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A review of regional science applications of satellite remote sensing in urban settings

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ABSTRACT

This paper reviews the potential applications of satellite remote sensing to regional science research in urban settings. Regional science is the study of social problems that have a spatial dimension. The availability of satellite remote sensing data has increased significantly in the last two decades, and these data constitute a useful data source for mapping the composition of urban settings and analyzing changes over time. The increasing spatial resolution of commercial satellite imagery has influenced the emergence of new research and applications of regional science in urban settlements because it is now possible to identify individual objects of the urban fabric. The most common applications found in the literature are the detection of urban deprivation hot spots, quality of life index assessment, urban growth analysis, house value estimation, urban population estimation and urban social vulnerability assessment. The satellite remote sensing imagery used in these applications has medium, high or very high spatial resolution, such as images from Landsat MSS, Landsat TM and ETM+, SPOT, ASTER, IRS, Ikonos and QuickBird. Consistent relationships between socio-economic variables derived from censuses and field surveys and proxy variables of vegetation coverage measured from satellite remote sensing data have been found in several cities in the US. Different approaches and techniques have been applied successfully around the world, but local research is always needed to account for the unique elements of each place. Spectral mixture analysis, object-oriented classifications and image texture measures are some of the techniques of image processing that have been implemented with good results. Many regional scientists remain skeptical that satellite remote sensing will produce useful information for their work. More local research is needed to demonstrate the real potential and utility of satellite remote sensing for regional science in urban environments.

Contents

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1. Introduction

Regional science can be defined as a discipline concerned with the study of social, economic, political and behavioral phenomena that have regional or spatial dimensions, using combinations of analytical and empirical research methods (Isard, 1975; Isserman, 2004). The spatial aspect involved in regional science research is what makes remote sensing appealing for extracting spatial data that can be related to the phenomena under analysis. Aerial photography has been used as input data in regional science applications in urban settlements since the late 1950s. The use of this type of remotely sensed data is supported by the hypothesis that the surface appearance of a settlement is the result of the human population's social and cultural behavior and interaction with the environment, which leave their mark on the landscape. Remotely sensed data from satellites can also be used to measure the context of social phenomena, to gather additional contextual data on the environment in which people live, and to measure the environmental consequences of social processes (Rindfuss & Stern, 1998, chap. 1). Lo and Faber (1997) state that it is through greenness (i.e., the amount of green vegetation) that remotely sensed environmental data can be combined with socio-economic census data and list early examples of the use of remotely sensed data for the social analysis of cities. Topics covered in those early studies included social structure and residential desirability (Green, 1957; Monier & Green, 1957), urban poverty (Metivier & McCoy, 1971; Mumbower & Donoghue, 1967), and urban quality of life (Weber & Hirsch, 1992). Mullens and Senger (1969) and Miller and Winer (1984) are also pioneering works that reported relationships between aerial remotely sensed data and demographic, social and economic characteristics of neighborhoods in a city. The application of empirical models to estimate biophysical, demographic and socio-economic variables has been reported as one of the top five recurrent research themes in applications of remote sensing to urban environments (Phinn, Stanford, Scarth, Murray, & Shyy, 2002).

The availability of remote-sensed data has increased significantly as its costs have decreased in the last two decades. These data provide a useful method for mapping the compositions of cities and analyzing changes over time (Weng & Quattrochi, 2006, chap. 4). The unique characteristics of remotely sensed data, such as repeat cycle and wide area coverage, provide means for exploring and testing hypotheses and models about urban areas and for constructing new theories that can help policy makers to analyze and respond to problems that involve urbanization processes (Rashed, Weeks, Stow, & Fugate, 2005). The increasing spatial resolution of commercial satellite imagery has been crucial to the emergence of new studies and applications related to urban settlements because it is now possible to identify the individual objects of the urban fabric, such as individual buildings and details of road networks and open spaces (Sliuzas, Kuffer, & Masser, 2010, chap. 5).[1]

The increased availability of high-resolution remote sensing data can also be considered a response to the growing need for high spatial and temporal resolution data on urban agglomerations.[2] The worlds population is now mostly urban, and information about urban settings, their internal compositions and their dynamics is very important to the preservation of certain standards of living (Phinn et al., 2002). Processes taking place in urban areas are among the main drivers of land change on local to global scales (Herold, 2009, chap. 2). According to the United Nations, the 20th century witnessed the urbanization of the world's population, with the percentage of urban dwellers increasing from 13% in 1990 to 49% in 2005, and this figure is expected to grow to 60% in 2030 (United Nations, 2007, 2008). In 2007, the populations of the Americas, Europe and Oceania were over 70% urban, and those of Asia and Africa were approximately 40% urban. Every year, a larger absolute number of persons is added to the world's urban population; this situation is believed to be more significant in the less developed regions of the world, whose population growth in urban areas is projected to account for almost all of the world population growth between 2005 and 2030 (United Nations, 2008). This situation brings attention to the existing inequities within urban settings. In developing countries, variations in poverty and health within urban areas can be larger than the differences between urban and rural settlements (Montgomery & Hewett, 2005; Stow, Lopez, Lippitt, Hinton, & Weeks, 2007); hence, urban settings need to be studied and monitored at very high spatial and temporal resolutions.

Remote sensing is widely known among urban planners, city planners and policy makers as a useful tool for extracting biophysical information about the urban environment, including land-cover and land-use mapping, urban morphology description and analysis, vegetation distribution and characterization, hydrography and disaster relief. This tool is also widely used in the field of natural resource exploration and management. However, little is known about the detection of the subtle relationships between the physical appearance of the urban landscape and the socio-economic conditions of the population. The data that are currently available from Earth observation systems present an opportunity to collect information about urban settlements at several scales and on several dimensions (Netzband & Jürgens, 2010, chap. 1), and urban population growth and problems will increase in relevance in the coming decades (Sembler, 2006; Stow et al., 2007; Weeks, Getis, Hill, Gadalla, & Rashed, 2004). Therefore, it is important to demonstrate how remote sensing tools can contribute useful information to the study of cities and urban settlements.

The two most recent reviews of the use of remote sensing imagery in research related to socio-economic issues in urban settings are Jensen and Cowen (1999) and Miller and Small (2003). Jensen and Cowen (1999) focused on the technical requirements of remotely sensed data to extract information related to urban and suburban infrastructure and socio-economic attributes. They reviewed only population estimation and quality of life indicators. They stated that one of the most important requirements for detecting those features of interest in the image is the spatial resolution of the remotely sensed data. In the last decade, we have witnessed a large increase in the use of very high-resolution space-borne sensors and programs and the introduction of "government-wide" data purchases, which, in turn, have resulted in an increase in the availability of imagery at very high spatial resolutions. Thus, the spatial resolution requirement has been met, and the temporal resolution issue is becoming more of a budget issue than a technical one. These technological advancements have created a clear opportunity for the regional science community to begin to explore and use remotely sensed data in their daily work.

Miller and Small (2003) reviewed the potential applications of remote sensing in urban environmental research and policy. They showed that remotely sensed data could be used to obtain internally consistent measurements of physical properties at a lower cost than that of in situ measurements. The use of remote sensing data is usually more suitable for measuring and monitoring urban environmental conditions than for urban planning purposes because in the latter case, governmental and private sector data are more easily obtained. However, new developments and applications have taken advantage of the consistency of the remote sensing data to study the spatio-temporal dynamics of urbanization,

[1] The complete Landsat archive is freely available through the University of Marylands Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) Internet sites.

[2] High-resolution population data in gridded format for 50 metropolitan statistical areas (MSAs) in the US have recently been released into the public domain.