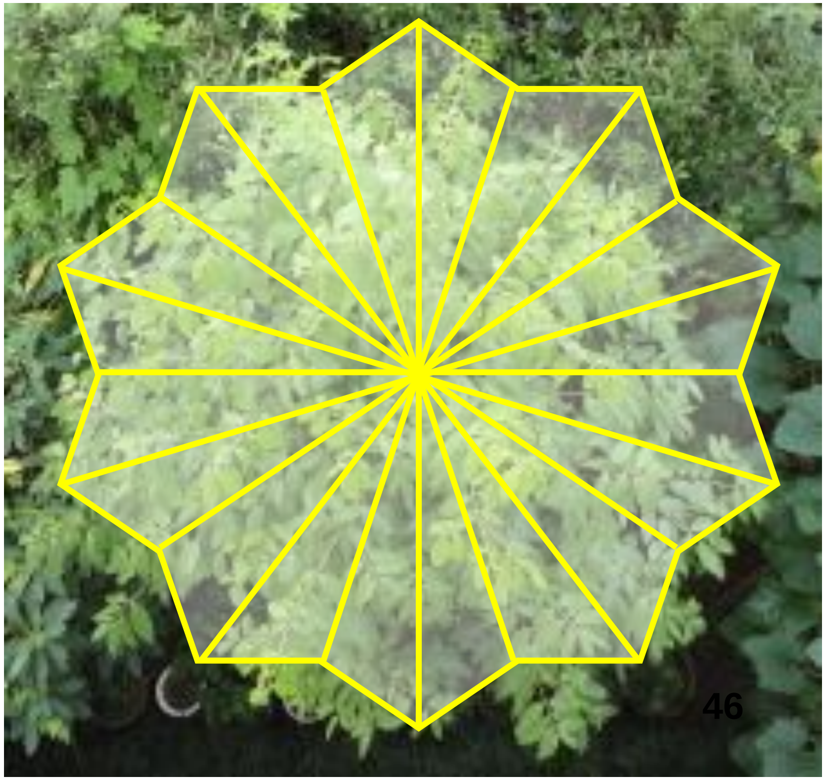
Tree Crown Delineation Based on Umbrella-frame Filter

In order to obtain the structural parameters such as tree height, crown height and crown volume, it is necessary to recognize the projection boundary of tree crown based on the results of tree crown detection, separate individual trees and determine the boundary position of their respective crowns. At present, the methods of tree crown boundary Delineation based on airborne LiDAR data can be summarized as follows:

1) **Image segmentation.**
2) **Moving window method.**
3) **Spoke wheel operator.**

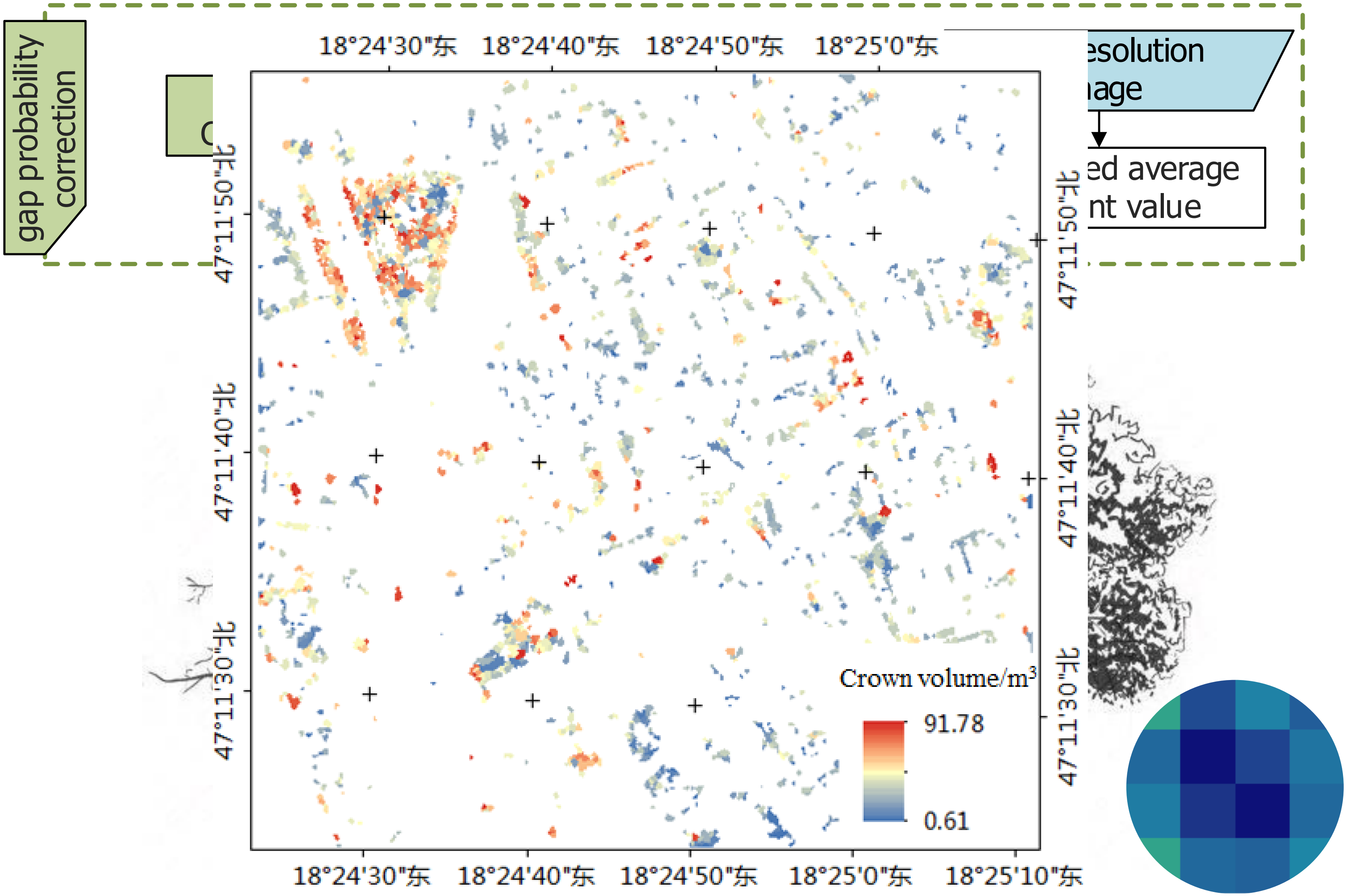
$$\left| I(C_i) - I(p) \right| \geq \sigma(W(p,n,m)), (0 \leq i \leq 4n)$$

To search for the intersection points, a sequence of line segments (spokes) Si and the evenly spaced angles ui were combined to form a spoke wheel W centred at common initial point p with k spokes. Then we connected them around the pixel p in a counter-clockwise direction on all spokes, which results in a closed polygon (crown edge).

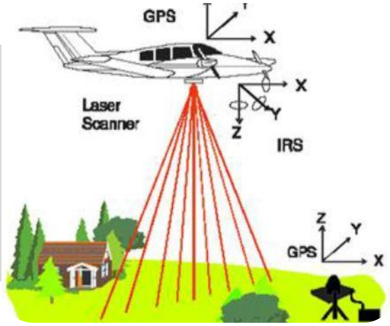


3-Dimension Canopy Parameters Retrieval

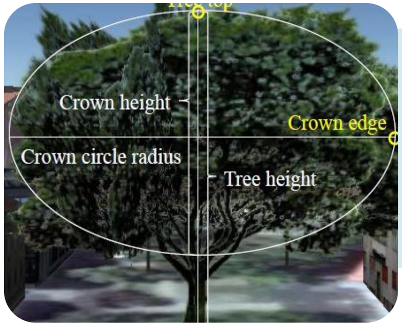
Canopy Cap Probability Correction Factor



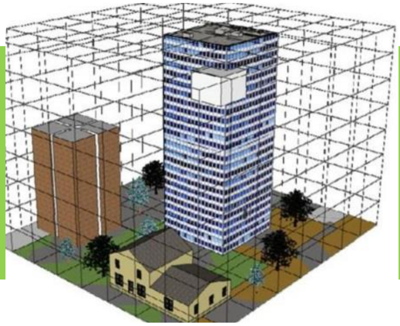
Multi-dimension Urban Green Retrieval



3D Canopy Information Retrieval



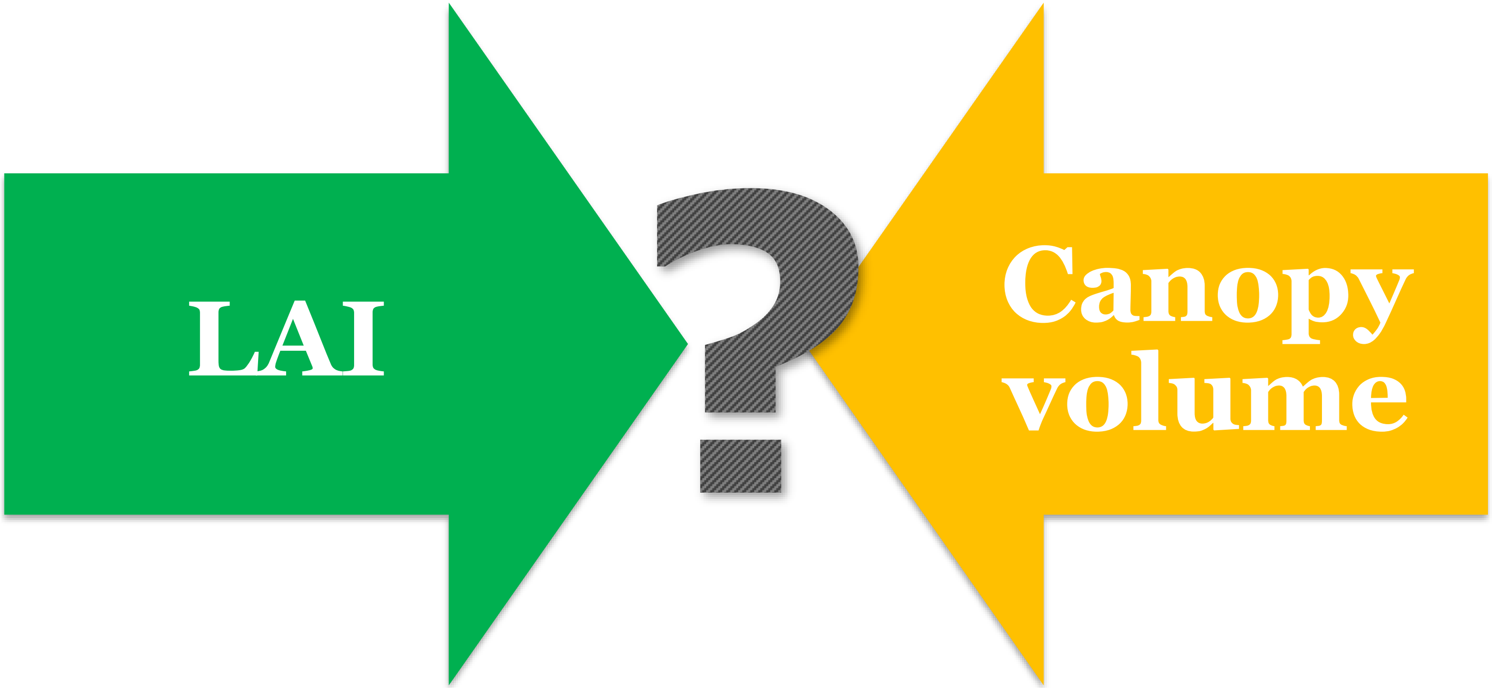
Correlation Analysis Between Canopy Structure And Eco-parameters



UGS Measurement Model

3-Dimension Canopy Parameters Retrieval

Correlation Analysis Between Canopy Structure and Eco-parameters



The inner relationship between canopy spatial structure and ecological factors is ignored.

3-Dimension Canopy Parameters Retrieval

Extraction of Physiological and Ecological Parameters of Vegetation

the sensitivity analysis of physiological and biochemical parameters of the model is

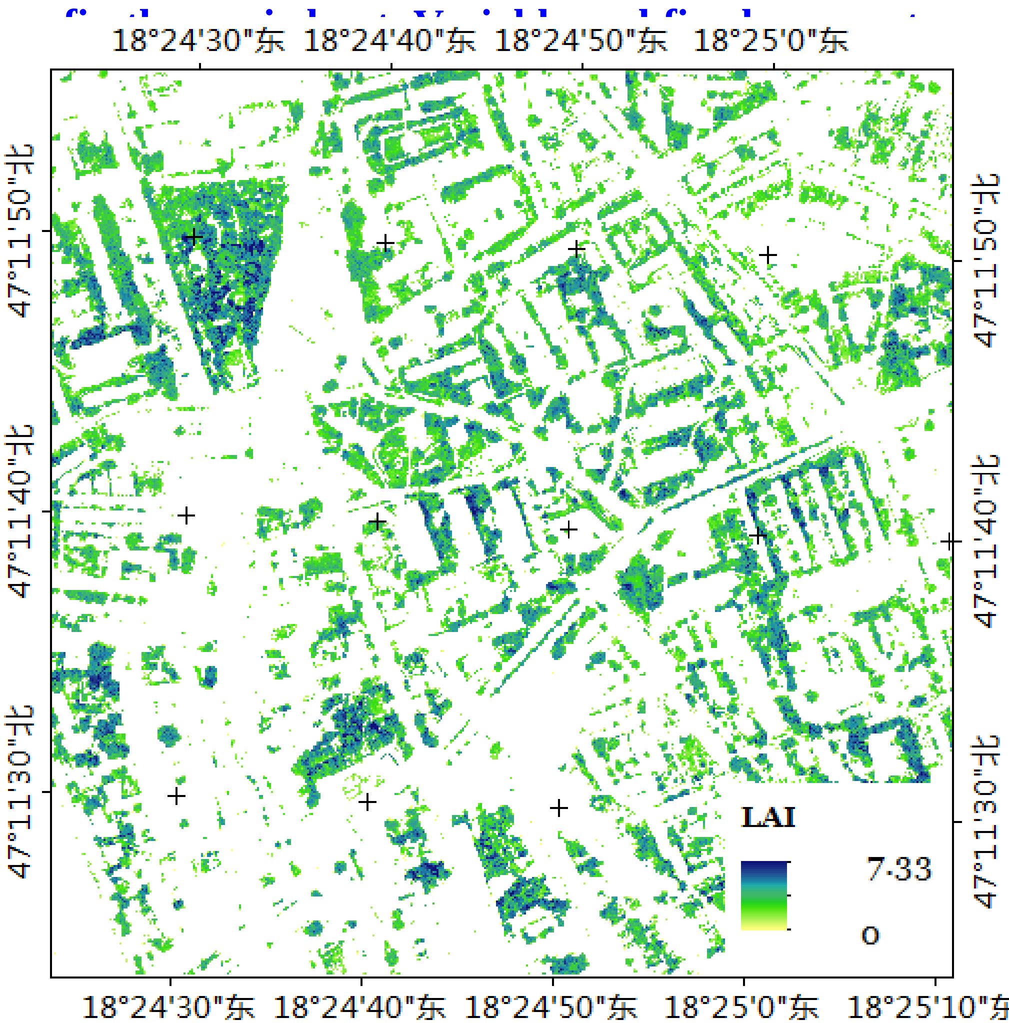
f the model are determined by sensitivity

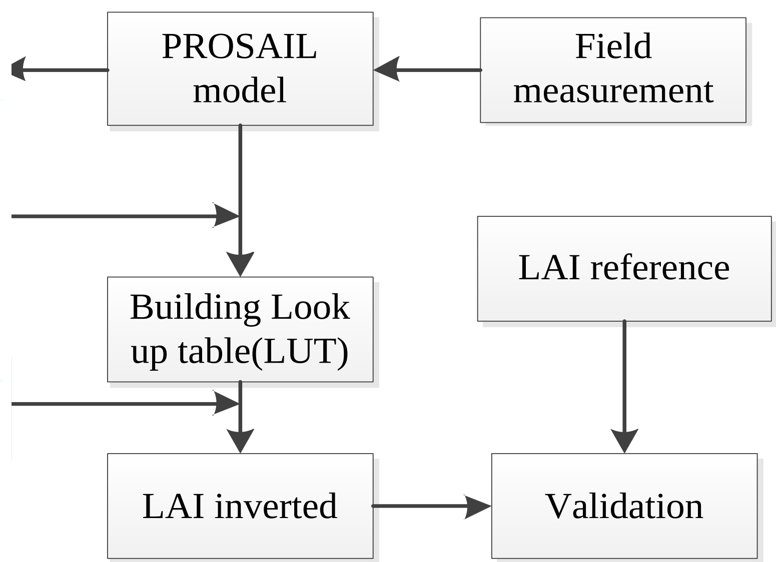
spectrum knowledge base for Hungary,

canopy LAI in research area. For LAI

lentify the parameter combinations that

l





Workflow of LAI inversion

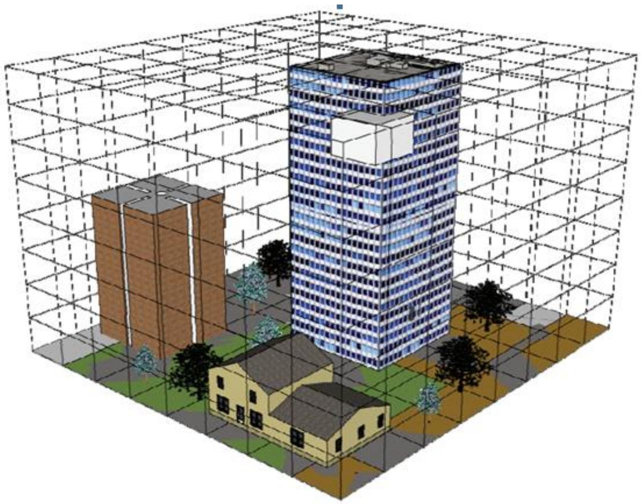
Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

3. Multi-scale Urban Green Perception

Urban green space is everywhere!

In work and life, to contact the urban green space through buildings. The quantity, quality, and distribution of vegetation around the building and the structure of the building determine the efficiency of residents enjoying the urban green space.



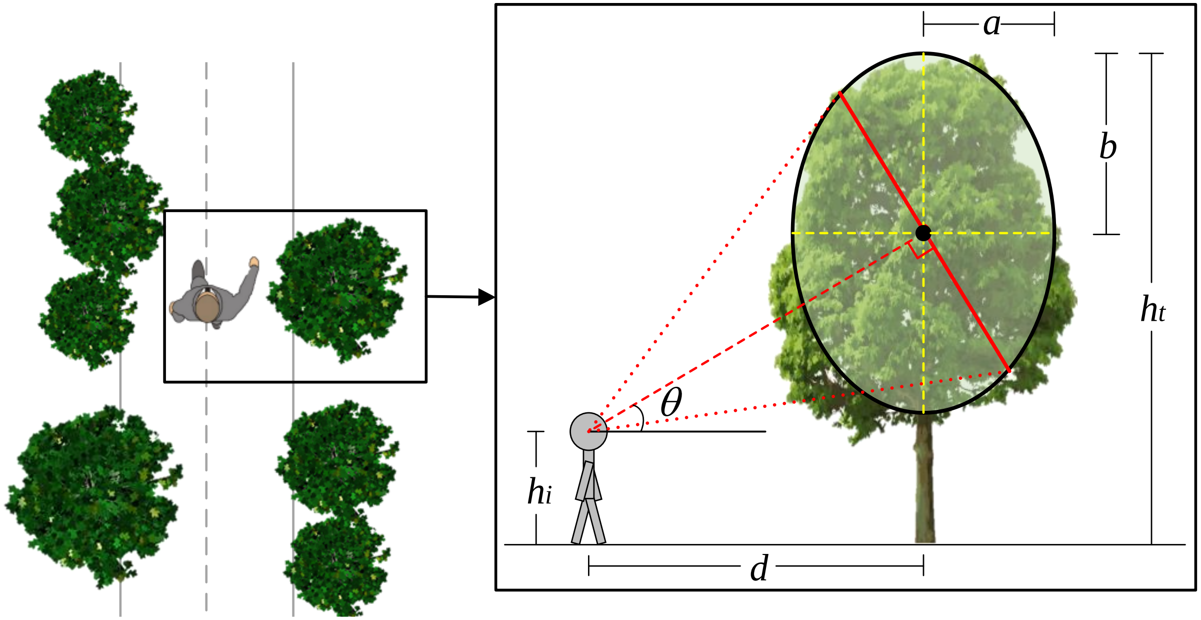
The relationship between architectural space and green space

Viewing the perspective of green space on different floors

When working at a desk, it is an important way to get in touch with the natural green space through the window and see the nearby vegetation.

3. Multi-scale Urban Green Perception

When walking on the street, the landscape quality and spatial distribution of the street trees determine the comfort of residents' travel. Daily visual contact with the street trees can enhance the positive mood of urban residents.



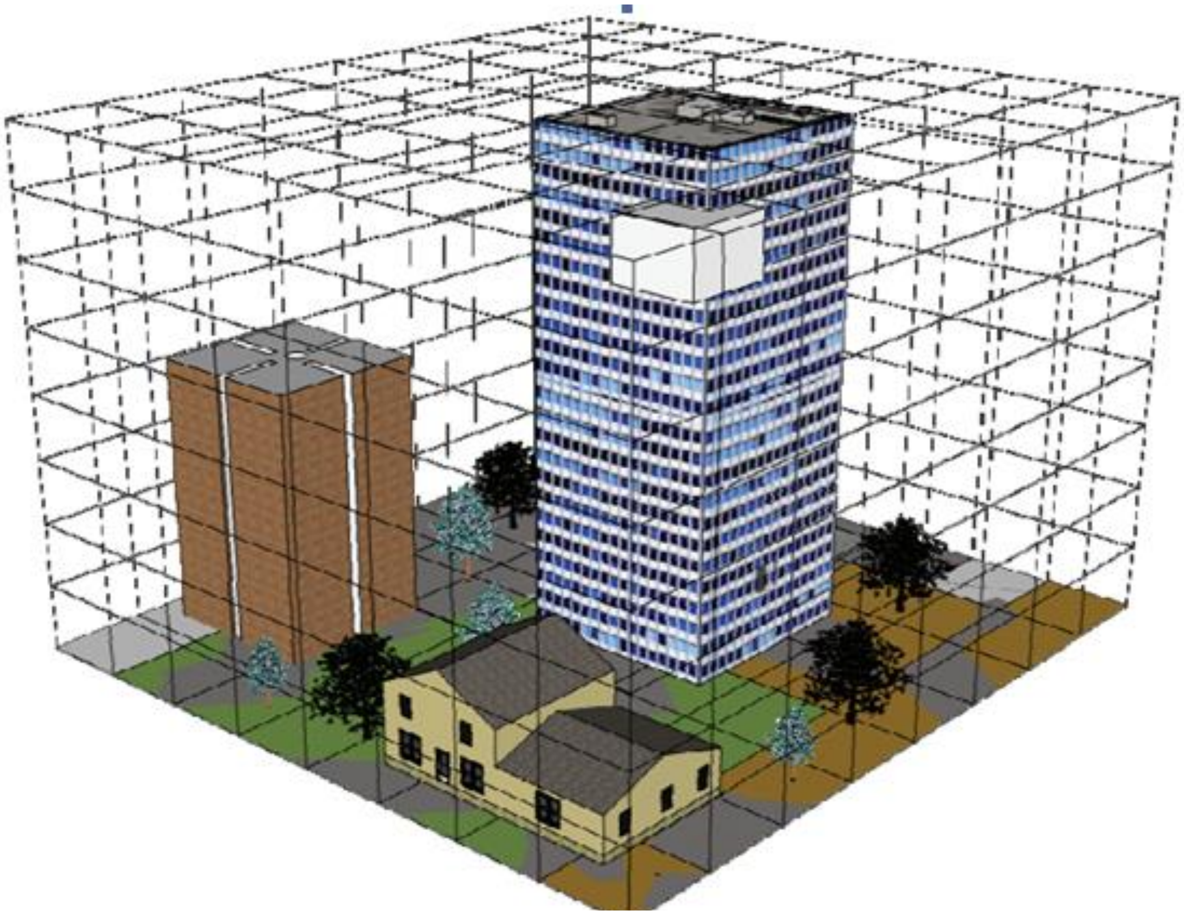
Schematic diagram of the spatial geometric relationship between the observer and the street tree

How to know how much urban green space we enjoy? Everyday apartments, streets, working offices... are our lives green enough?

Multi-Perspective Urban Green Perceiving

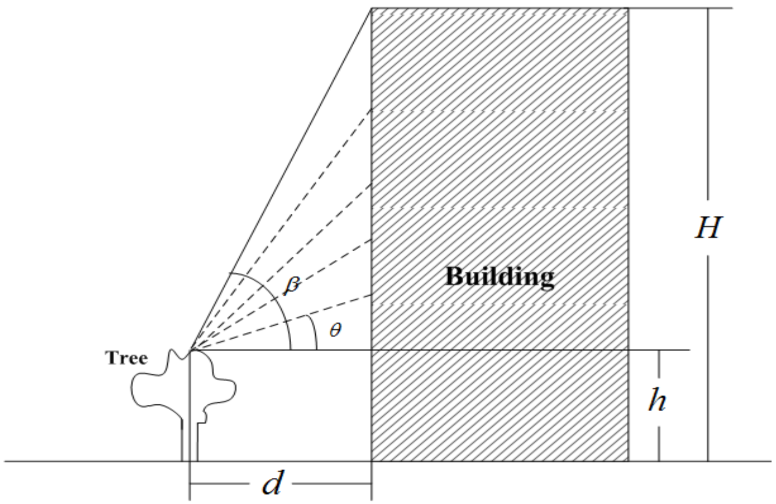
1. **Building Oriented Urban Green Perceiving**
2. **Floor Oriented Urban Green Perceiving**
3. **Street Oriented Urban Green Perceiving**

3-dimension Urban Green Perceiving



Spatial Configuration of Buildings and Green

Building's Accessibility to Green Space Index



$$\beta = \arctan\left|\frac{H-h}{d}\right|$$

$$D = \frac{\int_0^{\beta} \frac{d}{\cos\theta} d\theta}{\beta}$$

$$D = \frac{d}{\beta}\int_0^{\beta} \frac{1}{\cos\theta} d\theta$$

$$D = \frac{d}{\arctan\left|\frac{H-h}{d}\right|} \ln \frac{|H-h| + \sqrt{(H-h)^2 + d^2}}{d}$$

Proximity model of building and urban green

When assuming the height of grass is zero, equation D can be transformed into

$$D = \frac{d}{\arctan\frac{H}{d}} \ln \frac{H + \sqrt{H^2 + d^2}}{d}$$

3-dimension Urban Green Perceiving

Building's Accessibility to Green Space Index

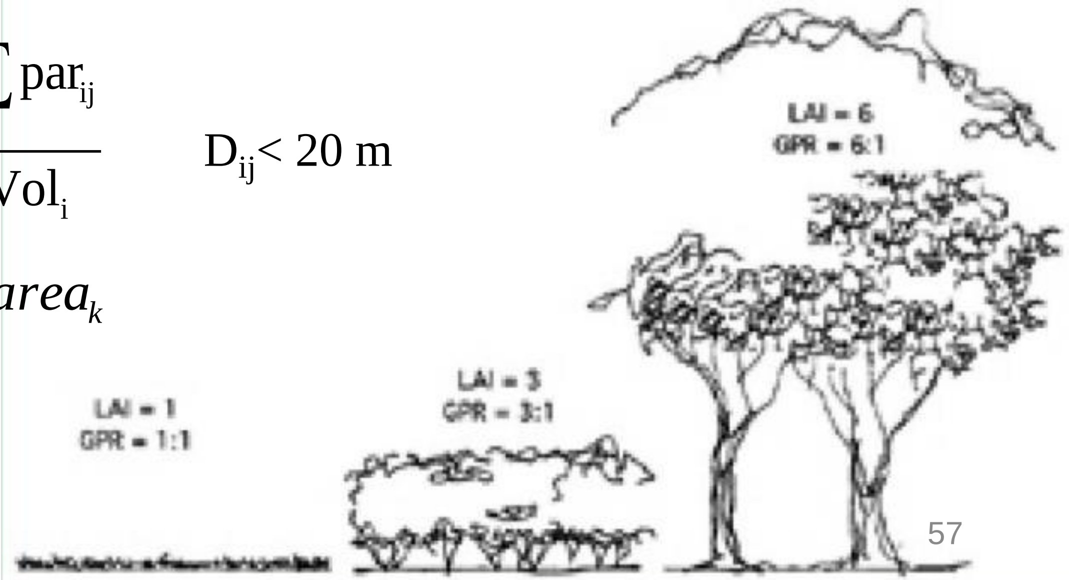
The ecological benefits of urban green has close relationship with vegetation's bio-physiological processes. The extent to which plants engage in these processes is directly related to the amount of green matter, usually found in the leaves of the plant (Ong, 2003)

$$BA\_BAGI_i = \frac{\sum_j par_{ij}}{B\_area_i} \qquad D_{ij} < 20\ m$$

$$vBAGI_i = \frac{\sum_j par_{ij}}{Vol_i} \qquad D_{ij} < 20\ m$$

$$G\_LAI_j = \sum_i area_i + 3\sum_j area_j + 6\sum_k area_k$$

- ***$area_i$* is the area of grass,**
- ***$area_j$* is the area of shrub**
- ***$area_k$* is the area of tree**



3-dimension Urban Green Perceiving

Vegetation index is used to indicate vegetation information by calculating the reflectance of vegetation in different bands. NDVI and RVI are the two most widely used vegetation index.

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad RVI = \frac{NIR}{RED}$$

Considering the three-dimensional structure of the ground object, the green space index based on the side area (BA_BAGI) and the volume-based green space index (vBAGI) can be further constructed:

$$BA\_BAGI_{NDVI} = \frac{\sum_j NDVI_{ij}}{B\_area_i} \qquad vBAGI_{NDVI} = \frac{\sum_j NDVI_{ij}}{Vol_i}$$

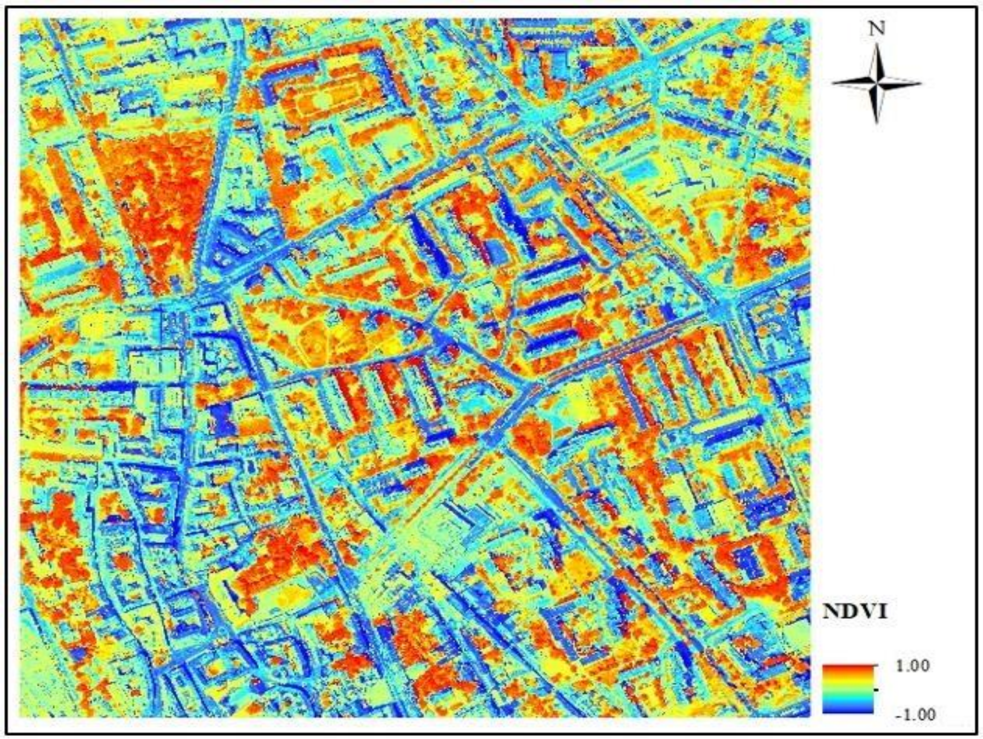
$$BA\_BAGI_{RVI} = \frac{\sum_j RVI_{ij}}{B\_area_i} \qquad vBAGI_{RVI} = \frac{\sum_j RVI_{ij}}{Vol_i}$$

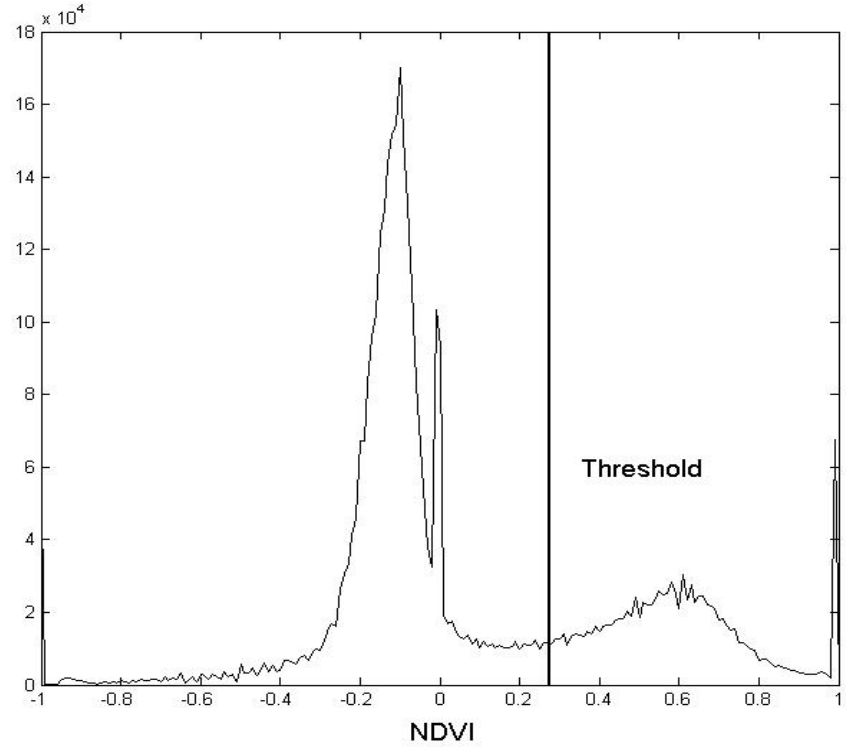
$D_{ij} < 20$ m

3-dimension Urban Green Perceiving

Extraction Result of Vegetation and Buildings

The optimal threshold is 0.25. According to the optimal threshold, the vegetation distribution map can be obtained by threshold operation on NDVI image.



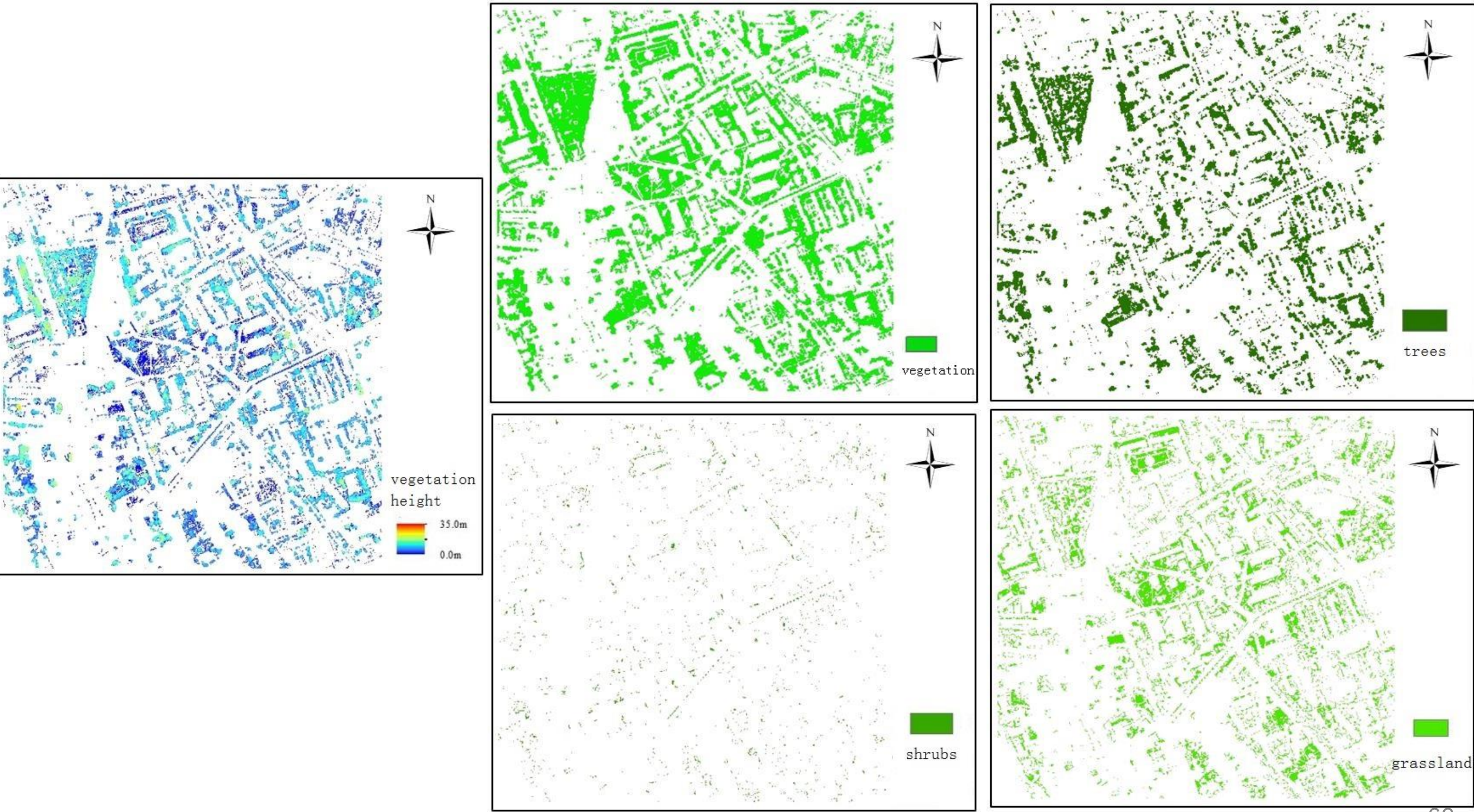


NDVI image of research area

NDVI histogram and the optimal threshold obtained using the OTSU algorithm

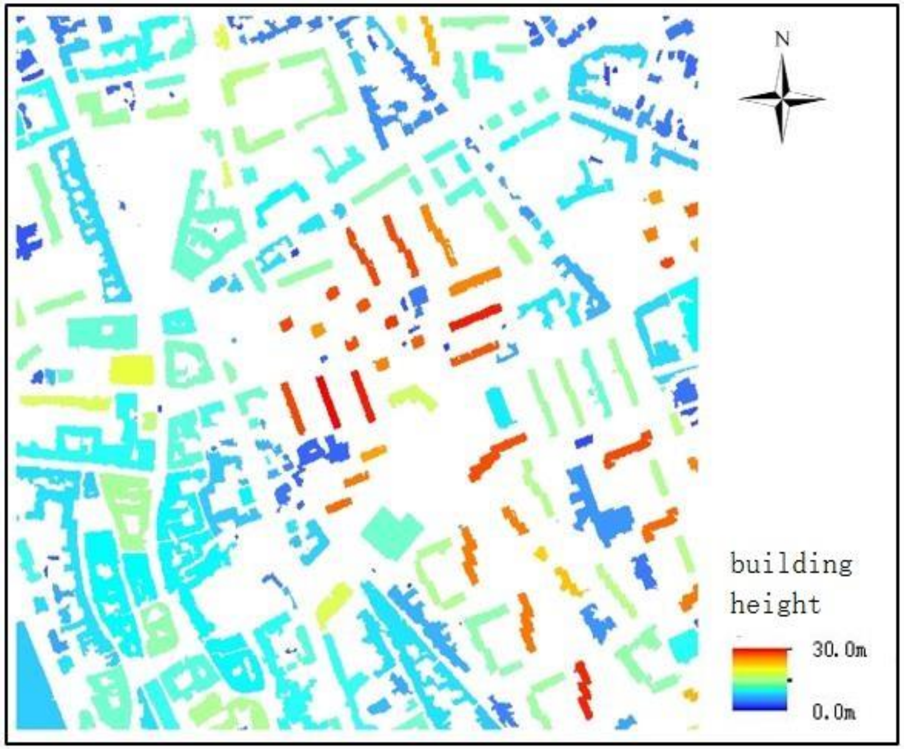
3-dimension Urban Green Perceiving

Extraction Result of Vegetation and Buildings



3-dimension Urban Green Perceiving

Extraction Result of Vegetation and Buildings

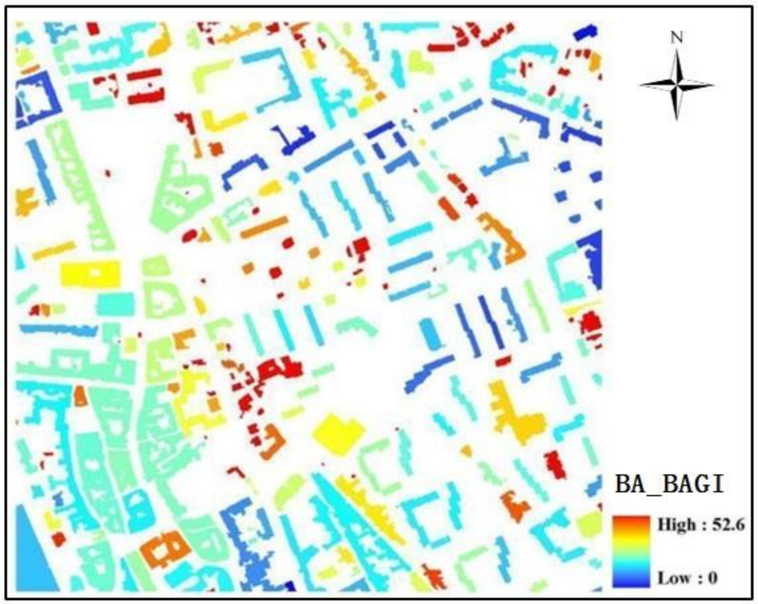


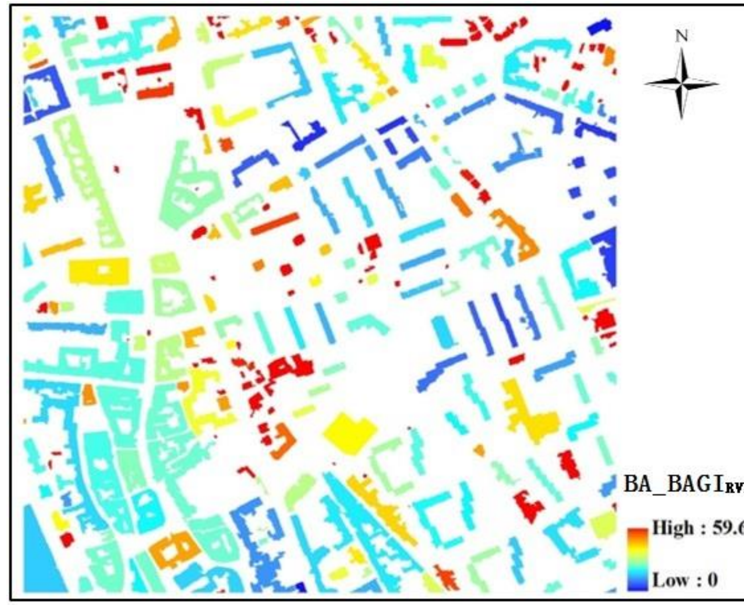
Distribution maps of buildings in research area

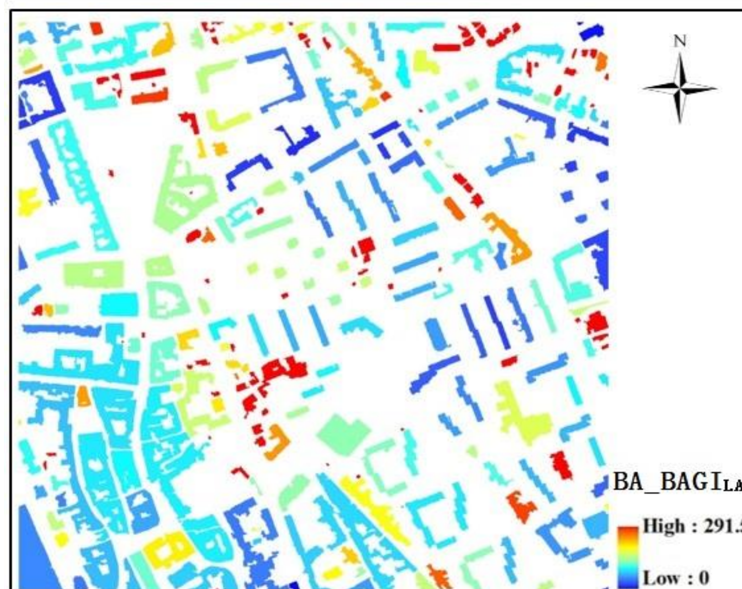
Height distribution maps of buildings

3-dimension Urban Green Perceiving

Distribution Map Of BA_ BAGI

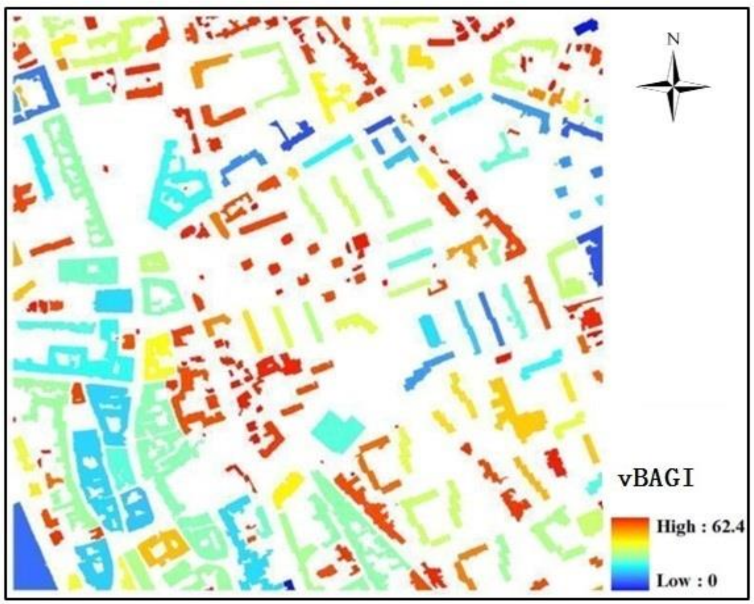


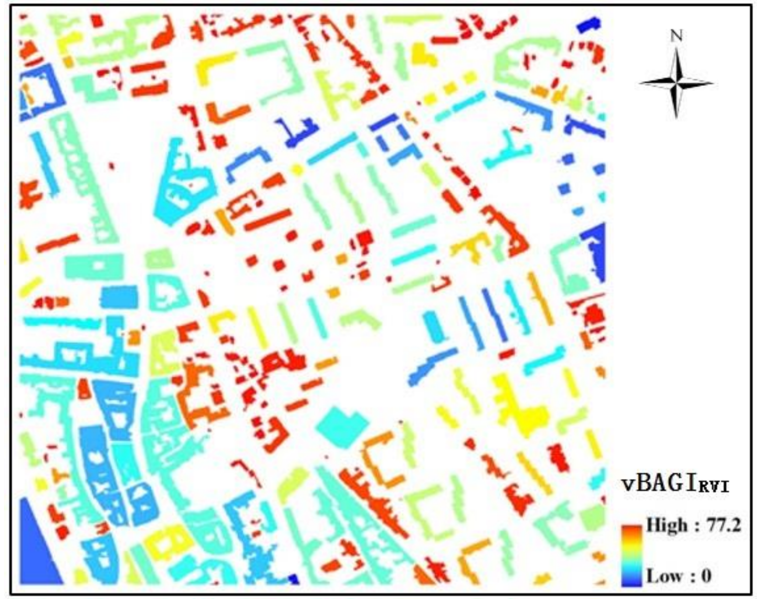




3-dimension Urban Green Perceiving

Distribution Map Of BA_ BAGI



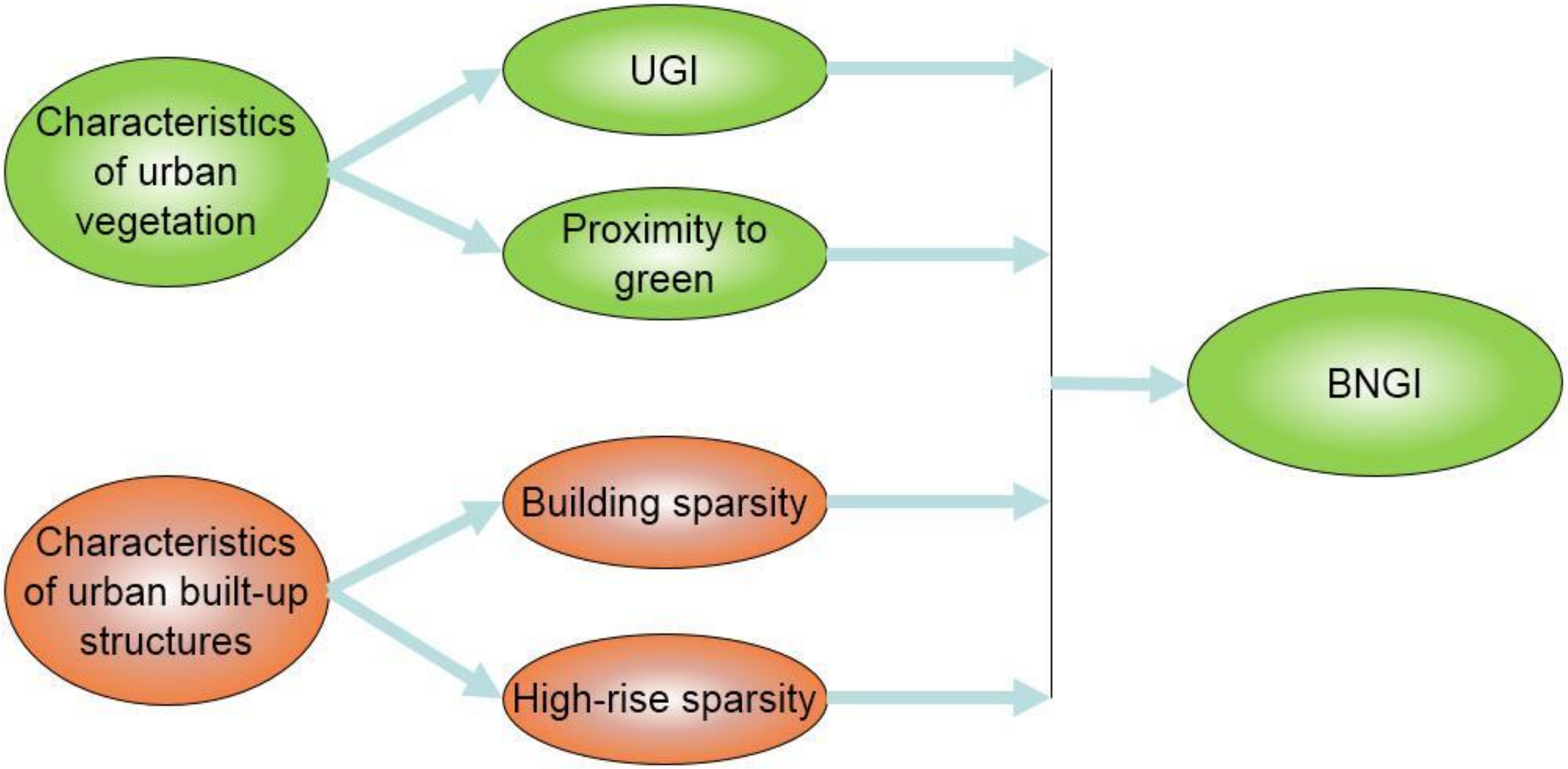


Buildings Neighboring Green Index

Building Neighborhood refers to the certain area of homogeneous or same characteristics, whether in terms of ethnicity, housing, type of development , etc. Buildings Neighboring Green Index（BNGI） can reflect the degree of resident enjoying the urban green space.

Based on neighborhood level, the urban green can be described with two parameters, vegetation amount and proximity to green. Similarly, urban buildings neighborhood level can be described also with two parameters: building density and high building density.

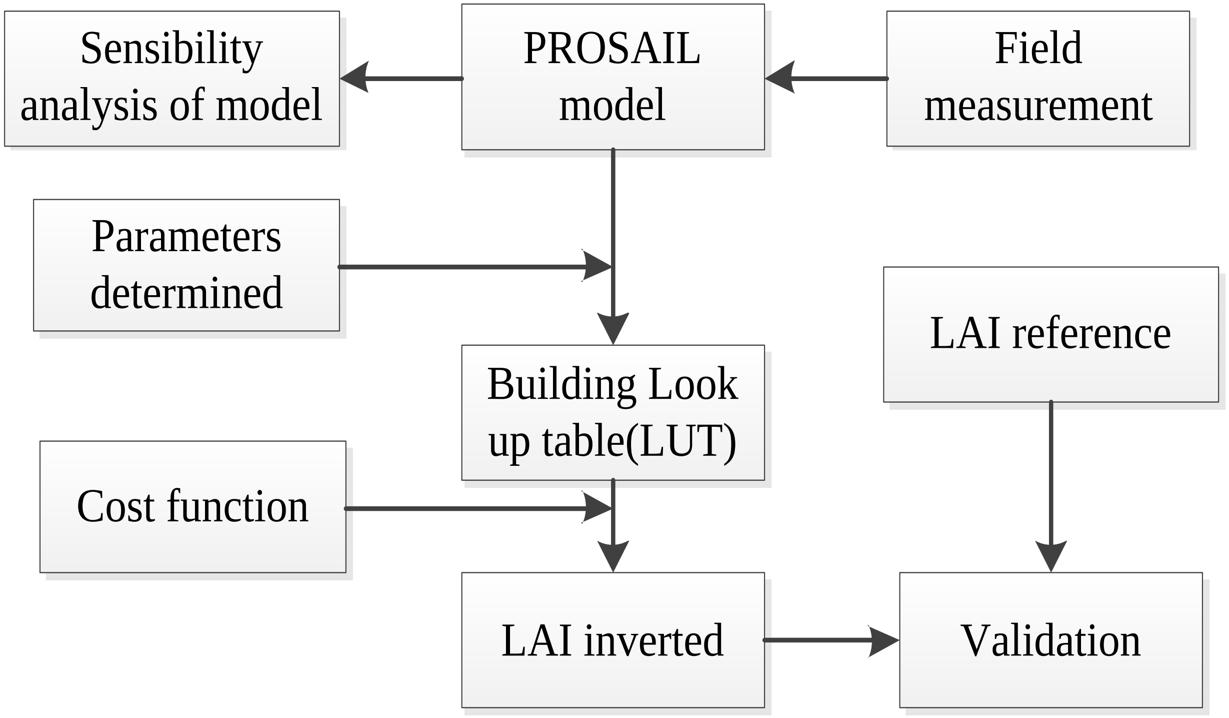
Buildings Neighboring Green Index



Buildings Neighboring Green Index

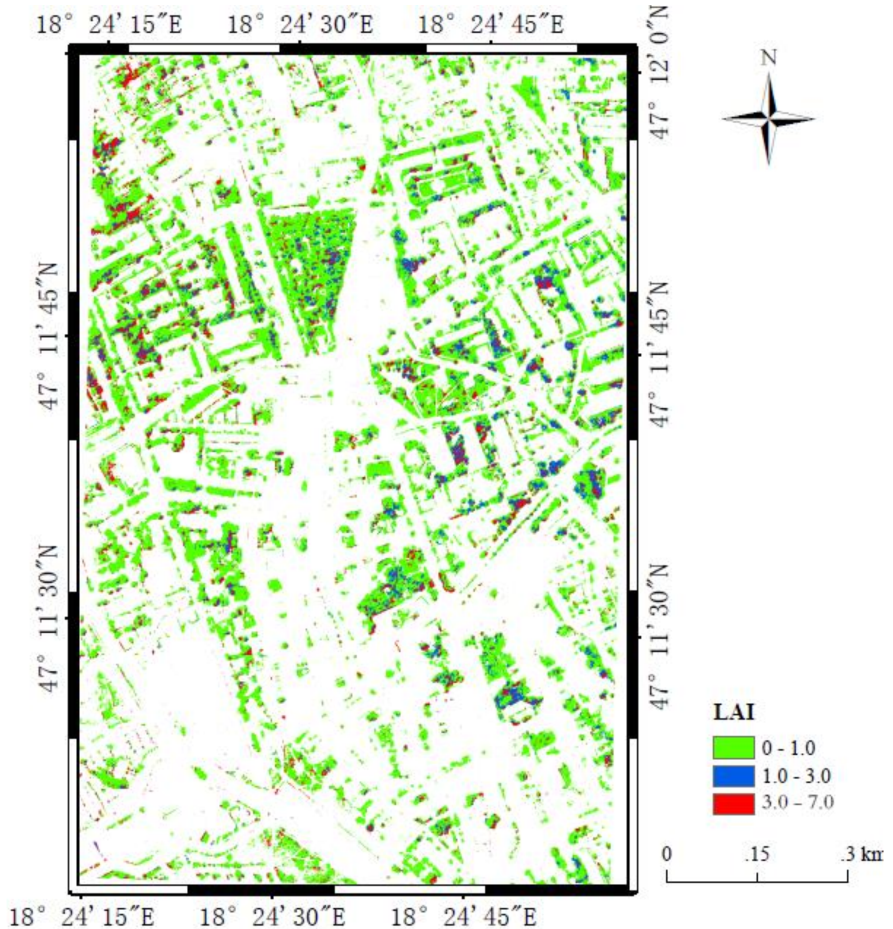
Leaf Area Index Retrieval

After sensibility analysis of PROSAIL model, and consulting LOPEX'93 (Leaf Optical Properties Experiment) data base and knowledge spectrum base of typical surface features, The LUT was built up and LAI was retrieved.



Buildings Neighboring Green Index

Leaf Area Index Retrieval



Leaf Area Index Retrieval Result in study area

Buildings Neighboring Green Index

Proximity to Green

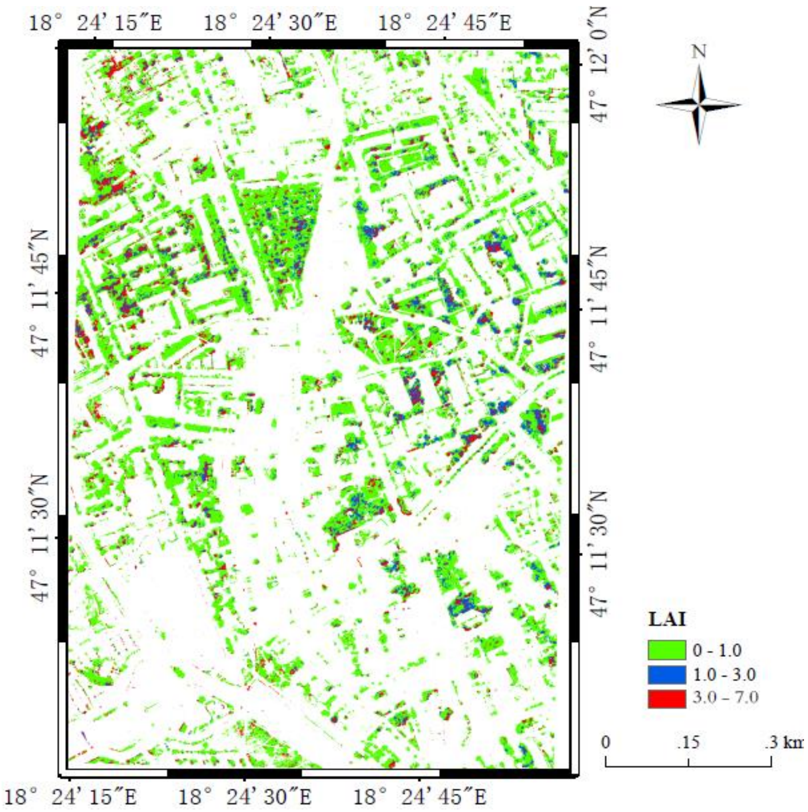
According to the LAI value, the vegetation was classified into different types. and the Degree of ecological Benefit Exposure to Vegetation （DBEV) were defined as the following.

$$\text{Proximity to green} = \sum_{j=1to3} W_j \times P_j$$

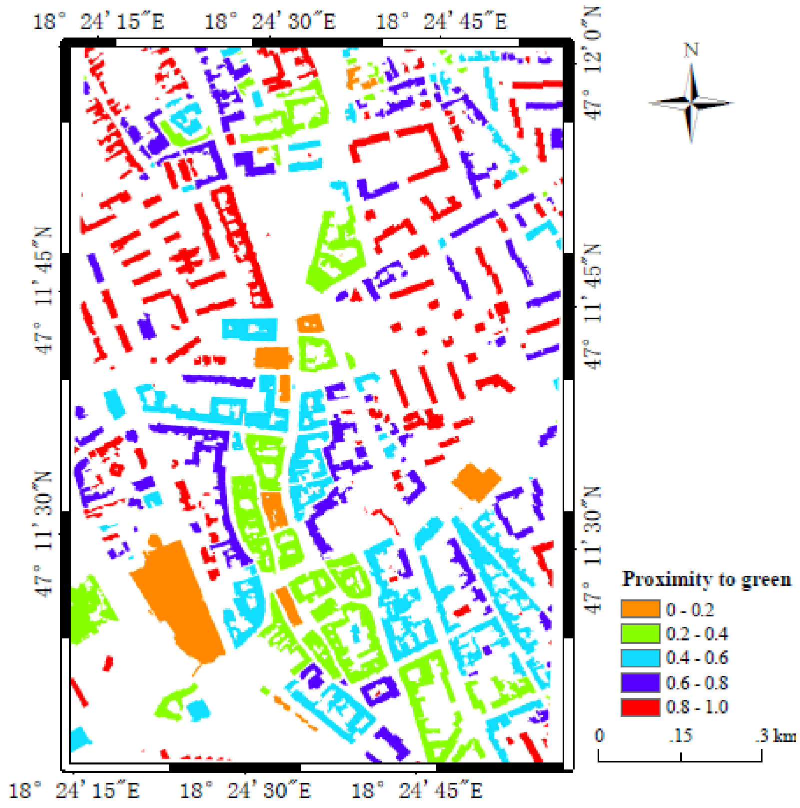
Where, Pj（j=1,2,3）is the ratio between gross area of exposure to different kind of vegetation type and area of buffer of single building. Wj is the weight of Pj.

Buildings Neighboring Green Index

Proximity to Green



Leaf area index in study area



Proximity to green in study area

Buildings Neighboring Green Index

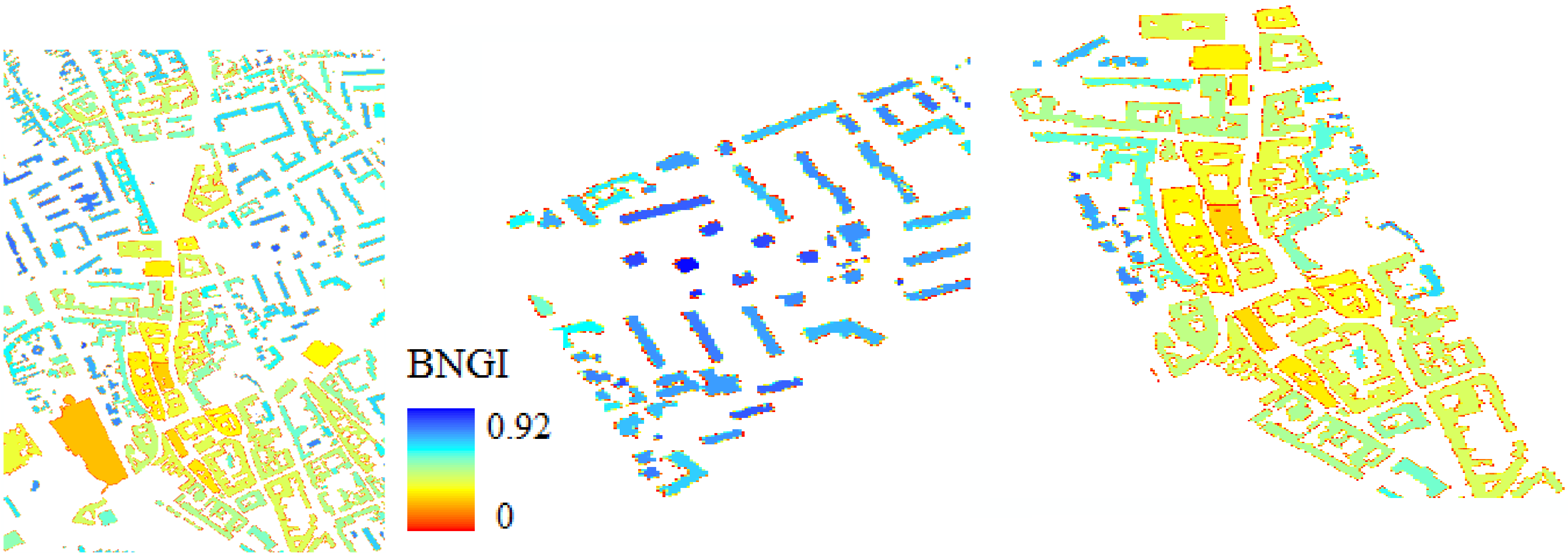
This study mainly considered four factors: green index, proximity to green, building density and high building density. Meanwhile, the weights of four factors are different.

$$BNGI = \sum_{j=1\ to\ 4}^{i=1\ to\ n} W_j \times P_{ij}$$

- **P_{ij} (j=1,2,3) represents the values of green index, proximity to green, building density and high building density respectively.**
- **Wj is the weight of P_{ij}, j represents four factors. i represents the relative single building.**

Buildings Neighboring Green Index

Validation of Buildings Neighboring Green Index



mixed-use district (test1) **Resident area (test2)** **Downtown (test3)**

Areas With Different Functions of Building

Buildings Neighboring Green Index

Validation of Buildings Neighboring Green Index

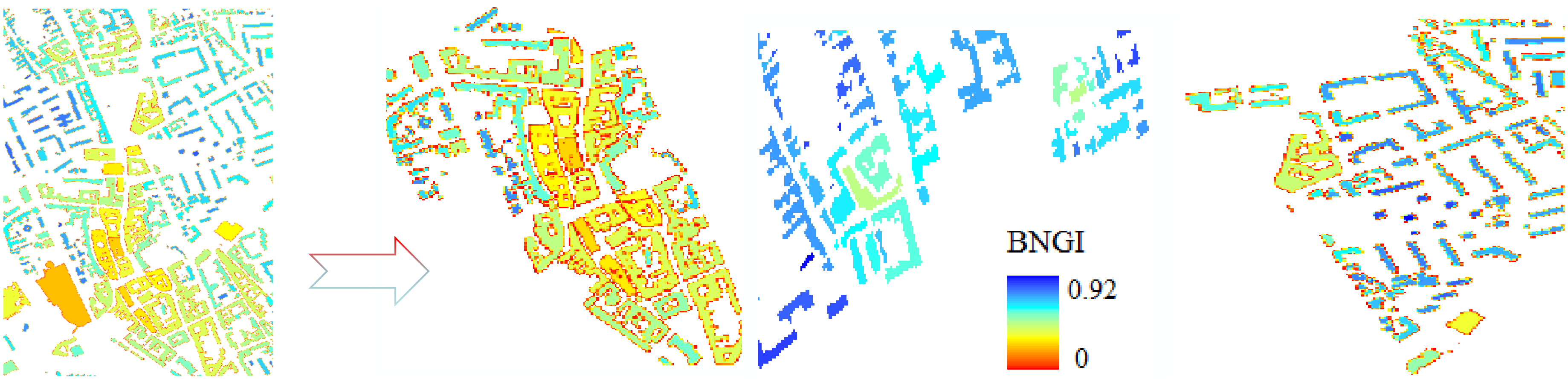
		BNGI	UGI
Test1	Mean	0.57	0.24
	SD	0.20	0.17
	Median	0.62	0.24
Test2	Mean	0.65	0.31
	SD	0.15	0.12
	Median	0.67	0.32
Test3	Mean	0.51	0.24
	SD	0.22	0.20
	Median	0.50	0.18

1、The SD value of resident area was lowest and the value of downtown was highest, which showed that the change of BNGI was most stable in resident area while least stable in downtown. It may be because of the uneven distribution of green in the area.

2、 The mean value and median value of BNGI in resident area were highest, which implied that people in the area enjoyed more green space and has high green space quality, while in the downtown the mean value and median value of BNGI were lowest.

Buildings Neighboring Green Index

Areas With Different Traits of Building Distribution



Study area in Székesfehérvár

High-rise and high density area test1

Low-rise and low density area test2

High-rise low density area test3

Buildings Neighboring Green Index

Areas With Different Traits of Building Distribution

		BNGI	UGI
Test1	Mean	0.55	0.25
	SD	0.21	0.19
	Median	0.59	0.23
Test2	Mean	0.63	0.25
	SD	0.15	0.13
	Median	0.66	0.26
Test3	Mean	0.59	0.25
	SD	0.19	0.14
	Median	0.65	0.26

1、In high building high density area (test1), mean value and median value of were lowest, and standard deviation of BNGI was highest，it showed that the resident in the area enjoying least green space;

2、In three different areas of city, the value of BNGI is not equal when the value of UGI is same, So BNGI showed more practical, which took more factors into account, including green distribution and building distribution.

Buildings Neighboring Green Index

Areas With Different Distribution of BNGI and UGI

Different statistics in various neighborhoods

Index type	High building low density（n=117）		Low building high density（n=72）		High building high density（n=86）	
	BNGI	GI	BNGI	GI	BNGI	GI
[0,0.25]	0	41.03%	0	44.29%	1.16%	51.16%
(0.25,0.5]	9.40%	55.56%	8.33%	51.43%	29.07%	36.05%
(0.5,0.75]	80.34%	3.42%	73.61%	4.29%	54.65%	11.63%
(0.75,1]	10.26%	0.01%	18.06%	0.01%	15.12%	1.16%
Total	100%	100%	100%	100%	100%	100%

It is found that BNGI was more practical and reliable. Unlike the distribution of BNGI and GI in the high building/low density and low building/ high density area, the gap of the proportion between BNGI and GI in （0, 0.5）decreased obviously. So conclusion can be drawn that BNGI consider more factors including building distribution and was more practical.

Multi-Perspective Urban Green Perceiving

1. Building Oriented Urban Green Perceiving
2. Floor Oriented Urban Green Perceiving
3. Street Oriented Urban Green Perceiving

Floor Oriented Urban Green Perceiving

- Rapid urbanization isolates people from natural scenes.
- Urban vertical greening has become a fashion and development trend.

Floor Oriented Urban Green Perceiving

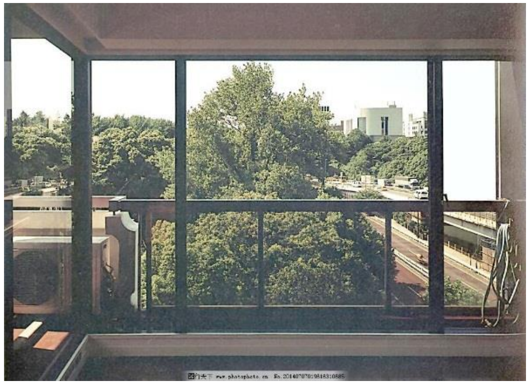
Exposure Opportunity Index，EOI

How to quantitatively evaluate vertical greening?

How to measure the perception of green space from different floors?

(exposure opportunity index，EOI)

Low floor



Middle floor

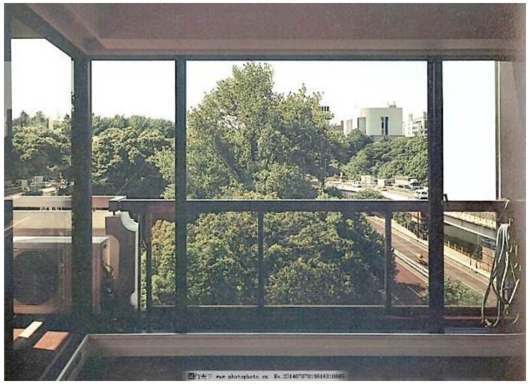
High floor

Floor Oriented Urban Green Perceiving

Exposure Opportunity Index，EOI

- To assess the exposure opportunity level of different floors.
- The three-dimensional spatial relationship between the building floor and surrounding green space is considered.
- Studies have shown that EOI can assess residents' perception of greenness indoors and is expected to become an effective indicator of urban garden planning and residential comfort assessment.

Low floor



Middle floor

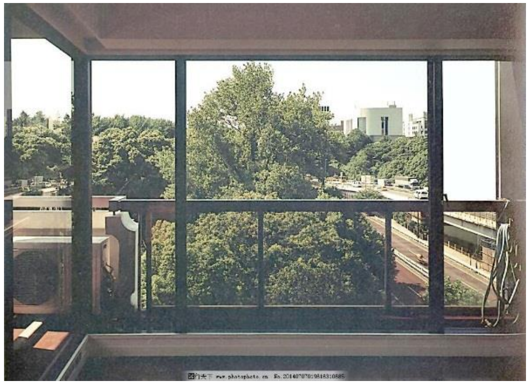
High floor

3. Research Method

Exposure Opportunity Index Model ——Calculation results of urban green radiation benefits

Aiming at urban residents' perception of greenness indoors, a new index, Green Exposure Index (EOI), was proposed to assess the level of urban greenness opening at different floors. The index takes into account the three-dimensional spatial relationship between the building floor and the surrounding green space.

Low floor



Middle floor

high floor

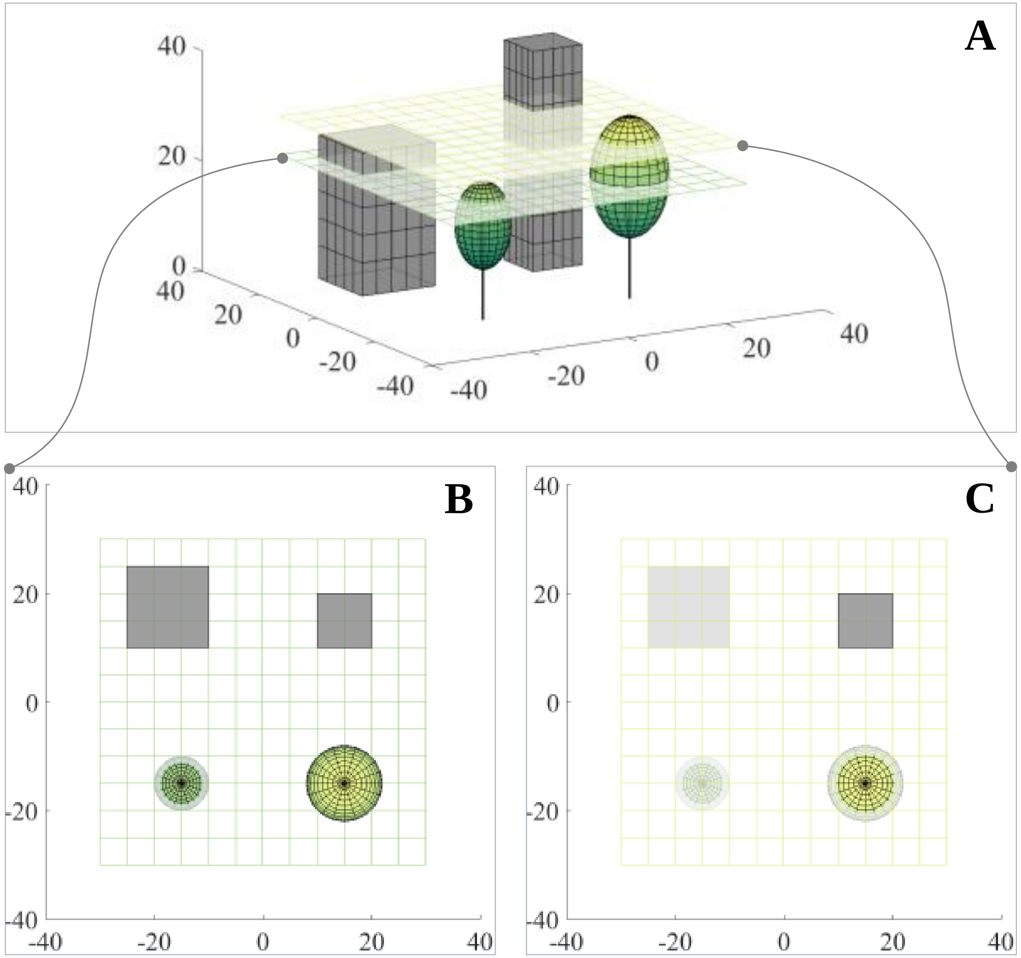
3. Research Method

Hierarchical Urban Landscape Model

The hierarchical urban landscape consists of a vertically upward cross section of the urban features.

By cutting these three-dimensional objects and projecting them onto the ground and several parallel planes, a hierarchical view of the position of the three-dimensional objects on different levels can be obtained.

Figure (A) shows how to stratify the landscape. Figure (B) and Figure (C) show the circular cross section of the canopy and the rectangular cross section of the building, respectively.



Demonstration of hierarchical urban landscape

3. Research Method

Construction of Exposure Opportunity Index

The perception of greenness space is positively related to proximity and greenness, so floor-level greenness perception is evaluated based on two factors:

Average distance between adjacent buildings in the study area

(inverse distance weighted, IDW)

a) Horizontal distance between floor location and surrounding green space within a fixed 30-meter buffer zone

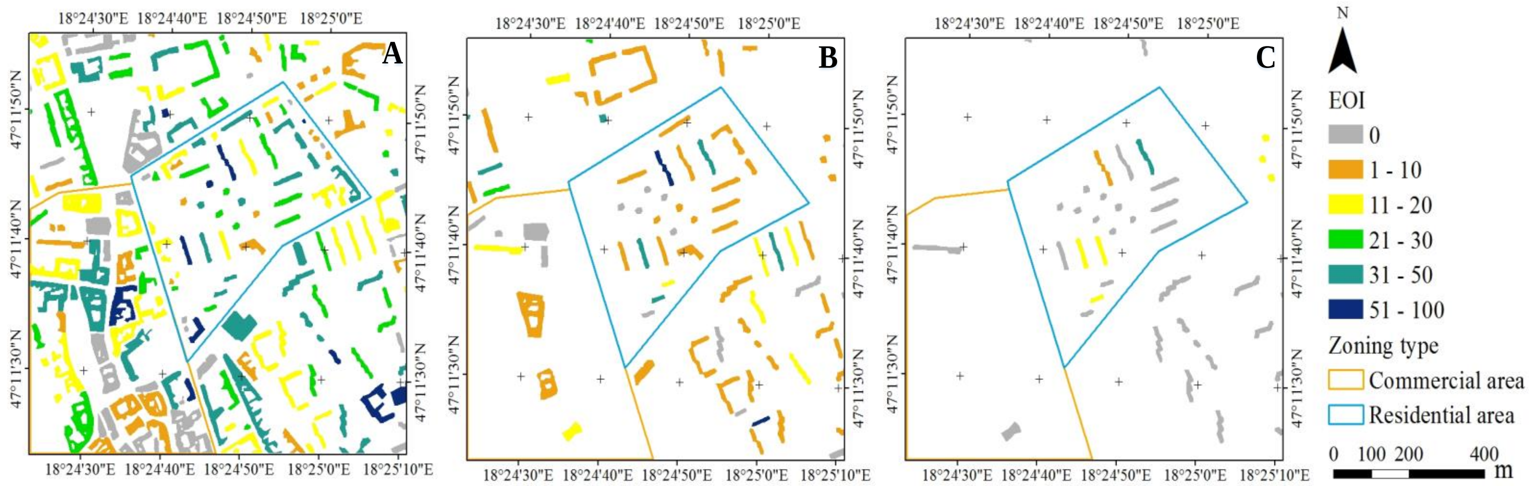
b) Cross-sectional area of each canopy at each floor height

$$\mathrm{EOI} = \sum_{i=1}^{n} \left(\frac{A_i}{d_i}\right) \Bigg/ \sum_{i=1}^{n} \left(\frac{1}{d_i}\right)$$

where A_i is cross sectional area of the ith canopy within a buffer zone, and d_i is Euclidean distance between the ith canopy and a given storey. The IDW function was repeated for each floor of the hierarchy urban landscapes and greater value indicated higher exposure opportunity.

4. Results and Analysis

EOI Calculation Results



EOI Calculation Results of the 3rd floor (a), the 5th floor (b), and the 7th floor (c).

The 3rd Floor： 90.9% of residential areas will be exposed to a certain amount of adjacent green space, while only 72% of commercial areas indicate that three-story residential buildings tend to have a better green environment than commercial buildings.

The 5th Floor： About 20% of people have difficulty perceiving the surrounding greenness, and 40.7% of them have an EOI index value below 15. This is caused by the sparse and uneven distribution of green space near high floors.

The 7th Floor： People who live in above the seventh floor have a 4.2-fold reduced chance of being surrounded by trees. This means that the scenery seen through the window feels less 'green'.

Meng, QY ;Chen,Xu et al. Exposure Opportunity Index Measuring People Perceiving Greenery at Floor level Effectively. Earth science informatics. DOI: 10.1007/s12145-019-00410-2

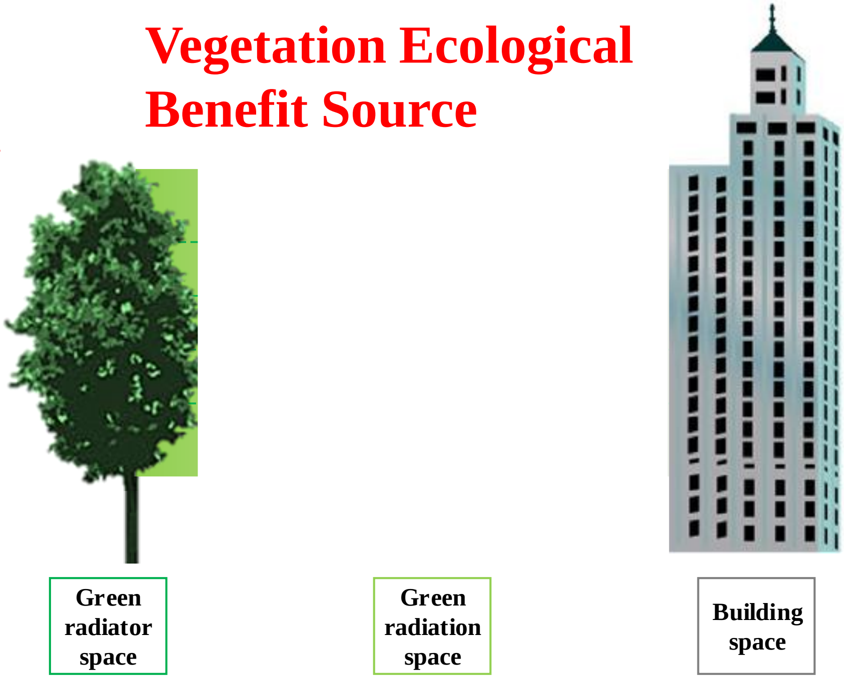
Floor Oriented Urban Green Perceiving

Green Radiation Benefit Model

Ecological Studies Show:

- The cooling and humidifying effect of green space is positively correlated with the amount of green.
- Leaf area index is an important parameter determining canopy transpiration.
- The vertical structure of green space has an impact on the ecological effect of green space.

——Construction of Vegetation Ecological Benefit Source



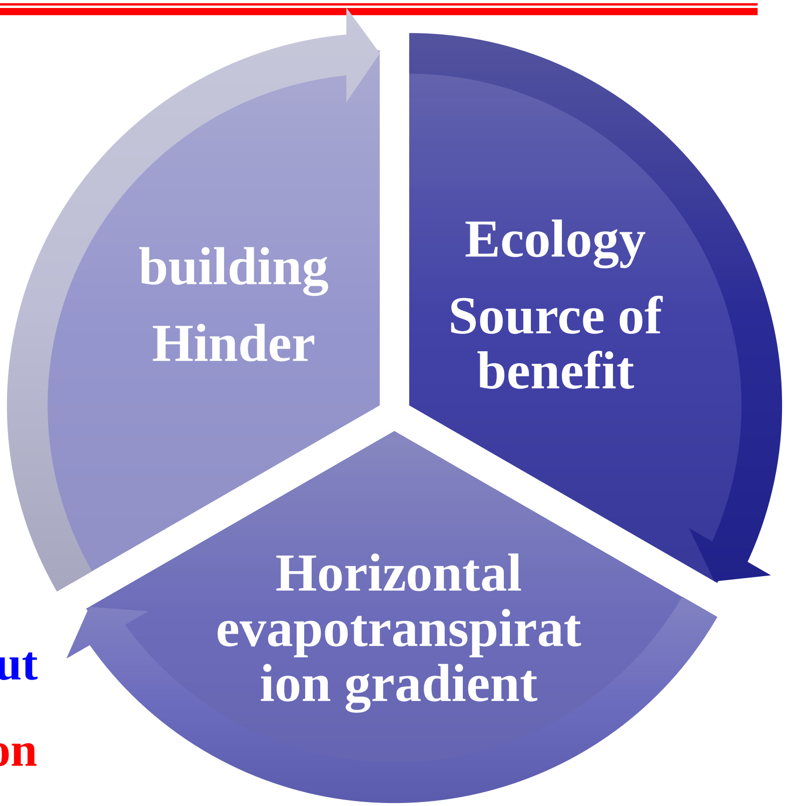
Existing Research Basis:

- Recognition of standing tree and extraction of canopy structure information.
- Correlation analysis between canopy spatial structure and ecological factors.
- LiDAR technology provides new perspectives for quantification of vertical canopy structure.

Floor Oriented Urban Green Perceiving

Green Radiation Benefit Model

- **The model to simulate the evapotranspiration effect of vegetation was established to describe the content and distribution scale of green radiation benefits in different buffer areas.**
- **The model includes three basic input parameters: sources of ecological benefits, diffusion gradients, and obstacles.**

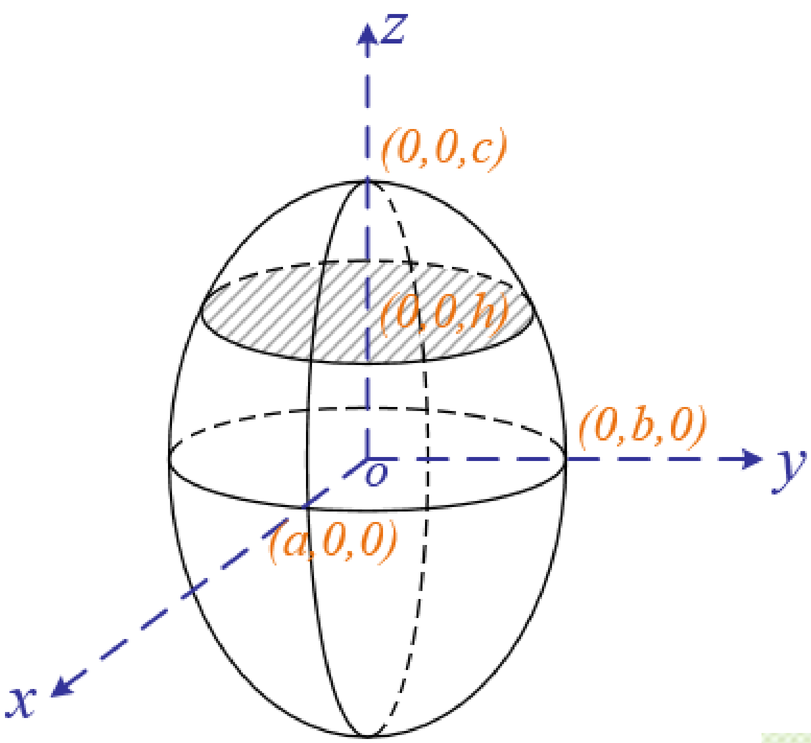


$$\begin{cases} X_i = LAI_{(h)} \cdot \rho_i & (i = 1) \\ X_{i+1} = \left(LAI_{(h)} - X_i\right) \cdot \rho_{i+1} & (2 \le i \le 5) \end{cases}$$

X represents the green radiation benefit within the buffer distance of the i layer (the buffer distance is 2m), LAI(h) represents the total LAI of the height layer, p represents the vegetation horizontal evapotranspiration gradient of the buffer distance of the i layer.

Floor Oriented Urban Green Perceiving

Green Radiation Benefit Model ——Green Space Index



- Calculus Theorem
- Green Space Index
- Obtain The Amount Of Leaf Area At Different Heights Of The Canopy

$$LAI_{(h)} = LAI \cdot \frac{S'_{(h)}}{V'} = LAI \cdot \frac{4(c^2 - h^2)}{3c^3}$$

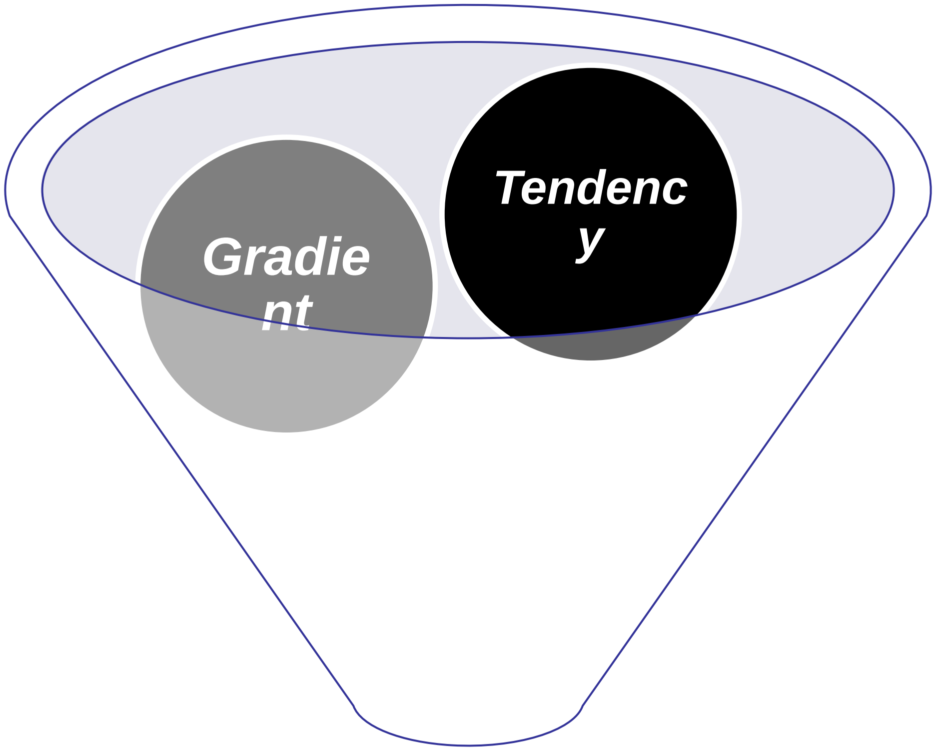
Green Space Radiation

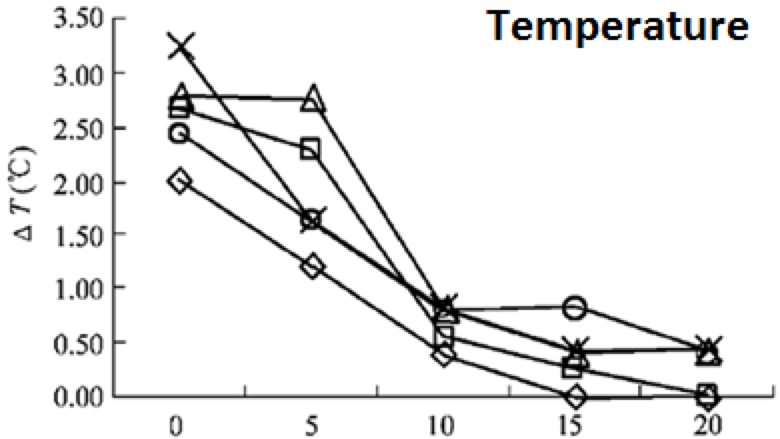
Humidifying

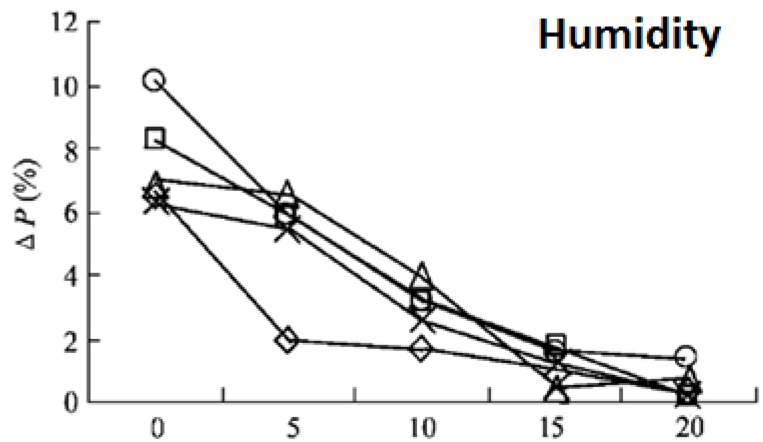
Cooling

Ecological Benefits Releaser + Green Space Radiation = Urban Green Space

Evapotranspiration Model







$$\begin{cases} X_i = LAI_{(h)} \cdot \rho_i & (i = 1) \\ X_{i+1} = \left(LAI_{(h)} - X_i\right) \cdot \rho_{i+1} & (2 \le i \le 5) \end{cases}$$

Floor Oriented Urban Green Perceiving

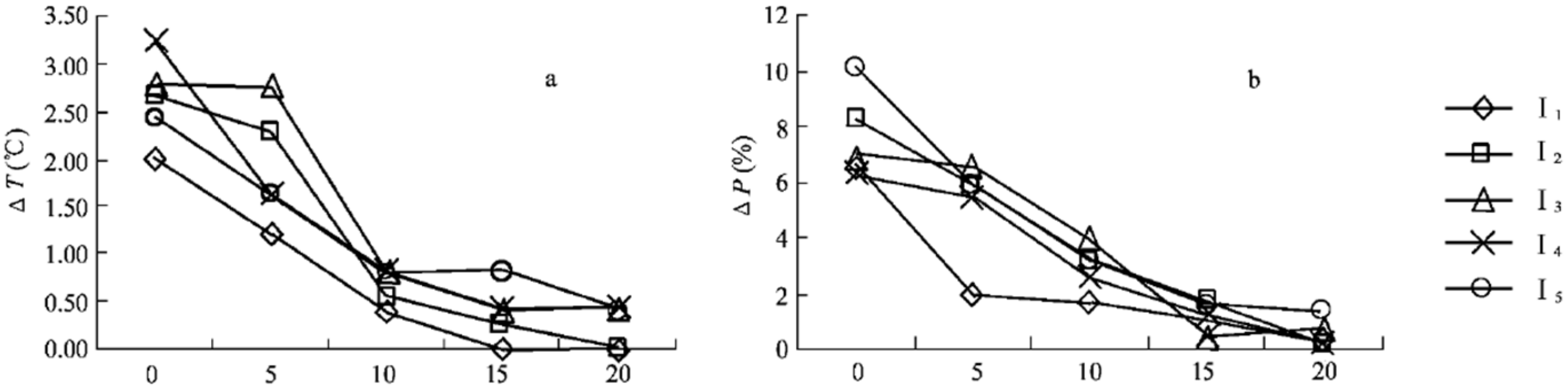
Green Radiation Benefit Model

——Estimation of vegetation horizontal evapotranspiration

Related Research Shows:

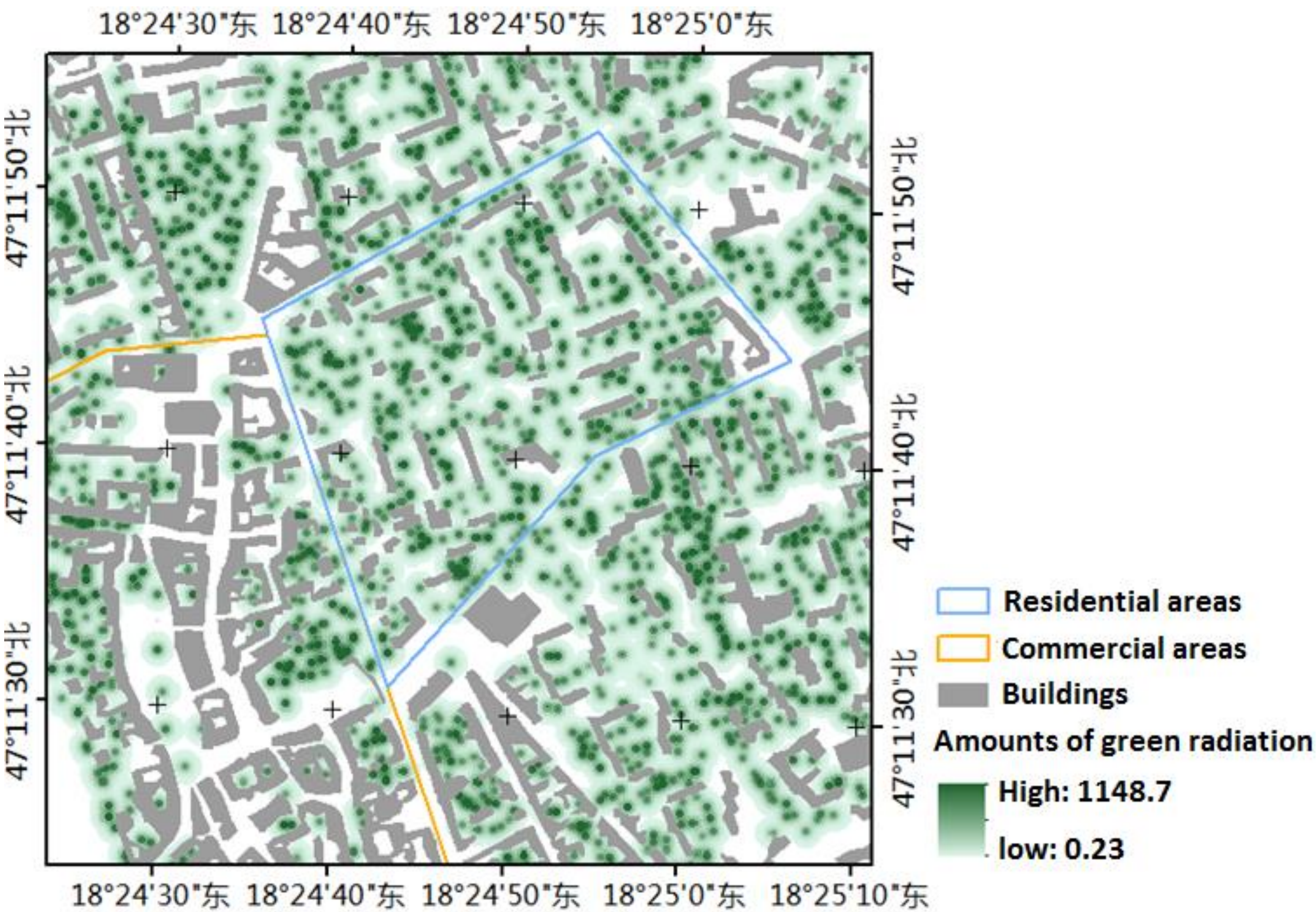
As the distance increases in the horizontal direction, the transport capacity of wet and cold air will decrease.

The positive effects of evapotranspiration on the surrounding environment will spread to 15 meters from the forest land, and the cooling and humidifying effect at 20 meters is not obvious.



* Image source: Wu Xiaogang et al. Correlation between cooling and humidifying effects of urban green space and its structural characteristics.

Green Space Radiation Computation

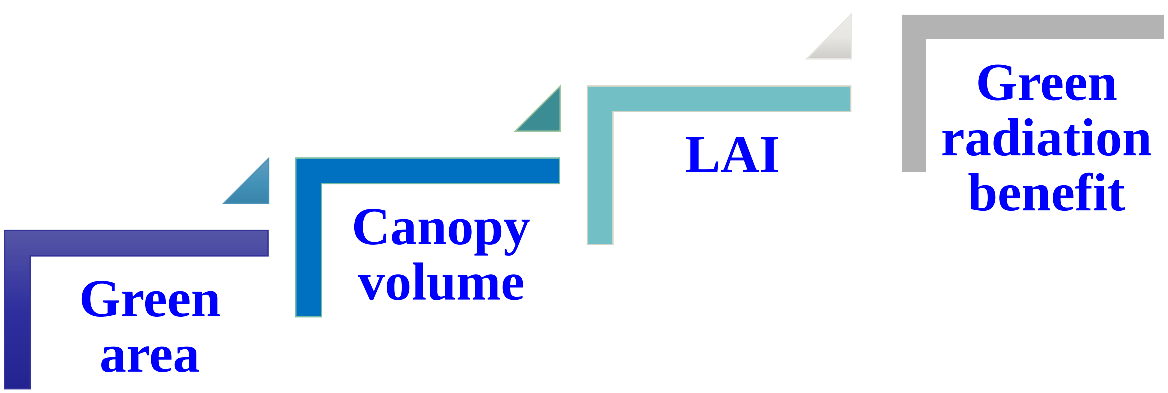


Floor Oriented Urban Green Perceiving

Green Radiation Benefit Model

——Comparison of Calculation Results of Different Green Space Indexes

region	Green area/m^2	Canopy volume/m^3	LAI	Green radiation benefit
Residential area	11594	45462.15	19475.18	2308050.81
	5.74%	0.75%	—	38.11%
Business district	8750	39984.94	12932.72	1530434.92
	3.64%	0.55%	—	21.19%

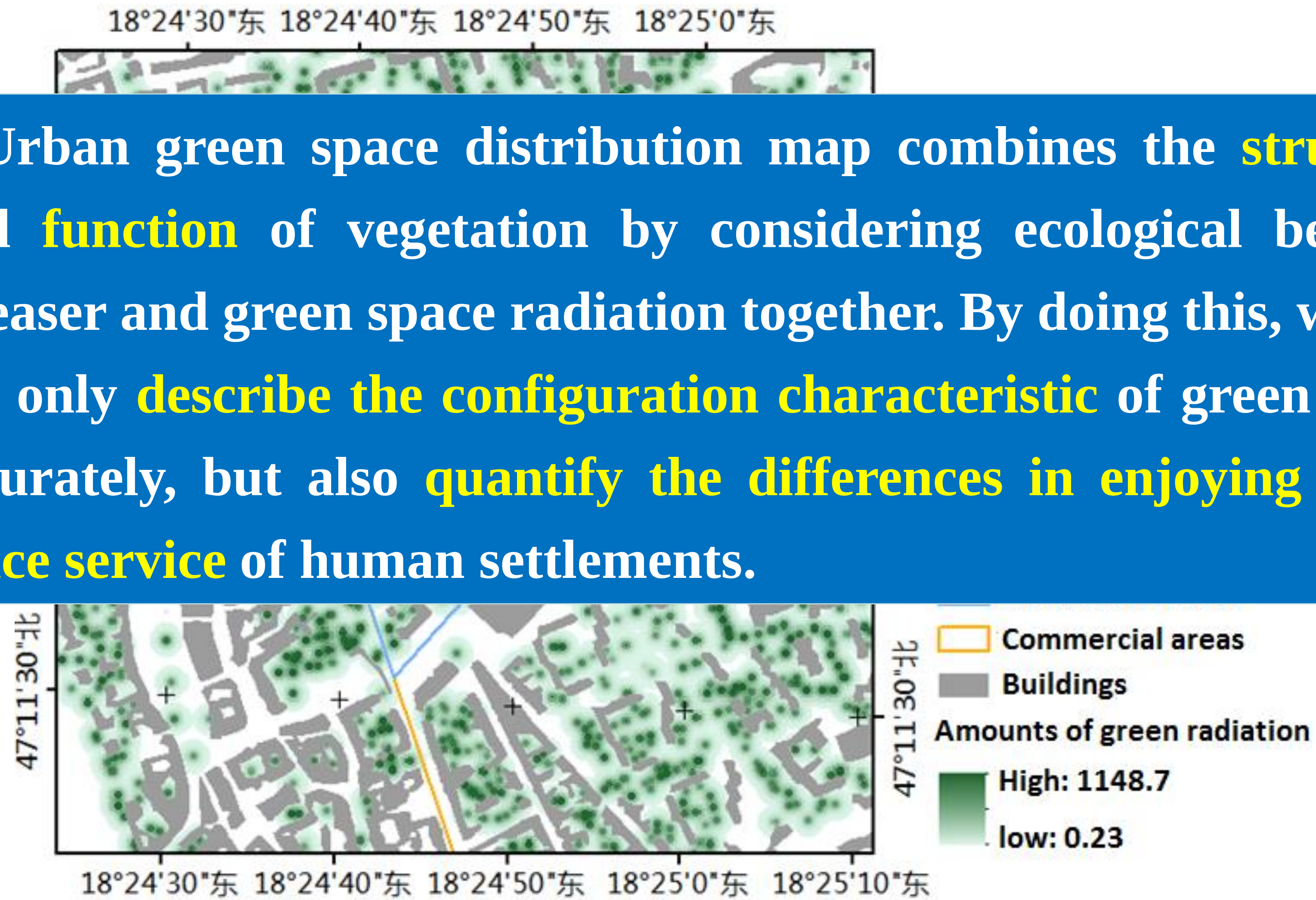


Floor Oriented Urban Green Perceiving

Green Radiation Benefit Model

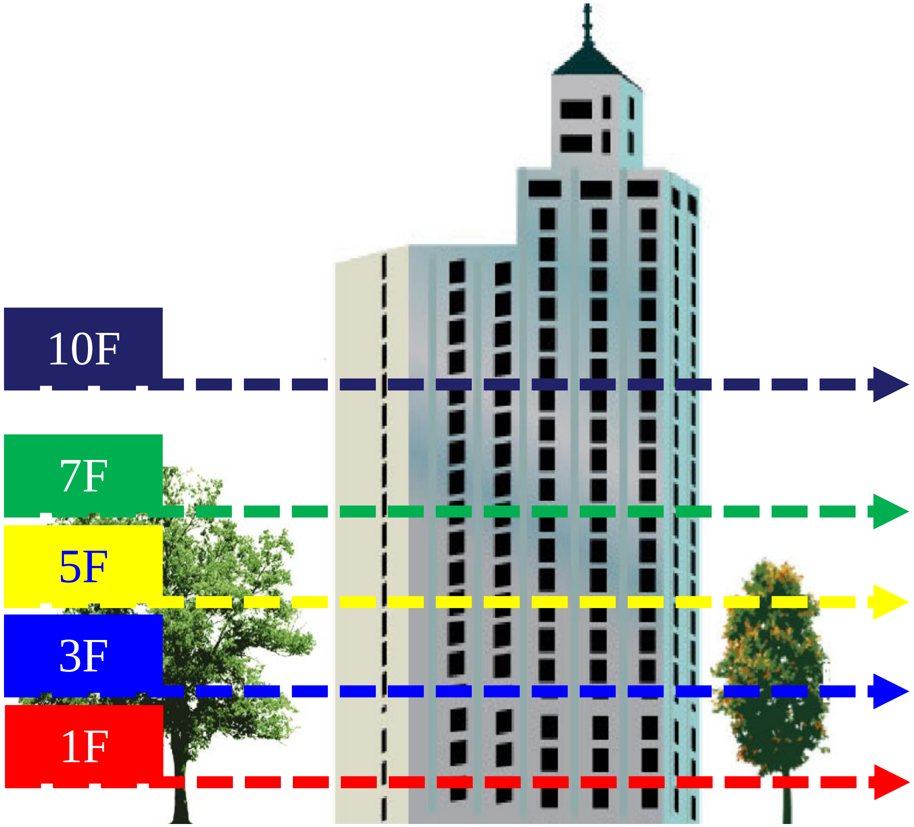
——Calculation Results of Urban Green Radiation Benefits

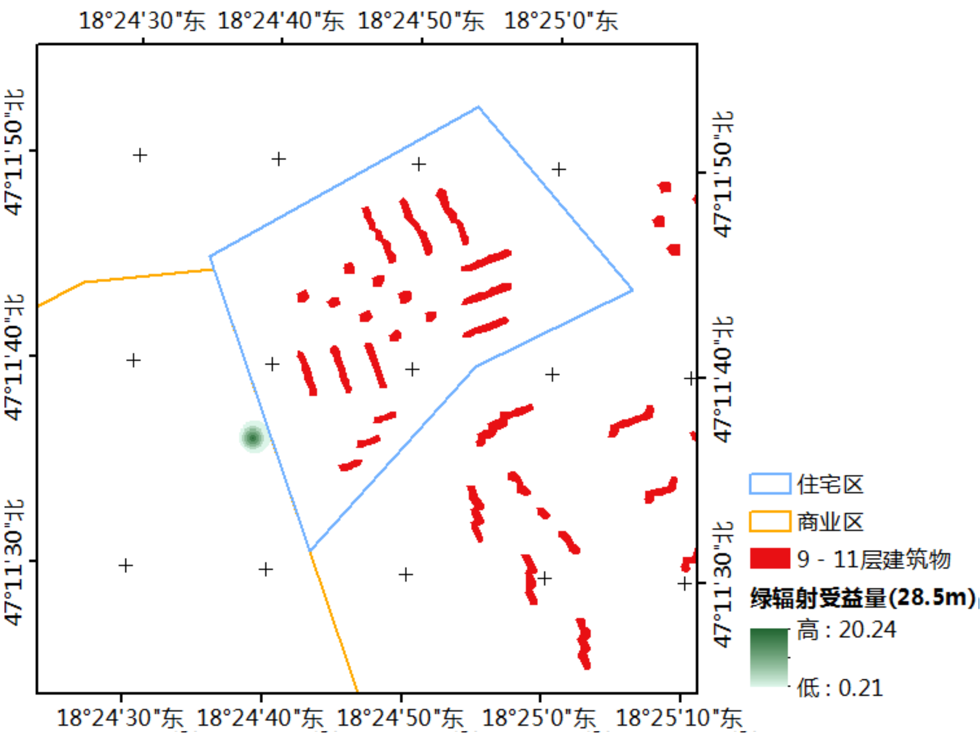
Urban green space distribution map combines the structure and function of vegetation by considering ecological benefits releaser and green space radiation together. By doing this, we can not only describe the configuration characteristic of green space accurately, but also quantify the differences in enjoying green space service of human settlements.



Floor Oriented Urban Green Perceiving

Choose typical floor heights （1F、3F、5F、7F、10F） and discover their horizontal distribution characteristic of UGS correspondingly





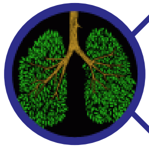
Green space radiation computation of different height of layers provides a quantitative method to describe urban green space layout and potential ecological space. Height dimension expand the concept of urban green and also reveal the blind spots of urban planning effectively due to the lack of knowledge.

Multi-Perspective Urban Green Perceiving

1. **Building Oriented Urban Green Perceiving**
2. **Floor Oriented Urban Green Perceiving**
3. **Street Oriented Urban Green Perceiving**

Street-scale urban green space perception

Street Tree is a kind of natural corridor network with ecological attribute, which is distributed in urban interior and Road neighborhood.



an important part of urban ecosystem

Ecological value

The main visual elements of street green landscape

Perspective value

Determine the success or failure of livable construction of urban living environment

Public service value

It is very important and urgent to measure and evaluate the street green environment from all directions and multiple perspectives!

Street-scale urban green space perception

Benefits Of Sidewalk Greening

Which street is more walkable?

Varies street greenery distribution

Evidence: **a more visible street greenery to people can generate stronger enjoyable feelings than a less visible street greenery.**

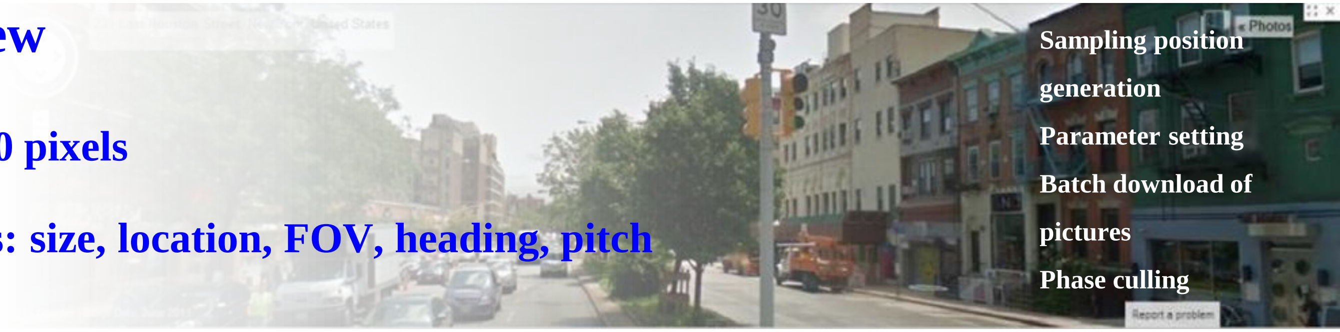
Street-scale urban green space perception

Data Source and Reprocessing

- **Google Street View**

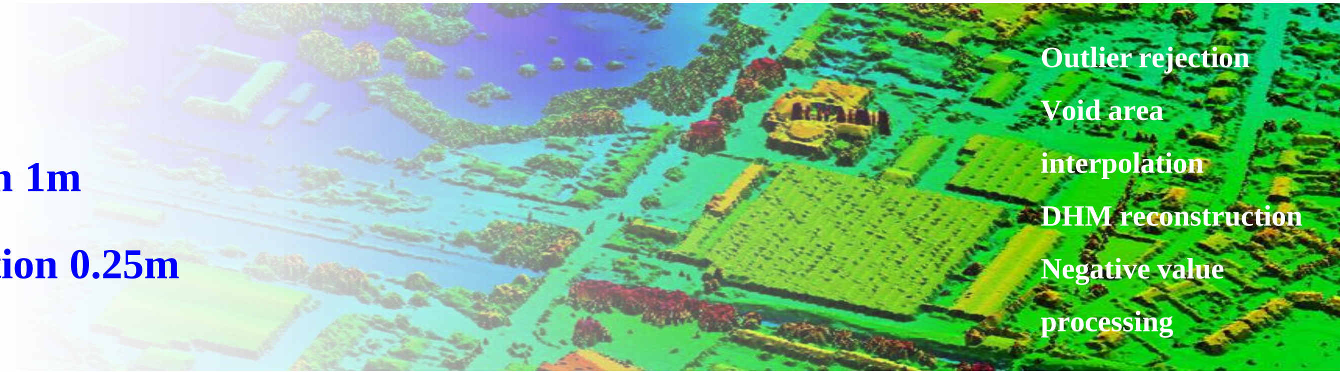
  Format: 300 × 200 pixels

  parameter settings: size, location, FOV, heading, pitch



Sampling position generation
Parameter setting
Batch download of pictures
Phase culling

- **LiDAR**
  - **Spatial resolution 1m**
  - **Elevation resolution 0.25m**



Outlier rejection
Void area interpolation
DHM reconstruction
Negative value processing

- **Aerial Imagery**

  Spatial resolution 0.5m

  Include band R, G, B, NIR

Orthorectification
Image mosaic
Area cropping

Street-scale urban green space perception

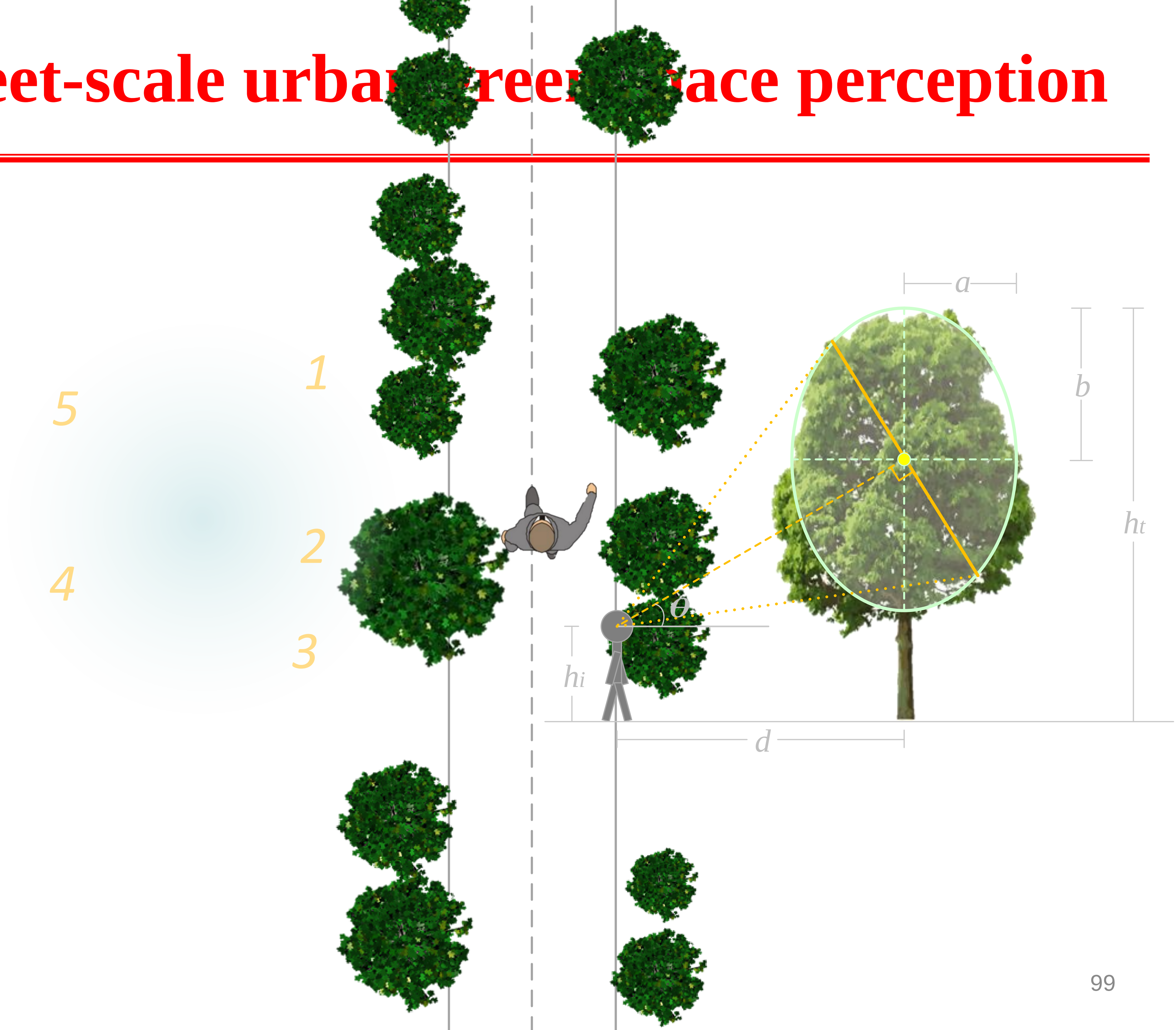
Definition of *Green Visible Area*

Green area of sidewalk trees

Refers to how much green the pedestrian trees can see from the street trees

green view index(qualitative)	Green Visible area (Quantitative)
Calculate the proportion of the green area of the sidewalk tree within the pedestrian's normal field of vision	Calculate the sum of the green visible area of the sidewalk tree that can be captured from the pedestrian perspective
Calculation method: pixel number ratio	Calculation method: visual scene restoration
Unit: Percent (%)	Unit: square meters (m^2)
Data source: street view, real photo	Data source: Airborne LiDAR

Street-scale urban green space perception

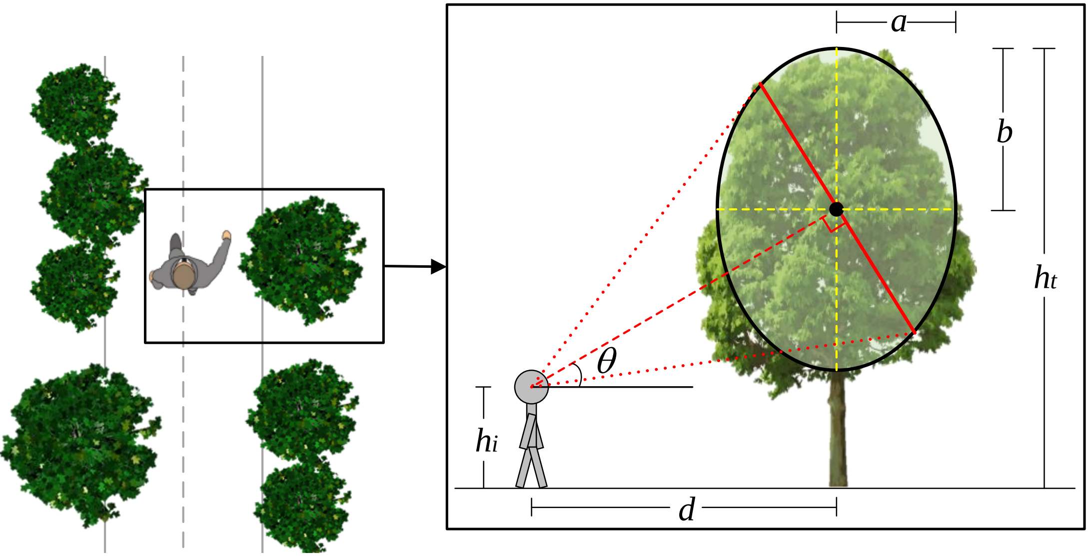


Street-scale urban green space perception

Green Visible Area Calculation

By geometric calculation of the spatial position relationship between the sample points and the visible street trees, the visual scene transformation from the 'ellipsoid' canopy to the ' elliptic surface ' green visible area is realized

$$S = k\pi ab$$



Distorted crown length *b*:

$$b = \sqrt{\frac{a^2b^2}{a^2cos^2\theta + b^2sin^2\theta}}$$

Elevation of line of sight *θ*:

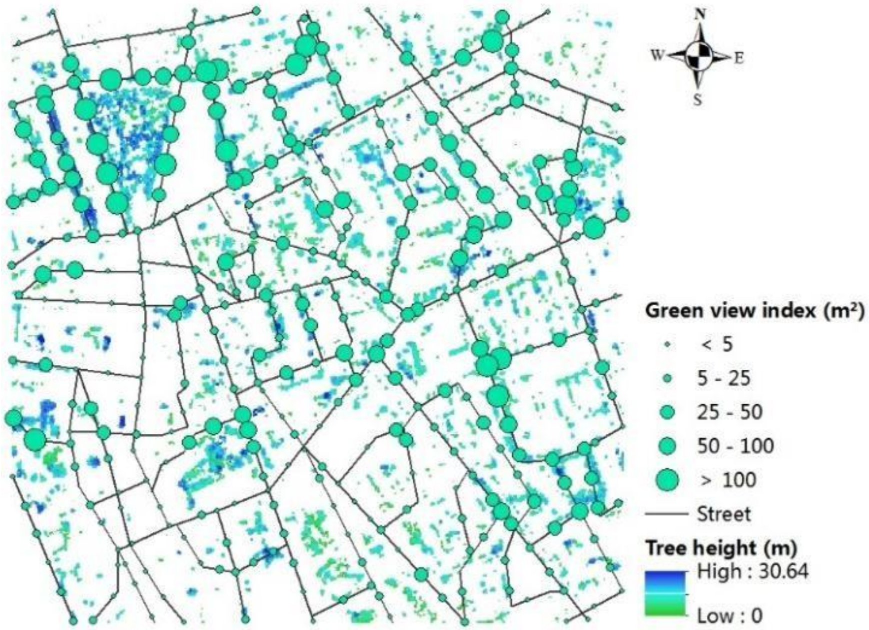
$$\theta = arctan\frac{(h_t - b - h_i)}{d}$$

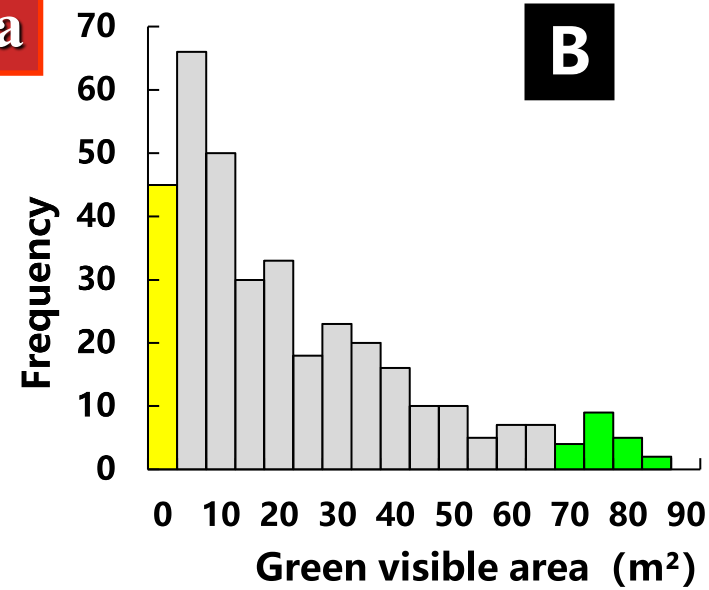
zoom coefficient *k* （0~1）：

$$k = \frac{1}{90^\circ}arctan\left(\frac{a}{\sqrt{(h_t - b - h_i)^2 + d^2}}\right)$$

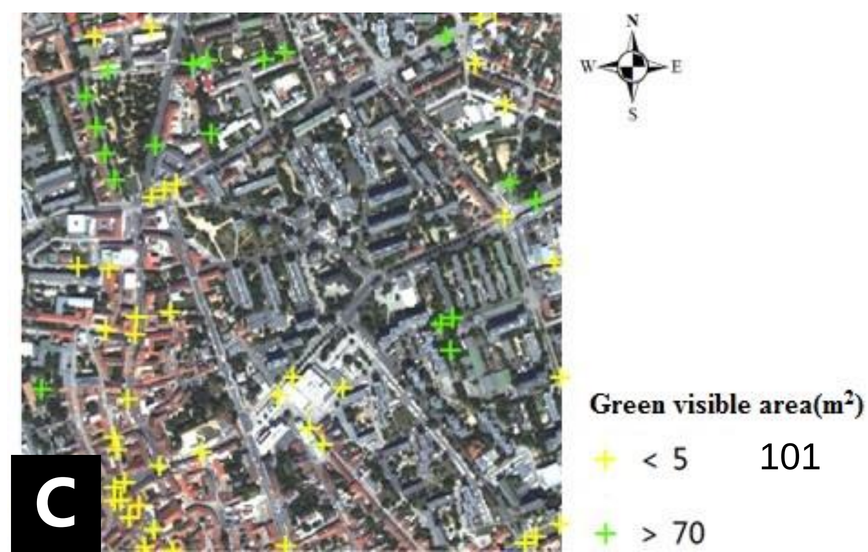
Street-scale urban green space perception

Calculation Results of Green Visible Area





A



A Green visible area map

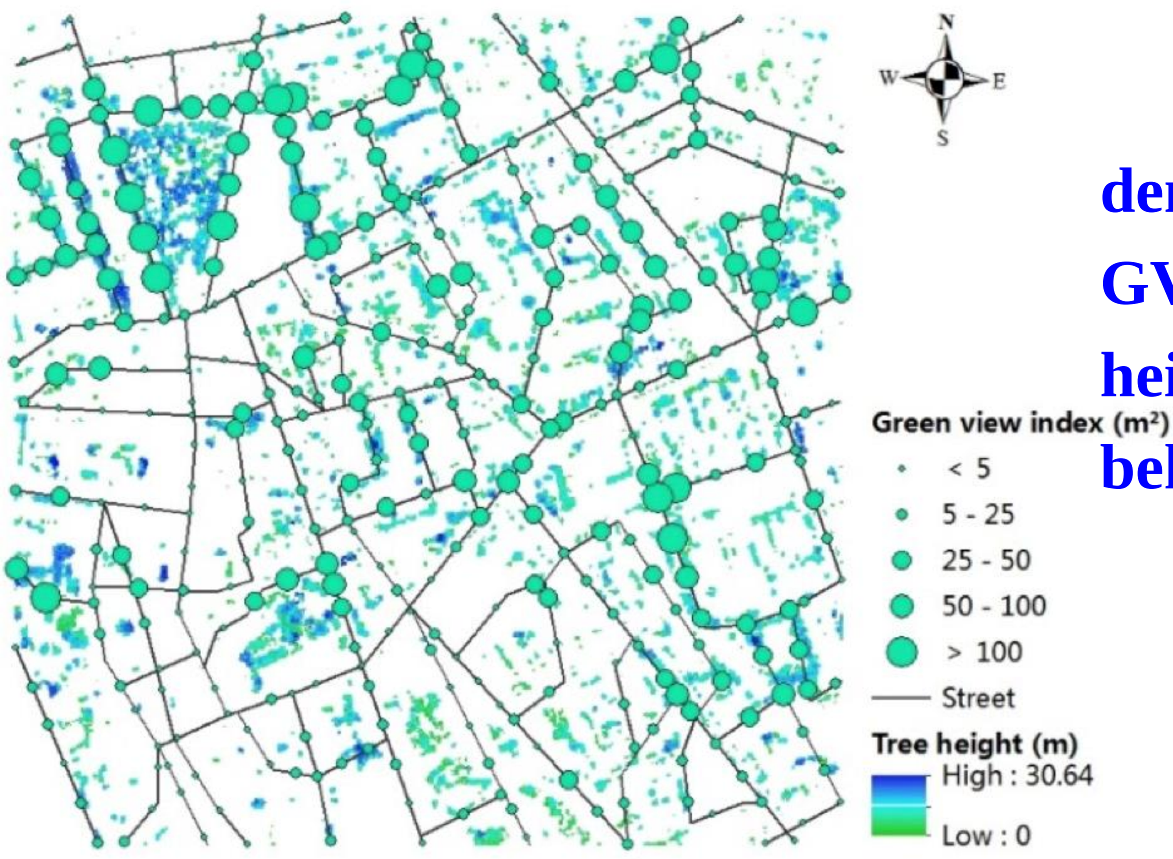
B Frequency distribution histogram of green visible area

C Sampling points location of high(low) value

What Can We Learn from The Map ?

GVI Map

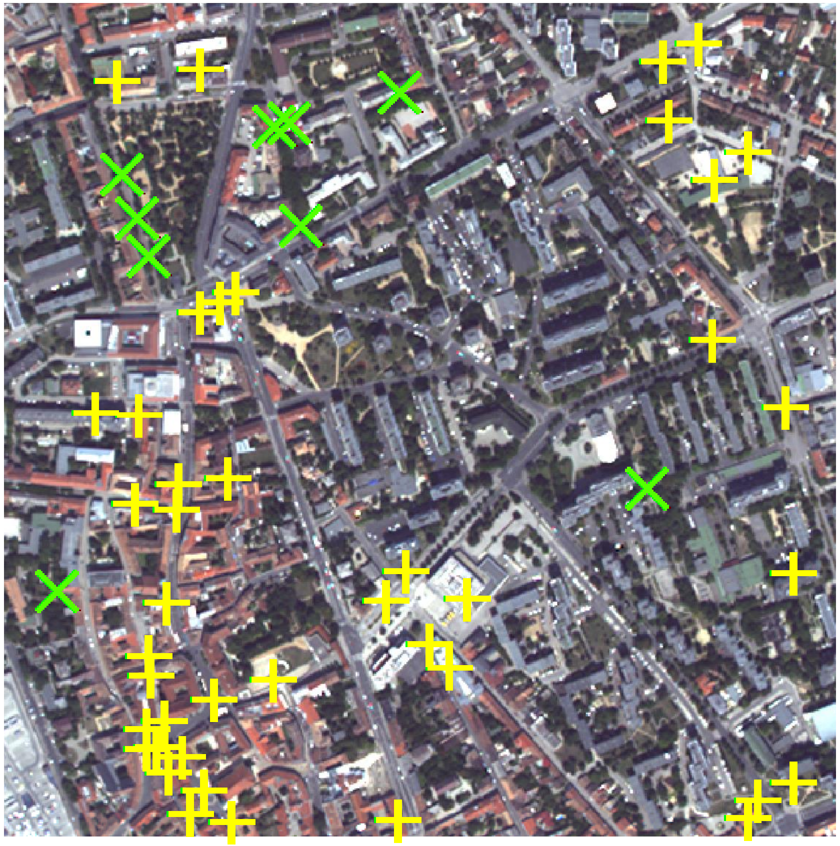
This picture shows the calculation results of 360 sample sites in the study area.

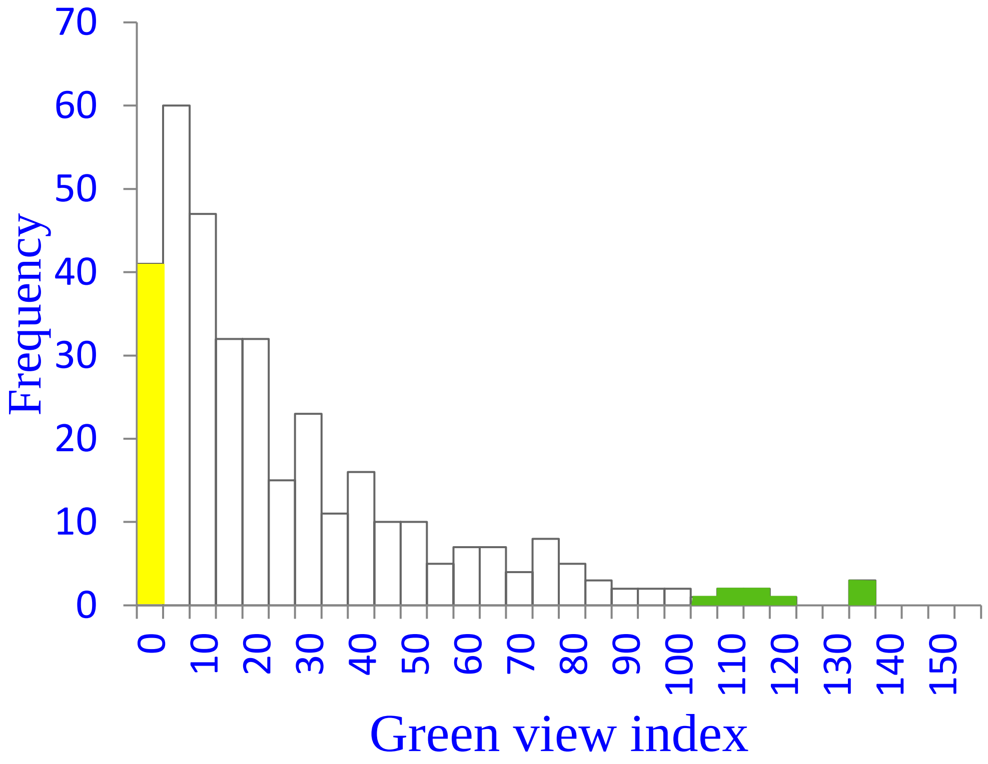


Different dot sizes denote the magnitudes of GVI values with the tree height map rendering behind.

Greener or Greyer ?

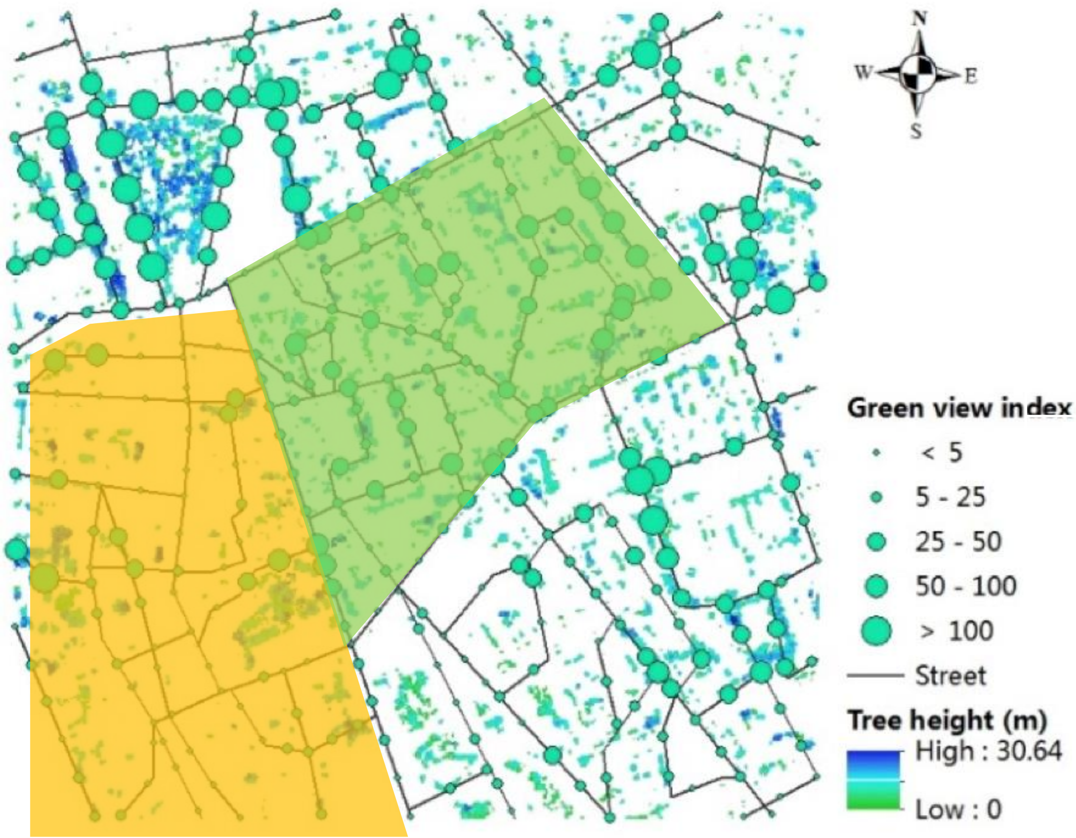
By selecting those GVI values greater than 100, we can easily identify the locations that may look greener in the eyes of citizens.





Street-scale urban green space perception

Conclusion: Pedestrians are more likely to enjoy a 'greener' walking experience in residential area than the commercial area.



	Residential area	Commercial area
Mean	27.33	12.66
Std.	22.72	26.76
GVI per m	0.67	0.23
Green_N	12	4
Grey_N	3	23

Street-scale urban green space perception

Walk Experience Visualization

Advantages of the method

- **A *quantitative* approach.**
- **Most of the processes can be done *automatically*.**
- **Time-saving.**

ZHANG Jiahui, MENG Qingyan*, SUN Yunxiao, et.al. Study on Urban Green View Index[J]. Journal of Geo-information Science, 2017, 19(6): 838-845.

MENG Qingyan*, WANG Xuemiao, SUN Yunxiao, et.al. Construction of green view index model based on street view data and research on its influence factors. Ecological Science， 2020(1):148-157

Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

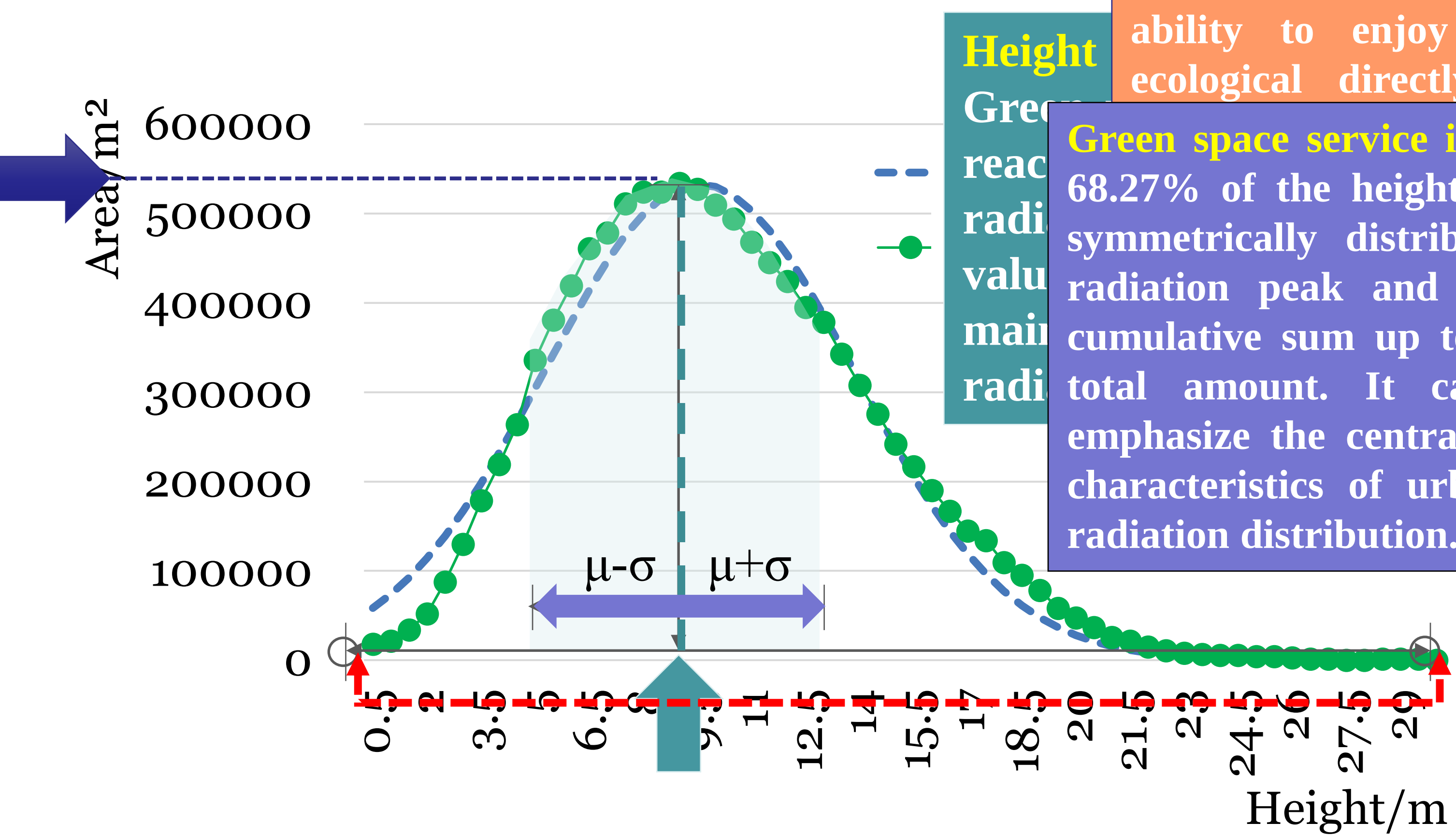
3D Configuration Curve of UGS

With the acceleration of urbanization, the contradiction between urban residential construction and allocation of green space resources has become increasingly prominent, and it is especially important to properly plan the spatial layout of green space.

How to objectively evaluate the distribution pattern and allocation relationship of urban green space in the process of urbanization is of great significance for maintaining sustainable development of urban areas.

3D Configuration Curve of UGS

3D green space curve – An objective description of the vertical distribution of urban green space.



Green radiation range Refers to the ability to enjoy the urban green ecological directly brought by the … ch … vel … he

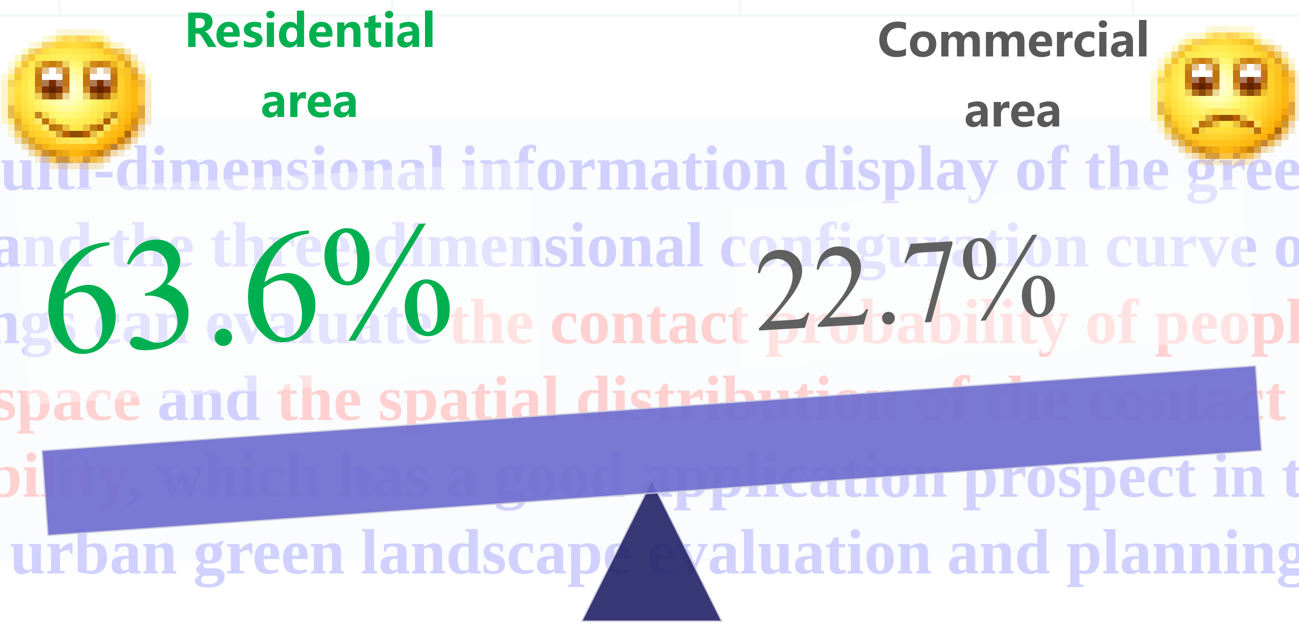
Green space service in force refers to 68.27% of the height range which is symmetrically distribute around the radiation peak and green radiation cumulative sum up to 68.27% of the total amount. It can be used to emphasize the centralized or discrete characteristics of urban green space radiation distribution.

3D Configuration Curve of UGS

Vertical configuration characteristics in different functional areas

- Parameter statistics of 3D configuration curve

area	Green-dificient area	Green-sufficient area	Green radiation balance point	Effective service ratio of green space
Residential area	36.42%	63.58%	3m	20.32%
Commercial area	77.34%	22.66%	8.5m	46.99%



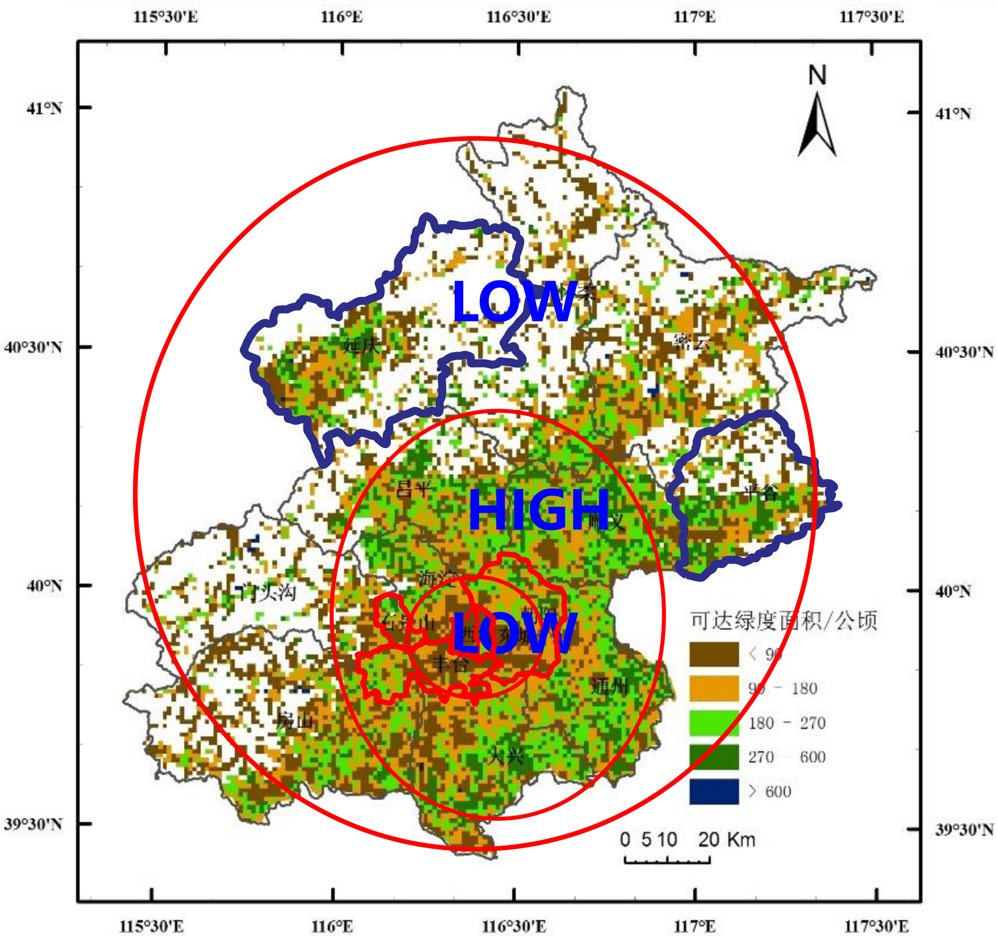
✓ The multi-dimensional information display of the green space and the three-dimensional configuration curve of buildings can evaluate the contact probability of people and green space and the spatial distribution of the contact probability, which has a good application prospect in the future urban green landscape evaluation and planning.

Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → **Accessibility measurement model** → Gradient analysis of accessibility



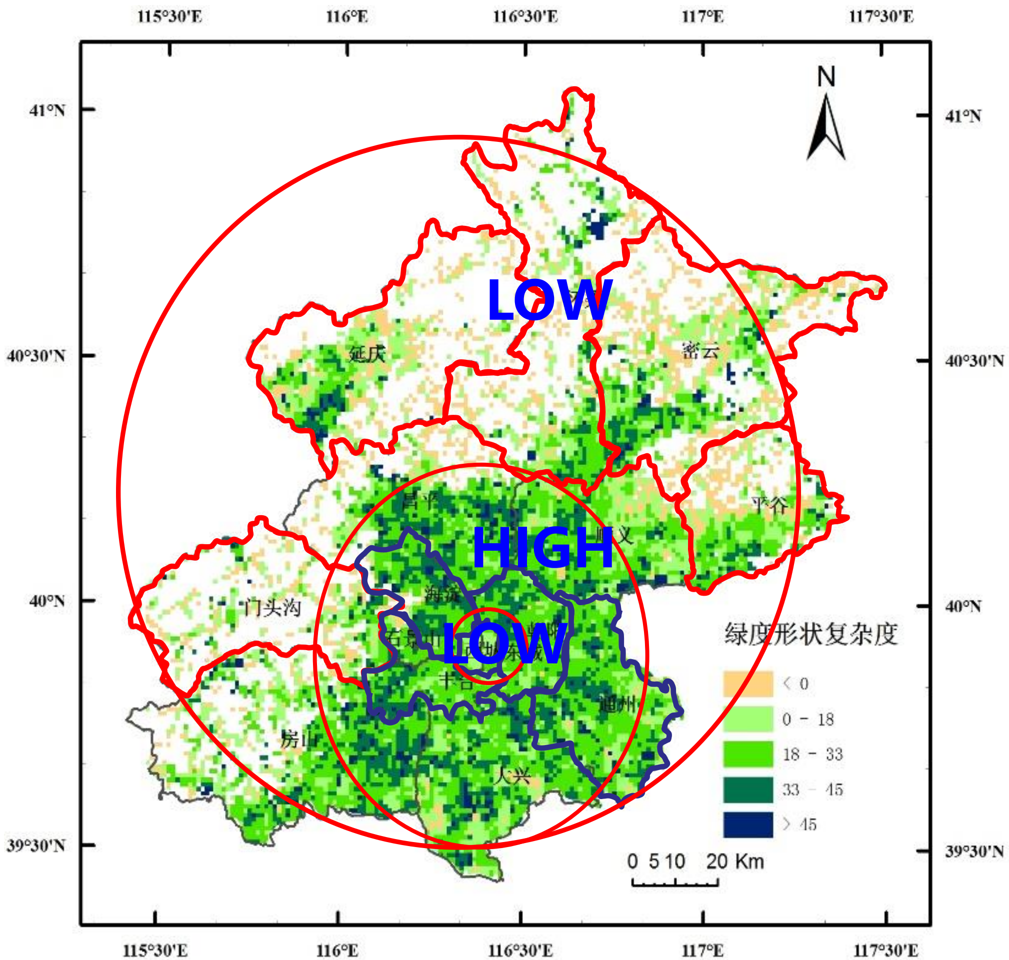
Spatial distribution of accessible green area in Beijing

Accessible Greenness Area

- From the edge of the city to the center, it first increases and then decreases, showing a trend of 'low - high - low'.
- It is minimal in Dongcheng district and Xicheng district.
- It is largest in pinggu and chaoyang.

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → **Accessibility measurement model** → Gradient analysis of accessibility



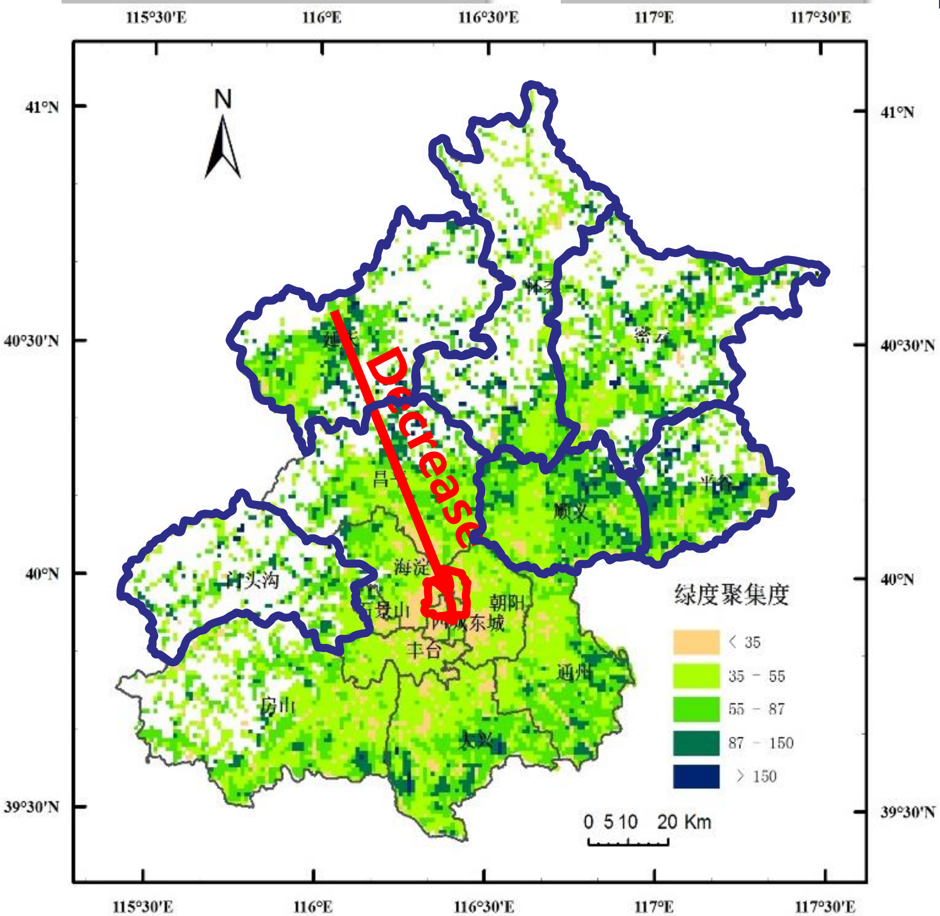
Shape complexity of greenspace

- From the edge of the city to the center, it first increases and then decreases, showing a trend of 'low - high - low'.
- It is minimal in mentougou, huairou, pinggu, yanqing and miyun district.
- It is largest in haidian, chaoyang, fengtai and tongzhou district.

Spatial distribution of the complexity of accessible greenness shapes in Beijing

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → **Accessibility measurement model** → Gradient analysis of accessibility



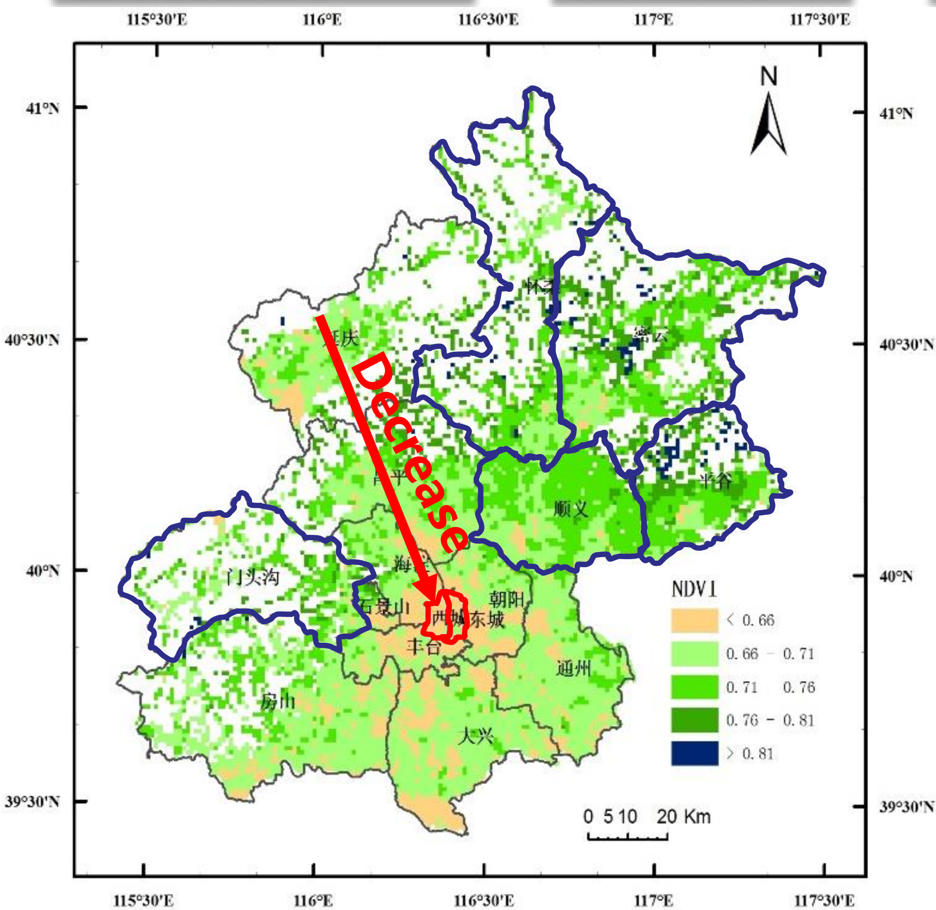
Distribution of accessible greenness aggregation index

Accessible greenness aggregation degree

- decreases from the urban fringe to the urban center, and shows a trend of 'high in the north and low in the south'
- It is minimal in dongcheng and xicheng district.
- It is largest in mentougou, shunyi, huairou, pinggu, yanqing and miyun district.

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → **Accessibility measurement model** → Gradient analysis of accessibility



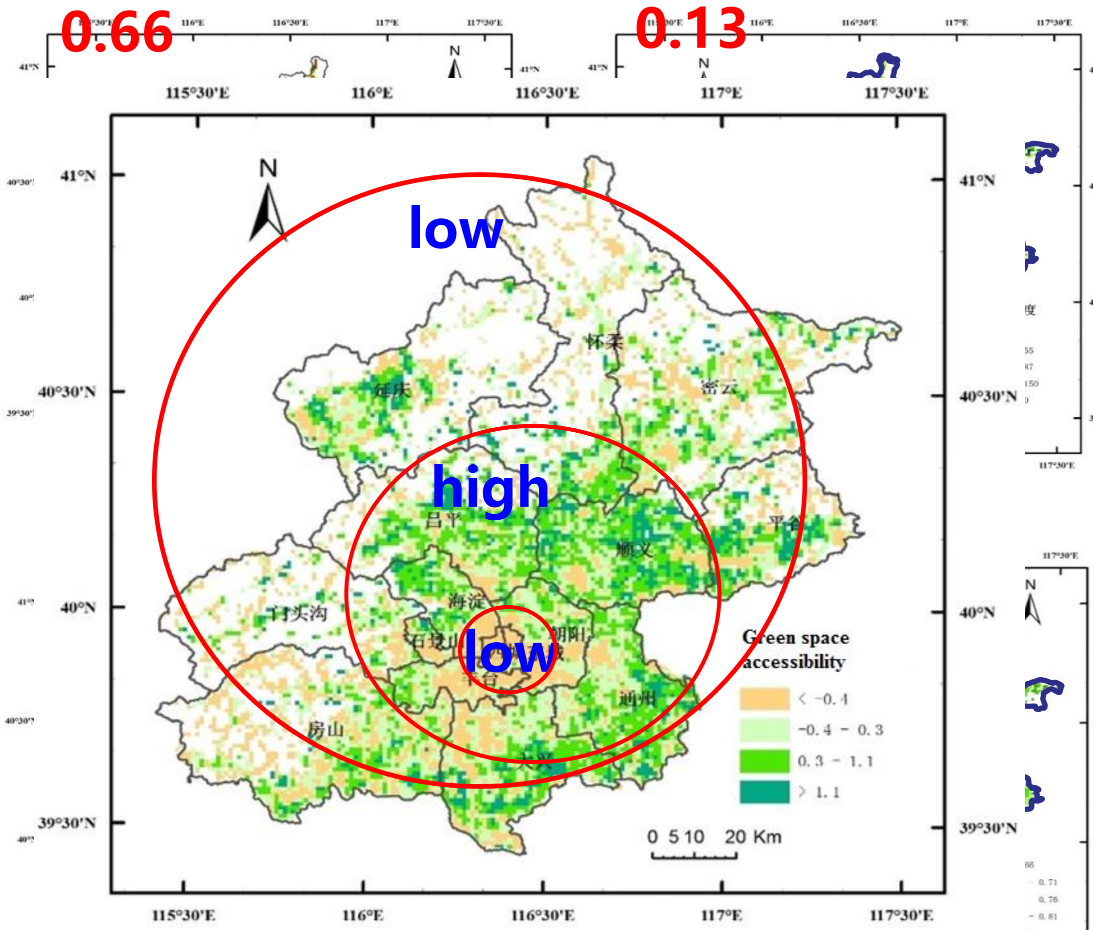
Spatial distribution of NDVI in Beijing

Accessible greenness NDVI

- decreases from the urban fringe to the urban center, and shows a trend of 'high in the north and low in the south'
- Average NDVI is minimal in dongcheng and xicheng district.
- Average NDVI is largest in shunyi, pinggu, miyun, mentougou and huairou district.

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → **Accessibility measurement model** → Gradient analysis of accessibility



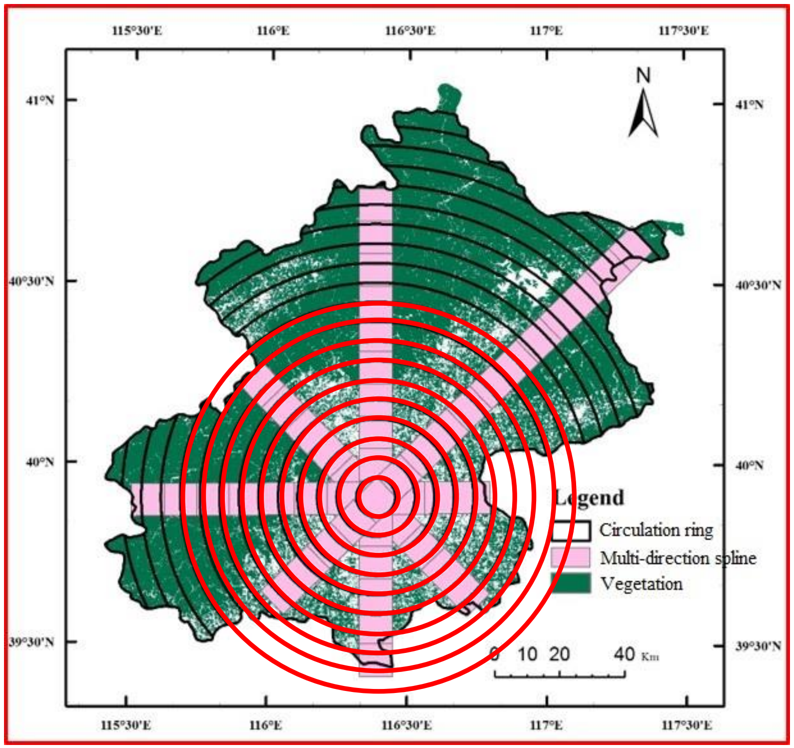
green space accessibility distribution in Beijing

Green Space Accessibility

- From the edge of the city to the center, it first increases and then decreases, showing a trend of 'low - high - low'.

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → Accessibility measurement model → **Gradient analysis of accessibility**



➢ Circulation Ring

Taking Beijing city center as the center of the circle, the radius is increased by 6km at a time, and 20 echelon rings are arranged in total.

➢ Multi-direction Spline

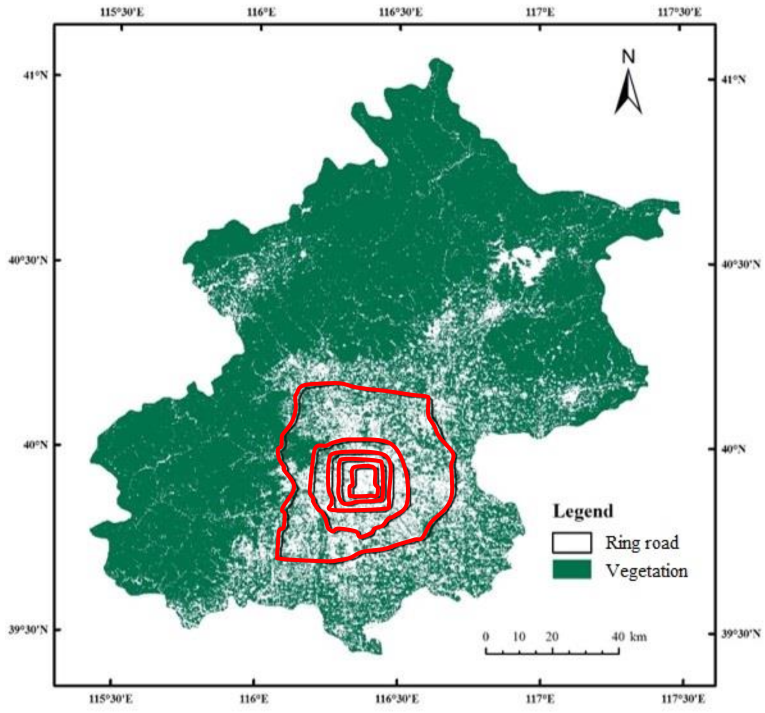
Four splines of north-south, east-west, northwestern-southeast and northeast-southwest with rectangular quadrat of 10km by 10km.

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → Accessibility measurement model → **Gradient analysis of accessibility**

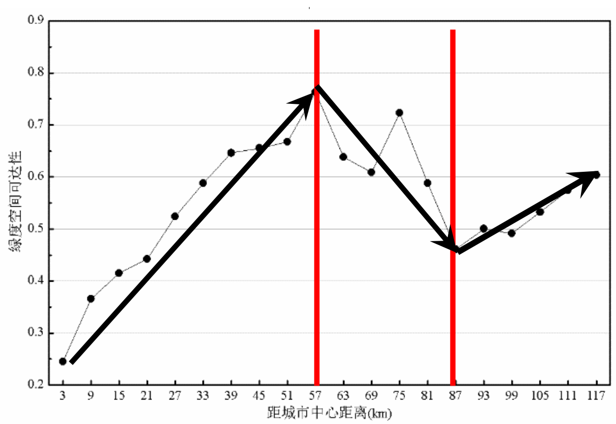
➢Loop Spline:

Taking Beijing 1-6 ring roads as the dividing line, 5 ring belts are arranged in 2 rings, 2-3 rings, 3-4 rings, 4-5 rings and 5-6 rings.



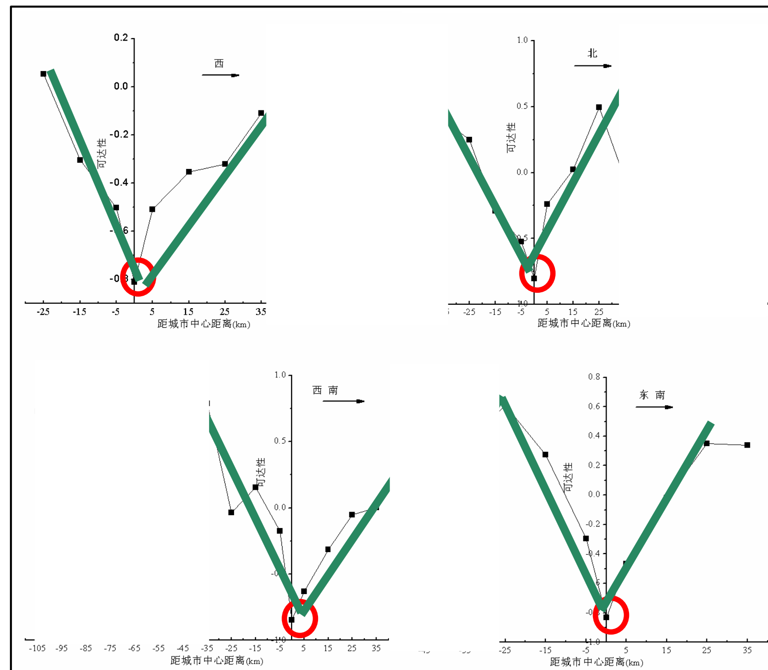
5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → Accessibility measurement model → **Gradient analysis of accessibility**



Green space accessibility on each echelon ring of Beijing

- **From the city center outward, the accessibility of green space 'goes up - down - up';**
- **The maximum accessibility reached 0.76 at 57km。**

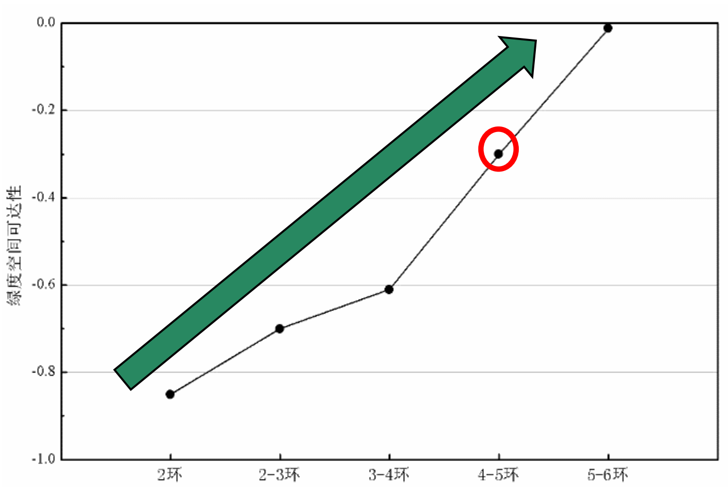


Green space accessibility in all gradient directions of Beijing

- **All directions reach minimum accessibility in the city center.**
- **The curves of the green space accessibility in four directions within ± 35km from downtown were all 'V'.**

5. Accessibility Measurement Model Based on Road Distance

Accessibility calculation unit determination → Accessible range calculation → Accessibility measurement model → **Gradient analysis of accessibility**



Green space accessibility in each loop of Beijing

- **From 2 to 6 rings, the green space accessibility increases monotonically.**
- **The green space accessibility increased obviously from 4-5 rings.**

Outline

1. Research Background and Necessity
2. Multi-dimension Urban Green Retrieval
3. Multi-scale Urban Green Perception
4. Spatial Allocation of Urban Green
5. Accessibility Measurement of Urban Green
6. Scientific Significance and Prospect

6. Scientific Significance and Prospect

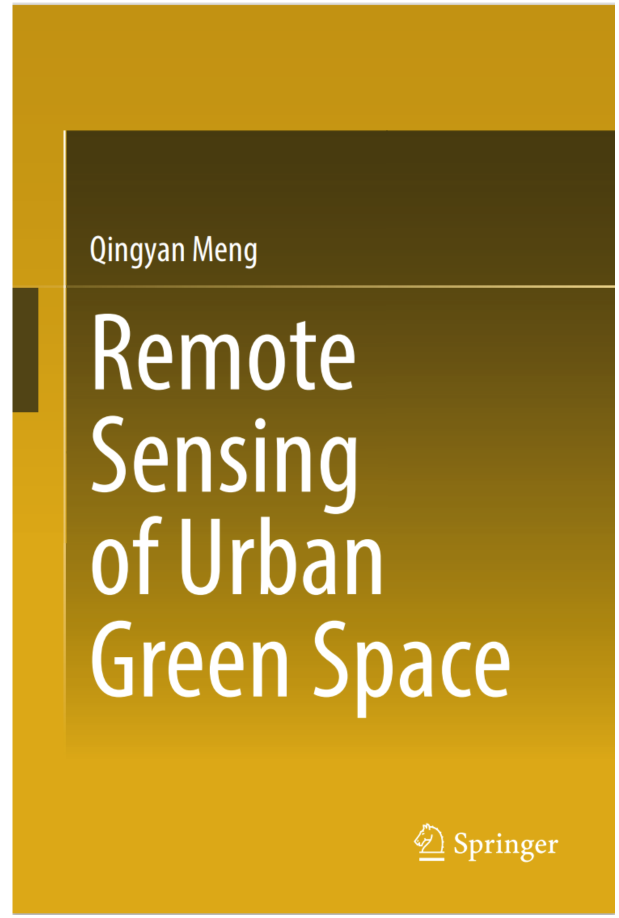
6. Scientific Significance and Prospect

1) Providing new perspective for exploring the effecting mechanism of people-green space-buildings.

2) It is the important science question to scientific perceive urban development status, having guiding significance for urbanization.

3) Urban green space is the frontier of remote sensing application, promoting the integration and intercrossing of subjects of remote sensing, urban, environment and landscape ecology.

6. Scientific Significance and Prospect



The English monograph Remote Sensing of Urban Green Space（https://doi.org/10.1007/978-981-99-0703-8）, was published by Springer Nature Group，selected as a textbook of the University of Chinese Academy of Sciences. The 10th Tsien Hsue-shen Gold Prize in Urbanism, November 2020.

6. Scientific Significance and Prospect

Urban Green Space Remote Sensing

- **Solving the measuremental problem of urban green for living standard contribution, enrich connotation of urban ecology.**
- **Developing a perfect study and system of urban green space high resolution remote sensing.**
- **It will be the important method of urban environment monitoring and decision basis of smart city construction and management.**
- **It gives important theoretical meaning and practical value!**

The Emerging Urban Ecological Scientific Problem

Major Application Requirements

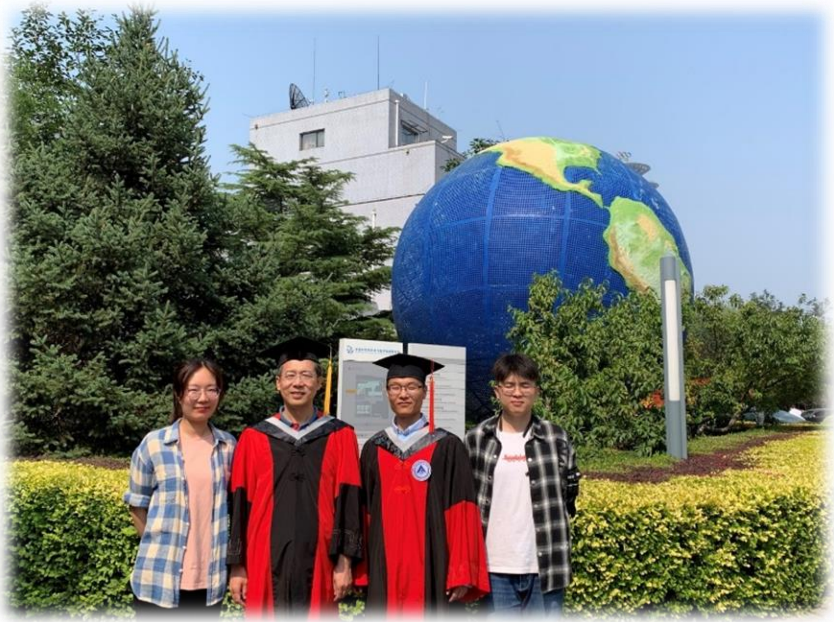
Urban Green Space Remote Sensing

Application Prospects of Urban Green Space

User Departments： **environmental Protection、housing Construction、landscape 、Forestry.**

- **Housing Construction ： urban Ecological Assessment ； landscape Planning；architectural Planning；support of Smart City and Eco-city; Sponge City Construction; Ugs Planning By The Real Estate;**
- **Assessment of Urban Development and Livability；**
- **Estimation of Biomass and Carbon ;Evaluation of Green Assets ；**
- **Assessment of Urban Environment; Environmental Audit When Leave One's Post；**
- **Urban Landscape Planning、urban Residential Green Evaluation、evaluation of Urban Vertical Greening Pattern.**

Thanks！



Sincerely thanks to the team: Li Xiaojiang, Liu Yuqin, Wu Jun, Zhang Jiahui, Sun Yunxiao, Chen Xu, Wang xuemiao, Liang Yan, Tian Jinyu and other comrades for their contributions to relevant research!

Thanks！


Li Xiaojiang


Zhang Jiahui


Liu Yuqin


Wu Jun


Sun Yunxiao


Chen Xu


Wang xuemiao


Liang Yan


Tian Jinyu


Thanks!