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Development of Time Series of Nighttime Light Dataset of China (2000–2020)

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Abstract: Nighttime light image data are a reflection of the brightness of the earth's surface light at night and represent the intensity of human activity. The long time series of nighttime light data provide an important reference for urban development. Based on version 4 of the Defense Meteorological Satellite Program Operational Linescan System (DMSP/OLS) nighttime light data and monthly Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (NPP/VIIRS) nighttime light data, the long time series nighttime light dataset of China (2000–2020) has been developed based on the use of data pretreatment, data correction and data fusion from the annual DMSP/OLS (2000–2013) nighttime light data and the monthly NPP/VIIRS (April 2012 to December 2020) nighttime light data. The dataset consists of four parts: (1) the revised EANTLI nighttime data from 2000 to 2013; (2) the processed monthly NPP/VIIRS nighttime light data from April 2012 to December 2020; (3) the annual NPP/VIIRS nighttime light data from 2012 to 2020; (4) the annual EANTLI_Like nighttime light data from 2000 to 2020. The spatial resolution of the monthly and annual NPP/VIIRS nighttime light data is 500 m, and for the others it is 1 km. The dataset is archived in .tif data format and consists of 750 data files of data size 2.21 GB (compressed into 1.71 GB in 6 files).

Keywords: DMSP/OLS; NPP/VIIRS; nighttime light remote sensing; data fusion

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1 Introduction

Nighttime light data offer the ability to measure the intensity of light emitted by sources on the earth's surface at night such as urban lighting and natural fires, which reflect the characteristics of urban lighting and natural sources[1]. Nighttime light data are large-scale and multi-temporal, and they may serve to characterize the intensity of human activities. Nowadays, nighttime light data from global satellite observations have been used widely as the geospatial data product[2]. As the most common nighttime light data, the DMSP/OLS and NPP/VIIRS data are widely used to assess urban sprawl, air pollution, and serve as an estimation of socio-economic indicators[3–5]. Given the differences in the sensors, the temporal-spatial resolution, the data processing methods, and the meaning of the pixel values between DMSP/OLS and NPP/VIIRS data, it is difficult to realize a reliable integration of long time series nighttime light data[6]. The aforementioned issues seriously limit the potential applications of nighttime light data and can impact on the research based on night light data.

The dataset described in this study was based on the collection of DMSP/OLS (2000–2013) and monthly NPP/VIIRS (April 2012–December 2020) data. The EANTLI data and the annual NPP/VIIRS data were obtained by procession of annually DMSP/OLS data correction and annual NPP/VIIRS data synthesis from monthly data. The long time series EANTLI_Like data were obtained by fusion of the EANTLI data and the annual NPP/VIIRS data. This dataset can be used as a research tool for research in urban development and provide basic support for research on urban planning, urban expansion, urban contraction, and urban structure.

2 Metadata of the Dataset

The metadata of the Long time series nighttime light dataset of China (2000–2020)[7] are summarized in Table 1. The metadata include the full name of the dataset, the short name, the authors, the year of the dataset, the temporal resolution, the spatial resolution, the data format, the data size, the data files, the publisher of the data, and the data sharing policy, etc.

3 Methods

3.1 Data Collection

The DMSP/OLS data selected for this study were obtained from 22 stable sources of light data from different sensors over the period 2000 to 2013 (e.g., F14, F15, F16, and F18), and were downloaded from the National Centers for Environmental Information of National Geophysical Data Center (NGDC)[1]. The monthly NPP/VIIRS data were produced by the Earth Observation Group (EOG) at the Payne Institute for Public Policy at the Colorado School of Mines and downloaded from the website of the EOG[2].

The mean annual enhanced vegetation index (EVI) data were used for correction of the saturation of the DMSP/OLS to minimize the saturation problem. The mean annual EVI data were produced from the MOD13A1 EVI data using Google Earth Engine.

3.2 Algorithm Principle

In this study, the DMSP/OLS and NPP/VIIRS data were used mainly to produce multiple

[1] National Centers for Environmental Information. https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

[2] The website of EOG. https://eogdata.mines.edu/products/vnl/.

nighttime light data over the period 2000 to 2020 by data preprocessing, correction and fusion.

Table 1 Metadata summary of the Long time series nighttime light dataset of China (2000–2020)

Items	Description			
Dataset full name	Long time series nighttime light dataset of China (2000–2020)			
Dataset short name	NTLChina_2000-2020			
Authors	Zhong, X. Y., School of Environment and Spatial Informatics, China University of Mining and Technology, 851676389@qq.com Yan, Q. W., Observation and Research Station of Ministry of Education for Resource Exhausted Mining Area Land Restoration and Ecological Succession, China University of Min-ing and Technology, yanqingwu@cumt.edu.cn			
Geographical region	China	Year	2000–2020	
Temporal resolution	Monthly, annually	Spatial resolution	500 m, 1,000 m	
Data format	.tif	Data size	2.21 GB (1.71 GB after compression)	
Data files	EANTLI nighttime data from 2000 to 2013; monthly NPP-VIIRS nighttime light data from April 2012 to December 2020; annual NPP-VIIRS nighttime light data from 2012 to 2020; annual EANTLI-Like nighttime light data from 2000 to 2020			
Foundations	The Fundamental Research Funds for the Central Universities (2021ZDPY0205); The National Special Project for Basic Science and Technology (2014FY110800); National Natural Science Foundation of China (42101459)			
Computing environment	ArcGIS, Google Earth Engine, Origin			
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn			
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China			
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the ‘ten per cent principal’ should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[8]			
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS			

3.2.1 DMSP/OLS Data Procession

The EANTLI data of 2000–2013 were obtained by data preprocessing, mutual correction and correction for saturation of the DMSP/OLS data. Mutual correction includes multi-sensor correction[9], annual fusion, and comparable correction for the time series data[10]. To alleviate the saturation effect of the DMSP/OLS, the enhanced vegetation index adjusted NTL index (EANTLI) [11] was used after mutual correction of the DMSP/OLS data of 2000 to 2013. The index can be expressed mathematically by the following equation:

$$EANTLI = \frac{1+(nNTL-EVI)}{1-(nNTL-EVI)} \times NTL \qquad (1)$$

where *NTL* represents the *DN* value of the DMSP/OLS data and *nNTL* is the normalized *NTL*, and *EVI* indicates the mean annual EVI value. The differences between the monthly dark images and the average annual number of dark images at the 95% split points in the NPP / VIIRS monthly data dark pixel histogram coincide.

3.2.2 NPP/VIIRS Data Procession

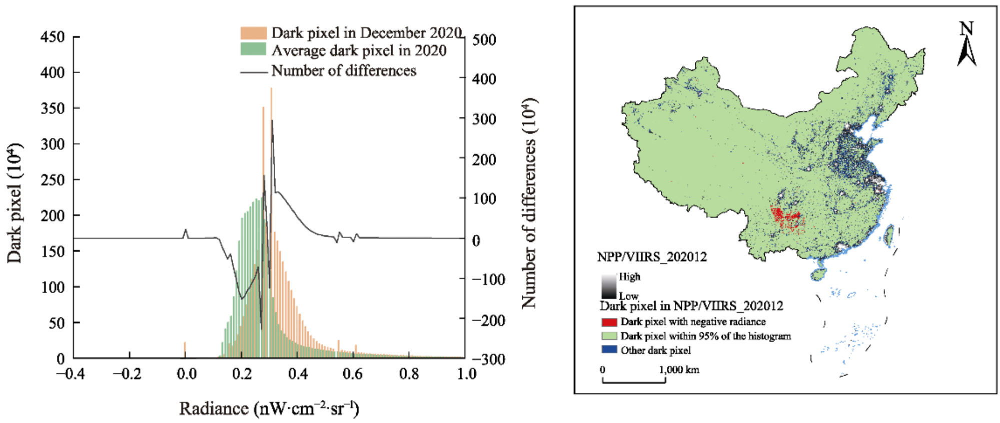
The monthly NPP/VIIRS data of April 2012 to December 2020 and the annual NPP/VIIRS data of 2012–2020 were compiled using data preprocessing, outlier processing and annual synthesis based on the median values. Outlier processing included noise reduction and treatment of extreme values.

During the noise reduction of the monthly NPP/VIIRS data, it was found that the difference between the dark pixel (values below 1 nW·cm^{-2}·sr^{-1}) of the monthly NPP/VIIRS data and the average annual NPP/VIIRS in the 95% split point of the histogram was found to be consistent. Due to this, Noise Reduction Based on Flexible Threshold (NRBFT) was adopted to remove the noise whereby the 95% split point in the dark pixel histogram was taken as the minimum threshold for the dark pixel.

$$DN(n,i) = \begin{cases} 0 & DN(n,i) < TH \\ DN(n,i) & \text{otherwise} \end{cases} \tag{2}$$

where $DN_{(n,i)}$ represents the pixel radiance of the NPP/VIIRS data, and TH indicates the minimum threshold (the 95% split point in the dark pixel histogram) between normal dark pixel and the noise.

Taking the NPP/VIIRS data of December 2020 as an example, the difference between the dark pixels of the NPP/VIIRS data of December 2020 and the average NPP/VIIRS data of 2020 at the 95% split point of histogram was consistent (Figure 1a). This meant that the 95% split point of histogram can separate most of the noise. This also showed that the dark pixels within 95% of the histogram points contain most of the noise and rest of the dark pixels are normal pixels distributed around the bright pixels (Figure 1b).



(a) Numerical distribution (b) Spatial distribution

Figure 1 Distribution of dark pixels of the NPP/VIIRS image in China in December 2020

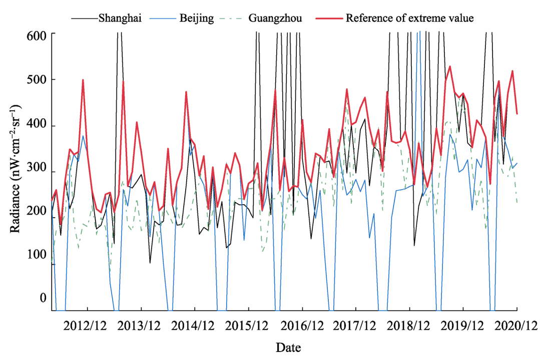


Figure 2 Monthly maximum value of NPP/VIIRS

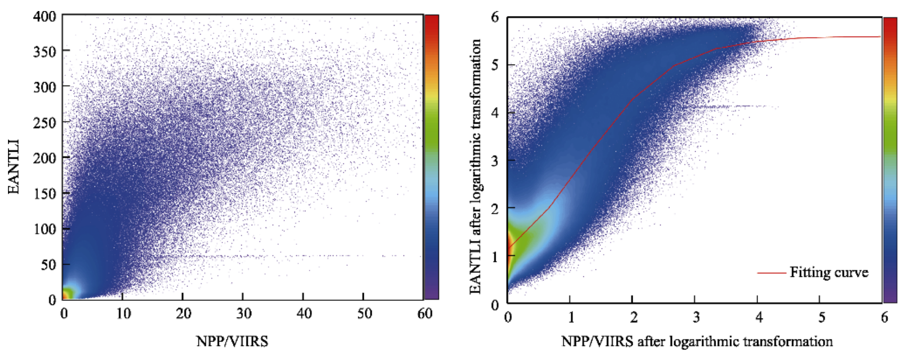
The monthly NPP/VIIRS data have some extremely high brightness pixels due to the influence of abnormally high reflective surface. Therefore, it is necessary to include extremely high values in the image. It is presumed that the nighttime light in other urban areas do not exceed the maximum nighttime light emanating from the center of megacities (Shanghai, Beijing, and Guangzhou)[12]. Abnormal pixels whose intensity values exceeded extreme values were removed dynamically using 5 × 5 mean filtering. Figure 2 showed that the monthly maximum value in Shanghai, Beijing and Guangzhou and extreme value reference values used in extreme value treatment.

3.2.3 Data Fusion of Long Time Series Nighttime Light Data

In traditional research, it is difficult to combine both the accuracy and high dynamic range of the values at different data. Long time series nighttime light data fusion has been proposed based on the EANTLI and NPP/VIIRS data. First, the annual NPP/VIIRS synthetic data were resampled spatially based on the kernel density[13]. This data treatment can make uniform the spatial resolution of the different nighttime light data. Then, the brightness value attributes of the nighttime light data were unified by logarithmic transformation, construction of the fitting model and exponential transformation. Finally, the long time series EANTLI_like data were obtained by continuity correction of the time series nighttime light data of 2000 to 2020[10]. As shown in Figure 3, a characteristic “S”-shaped curve between the EANTLI data and the annual NPP/VIIRS data may be obtained after logarithmic transformation. Therefore, the logistic model with “S”-shaped curve characteristics can be used for the fitting model, and the Boltzmann function (Equation 3) gives the best fit.

$$\log EANTLI_i = A + \frac{A-B}{1+e^{(\log NPP/VIIRS_i - C)/D}} \tag{3}$$

where log*NPP/VIIRS* represents the pixel value of the NPP/VIIRS data after logarithmic transformation, and log*EANTLI* is the pixel value of the EANTLI_Like data after logarithmic transformation, and which were obtained by fitting the Boltzmann function to the NPP/VIIRS data after logarithmic transformation. A, B, C and D are parameters in the Boltzmann function, the values being –1.395,1, 6.966,3, 1.125,7, and 1.304,4 after fitting, respectively.



(a) Scatter density plots between EANTLI and NPP/VIIRS

(b) Scatter density plots between EANTLI and NPP/VIIRS after logarithmic transformation

Figure 3 Scatter density plots of nighttime light image in China in 2013

3.3 Technical Route

As outlined in Figure 4, the main development process for the dataset consists of the following. First, the annual DMSP/OLS data (annual EANTLI data) are obtained by data preprocessing, mutual correction, and saturation correction of the DMSP/OLS image (2000–2013). At the same time, the annual NPP/VIIRS data (2012–2020) are composed by data preprocessing, outlier processing and annual synthesis based on the median values. The annual EANTLI data and NPP/VIIRS data are used in order to combine the long time series nighttime light data (EANTLI_Like data), including integration of the spatial resolution, construction of the fitting model and continuity correction of the time series of the two types of nighttime light data.

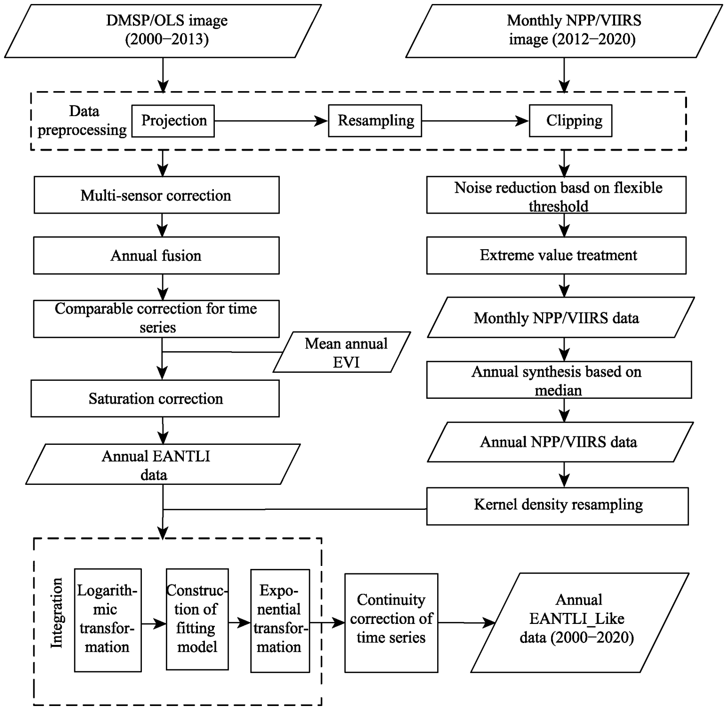


Figure 4 Flowchart for data processing

4 Data Results and Validation

4.1 Data Composition

The long time series nighttime light dataset of China includes mainly the annual EANTLI dataset of 2000–2013, the monthly NPP/VIIRS dataset of April 2012–December 2020, the annual NPP/VIIRS dataset of 2012–2020 and the EANTLI_Like dataset of 2000–2020 (Table 2).

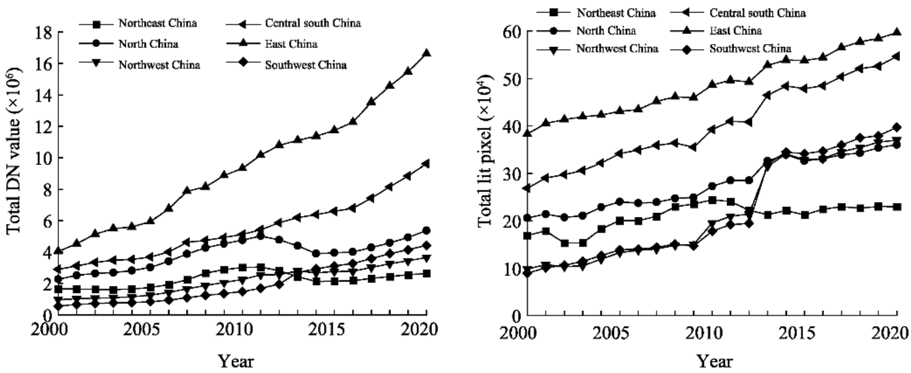
Table 2 Composition of dataset and description

Folder name	Nomenclature	Data introduction	Data format	Data record	Data size
EANTLI_2000-2013	EANTLI_yyyy	EANTLI data of yyyy	.tif	14	122 MB
NPP_VIIRS_201204-201412	NPP_VIIRS_yyyymm	Monthly NPP/VIIRS data of mm, yyyy	.tif	105	1.26 GB
NPP_VIIRS_2012-2020	NPP_VIIRS_yyyy	NPP/VIIRS data of yyyy	.tif	9	121 MB
EANTLI_Like_2000-2020	EANTLI_Like_yyyy	EANTLI_Like data of yyyy	.tif	21	219 MB

Notes: Each dataset consists of five files. Where .tif is the image file, .tfw is the image coordinate file, tif.ovr is the pyramid file, tif., .aux, .xml is the auxiliary image file, and .tif, .xml is the text information of the image.

4.2 Data Results

To reveal the trend of nighttime light, the total DN values and the total illuminated pixels in the six regions of China were divided into statistical groups. Except for northeast China and north China, the total DN values in the other four regions all showed a continuous upward trend, among which the total DN value for east China which had a more developed economic level increased the most. The combined total DN value in northeast China and north China both declined somewhat during 2011–2014, probably due to a decreased population and a decrease in the urban night vitality in the northern region of China during this period (Figure 5a). In addition to northeast China, the total lit pixels in the other five regions showed an increasing trend, among which the total lit pixels in northwest China and southwest China increased significantly between 2012 and 2013 (Figure 5b). This may have been caused by the rise of infrastructure construction in the western region. In addition, because the spatial resolution for the NPP/VIIRS raw data is higher than that for the DMSP/OLS data, more small nighttime light areas in the western region may have been retained. The total number of lit pixels in Northeast China dropped significantly for many times, which indicates that there was not only a loss of population, but also the phenomenon of urban contraction, whereby the nighttime light in some areas had become dimmer or even disappeared.



(a) Total DN value (b) Total lit pixels

Figure 5 Nighttime light changes in the six regions of China

4.3 Data Validation

The time series of nighttime light data (EANTLI_Like data) obtained in this study were compared with that of Chen[14]. Due to the different spatial resolutions of the EANTLI_Like data and the NPP/VIIRS_Like data, more attention needs to be paid to the change rather than the size of the values. It was shown that the mean value, the standard deviation, the information entropy, and the average gradient of the EANTLI_Like data were larger than those for the NPP/VIIRS_Like data. The trend for the various indicators of the EANTLI_Like data was relatively smooth, and shows a stable upward trend, while the indicators for the NPP/VIIRS_Like data have certain fluctuations, and the changes are irregular (Figure 6).

The nighttime light data are highly correlated with the socio-economic data, and Figure 7 shows the comparison between the EANTLI_Like data and the NPP/VIIRS_like data and including the linear regression coefficients R^2 for the GDP and electricity consumption at the provincial level. Except for 2018–2020, the R^2 value for EANTLI_like and GDP was better than that for the NPP/VIIRS_Like data. The mean R^2 values for both datasets were 0.851,6 and 0.787,7, respectively. This means that compared to the NPP/VIIRS_Like data, the correlation between the EANTLI_Like data and the GDP at the provincial scale was increased significantly (Figure 7a). The R^2 value for the EANTLI_Like data and power consumption was always higher than that for the NPP/VIIRS_Like, with average values of 0.859,7 and 0.768,9, respectively. This means that the EANTLI_Like data are more relevant for gauging the socioeconomic parameters at the provincial level (Figure 7b).

5 Discussion and Conclusion

The long time series nighttime light dataset for China was obtained by image correction and

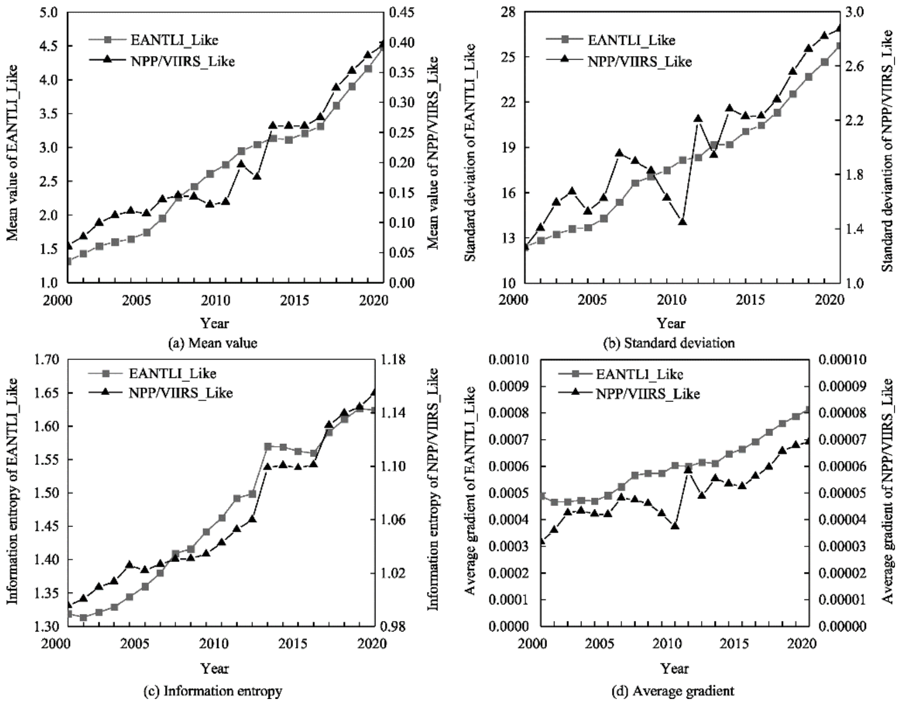


Figure 6 Statistical attributes of time-series of nighttime light images

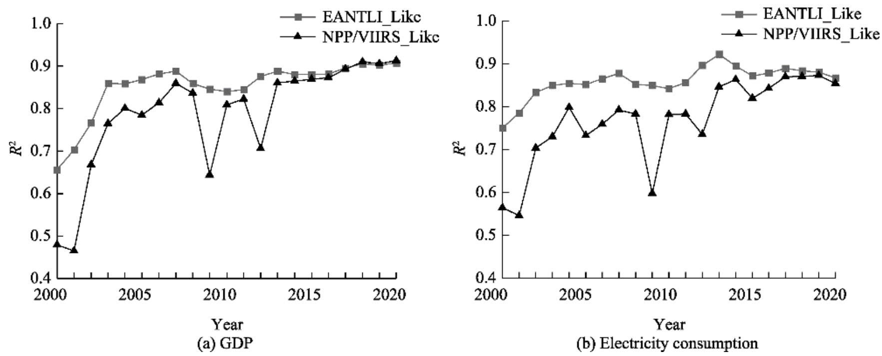


Figure 7 Determinations of the linear regression coefficients for GDP, electricity consumption and time-series of nighttime light data at the provincial scale

data fusion based on processing the annual DMSP/OLS data and the monthly NPP/VIIRS data. The EANTLI data, and the monthly and annual NPP/VIIRS data were uploaded to share as interim development. The dataset covered all the annual nighttime light images for 2000–2020 and the monthly nighttime light images for April 2012–December 2020. The NRBFT was adopted for processing outliers in the monthly NPP/VIIRS data. This method can remove most of the noise and retain the normal dark pixels without other auxiliary data.

When constructing the long time series nighttime light data, existing studies have mostly built models based on DMSP/OLS and NPP/VIIRS data and achieved DMSP/OLS_like data with low resolution[13], or combined EVI data to obtain NPP/VIIRS_like data using machine learning with high resolution[14]. The former does not deal with the saturation effect of the DMSP/OLS data but does reduce the range of brightness of the NPP/VIIRS data. It is difficult to take full advantage of the high dynamic range of the brightness values of the

NPP/VIIRS data. The latter uses machine learning to improve the spatial resolution and the range of brightness values of the DMSP/OLS, however, it is unable process unstable pixels in the time series, and it will have an impact on the temporal continuity of the data. The EANTLI data were realized by combining the EVI data for saturation correction of the DMSP/OLS data, which have a lower saturation effect and a higher dynamic range of brightness values. Continuity correction of the time series was applied after integration of the temporal and spatial resolution between the DMSP/OLS data and the NPP/VIIRS data, which can ensure the consistency of the pixel brightness and remove unstable pixels in the time series.

The time series of nighttime light data of this dataset has strong temporal continuity, and strong correlation with socioeconomic data. Verification of accuracy demonstrates that the dataset is reliable. The dataset can be used to analyze the evolution of urban night light in China and serve in supporting research on urban development, including evaluation of topics such as urban vitality, urban expansion, and urban contraction.

Author Contributions

Zhong, X. Y. was responsible for data processing and analysis and wrote the paper; Yan, Q. W. planned the experimental design and preparation of the final dataset; Li, G. E. was responsible for verification of the data.

Conflicts of Interest

The authors declare no conflicts of interest.

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