Spatial variation and threshold analysis of the urban wetland cooling effect—a case study of Changchun city

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Abstract. Due to the complexity of the surrounding environment, the cold and wet effects of urban wetlands and the quantitative descriptions of the cold and wet effects of the wetlands are not clear. Therefore, the focus of current research is gradually shifting towards the impact of the microspatial morphology and quantity differentiation of urban wetlands. This paper adopts the July 4, 2016 Landsat 8 data of cloud cover that is less than 0.2, the 10th band as the data source using single window algorithm surface temperature inversion, and further analysis of urban spatial distribution characteristics of land surface temperature. Secondly, based on the numerical analysis of the difference in surface temperature between urban wetland types, shapes, and independent wetland space sizes, the cold temperature effect and spatial distribution of urban wetlands were discussed. Temperature inversion results show that the lowest temperature is 17.94 °C, which appears in the Songhuajiang wetland, and the highest temperature is 32.52 °C, which appears in the FAW Industrial Concentration Zone in the main urban area of Changchun City. From the perspective of the spatial difference of the temperature distribution, the areas with high temperatures are generally distributed in the industrial concentration area in the southwest of Changchun, followed by other areas with high temperatures in the western part of Changchun. Low-temperature areas are mainly distributed in areas with relatively high distribution densities of rivers and lakes in the northeast and central parts of Changchun. This shows that the temperature is directly related to the urban building density. The temperature is higher in places with high building density. Wetland water bodies generally belong to low temperature areas and are generally 1-2 °C lower than the surrounding environment. For the main urban area, the wetland water body is, on average, 2-4 °C lower than the surrounding environment, while in areas with high building density, the wetland water temperature is 6-8 °C lower than the surrounding area. And further urban wetlands with micro difference threshold temperature distribution characteristics are as follows: (1) The cold and wet effects of the wetland are related to its shape; and, the cooling and influence range of circular wetlands are larger than that of striped wetlands. (2) The cooling effect of a wetland in a circular wetland typified by a lake wetland is not related to the size of the water area when the area exceeds 92 hm²; and, the cooling range of a strip-shaped wetland has nothing to do with the width of the water surface. However, impact range is related to the width of the water surface, the larger the width of the river surface, the larger the range of influence. (3) The cooling effect of wetlands are related to the surrounding environment. When the surrounding area is hard ground, the cooling rate is large, and when the surrounding area is green land, the cooling rate is small.
1. Introduction

Wetlands, known as "the kidney of the earth", produce cooling and humidifying effects on the surrounding environment with its unique surface material composition and radiation properties; namely, "cold and wet" effects. And, the urban surface has a heat island effect that has the opposite effect. A consensus of experts and scholars at home and abroad has been reached [1-5,7,9,11,12,17] With the deepening understanding of the urban heat island effect and the need to alleviate it, more and more attention has been paid to the micro-scale wetlands distribution in the city that can be used to perform the inverse effect of urban heat island. However, due to the complexity of the surrounding environment of urban wetlands, the effects and the description of quantitative relationships of the cold and wet effects are not clear. Therefore, a rapidly increasing number of scholars have begun to quantify the cooling and humidifying effect of urban wetlands. The research focus of urban wetlands has shifted from the spatial distribution pattern of urban wetlands, wetland landscape change characteristics, wetland change driving force, and environmental effect and impact caused by micro-spatial form and the quantity differences of urban wetlands. In 2009, Fan Xiaodan studied the cooling effect through field observations of urban wetlands and pointed out that the cooling effect of wetlands was significantly different with the change of solar radiation within a day, as well as the difference in location of the wetlands. Cui Lijuan et al. [6] and Kang Xiaoming [8], taking Beijing as an example, discussed the differences in the cooling effect of different wetland types, and pointed out that the cooling effect of lake wetlands was significantly better than that of river wetlands. Zhang Wei [15] took the west lake as an example to compare the cooling characteristics of urban wetlands by fixed-point observation and statistical analysis. With the development of remote sensing technology and remote sensing image processing methods (for improving the accuracy of the retrieval of surface temperature) as well as an improvement in the ability to obtain the spatial distribution of surface wetlands, it is possible to achieve wetland cooling effects with the help of remote sensing.

From the perspective of practical application, Eco-city is the highest form of modern urbanization, and the significant cold and wet effect of urban wetlands is a growing concern for urban planners [10,13,14]. It is an important reference for future Eco-city planning to study the strength, effect, and scope of the cold and wet effect brought by micro-spatial form and quantitative characteristics of urban wetlands. This study takes Changchun, a city where wetlands are distributed throughout the entire city to cover as much as 10% of the land. The study focuses on the spatial characteristics of the cooling effect of urban wetlands and provides a scientific reference for future urban eco-city expansion and spatial layout.

2. Data and research methods

2.1. Study area

Changchun is located in the central part of Jilin province, with latitude 43°05’~45°15’N and longitude 124°18’~127°05’ E. Located in the northeast plains of China with ups and downs of 250-350 m, the city belongs to the north temperate continental monsoon climate. The average precipitation ranges from 522mm to 615mm per year, and the city cycles through four distinct seasons. The average annual temperature is 4.8°C, and the city has a large temperature range with a maximum of 39.5°C and a minimum of -39.8°C. Changchun City has the Songhuajiang tributary Yitong River passing through the main urban area, plus other tributaries. The rich water resources form the wetlands, mainly consisting of the Yinma river that flows though Dehui city and other major wetlands such as South Lake, North Lake Wetland Park, Jingyueten National forest park, and Xinlicheng reservoir. According to the data of remote sensing interpretation in 2014, the total area of wetlands in Changchun is 2464.3km2, and the rate is 11.9%, which is higher than the average level of wetlands in Jilin province. The spatial distribution is shown in figure 1(a).

2.2. Data source and processing

The primary data source for the inversion of surface temperature is Landsat 8 OLI_TIRS data from the
geospatial data cloud of July 4, 2016. Data details are with row number 118 and column number 30, a center longitude of 125.3919 and a center latitude of 43.1847, data identification as LC81180302016186LGN00, and cloud cover 0.12. With row number 118 and column number 29, a center longitude of 125.8894, a center latitude of 44.6082, data identification as LC81180292016186LGN00, and cloud cover 0.10.

The Changchun city 2016 monthly average surface temperatures are shown in Table 1. The website to query the atmospheric transmission index was downloaded from http://atmcorr.gsfc.nasa.gov.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----------------|
| Lat43.9 | 15.9 | 10 | -0.26 | 10.3 | 18.2 | 22.3 | 22.7 | 21.4 | 16.1 | 8.32 | -2.3 | -11.3 | 6.72 |

2.3. Inversion method of surface temperature

Surface temperature inversion was conducted by the most widely used single-window algorithm based on Landsat TM/ETM+ remote sensing image data proposed by Qin Zhihao. First, the radiation temperature according to the radiation intensity is calculated. At the same time, the surface specific emissivity is calculated based on the calculated NDVI index and FVC. Finally, the surface temperature is finally calculated by combining the average atmospheric temperature and atmospheric passage rate. The specific calculation formula is as follows:

\[ T_s = \frac{a(1-C-D)+[b(1-C-D)+C+D]\cdot T_b-D\cdot T_a]}{C} \]  

\[ C = \varepsilon \cdot \tau \]  

\[ D = (1-\tau)^{[1+(1-\varepsilon)\cdot \tau]} \]  

\( T_s \) is the surface temperature; \( T_b \) represents the demand for radiation brightness; \( T_a \) is used for estimating the average atmospheric temperature. Meanwhile, \( C \) and \( D \) are based on the surface than emissivity epsilon and atmospheric transmittance, \( \tau \) is built in the middle of the variables, and \( a \) and \( b \) are fitting coefficient. When the local surface temperature is 0-70 ℃, \( a=-67.355351, b=0.458606 \).

3. Results and analysis

3.1. Spatial distribution of surface temperature in wetlands

The surface temperature inversion results of Changchun city were obtained based on the single-window algorithm in figure 1(b). The highest temperature in Changchun was 32.5℃ on July 4, 2016. Compared with actual weather conditions, the highest temperature in Changchun on July 4, 2016 was 32℃, and the lowest temperature was 21℃. This shows that the inversion temperature is in good agreement with the actual temperature. The high temperature areas are mainly distributed in the main urban areas with concentrated buildings and dense population. This includes the Chaoyang district, Kuancheng district, Erdao district, and Green park district. These areas are densely built, less green space planning, more densely populated, less wetland water, and surrounded by many residential areas and factories. In contrast, the lowest temperature in Changchun was 17.9℃ at the Xinlicheng reservoir in the upper reaches of the Yitong river. Low temperature areas are mainly distributed in the south of Changchun city and near the North lake wetland park. Because of the distribution of green space and wetland water, buildings in these areas are relatively dispersed, and population density is relatively low. Regardless of the size of the water area, the surrounding temperature can be reduced. However, the cooling range is not consistent, although the temperature of large areas of water is lower, the impact range is larger.
3.2. Analysis on the difference of wetland cooling

3.2.1. Analysis of different types of wetland cooling differences

The wetland types in Changchun city are mainly classified into river wetland, lake wetland and artificial wetland. In order to explore the difference of temperature drops in different wetland types, this paper made transverse profile temperature curves for different types of wetlands and collected a total of 18 profile lines for river wetlands, lake wetlands, and artificial wetlands. The temperature change curves are shown in figure 2. According to the figure and statistical analysis, the cooling effect of the lake wetland is obvious, with a large cooling area and a wide range. However, when the lake area increases to 92 hm², the cooling effect will not be improved; that is, the temperature will not change with the increase of lake area. The cooling effect of river wetlands is not as obvious as that of the lake wetlands, but the cooling amplitude of river wetlands has nothing to do with the width of water surface; however, the range does have something to do with the width of the water surface. According to the statistics of this test, the width of the water surface that the range of influence stops changing as the width of the water surface increases is around 600m. The cooling range of artificial wetlands is the smallest of the three types of wetlands. The cooling effect and amplitude of the three types of wetlands are shown in table 2.
Figure 2. Temperature distribution curves of different wetland types

| Table 2 Cooling effect of different wetland types |
|-----------------------------------------------|
| Wetland type     | Wetland name          | Temperature range (°C) | The Maximum cooling range (°C) | The Maximum impact distance (m) |
|------------------|-----------------------|-------------------------|-------------------------------|--------------------------------|
| Lake wetland     | Xinlicheng reservoir  | 21-22                   | 6                             | 1200                           |
|                  | South lake            | 22-23                   | 9                             | 1500                           |
|                  | Bayi reservoir        | 22-23                   | 7                             | 1200                           |
|                  | North lake            | 22-23                   | 8                             | 1200                           |
|                  | the bubble lake       | 22-23                   | 8                             | 900                            |
|                  | Stone gate reservoir  | 21-22                   | 4                             | 1800                           |
|                  | Jingyuetan            | 22-22.5                 | 3                             | 1500                           |
| River wetland    | Yitong river          | 24-25                   | 6                             | 300                            |
|                  | Yinma river           | 22-22.5                 | 3                             | 450                            |
| Artificial wetland | The Songhuajiang river | 18-19                  | 5                             | 600                            |
|                  | Paddy fields along the Songhuajiang river | 22-23 | 4 | 900 |

3.2.2. The difference in temperature for different wetland shapes
The cause of wetlands often determines the wetlands space morphology while determining the type of wetland. The river wetland is mostly distributed on both sides of the river in a striped and braided shape, while the lake wetland is mostly distributed in a circular and near-circular shape. Based on the difference statistics of the surface temperature inversion, it is shown that the cooling effect of near-circular lake wetlands is better than that of striped river wetlands. However, there are some differences in the cooling effect of wetlands of the same type and similar shape, which are found to be mainly related to the surrounding environment through the analysis of differences with the surrounding environment. When there is a significant difference between wetland and surrounding cover types, such as the Bayi reservoir and South lake, a near-circular wetland surrounded by buildings, the cooling range reaches 8-9°C. While in the surrounding areas of the Shitoumen reservoir and Jingyuetan are grassland or farmland, the cooling range is only 4-6°C. Similarly, for the strip-shaped Yitong river and Yinmahe wetland, the
former is built with buildings along both sides, with a significant cooling range of 4-6°C. On the other hand, the Yinma river and Songhuajiang tributaries are sounded by greenbelts and paddy fields and only have a small cooling range of 3-4°C.

4. Conclusions
Based on the Landsat 8 remote sensing image of Changchun city on July 4, 2016, this paper was able to obtain the surface temperature by performing a temperature inversion using the single-window algorithm. According to the distribution information of Changchun wetlands obtained in the same time period, the statistical analysis of surface temperature was carried out, and it was concluded that urban wetland has a significant cooling effect on urban surface temperature. The main conclusions are as follows:

(1) The surface temperatures in densely distributed areas of urban buildings were significantly higher than those in other areas, therefore causing a high temperature area on the urban surface. The highest temperature is 32.52°C, which appears in the FAW area in the southwest of the city. However, low-temperature areas are mainly distributed in urban wetlands and surrounding farmland, with the lowest temperature of 17.94°C in the Songhuajiang basin.

(2) The cooling effect of urban wetlands has obvious correspondence with the type of wetland. Lake wetlands have a better cooling effect than river wetland. However, the cooling extent of strip-shaped wetlands has nothing to do with the width of the water surface; but, the influence of range is related to the width of the water surface.

(3) The cooling effect of a wetland is related to its shape. The cooling range and influence range of circular wetlands are larger than that of striped wetlands. The cooling effect of a wetland is related to the surrounding environment. The cooling range is large when the surrounding area is hard, and the cooling range is small when the surrounding area is green land.

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