

Progress in the Application of Satellite Remote Sensing Technology in Urban Night Light Pollution Monitoring

Dongyue Wang *

School of Energy and Power Engineering, Beihang University, Beijing, China

* Corresponding author: 21374037@buaa.edu.cn

Abstract. The satellite remote sensing technology has provided good research conditions for analysing urban light pollution intensity. Many types of satellites are used worldwide to monitor light pollution. This article describes the application progress of satellite remote sensing technology in urban night light pollution monitoring, analyzes their technical characteristics and advantages, and summarizes the important role of satellite remote sensing technology in light pollution monitoring. By summarizing the technical parameters of satellite data, such as spatial resolution, temporal resolution, and spectral range, it shows that remote sensing technology provides long-term and stable data support for global and regional light pollution monitoring, especially for the study of the spatial distribution and changing trends of light pollution, which has unique advantages. This paper analyzes the temporal and spatial distribution of night light brightness in different areas based on specific cases and reveals the relationship between light pollution, urbanization and economic development. Although remote sensing technology has significant advantages in light pollution monitoring, it still faces some challenges during its application, including limited data resolution, insufficient sensitivity to new light sources such as LEDs, and high data acquisition costs. This paper also proposes future research directions, including improving the resolution of sensors, expanding spectral bands, optimizing data processing methods, and combining multi-source remote sensing data and ground measurement data to achieve more accurate light pollution monitoring.

Keywords: Satellite Remote Sensing Technology; Urban Light Pollution; DMSP-OLS; NPP-VIIRS; EROS-B.

1. Introduction

Since the invention of electric lights, artificial light sources have become increasingly common. It has provided great convenience for human production and life. At the same time, excessive artificial lighting has also created a new environmental problem - night light pollution. The International Dark-Sky Association defines light pollution as artificially making outdoor light levels different from natural light levels and believes that excessive lighting or misuse of light colors has a negative impact on many organisms, including migratory birds, pollinating insects, turtles and mammals [1]. Austrian scientists have found that a small advertising light box can kill thousands of insects a year. American ornithologists have calculated that tens of thousands of birds die every year around the world because they hit advertising lights on high buildings. In addition, excessive urban night lighting will interfere with normal astronomical observations. Now, more than two-thirds of the world's people cannot see the Milky Way. In addition, excessive night lighting also consumes unnecessary electricity, resulting in a huge waste of energy. Therefore, it is particularly important to monitor urban night light pollution.

The development of satellite remote sensing technology has provided more conditions for monitoring light pollution. Many satellites carry sensors that can identify and record night light data, providing researchers with rich research data. The parameters of several night light remote sensing sensors are shown in Table 1. The OLS sensor, carried by the DMSP satellite launched by the United States in 1975, can detect weak light on the surface at night. It is the earliest remote sensing sensor widely used to monitor the spatial distribution of large-scale night brightness. In 2006, the satellite EROS-B launched by Israel's ImageSat company, carried a CCD-TDI sensor that can provide customers with high-resolution images, allowing researchers to monitor light pollution in specific areas of the city. In 2011, the United States' NPP satellite carried a new generation of night light remote sensing sensor



VIIRS. Compared with DMSP-OLS, NPP-VIIRS has a higher resolution, it has a unique day and night band (DNB), which can better monitor the distribution of weak lights at night. Furthermore, the night light remote sensing sensor carried by the "Luojia-1" satellite developed by Wuhan University has a high resolution and can also provide a good remote sensing data source for light pollution monitoring [2-4]. In summary, this paper explores several existing application examples of satellite remote sensing monitoring of light pollution, summarizes and analyzes their respective advantages and disadvantages.

Table 1. Parameters of several night light remote sensing sensors [2-4]

Satellite	DMSP	EROS-B	Suomi NPP	Luojia-1
Launch year	1973-2009	2006	2011	2018
Operator	USDD	Israel ImageSat	NASA/NOAA	Wuhan University
Data year	1992-2013	2006-present	2011- present	2018- present
Sensor	OLS	CCD-TDI	VIIRS	CMOS
Orbit altitude/km	840	824	500	645
Spatial resolution/m	2700	0.7	750	130
Spectral resolution/nm	400~1100	400~900	410~1200	480~800
Radiometric resolution	6	10	12/14	15
Width/km	3000	7	3000	250
Temporal resolution	24h	5d	12h	15d

2. Application of Satellite Remote Sensing Monitoring

2.1. DMSP-OLS

DMSP was first equipped with the OLS on the F-1 satellite launched in 1975. OLS has low-light visible and thermal infrared imaging capabilities and can monitor the night light radiation on the ground. The spatial resolution of DMSP-OLS reaches 2700m, the spectral resolution covers the 400~1100nm band and has the highest sensitivity in the 500~650nm band, which covers the main radiation range of artificial lighting lamps. In general, DMSP-OLS has a high resolution, rich and easy-to-obtain data, can detect low-intensity lighting, is not affected by light shadows, can provide dynamic data on large-scale lighting changes, and provides conditions for urban night light pollution monitoring.

For example, in 2001, Cinzano et al. [5] used DMSP-OLS data, combined with accurate modeling of light propagation in the atmosphere. They considered the influence of many external factors, such as atmospheric scattering, cloud cover, altitude, light saturation, and light spill, drawing a night sky brightness map that covers almost the entire world. The results showed that about two-thirds of the world's population lives in areas with severe light pollution, so that the Milky Way cannot be seen with the naked eye (see Figure 1). Their research provided a reference for subsequent researchers. Han et al. [6] studied the changes in urban light pollution in China from 1992 to 2012. Considering that the data covers a long time and DMSP-OLS has no airborne calibration, the researchers referred to a second-order regression model so that the composite maps of different years can be compared together. They found that the increase in light pollution is mainly located in coastal cities in eastern China, while some industrial inland towns show a downward trend (see Figure 2). Small et al. [7] conducted a spatial analysis of 17 cities worldwide based on DMSP-OLS data. They investigated the halo problem caused by the low resolution of DMSP-OLS and the large overlap between adjacent pixels. They proposed various correction methods and obtained city night brightness maps with smaller errors.

As one of the earliest nights light remote sensing sensors, DMSP-OLS provided a wealth of research data for researchers at the time and a reference method for subsequent light pollution monitoring.

However, the monitoring data is unstable and needs to be updated and iterated due to differences in satellite operation and sensors, as well as the oversaturation and spill of city lights on the sensors.

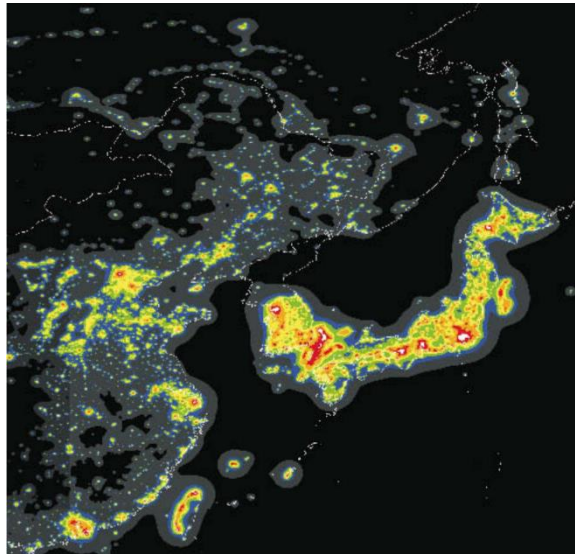


Figure 1. Brightness of the night sky with artificial light in East Asia [5]

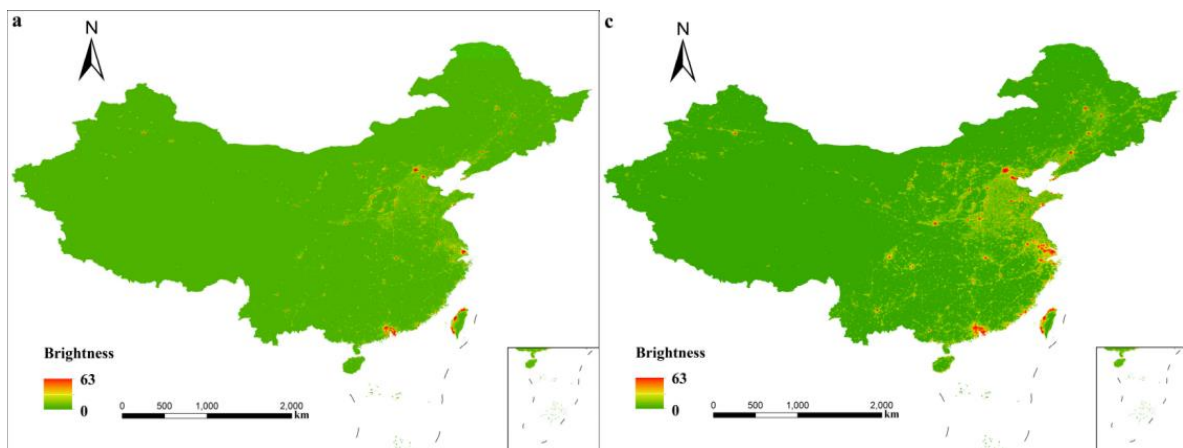


Figure 2. (a) 1992, (b) 2012 images of night light in China [6]

2.2. NPP-VIIRS

On October 28, 2011, NASA and NOAA jointly launched the Suomi-NPP, equipped with five Earth observation sensors, including the VIIRS. This is a visible infrared imaging radiometer. As a new generation sensor to replace DMSP-OLS, it has a spatial resolution of 750m and includes 22 spectral bands from 410nm to 1200nm. It also has a unique DNB that is extremely sensitive to low-light conditions. This marks the beginning of a new era in collecting and applying night brightness data.

NPP-VIIRS is popular among the public. For example, in 2016, Falchi et al. [8] used NPP-VIIRS to draw a global night sky brightness map with higher resolution and accuracy (see Figure 3). Levin et al. [9] analyzed VIIRS data and studied the correlation between night sky brightness and related influencing factors such as population, urban area, GDP index, road network density, snow cover, and vegetation index. Netzel et al. [10] used VIIRS and Landsat images as reference data, combined with field measurement data, based on Berry's [11] model, proposed a method for calculating the night sky brightness in a certain area with high efficiency and high accuracy, finally drew a night sky brightness map with a resolution of 100m over Poland (see Figure 4).

Because urban lighting is transitioning from traditional electric lights to LEDs, the night spectrum is shifting toward blue wavelengths. However, VIIRS is not sensitive to wavelengths below 500 nm, so

the light pollution monitoring results will be low. The OLS detection channel is significantly more sensitive than VIIRS in this band, making it more accurate when monitoring LED lighting.

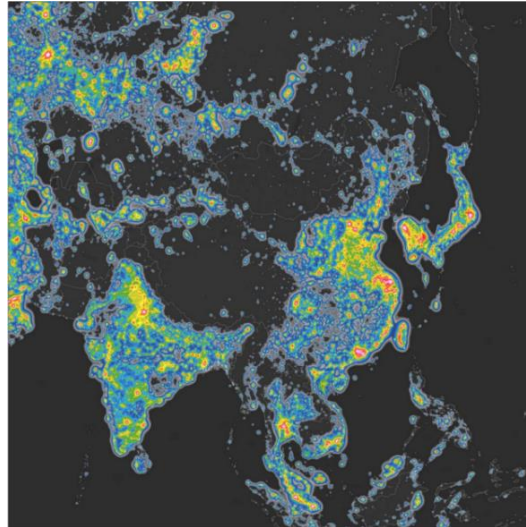


Figure 3. Brightness of the night sky from artificial light sources in East Asia [8]

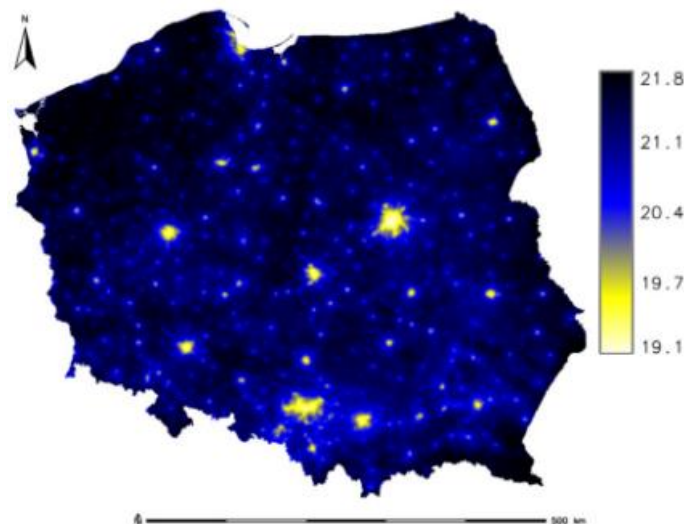


Figure 4. Night sky brightness map over Poland with a resolution of 100m [11]

2.3. EROS-B

EROS-B is a satellite launched by Israel's ImageSat in 2006. It can provide customers with images of up to 0.7m resolution. The EROS-B satellite carries an NA50 camera and uses a CCD-TDI sensor. The spectral resolution covers 400-900nm, and the image scanning width is about 7km. Its high resolution allows researchers to explore light pollution in urban areas further. In addition, EROS-B remote sensing images can be purchased through online platforms, so many researchers have conducted research based on EROS-B, opening up a new way of light pollution monitoring research.

For example, Levin et al. [12] used images of Brisbane, Australia, provided by the EROS-B satellite. The study combined images with data on human activities and land use to successfully explain 89% of the changes in night light (see Figure 5).

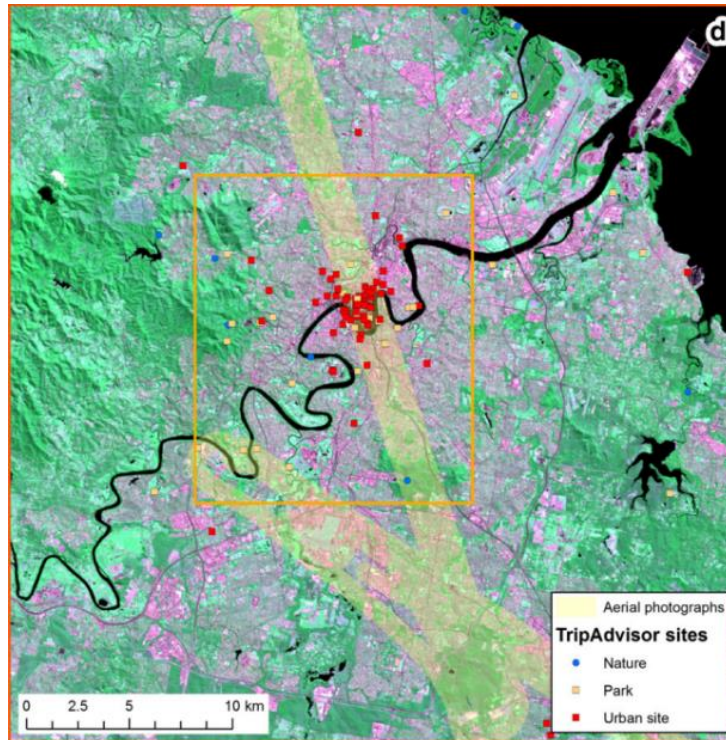


Figure 5. Remote sensing images of night light in Brisbane and the Gold Coast in 2012 [12]

3. Discussion

3.1. Characteristics of Remote Sensing Technology In Light Pollution Monitoring

The remote sensing technology has the following characteristics based on literature review:

First, the spatial scale is large. Researchers can use remote sensing data to monitor light pollution at the regional, national, intercontinental and even global scales. As the resolution is further improved, the research scope is smaller, and the research results are more accurate, so light pollution can be more comprehensively monitored. Secondly, the time scale is wide. Several night light remote sensing sensors have been in operation for more than ten years, allowing researchers to study the annual, quarterly and monthly changes in light pollution in different regions to monitor the temporal distribution of light pollution comprehensively. Finally, remote sensing images from multiple satellites can be combined for comparison and correction, giving full play to the advantages of remote sensing from different satellites, so that the research results are closer to the actual situation.

Although remote sensing satellites have many advantages, they still have some limitations: most remote sensing brightness represents artificial light emitted upward, and it lacks detection of spill light, which results in loss of assessment of light pollution on the ground. In addition, remote sensing data acquisition requires certain channels, so compared with ground measurements or even aerial remote sensing measurements, satellite remote sensing data has limited ability to acquire freedom. For example, EROS-B remote sensing data requires payment, which limits the freedom of researchers.

In addition, due to limitations such as atmospheric conditions, cloud cover, surface reflection, and sensor spatial resolution and spectral band recognition, remote sensing data may have a series of problems such as saturation, overflow, and bias. Therefore, in many cases, it is necessary to combine field measurements, mathematical models, or aerial remote sensing methods for correction. For example, Tang et al. [13] used an iPhone with a CMOS sensor on a volunteer civil airliner to take and process night urban images with a resolution of about 8 meters. Some large research balloons can carry more than 1 ton of load and fly at altitudes far exceeding 30 kilometers. Compared with most remote sensing data, research balloon data has higher resolution, can provide color information, can fly on demand, and can image at night; compared with most aerial surveys, research balloons are

cheaper, easier to repeat, can provide a larger mapping coverage area [14]. In addition, Li et al. [15] used a GM1040 illuminance meter in Nanjing to receive light within a 180° solid angle in the observation direction. Its measurement range was 0 to 200,000 lx. Combined with the LuoJia-1 remote sensing data, they more accurately measured the night light pollution level in Nanjing. Katz et al. [16] referred to Landsat and EROS-B remote sensing data and used the sky quality meter (SQM) device to measure the upward, horizontal, and downward directions of the ground in Jerusalem. They also conducted a comprehensive analysis of the three data types. They found that the bright areas on the EROS-B remote sensing image were highly correlated with regions with low vegetation coverage and high albedo, emphasizing light pollution recognition.

3.2. Problems and Prospects of Remote Sensing Technology in Light Pollution Monitoring

Human urbanization has not stopped, and light pollution will only become increasingly serious and complex. Therefore, the monitoring technology for light pollution must keep pace with the times. There is still room for improvement in the following aspects of the application of satellite remote sensing technology in light pollution monitoring:

The first is to improve the spatial and temporal resolution. For example, the spatial resolution of the EROS-B satellite has reached 0.7m. Future satellites should have a spatial resolution higher than 1m and a temporal resolution of no more than 1 day. The second is to increase the spectral band range and improve the sensitivity. Today's artificial light source band range is relatively wide, and many visible light remote sensing sensors are not sensitive to low-wavelength bands, which will underestimate the actual light level and cause errors. In addition, the light pollution monitoring method should be improved, the mathematical model, calculation method, and correction method should be further optimized to make the measurement results closer to the actual light level. More data will be open-sourced in the future, and the development of civilian scientific research satellites is encouraged, such as the night light remote sensing satellite launched by Wuhan University in 2018, which can provide researchers worldwide with richer and more accessible data. Combining multiple satellite data with field measurements and aerial remote sensing is also a development trend for light pollution monitoring in the future.

Although light pollution poses many hazards to life and the environment on Earth, unlike other environmental pollution, it can be quantitatively eliminated at any time and has not yet attracted most people's attention. Many regions even measure their level of development by the level of night light. Therefore, light pollution monitoring aims to attract the attention of more people and governments, control the level of light in cities at night, protect the environment, save energy, and develop satellite remote sensing technology to provide more accurate data for light pollution monitoring, making research more accurate and convincing.

4. Conclusion

This paper reviews the application progress of satellite remote sensing technology in urban night light pollution monitoring, focusing on the technical characteristics and application examples of satellites such as DMSP, NPP, EROS-B and LuoJia-1. By comparing the spatial resolution, temporal resolution, spectral range and other parameters of different satellites, this paper explains the role of these satellites in light pollution monitoring, especially their performance in monitoring urban night light brightness and its changing trends on a global scale.

Satellite remote sensing technology has wide spatial coverage and long-term temporal data accumulation in light pollution monitoring. This can help researchers analyze the spatial distribution and temporal changes of light pollution, especially in the context of rapid urbanization. Different satellites have their advantages but face challenges such as insufficient spatial resolution, insufficient sensitivity to specific light bands, and high data acquisition costs.

Future research directions are proposed to improve the accuracy and breadth of monitoring, such as enhancing the spatial and temporal resolution of remote sensing satellites, expanding the spectral

band, optimizing data processing and model correction methods, and opening up more remote sensing data resources. The paper also emphasizes the necessity of combining ground measurements, aerial remote sensing and multi-source satellite data to improve the overall accuracy of light pollution monitoring.

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