Study on Regulation of Urban Heat Island Effect through Remote Sensing

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Abstract. Globally, the heat island effect is a major environmental problem that has a considerable impact on metropolitan climate, energy use, urban planning, and human health. So controlling the urban heat island effect is essential. The satellite remote sensing technology plays an essential role in observing and studying the urban heat island effect, providing critical scientific and technological support for its regulation. This article examines the fundamentals of regulating the urban heat island effect as well as the crucial function of remote sensing satellites. A summary of the advantages of using remote sensing satellites to observe and analyze the urban heat island effect is given, along with a study of the characteristics of popular remote sensing observation techniques. The possibility of further advancement and use of satellite remote sensing technologies in reducing the urban heat island effect has also been raised. Research on the control of the urban heat island effect may use this article as a reference.

Keywords: Urban Heat Island Effect; Satellite Remote Sensing; Urban Planning; Urban Climate.

1. Introduction

Human activity and building construction contribute to urban heat islands, which raise temperatures in metropolitan areas relative to their rural surroundings. The urban heat island effect, which has a significant impact on urban temperature, energy consumption, urban planning, and human health, has become a critical worldwide environmental concern with the fast rise of urbanization and industrialization. It is particularly crucial to control the urban heat island effect. for analysis on how to control the urban heat island impact.

The urban heat island effect is the result of the combined effects of urban land types, human activity heat sources, building density, and thermal radiation between buildings. Its regulatory principle involves reducing the absorption, storage, and release of urban heat, promoting air flow and heat transfer, thereby lowering urban temperatures and alleviating the impact of the heat island effect. Satellite remote sensing provides critical technological support for analyzing the urban heat island effect, as it can obtain large-scale, high-precision, and long-term remote sensing image data.

This article introduces the technological trends and development history of satellite remote sensing technology for monitoring the heat island effect, analyzes the critical role of remote sensing satellites in controlling the urban heat island effect, and summarizes the significance and benefits of remote sensing satellites in observing and studying the urban heat island effect. This article also examines the characteristics of popular remote sensing observation techniques and projects how satellite remote sensing technology will advance and be employed in the future to mitigate the urban heat island effect.

2. Causes and Harm of Urban Heat Island

2.1. Causes of Urban Heat Island

A number of elements, including urban terrain types, heat sources from human activity, building density, and thermal transmission between buildings, contribute to the urban heat island effect. The main causes include the following two points:

The underlying surface of the city is mainly artificial constructions, leading to a rapid rise in heat. The characteristics of materials such as reinforced concrete and asphalt roads are fast heat absorption but small heat capacity. Compared to natural substrates (such as grass, water surface, soil, etc.), they heat up faster and cannot store much heat, leading to an increase in heat, thereby causing the source of the urban heat island effect.

Anthropogenic heat sources include manufacturing processes, commerce, transportation, and resident everyday activities that release carbon dioxide and dust. These materials create a greenhouse effect by absorbing the heat from the subsurface, raising the temperature of the atmosphere and enhancing the urban heat island effect.

2.2. Harm of Urban Heat Island Effect

Human health is negatively impacted by the urban heat island effect. Humans will experience heat stress and pain from prolonged exposure to high temperatures, which will increase their risk of developing cardiovascular, gastrointestinal, and nervous system disorders [1].In addition to affecting air quality, high temperatures in cities worsen air pollution issues[2]and raise the prevalence of respiratory illnesses.

Energy use rises as a result of the urban heat island effect. Increased usage of air conditioners, freezers, and other cooling equipment as a result of rising temperatures in metropolitan areas increases the stress on the power grid [3]. The urban heat island effect is made worse in order to sustain the availability of power.

3. Basic measures of urban heat island effect regulation

3.1. Principles of regulation

A combination of urban land types causes the urban heat island effect, building density, and other human activities, which has a effects on human health and city operation. The urban heat island effect can be effectively controlled and mitigated by optimizing the land use of urban areas, controlling the scope of urban construction, and reducing human activities. Fundamentally, the principle of heat island effect regulation is to reduce the urban temperature by reducing the absorption, storage and production of heat, as well as promoting airflow and heat transfer. The principle can be divided into four parts:

1. Reducing the absorption of solar radiation: Buildings and roads can be constructed from highly reflective materials to minimize heat absorption.

2. Increasing heat radiation and dissipation: Vegetation and water bodies absorb heat through transpiration and evaporation, lowering the temperature of the surrounding air.

3. Promoting air flow: Ventilation corridors, green corridors and open spaces can be built to promote air flow and reduce local temperatures.

4. Optimizing building design: Climate-adaptive buildings can be adopted to reduce heat absorption and the need for air-conditioning systems.

3.2. Measures of regulation

Through rational planning of urban land layout, improvement of urban building design, urban energy structure adjustment and other measures, urban surface temperature and energy consumption can be reduced.

3.2.1 Rational planning of urban land layout

Urban functional areas are divided on the base of urban land type. Different urban functional areas produce different amount of heat. Reasonable optimization of the layout of urban functional areas can effectively mitigate the urban heat island effect.

Optimization of urban green space layout: The increase in area under cultivation, forest land and water bodies is a key factor to reduce the heat island intensity [4]. When the vegetation cover of a certain area reaches 30%, the green space will significantly reduce the heat island effect [5].

Improvement of road traffic efficiency: By optimizing traffic signal timing, excessive heat emission and unnecessary energy consumption due to traffic congestion can be reduced. In addition, green space can be built in high-traffic sections to alleviate the greenhouse effect caused by excessive anthropogenic heat generation.

Planning urban ventilation corridors: Wind power can effectively evacuate heat and improve the efficiency of air flow in the city, which is conducive to alleviating the urban heat island effect. The heat dissipation efficiency of the city can be improved by building ventilation corridors.

3.2.2 Improvement of urban building design and layout

Green vegetation can be added to the roof to reduce the external temperature by absorbing the surrounding heat and solar radiation.

Light-colored building materials or paints, and good building envelope materials are also influential factors, as they obtain lower surface temperatures by scattering the sun rays and other means.

The spacing and height between buildings affects the circulation of wind and the emission of heat, and a reasonable building layout can improve the ventilation of the city and reduce the heat island effect.

3.2.3 Urban energy structure adjustment

Improving building air conditioning technology: Energy consumption can be reduced by improving air-conditioning equipment.

Actively exploring and popularizing new energy technologies: ground source heat pump technology realizes the heat transfer between buildings and earth through the circulation of liquid in the closed underground buried pipe.

Building urban forests in the city for three-dimensional greening: planting trees around buildings can save 4-40% of the energy consumption for cooling [6].

4. Application of satellite remote sensing technology in heat island effect regulation

The land surface temperature (LST) is a crucial consideration for assessing the urban heat island impact. The satellite remote sensing technology utilizes various sensors to obtain electromagnetic wave information of the earth’s surface objects. LST can be obtained by thermal infrared remote sensing technology, and it can also be inferred or calculated based on remote sensing data combined with mathematical or physical models. The use of satellite remote sensing technology to monitor UHI provides a large scale, high precision and long time series remote sensing image data, which provides an important technical assistance for the study of the urban heat island effect.

4.1. History of remote sensing technology in heat island effects monitoring

In the investigation of the urban heat island effect, remote sensing technology has a lengthy history. Early research mainly relied on thermal infrared remote sensing data, which can infer the urban heat island effect by measuring LST. The earliest history of satellite remote sensing dates back to the 1970s when the rise of satellite technology made it a useful tool for detecting urban heat island effect. In 1972, Rao used satellite remote sensing to get urban LST [7]. Lee analyzed the macroscopic form and structure of UHI by comparing LST data obtained from 1-kilometer spatial resolution NOAA satellite images (AVHRR) with remote sensing thermal data [8]. However, the limited spatial resolution of the images meant that they were not suitable for monitoring partial changes. In the 1980s, the invention of Landsat TM overcame the spatial resolution issue, and many cities began to use high-resolution images for the research in this field [9]. With the development of computer technology, researchers started using remote sensing data in combination with meteorological data to build heat island models for evaluating and predicting their impact. In 1993, Gallo and his team first used Normalized Difference Vegetation Index (NDVI) obtained from AVHRR data to evaluate urban heat island effects [10], and they believed that NDVI could monitor urban heat island effects. In order to explore the geographical distribution model of the built-up index and the heat island effect, Wu and his team used Landsat TM images to extract the Normalised Difference Built-up Index (NDBI) of Beijing [11]. After that, high-resolution remote sensing images have become the first choice for researchers. Chinese scientists developed the HJ-1B/IRS and FY-3/MERSI independently have achieved a resolution level of about a hundred meters, and the return periods were shortened significantly, which providing the possibility to analyze UHI influencing factors.

4.2. Benefits of Using Remote Sensing to Research Urban Heat Island Effects

Prior to using satellite remote sensing technologies, scholars mostly rely on ground-based meteorological station data to study urban heat island effects, known as the stationary observation method. The efficiency and accuracy of this method still remains limited. In contrast, the remote sensing technology surpasses the limitations of traditional methods and provides substantial technical advantages for observing urban heat islands. Providing real-time data feedback, remote sensing satellites capture satellite images that offer wide spatial coverage and precise temporal synchronicity. Therefore, they can supply extensive spatial variability information, facilitating the analysis of the inversion of the intensity of UHI and the geographical distribution features of city heat fields at different spatial resolutions. These satellite images serve as fundamental data for studying the distribution of UHI effects in terms of space[12].

4.3. Key Technologies for remote sensing observing of Urban Heat Island

There are three main categories of remote sensing monitoring methods: methods based on temperature, methods based on vegetation index and thermal landscape-based monitoring methods.

Temperature methods are the most direct and currently most commonly used means of observation which can be subdivided into two categories: surface temperature method and ground brightness temperature method. The principle is to use the radiation information contained in the thermal infrared band for LST inversion. The surface temperature method uses sounding data and surface specific radiance for inversion [13]. Researchers obtain data in specific infrared bands to form spatial distribution maps of surface temperature through thermal infrared sensors of satellites over a wide area. In particular, the raw radiation received by the satellite sensors can be classified into three types: the surface thermal radiation received by the sensors after passing through the atmosphere, which is generally attenuated by the atmosphere, the radiation that travels downward from the atmosphere to the surface and then reflected by the surface before it passes through the atmosphere, where the radiation be attenuated by again, and the radiation that travels upward through the atmosphere. When performing LST inversion, in order to obtain a true and accurate surface temperature, the noise in the satellite signal due to the atmosphere needs to be removed, a step known as atmospheric correction. Once the processing of the data is completed, different algorithms for inverting LST can be developed using various approximate simulations of the atmospheric radiative transfer equation with known surface specific radiance, such as split-window algorithms, multi-channel multi-angle algorithms, mono-window algorithms [14].

The ground brightness temperature method has different data sources with the surface temperature method, which also uses satellite thermal infrared radiation sensors for data collection, but the main data that can be exploited is the thermal infrared channel radiation intensity. Surface brightness temperature can closely related to the type of subsurface, and the specific correlation factors will also vary depending on the season and diurnal shift.

Temperature methods have been developed for the longest time, and in this type of method, the main problem to be solved at present is how to achieve accurate inversion, considering that the inversion accuracy can be affected by satellite products and atmospheric conditions.

The second category of methods analyses the relationship between surface vegetation and UHI. The aim is to infer the vegetation cover and vegetation status that influence the UHI from remote sensing information [15]. In these methods, NDVI is the most frequently employed and efficient data source, which describes the state of the landcover using reflectance spectral information in the near-infrared and visible bands [16]. An increase in urban area is generally accompanied by a decrease in green space area, which illustrates a significant negative correlation with surface temperature. Surface temperature is positively correlated with NDVI during the daytime while NDVI slows down the temperature increase at night and is negatively correlated with surface temperature [17].

The thermal landscape method uses landscape science as an auxiliary model of remote sensing technology to analyse the connection between the landscape and the spatial organization of the thermal environment and to describe the thermal landscape characteristics [18]. This method mainly calculates the weight of different thermal landscape indexes to analyse and characterize the pattern and change of thermal landscape. The simulation results of Landsat data reveal that the intensity of the UHI effect of green space and water is lower, while the urbanized area and arable land have higher intensity of the UHI. The indirect effect or the neighbourhood effect is obvious as well, the degree of continuous concentration of the green space has an impact on the cooling effect [19,20].

The use of these key technologies helps to optimise urban planning and landscape layout to a certain extent and can effectively mitigate some of the detrimental effects of the UHI effect.

4.4. Development trends of remote sensing technology in monitoring heat island effects

Nowadays, the remote sensing technology has made significant developments in studying and monitoring urban heat island effect. Nevertheless, the resolution of the data collected by thermal infrared sensors on remote sensing satellites is still low [21]. Obtaining detailed monitoring data relies on high spatial and temporal resolution thermal infrared remote sensing images.

In the realm of monitoring environmental pollution accidents and natural disasters, satellite remote sensing techniques are typically used for retrospective analysis [17]. When dealing with the emergency circumstances, improving the effciency in in transmitting satellite remote sensing data is crucial. The future development trend will mainly focus on dynamic observations of cities, studying the spatiotemporal trends of temperature and urban heat island effects through long time series of remote sensing images, analyzing potential urban issues, and exploring the seasonal and daily variations of heat island effects.

With the rapid development of technology, the big data technology is widely applied in various industries, bringing people to a new data-driven era with its powerful capabilities. Apart from the remote sensing data, other data resources such as meteorological data and land use data can be utilized for evaluating UHI. The combination of data has a positive implication for a comprehensive analysis of the formation mechanism of urban heat island effects and mitigating their impacts.

The rapid rise of machine learning and artificial intelligence technologies contributes to improving the efficiency and accuracy of remote sensing data analysis. By combining urban building's three-dimensional information and establishing three-dimensional thermal imaging models, the machine learning can efficiently integrate urban resources through multi-terminal coupling [22]. The best models matching by machine learning can explore the interaction relationships between them, providing data support for mitigating urban heat island effects. Improving monitoring efficiency and accuracy through these technologies is a vital research direction today.

5. Conclusion

With the accelerated urbanization and industrialization, sustainable development and climate change are becoming more and more prominent globally. The urbanization and industrialization has significant impacts on urban climate, energy consumption, urban planning and human health, which further promotes the research on the regulation of UHI. From the perspective of urban planning, this paper is aimed at the regulation of UHI effect. The important role played by remote sensing satellites in the regulation of UHI effect is analyzed. Through remote sensing technology, researchers are able to obtain a wide range of high-precision surface temperature data, and its high efficiency, high precision and spatial and temporal continuity are the obvious advantages that distinguish it from other methods. The three main categories of methods currently used for monitoring are also the fundamental technologies for regulation of UHI, among which the temperature method has become mature, and the vegetation method and the thermal landscape method are also being gradually improved.

Considering the ongoing advancements in science and technology, remote sensing technology will be further developed in the and field of UHI monitoring, and the emergence of satellite products with higher resolution wider coverage will further enhance people's cognitive ability of UHI effect. Combined with technologies such as artificial intelligence, automated UHI monitoring and prediction will become possible, it can provide more accurate data support for urban planning and decision-making.

Through remote sensing technology, researchers will be able to comprehensively perceive and analyse the UHI effect, thereby giving a scientific foundation for rational urban design and the formulation of UHI regulation measures, reducing its negative impacts, and providing support for the creation of more livable, comfortable and sustainable environments for human beings.

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