Study on the Temporal and Spatial Pattern Differences of Chinese Light Curl Based on DMSP/OLS

Xiaowei Wang¹, Hui Cheng¹*  
¹School of tourism, Shandong Women’s University, Jinan, China  
*Corresponding author e-mail: chenghuiwhu@163.com

Abstract. Nighttime light data can detect surface gleams that can intuitively reflect human socioeconomic activity. This paper uses the DMSP/OLS nighttime lighting data from 2001 to 2007 to analyze the coupling relationship between regional economic development and nighttime light intensity in China using regression model. The results show that the brightest areas of nighttime light are mainly concentrated in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Pearl River Delta region. With the change of the year, the brightness of the three regions is brighter year by year, indicating that the economy is more and more developed. The linear regression model of total brightness and GDP of regional light: Y=792.218+0.024X, linear slope is 0.024, indicating a positive correlation trend. The provinces and cities with the highest total brightness of the provinces and cities are Guangdong Province, Shandong Province, and Jiangsu Province, and the lowest provinces and cities are Qinghai Province and Tibet Autonomous Region. The total brightness of regional lights in China's provinces and cities is well coupled with GDP. The total brightness of regional lights in all provinces and cities is weakened from east to west. The brightness of the 11 provinces in the eastern region is the strongest, including Beijing, Tianjin, Hebei, Liaoning, Shanghai, and Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan Province. The second most powerful lighting is the eight provinces in the central region including Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The weakest lighting is in the western regions of Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Inner Mongolia and other provinces (cities). In the east of the Hu Huanyong line, the nighttime lighting is higher than the west of the Hu Huanyong line. The eastern part of China's seven geographical divisions (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian, and Taiwan) has the brightest night lights. The northwestern region (Shaanxi, Gansu, Qinghai, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region, and Inner Mongolia Autonomous Region) has a weak night light. The brightness information of nighttime remote sensing data selected in this study can reflect the level of regional economic development.

1. Introduction  
The continuity of nighttime lights in time and space can make up for the shortcomings of statistical data with different calibers and incomplete data. The nighttime lighting data is simple in form and rich in connotation, which can effectively overcome the shortcomings of single indicators and multiple indicators. Nighttime light data can detect surface gleams that can intuitively reflect human socioeconomic activity[1]. Since the reform and opening up in 1978, China's economy has continued to develop rapidly, and its comprehensive national strength has increased remarkably. Different economic regions have shown a good running trend of sustainable development. Since 1990, with the rapid growth of China's economy, the growth of different economic regions has shown obvious
differences, and the gap between various economic regions has been expanding. The problem of regional development imbalance has become a major challenge for China's social and economic development, and it is also a hot spot in academic research.

The development of space remote sensing technology and the increasing enrichment of remote sensing satellite data provide a new way to use remote sensing to study regional economic development. The application of remote sensing technology to regional economic development has been in China for a long time, but it is mainly concentrated in small-scale urban research on land use classification, land change detection, urban spatial expansion and ecological environmental benefits. Studies, especially in large-area and even nationwide economic development studies, have relatively few applied research on remote sensing. The reason may be due to the lack of remote sensing satellite data suitable for large spatial scales and capable of effectively studying economic development. According to the research results of scholars in large-scale space, it can be concluded that there is a clear correlation between economic activities\[2,3\] and nighttime light distribution, and the feasibility of applying nighttime lighting data to economic analysis\[4\]. Nighttime light data can detect different intensity of light produced by cities, small-scale residential areas, etc.\[5\], which is a better data source reflecting the intensity of human activities.

The Operational Linescan System (OLS) sensor on the US Meteorological Satellite Program (DMSP) provides a new means of data acquisition for large-scale socioeconomic development research. The DMSP/OLS sensor can work at night and can detect it. The low-intensity lights emitted by city lights and even small-scale residential areas, traffic, etc., make it clearly distinguishable from the dark background. In this paper, the GIS platform is used to extract the nighttime lightness data of each provincial administrative unit of DMSP/OLS. According to the characteristics of the remote sensing data, the spatial information is mined, and the GDP data of each provincial administrative unit is analyzed to verify the night light. The data shows the applicability of economic development level on the provincial scale. Finally, combined with nighttime lighting data, it analyzes the level of provincial economic development in China.

2. Data and methods

2.1. Research area

This study is based on 31 provincial administrative divisions (excluding Hong Kong, Macao and Taiwan). China is located in the eastern part of Asia, on the west coast of the Pacific Ocean. The territorial sea consists of the Bohai Sea (Inland Sea) and the Yellow Sea, the East China Sea and the South China Sea. China is located between 3°51′-53°33′north latitude and 73°33′-135°05′east longitude. It is about 5200km long from east to west and 5500km wide from north to south. The total area of the territory is about 14.3 million square kilometers. The land area is 9.6 million square kilometers. The coastline of the eastern and southern continents is more than 18,000 kilometers, and the waters of the inland sea and the frontier sea are about 4.7 million square kilometers. China's terrain is high in the west and low in the east. It is complex and diverse. The proportion of various terrains to the national land area is 33.3% in the mountains, 26% in the plateau, 18.8% in the basin, 12% in the plain, and 9.9% in the hills. The terrain forms a three-level ladder from the west to the east: the western part has the highest Tibetan Plateau in the world. It has the highest terrain and more than 4,000 meters above sea level. It consists of extremely high mountains and plateaus. It is known as the “roof of the world” and is the first step. The Kunlun Mountains, the Qilian Mountains, the Hengduan Mountains and the second-level steps are bounded; the east of the Qinghai-Tibet Plateau is the second step between Daxing'anling, Taihang Mountain, Wushan and Xuefeng Mountain. The altitude is generally 1000-2000 meters, mainly from the mountains, Plateau and basin composition; the broad plains and hills in eastern China are the third step.
2.2. Research data

The basic geographic data used in this study is mainly the provincial administrative division boundary vector data. The socio-economic statistics are mainly the annual GDP data of the provincial administrative units. The GDP statistics are derived from the China Statistical Yearbook. In ArcGIS 10.2 software, vector data is uniformly converted into China_Lambert_Conformal_Conic projection coordinate system. Then, fields of each year's GDP data and nighttime light remote sensing brightness information are established in the vector data of each provincial administrative unit, and the corresponding data is input into the spatial database for later data analysis and processing. The DMSP/OLS nighttime remote sensing data used in this study is an image obtained by the OLS (Operational Linescan System) sensor mounted on the US Military Meteorological Satellite (DMSP). DMSP/OLS nighttime lighting data is sourced from the National Geophysical Data Center website (http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html), which is corrected for the effects of accidental noise such as clouds and flares. Direct averaging of visible light and NVIR channel gray values throughout the year. The data is converted and image-cut with the support of ArcGIS 10.2 software, and combined with the existing research results, the lighting area reflecting the socio-economic status of the study area is extracted.

DMSP/OLS data provides a new means of data for large-scale socioeconomic development research. DMSP/OLS differs from LANDSATTM, SPOT HRV and NOAA AVHRR sensors that use features to monitor the reflected radiation characteristics of sunlight. The OLS sensor can work at night, detecting low-intensity lights from urban lights and even small-scale residential areas, traffic, etc., making it distinct from the dark background of the night [41], which has comparable spatial and temporal resolution to AVHRR. It is more suitable for dynamic monitoring of macroeconomic development. The DMSP satellite crosses the equator at 10:50 and 22:50 local time. It flies at 14 tracks per day. Each OLS sensor can capture images of global night and daytime. The entire satellite system can provide 4 globals a day. Observations of the time period: dawn, day, dusk and night. The DMSP satellite was first equipped with an OLS sensor in September 1976. The sensor has two channels: (1) visible light, near-infrared channel, band range 0.40-1.10 um, gray value range 0-63; (2) thermal infrared channel, The band range is 10.0-13.4 um and the gray value range is 0-255. The OLS sensor acquires an image width of 3000 km and a full resolution data (Full Resolution) with a spatial resolution of 0.56 km.

2.3. Research method

In order to test whether the brightness information of nighttime remote sensing data reflects the economic development level of the region, this study conducts a linear regression analysis based on the extracted nighttime light intensity data and the GDP data of each provincial administrative unit to explore the relationship between the two.

The linear regression model focuses on a particular variable y (dependent variable), while the other variable x (independent variable) is considered as a factor affecting this variable, and the relationship between the variables is expressed through appropriate mathematical models. The value of the dependent variable is predicted by the value of an independent variable. In the regression analysis, the linear relationship between the dependent variable y and the independent variable x, and the equation describing how the dependent variable y depends on the independent variable x and the error term is called the regression model. A linear regression model involving only one independent variable can be expressed as:

\[ y = \beta_0 + \beta_1 x + \varepsilon \]  

\( \beta_0 \) and \( \beta_1 \) is the parameter of the model.

In a linear regression model, y is the linear function of x (\( \beta_0 + \beta_1 x \)) plus the error term \( \varepsilon \). \( \beta_0 + \beta_1 x \) reflects linear changes in y due to changes in x. \( \varepsilon \) is a random variable called an error term,
which is the influence of a random factor other than the linear relationship between \( x \) and \( y \) on \( y \), and is the variability of \( y \) that cannot be explained by the linear relationship between \( x \) and \( y \).

3. Results and discussion

3.1. DMSP/OLS night light data processing results

In the ArcGIS 10.2 software, the pixel gray value of the study area light data is calculated, and the final 3D DMSP/OLS night light data processing result of the research area is extracted by the threshold value. It can be clearly seen from the map that the brightest areas of nighttime lights are mainly concentrated in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Pearl River Delta region. And with the change of the year, the brightness of the three regions is getting brighter year by year, indicating that the economy is also more and more developed. From the distribution of nighttime light values, the brightness of the lights is in the east > central region > western region. The eastern regions are mainly 11 provinces (cities) such as Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The central region is mainly composed of 8 provinces (cities) such as Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. There are 12 provincial administrative regions in the western region, namely Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, and Inner Mongolia. In the east of the Hu Huanyong line, the nighttime lighting is higher than the west of the Hu Huanyong line. According to the comparison of the seven geographical divisions of China's natural geographical division, the nighttime lights in East China (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian, and Taiwan) are the brightest. The second nighttime lighting intensity is in North China (Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia Autonomous Region). The third nighttime lighting intensity is in southern China (Guangdong Province, Guangxi Zhuang Autonomous Region, Hainan Province, Hong Kong Special Administrative Region, Macao Special Administrative Region). The northwestern region (Shaanxi, Gansu, Qinghai, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region, and Inner Mongolia Autonomous Region) has a weak night light.

3.2. Regional lighting total brightness and GDP index calculation

On the basis of pre-processing of nighttime remote sensing data, the total brightness information of each province and city area is calculated, and the total brightness of regional lights in each province and city, and the total brightness and GDP of each area are calculated. Through data analysis, the total brightness of the regional lights in each year is significantly positively correlated with GDP. In 2001, the provinces and cities with the highest total brightness of the provinces and cities were Guangdong Province, Shandong Province, and Jiangsu Province. The highest GDP was in Guangdong Province, Jiangsu Province, and Shandong Province. The provinces and cities with the lowest total brightness of provinces and cities are Ningxia Hui Autonomous Region, Qinghai Province and Tibet Autonomous
Region. The lowest GDP is also Ningxia Hui Autonomous Region, Qinghai Province and Tibet Autonomous Region. In 2004, the provinces and cities with the highest total brightness of the provinces and cities were Guangdong Province, Shandong Province and Jiangsu Province. The highest GDP was in Guangdong Province, Jiangsu Province and Shandong Province. The provinces and cities with the lowest total brightness of provinces and cities are Guizhou Province, Qinghai Province and Tibet Autonomous Region. The lowest GDP is Ningxia Hui Autonomous Region, Qinghai Province and Tibet Autonomous Region. In 2007, the provinces and cities with the highest total brightness of the provinces and cities were Guangdong Province, Jiangsu Province and Shandong Province. The highest GDP was in Guangdong Province, Jiangsu Province and Shandong Province. The provinces and cities with the lowest total brightness of provinces and cities are Guizhou Province, Qinghai Province and Tibet Autonomous Region. The lowest GDP is Ningxia Hui Autonomous Region, Qinghai Province and Tibet Autonomous Region. From the perspective of three years, the status of GDP in the three provinces of Guangdong, Jiangsu and Shandong provinces is completely matched with the total brightness of regional lights in 2007.

3.3. Construction of regional light total brightness regression model

In 2001, 2004 and 2007, the regional total brightness and GDP statistical indicators of provincial administrative units were sampled, and a remote sensing estimation model of GDP at the provincial level was established. The estimation model is as follows.

The linear regression model based on the total brightness and GDP of the regional light can fit the sample point well, \( Y = 792.218 + 0.024X \), where \( Y \) represents GDP, \( X \) represents the total brightness of the regional light, and the linear slope is 0.024, indicating a positive correlation trend. The coefficient of \( R^2 = 0.720 \) can be determined, indicating that the total brightness of the area light can explain about 72% of GDP change. From the regression analysis results, it can be seen that the DMSP/OLS nighttime light remote sensing data is suitable for the study of regional economic development. The total brightness data of regional lights in this study can reflect the level of regional economic development.

3.4. Provincial level analysis based on total brightness of regional lights

By comparing the total brightness of the regional lights and GDP levels in China's provinces and cities from 2001 to 2007 on the provincial scale, it can be seen that between 2001 and 2007, China's economic development showed the following typical characteristics. (1) The level of comprehensive economic development is centered on Beijing, Shanghai, and Guangdong, and decreases from the eastern coast to the western interior. In particular, the semi-annular area gradually extending from the Beijing-Shanghai line to the west is more obvious. (2) The radiation range of Beijing and Shanghai is larger than that of Guangdong. The economic development level between Beijing and Shanghai and surrounding provinces is relatively high, such as: Shandong, Jiangsu, Zhejiang, Tianjin, Hebei, Liaoning, etc. Only Fujian has a slightly higher level of economic development around Guangdong. As the economic center of South China, Guangdong should further promote the development of surrounding cities and regions and contribute to the realization of common prosperity. (3) From the perspective of three years of economic development, the economic development level of most regions has increased, such as: Beijing, Tianjin, Shandong, Jiangsu, Jilin, Shanxi, Inner Mongolia, etc. However, there are also some areas where the level of economic development has declined, such as Yunnan, Xinjiang, and Tibet. The total brightness of regional lights in China's provinces and cities is well coupled with GDP. The total brightness of regional lights in all provinces and cities is weakened from east to west. The brightness of the 11 provinces in the eastern region is the strongest, including Beijing, Tianjin, Hebei, Liaoning, Shanghai, and Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan Province. The second most powerful lighting is the eight provinces in the central region including Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The weakest lighting is in the western regions of Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, Inner Mongolia and other provinces (cities). The study of provincial
economic development level using nighttime remote sensing data shows that the typical characteristics of China's economic development are the same as those obtained in previous studies. The nighttime light remote sensing data can reflect the economic development level of the provincial administrative units.

4. Conclusion
The balanced development of the economy is an important part of social and economic construction. The overall grasp of the level of economic development on the macro scale is the primary task of resolving the gap in the level of regional economic development. Therefore, the level of economic development in different regions is evaluated, and the spatial distribution and time are analyzed. The changing characteristics have become the first step in studying regional economic differences. Based on the systematic review and summarization of the research status of economic development level at home and abroad, this paper uses DMSP/OLS remote sensing image data and socio-economic statistical data to analyze the brightness information of nighttime remote sensing data and the linear regression analysis of GDP of each province and city. The evaluation and analysis of the economic development level of China's provincial administrative units are carried out. In the east of the Hu Huanyong line, the nighttime lighting is higher than the west of the Hu Huanyong line. The eastern part of China's seven geographical divisions (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian, and Taiwan) has the brightest night lights. The research results confirm that the DMSP/OLS nighttime remote sensing data can reflect the economic development of the region well, and its practicability is very strong.

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