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Urbanization in European regions based on night lights

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ABSTRACT

Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) night lights are used as a source to capture urbanization trends in European regions. The data are intercalibrated to form a comparable time series. The Sum of Lights (SoL) index is then calculated per region. To eliminate the problem of annual fluctuation, the overall and the decadal slope of the SoL trend are also calculated. The analysis of the results shows that there exist significantly diverse urbanization patterns within European regions that can be effectively captured by DMSP/OLS data. It is also shown that GDP and population are positively associated with urbanization in Europe, however less strongly at regional than national levels. Overall, the interpretation of SoL changes in the European regions is more complex compared to those in the developing parts of the globe, primarily due to differences in energy saving polices.

1. Introduction

Cities occupy approximately 3% of the earth's surface but their "ecological footprints" are tens to hundreds of times their area, resulting to significant land use changes (Grimm et al., 2008). Despite the importance of cities, the design of earth observation sensors has been focused on natural systems (Elvidge et al., 1999). Recently, efforts to map urban areas at continental and global scales have been successful in exploiting the capacity of optical sensors, primarily by MODIS and LANDSAT data (Schneider et al., 2010; World Bank, 2015). These efforts resulted for the first time to a relatively accurate and independent estimate of urban extent and form. The coverage and spatial resolution (250–500 m) of MODIS is suitable for mapping urban areas at regional and national scales. The main drawback is however that MODIS data do not go back much in time. The sensor was launched in 1999. LANDSAT's archive, covering more than four decades, is also not suitable in this case. Its small footprint requires laborious mosaicking to cover continental scales. The high associated costs render repetition infeasible. In terms of content, the main barrier in processing optical data is the fact that urban areas are spectrally mixed with barren land, especially in parts of the globe where cities are not surrounded by vegetation which has a conveniently distinct spectral signature (Stathakis and Faraslis, 2014; Stathakis et al., 2012).

One appealing alternative to bridge the data gap for monitoring urban areas is the Defense Meteorological Satellite Program–Operational Linescan System (DMSP/OLS) sensors. The OLS instrument has a broad 0.5–0.9 μm VNIR band (Elvidge et al., 1999), approximately corresponding to LANDSAT's panchromatic band (TM bands 1–4 combined). DMSP/OLS sensors capture images during the night, typically between 8:30 and 9:30 p.m. local time (Amaral et al., 2005). However, overpass times can differ by as much as two hours (Elvidge et al., 2014). Night lights observed from space are a quite straightforward indication of human presence. Inhabited areas are clearly outlined (Croft, 1973; Imhoff et al., 1997a, 1997b). Human presence in night lights is not purely related to nighttime (census) population (Elvidge et al., 1999). Features of day-time population (a.k.a. ambient population) are also evident (industry, businesses, traffic etc.). The radiometric resolution of OLS is relatively coarse. Only six bits are available

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Fig. 1. NUTS II polygons and corresponding codes. EU28 country codes are also shown for reference.

(DN in [0,63]) (Elvidge et al., 1999). OLS is much more sensitive compared to TM, detecting at least four times lower reflection (Elvidge et al., 1999; Imhoff et al., 1997a, 1997b). The orbital parameters of the OLS permit a daily global coverage (Elvidge et al., 1999). The daily data are processed to reach the 'stable lights' annual composite product in which ephemeral lights are removed (Baugh et al., 2010). In 'stable lights' the data is resampled to approximately 1 km at the equator. This resolution is roughly ten times less than optimal to retain the primary features of an urban environment (Elvidge et al., 2009a, 2009b, 2009c). Nevertheless, the coarse resolution also means that only a fraction of the data volume (as less as 1%) is needed for OLS compared to LANDSAT to cover the same area on the ground (Elvidge et al., 1997). This translates to potential for a low-cost means of detecting urban change (Cova et al., 2004). A common method of evaluating the accuracy of urban maps derived from DMSP/OLS is by exploiting their strong correlation with Gross Domestic Product (GDP) and population data (Ghosh et al., 2010; Sutton, 1997).

Asia is currently the hot spot for urbanization. In a single decade the number of people that have moved to urban areas in East Asia is equal to the population urbanized in more than five decades in Europe (World Bank, 2015). Night lights have recently been used to study urbanization with a national focus on China (Gao et al., 2015; Fan et al., 2014; Ma et al., 2012; Liu et al., 2012) as well as a continental focus on Asia (Small and Elvidge, 2013). Similar studies have been done at the global scale (Elvidge et al., 2007a, 2007b, 2014) as well as with a national focus on the USA (Imhoff et al., 1997a, 1997b).

The European continent has so far been studied based on DMSP/OLS only at national level, in the context of global studies. However, due to the incremental enlargement of the European Union, combined with the integration of parts of the former soviet union that collapsed in 1991, the recent economic crisis and other factors, some very interesting patterns are evident. These patterns are relatively unexplored due to the lack of comparable transnational time series data. The objective of this paper is to depict urbanization trends through time, based on DMSP/OLS, explicitly in Europe. Therefore, the main novelty is (i) the European focus, with the brightness of night-time lights being influenced by multiple drivers rather just actual urbanization as is frequently the case in developing countries (ii) the subnational level of analysis (European regions) which provides opportunities to analyze more precisely a complex picture of changes due to