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A likelihood-based spatial statistical transformation model (LBSSTM) of regional economic development using DMSP/OLS time-series nighttime light imagery

Chang Li [a], Guie Li [a], Yujia Zhu [a], Yong Ge [b], Hsiang-te Kung [c], Yijin Wu [a,*]

[a] *Key laboratory for Geographical Process Analysis & Simulation, Hubei Province, College of Urban and Environmental Science, Central China Normal University, Wuhan, China*
[b] *State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences & Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[c] *Department of Earth Sciences, University of Memphis, USA*

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ABSTRACT

In a regional economy, the central city of a metropolitan area has a radiative effect and an accumulative effect on its surrounding cities. Considering the limitations of traditional data sources (e.g., its subjectivity) and the advantages of nighttime light data, including its objectivity, availability and cyclicity, this paper proposes a likelihood spatial statistical transformation model (LBSSTM) to invert for the gross domestic product (GDP) of the surrounding cities, using time series of Sum of Lights (SOL) data covering the central city and taking advantage of the economic and spatial association between the central city and the surrounding cities within a metropolitan area and the correlation between SOL and GDP. The Wuhan Metropolitan Area is chosen to verify the model using time series analysis and exploratory spatial data analysis (ESDA). The experimental results show the feasibility of the proposed LBSSTM. The prediction accuracy of our model is verified by cross-validation using data from 1998, 2004 and 2011, based on the 3σ rule. This model can quantitatively express the agglomeration and diffusion effect of the central city and reveal the spatial pattern of this effect. The results of this work are potentially useful in making spatio-temporal economic projections and filling in missing data from

* Corresponding author.
E-mail address: shaka_li@qq.com (Y. Wu).

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some regions, as well as gaining a deeper quantitative and spatio-temporal understanding of the laws underlying regional economic development.

1. Introduction

Statistical data often become important data sources in traditional research on regional economies. The use of this kind of data enables evaluation of the condition of regional economic development objectively, to a certain extent. However, due to the uncertainties involved in obtaining the data, as well as its long refresh cycle, low frequency and high cost, the availability of regional statistical data, especially data covering localized or special regions, is one of the issues that researchers often consider (Ronchi et al., 2002). The nighttime light data collected by the sensors of the Operational Linescan System (OLS), which is carried by the satellites of Defense Meteorological Satellite Program (DMSP), are objective, cyclical, relatively reliable and easy to obtain, and they have been successfully used in many research fields. These applications include the evaluation of the expansion of cities and its underlying mechanisms (Small et al., 2005; Zhang and Seto, 2011; Liu et al., 2012; Ma et al., 2012; Pandey et al., 2013; Chowdhury and Maithani, 2014; Wei et al., 2014; Ma et al., 2015), light pollution (Cinzano et al., 2000; Kuechly et al., 2012), regional populations and population densities (Sutton, 1997; Lo, 2001; Zhuo et al., 2009), emissions of carbon dioxide (Meng et al., 2014; Shi et al., 2016a, b), electricity consumption (Meng et al., 2014), power consumption (Cao et al., 2014), and regular patterns of long-term variations in artificial light (Small and Elvidge, 2013), as well as monitoring forest fires (Chand et al., 2006), mapping urban areas (Imhoff et al., 1997; Elvidge et al., 1999; Zhou et al., 2014), and estimating rural populations without access to electricity (Doll and Pachauri, 2010). They are also used for humanitarian research (Li et al., 2013a). The data are also used to identify the relationships between population, energy consumption (Amaral et al., 2005), electricity consumption, GDP (Wu et al., 2013), various land cover types and SOL (Li et al., 2014). From the perspective of the fields in which it is applied, nighttime light data are widely used in research concerned with the social development of human beings, and they have considerable advantages in analysing the development of societies. Some researchers have also found that nighttime light data have considerable capacity in evaluating and calculating the degree of regional economic development (Doll et al., 2006). The data correlate well with indicators that represent regional economic development, such as GDP (Elvidge et al., 1999; Levin and Duke, 2012; Li et al., 2013b). They are also useable for researching the development process of both regional economies and societies (Levin and Duke, 2012) and representing the degree of development of regional economies, together with other indicators (Keola et al., 2015). In conclusion, pre-existing studies demonstrate that nighttime light data and the degree of regional development are well correlated, and nighttime light data can be regarded as an important data resource in evaluating regional economic development. It has also been shown that there is a significant correlation between SOL and GDP, which provide reliable evidence and a mathematical basis for us to build up an LBSSTM between SOL data covering a central city and the GDP of the surrounding cities.

Metropolitan areas with large cities at their centres are a type of human landscape that coordinates and develops the relationship between human beings and natural environments, and they accompany the great progress gained by human civilization (Chen, 2003). The development of metropolitan areas is increasingly important for regional economies. As the cores of metropolitan areas, central cities play an extremely important role in regional development and have agglomeration and diffusion effects on the surrounding cities. In other words, the central city influences the surrounding cities greatly. For example, the development of metropolitan areas in both the Pearl River Delta and the Yangtze River Delta in China benefits from the radiation effects of the central cities (Yu and Wang, 2011). In addition, the effects of the central cities on the surrounding cities are closely concerned with the degree of development of the surrounding cities (Qian et al., 2015). Based on the preceding discussion, as the global and regional economies develop and become integrated, the importance of