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A global analysis of factors controlling VIIRS nighttime light levels from densely populated areas

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A B S T R A C T

Remote sensing of nighttime lights has been shown as a good surrogate for estimating population and economic activity at national and sub-national scales, using DMSP satellites. However, few studies have examined the factors explaining differences in nighttime brightness of cities at a global scale. In this study, we derived quantitative estimates of nighttime lights with the new VIIRS sensor onboard the Suomi NPP satellite in January 2014 and in July 2014, with two variables: mean brightness and percent lit area. We performed a global analysis of all densely populated areas ($n = 4153$, mostly corresponding to metropolitan areas), which we defined using high spatial resolution Landscan population data. National GDP per capita was better in explaining nighttime brightness levels ($0.60 < Rs < 0.70$) than GDP density at a spatial resolution of 0.25° ($0.25 < Rs < 0.43$), or than a city-level measure of GDP per capita (in proportion to each city's fraction of the national population; $0.49 < Rs < 0.62$). We found that in addition to GDP per capita, the nighttime brightness of densely populated areas was positively correlated with MODIS derived percent urban area ($0.46 < Rs < 0.60$), the density of the road network ($0.51 < Rs < 0.67$), and with latitude ($0.31 < Rs < 0.42$) at $p < 0.001$. NDVI values (representing vegetation cover) were found to be negatively correlated with cities' brightness in winter time ($-0.48 < Rs < -0.22$), whereas snow cover (enhancing artificial light reflectance) was found to be positively correlated with cities' brightness in winter time ($0.17 < Rs < 0.35$). Overall, the generalized linear model we built was able to explain >45% of the variability in cities' nighttime brightness, when both physical and socio-economic variables were included. Within the generalized linear model, the percent of national GDP derived from income (rents) from natural gas and oil, was also found as one of the statistically significant variables. Our findings show that cities' nighttime brightness can change with the seasons as a function of vegetation and snow cover, two variables affecting surface albedo. Explaining cities' nighttime brightness is therefore affected not only by country level factors (such as GDP), but also by the built environment and by climatic factors.

1. Introduction

Artificial nighttime lights present one of humanity's unique footprints that can be seen from space (Croft, 1978). Resulting light pollution has been shown to negatively impact the community of astronomers and our ability to observe the night sky (Cinzano et al., 2001). However, the negative effects that light pollution has on ecological systems and on our health, through changes in circadian exposure to light and changes in the wavelengths we are exposed to, might have more important and far-reaching consequences (Longcore and Rich, 2004; Falchi et al., 2011; Gaston et al., 2013). Light pollution and artificial lighting has been shown to vary greatly in space and in time, as a function of population and economic activity. However, most studies examining the factors explaining global spatial variability in lit areas were conducted at national and provincial levels using the DMSP/OLS sensor (e.g., Elvidge et al., 1997; Chen and Nordhaus, 2011; Wu et al., 2013; Keola et al., 2015). While offering the only globally available time series of nighttime lights imagery from 1992 onwards (Bennie et al., 2014a), DMSP imagery has various drawbacks as it is not calibrated, its spatial resolution is coarse, it contains overglow beyond urban boundaries and it is saturated in urban areas (Small et al., 2005; Doll, 2008). Temporal changes in cities' lights and the spatial characteristics of cities' nighttime brightness have been examined in several countries using DMSP data

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(e.g., Lo, 2002; Ma et al., 2012; Zhang and Seto, 2013). Most of the studies which used DMSP data for urban studies have used annual datasets, whereas daily and monthly datasets were used to identify more dynamic and time varying features, such as forest fires, wars and fishing vessels (Huang et al., 2014). New studies using DMSP datasets for quantifying urban patterns are continuously being published (e.g., Ma et al., 2015; Weidmann and Schutte, 2016), however, annual products of DMSP night lights data are no longer being produced, the last one available being that of 2013.

Recently, new studies have attempted using finer spatial resolution (≤1 m) nighttime imagery to examine the factors explaining spatial patterns of nighttime lights within cities (Kuechly et al., 2012; Hale et al., 2013; Levin et al., 2014; Katz and Levin, 2016). Astronaut photography taken from the International Space Station presents an additional source of information about spatial patterns of cities at nighttime (de Miguel et al., 2014, de Miguel, 2015). Levin and Duke (2012) have used ISS imagery showing that not all towns and cities are equally lit, and that economic, infrastructure and

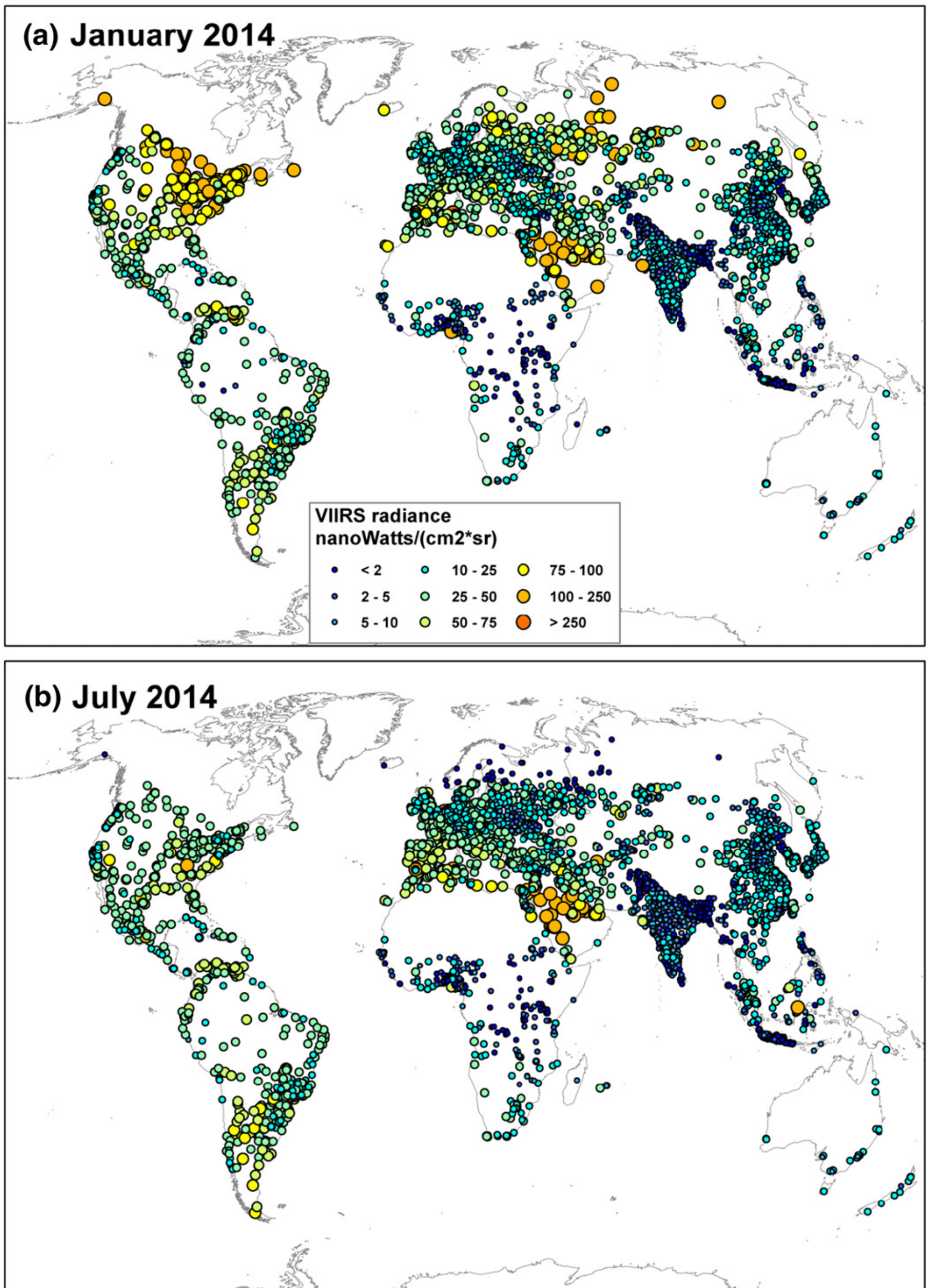

Fig. 1. The distribution of the 4153 urban areas analyzed in this study, presenting mean VIIRS radiance values in January 2014 (a) and in July 2014 (b). Changes in brightness between the two months are given in absolute values (c) and as percentages (d).