EXPLORING VIIRS-NPP NIGHT-TIME LIGHT DATA IN THE AMAZON RAINFOREST

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ABSTRACT

The goal of this work is to explore variables that are recurrently pointed out as factors influencing the night-time levels around the world, in the Amazonian context. In order to do that, we generalized variables related with physical, anthropogenic and socioeconomic contexts at the city level and analyzed their correlation with the night-time radiance data from the Day-Night Band (DNB) sensor, a detector from VIIRS-NPP. We found that the GDP per capita, road network density and the total number of households have the greatest correlation coefficients and Spearman's coefficients. Our approach focused on the residual values of the variables, and so we found that cities with the greatest residual values were also cities with a similar historical context of development, such as mining and populational nuclei. Our results suggest that, when associated with other indicators, night-time data is useful for identifying patterns of socioeconomic dynamics.

Key words **—** Amazon, VIIRS, socioeconomic, night-time lights.

1. INTRODUCTION

Night-time lights (NTL) are the most evident anthropogenic trace over the Earth's surface. In 2011 the Visible Infrared Imaging Radiometer Suite (VIIRS) was launched on board the Suomi National Polar-orbiting Partnership (Suomi-NPP) and thenceforward has become the main source of night-time light data. Compared to its predecessor, the Operational Line-Scan System, the VIIRS's Day Night Band (DNB) has many advantages, such as the spatial resolution, greater quantization, and an internal on-board calibration system.

Although those enhancements have contributed to novel applications through the last decade, the NTL remote sensing still in its infant stage, when compared with daytime optical and microwave remote sensing [1]. In the socioeconomic scope, many works explored the potential relation of the VIIRS NTL data with distinct variables, such as house vacancy rate in metropolitan areas, economic growth, and decline, urbanization, monitoring natural disasters and conflict zones [2]. In this respect, Levin and Zhang [1] presented three main categories of factors controlling VIIRS NTL radiance levels: physical, anthropogenic and socioeconomic.

The first category of factors is represented by the change of the physical conditions of the landscape over time and space whereon the NTL source is set. Phenological cycles of plants, rainfall and snow may induce drastic changes in the albedo's surface, factors that will influence the radiance levels registered by the sensor. The second is represented by built artifacts, whose shapes and arrangements might reflect the characteristics of the infrastructure and, therefore, patterns of light sources. The third category of factors refers to the dynamic of the socioeconomic processes within a region and how they can influence the intensity and distribution of NTL. In spite of the categories, the variables are only virtually independent. In practice, the physical medium has influence and is influenced by the anthropogenic and socioeconomic mediums, in a way that these relations are interchangeable in all directions.

In the Amazonian context, the relationship between those categories is even closer. The urbanization process of Brazilian states inserted in the Amazon rainforest occurred in two moments: the period before 1960, slower and dependent on rivers; and after 1960, faster due to the mineral exploitation and large agrarian projects, through roads [3]. This process resulted in a deep relation between the physical space and the socioeconomic context, leading to diverse scenarios of occupation. Given the hypothesis that the distribution and intensity of NTL sources are a result of the association of those factors, this work aims to investigate the influence of the NTL's radiance levels on socioeconomic, physical and anthropogenic variables, for the Amazon context. These relations can reveal patterns that might contribute to the advance of the discussion about the utility of NTL data in regional scales.

2. MATERIAL AND METHODS

2.1 Study area

The Pará State, Brazil, is one of the 27 Brazilian federated units, the second larger in extent and with a population of circa 8,513,497 inhabitants [3] (Figure 1). Although the state has a diverse vegetation composition due its large extent, the Amazon rainforest is the most representative. Besides being the greatest economy of the Northern region, the state holds the national first position on bauxite, kaolin and manganese production, and the second on iron production [4]. Pará also leads the extractive fishery market and it is the fifth greatest on the cattle farming in Brazil. Despite its notorious commercial development on the last decade, represented by the second greatest credit in the balance of trade, its poverty rate reached 32% in 2017, the fourth greatest of the country [4].

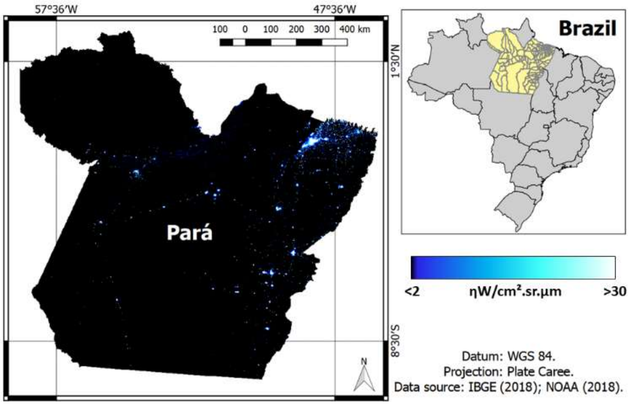

Figure 1 – Study Area: Pará State,VIIRS DNB - 2012.

2.2 Data source and preprocessing

In response to the considerations about the factors with potential for controlling the distribution and intensity of VIIRS NTL, the following variables were chosen: total cloud-free observations and mean NDVI (physical), road network density (anthropogenic), GDP *per capita*, and the total number of households (socioeconomic),

The NTL data are distributed by the NOAA in a monthly composition from the average radiance of all cloud-free observations within a month. The composition is resampled to a pixel size of approx. 450 m and has a quantization of 14 bits. The monthly product is not undergone an outlier removing process, hence, we removed the outliers and background noises using a thresholding method [5]. The chosen composition refers to July of 2012, due to its greater number of cloud-free observation over the study area. The total radiance at the municipality scale was calculated by the sum of all pixels within a municipality area, hereafter referred to as cities. The total cloud-free observation is an ancillary data of the monthly NTL VIIRS composite (https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html/). The NDVI data is a seven-day composite of radiance levels form the MODIS AQUA radiance data, dating from the same period of the VIIRS data (http://www.earthexplorer.com/).

The density of road network is based on the OpenStreetMap vectors [6], obtained from Geofabrik (http://geofabrik.de/). All the roads from major roads to tertiary roads were included in this analysis. Although the layers of roads correspond to the last version, i.e., 2018, it is expected that the most recent version of the data has fewer errors related to temporal lag than errors related to omission from an older version.

The GDP *per capita* is estimated by exhaustive sampling of the national accounts and regional accounts and then disaggregated at the municipal level [3]. The total number of households is based on the National Record of Addresses for Statistical Purposes (in portuguese, Cadastro Nacional de Endereços para Fins Estatísticos, CNEFE), surveyed in 2010. We choose to discriminate residential addresses from the other types (i.e., commercial, institutional and others) because they were highly correlated to each other. The data are provided in a vector format, where the smallest geometry corresponds to a single side of a street or public area. The geometries, together with the count of addresses, were then generalized to the city level, based on the area of the municipality. The relationship between the variables was evaluated with the analysis of the Pearson correlation coefficient under the hypothesis of a linear correlation, and the Spearman's coefficient under the hypothesis of a monotonic correlation. The homoscedasticity was also considered in the choice of the variables on which the discussion session is focused.

3. RESULTS AND DISCUSSION

After analyzing the results of all regressions, we investigated the dispersion between the total radiance and the variables with the most significant coefficients of correlation and Spearman's (Table 1).

Table 1 – Pearson coefficient of correlation (R) and Spearman's coefficient (Sp), α = 0.05, (-) not significant.

	Total Rad.		Mean Rad.	
	R	Sp	R	Sp
GDP *per capita*	**0.48**	**0.52**	0.05	0.13
Mean NDVI	-0.02	-	0.16	0.36
Total cloud-free observations	0.11	0.10	-0.08	-0.67
Mean of cloud-free observations	0.07	0.10	-	0.09
Total of addresses	**0.85**	**0.83**	0.42	0.37
Road network density	0.45	0.38	**0.98**	**0.83**

Only the variables with a pair of coefficients greater than 0.45 were selected for the following analysis. Because our discussion does not aim to express a model of the NTL data, we approached the residuals values of the regression with the goal of identifying the cities with an uneven relation between the variables. The results hereunder stand out cities with specific contexts of development, such as populational nuclei and cities within a mining economy context of development.

3.1 Gross Domestic Product *per capita*

Most of the cities that stand out of the linear regression with the NTL data belongs to Belém Metropolitan Region (BMR). The BMR covers seven municipalities up to the moment: Ananindeua, Belém, Benevides, Castanhal, Marituba, Santa Bárbara do Pará e Santa Izabel do Pará [7]. Among those cities, only Santa Bárbara do Pará e Santa Izabel do Pará are not between the 20 cities with the greatest radiance values of the state. Both have also the lowest GDP *per capita* from the BMR (Figure 2). Nevertheless, cities such as Belém, Marabá, Santarém e Ananindeua have uneven values of GDP *per capita* versus total radiance, when compared to most of the cities, with a predominance of radiance values over GDP *per capita.* Ananindeua belongs to the BMR, being the second most populous city from Pará, only behind Belém, the capital. Santarém and Marabá hold the third and fourth position, respectively [3].

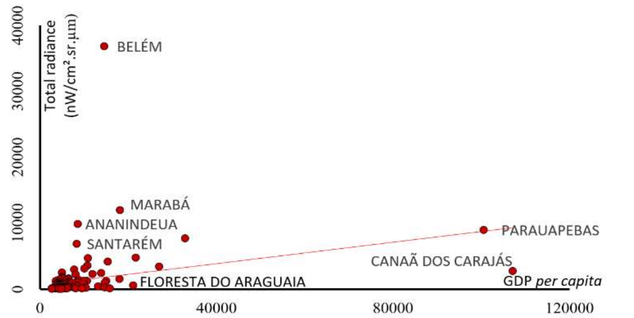

Figure 2. Dispersion of the GDP *per capita* and total radiance of the municipalities of Pará (2012), Pearson = 0.48, Spearman = 0.52, α = 0.05.

A few cities can be pointed up from their predominance of the GDP *per capita* over the total radiance values. The city of Canaã dos Carajás, the highest GDP *per capita* of the state, has low values of GDP in 2012, when compared to its total radiance values. The city locates the Sossego Project, a copper mining project from the 1990's, which has increased significantly the city's GDP since then, resulting in the ascension of the GDP from 8,632.45 in 2002, to 110,230.81 in 2012 [8]. Its neighbor, Parauapebas, has the same economic context, since the city has been developed around a mining project of iron ore from the 80's. Parauapebas also has a less expressive value of total radiance compared with its GDP. Floresta do Araguaia, for example, despite having the seventh greatest PIB of the state, mainly related to mining activities, holds only the 65º position on total radiance, an insight of how the NTL are associated with the basic infrastructure of occupied areas.

3.3 Road network density

Concerning the road network density, the cities within the BMR expressed the greatest density in the state (Figure 3). In this case, their values represent outliers when compared with other municipalities. It is notorious that, even though the extends of the municipalities of the state of Pará are very distinct, ranging from 6,546 km² (Marituba), to 4,722,320 km² (Altamira), the road network density still holding a close relation with the NTL levels. It must be addressed that the comparison of the correlation between the mean radiance levels and the road network density with the total length of the road network and the total radiance would lead to the exact same results.

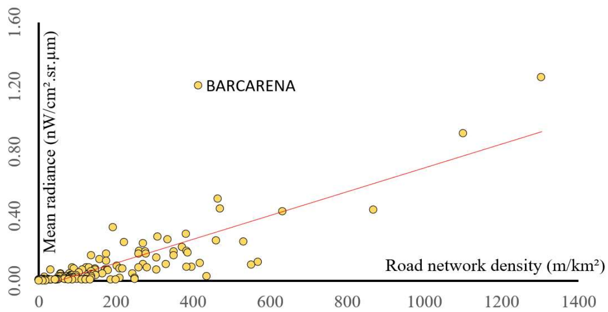

Figure 3. Road network density and mean radiance of the municipalities of Pará (2012), Pearson = 0.98, Spearman = 0.83; α = 0.05.

3.4 Residential addresses

Among the analyzed variables, the number of households at the municipal level is the one that better represents the total intensity of the total radiance levels (Figure 4). Although the R value is only the second greater, the residual values are normally distributed and the outliers seems to have common socioeconomic aspects. We identified two different groups of outliers: socioeconomic nuclei (Ananindeua, Parauapebas, Benevides, Marituba, and Marabá); and cities related to mining activities (Ourilândia do Norte, Canaã dos Carajás, Barcarena, Marabá, and Parauapebas). Marabá is the only city in a mining economy context with high values of both variables. However, its economy base has been developed in a more diverse way, compared to the other cities with this mining background. From the extractivism of latex and Brazilian nut to the cycle of diamond and gold mining, Marabá became a well-developed steelworks and metallurgy site, centred in processing the ores extracted from the mountain ranges of Carajás region (Serra dos Carajás) [9].

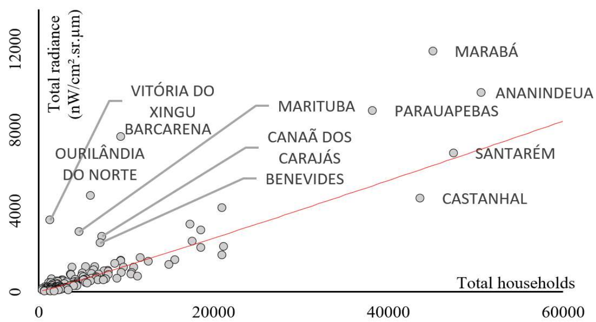

Figure 4. Number of households and total radiance of the municipalities of Pará (2012), Pearson = 0.85; Spearman = 0.83; α = 0.05.

In respect of the proportion of NTL and the total number of households, the cities with higher radiance levels share negative aspects regarding their growth through history. Vitória do Xingu is an inland port city that had its colonization promoted by the National Institute of Colonization and Agrarian Reform (INCRA) since the 1970's, but faces a harsh social framework from the 1990's due the relinquishment of public policies oriented to the favoring of migrants [10]. In 1991 the city was emancipated from Altamira and later had to struggle with a major rural population impacted by the installation of the Belo Monte Dam. There are still controversies about the pros and cons, but the literature tends to agree that the implantation of the Belo Monte hydroelectric complex has contributed to the rise of violence between 2007 and 2013 in the region [11].

Barcarena, at only 15 kilometers from the capital, is also a hosting city of mining industries, but with a different socioeconomical history from the cities in the region of Serra dos Carajás. The primary aluminum production from the local bauxite mines began in the 1980's and have been extended until these days [12]. The industrial sites built for the installation of those businesses have been riven by spontaneous occupation sites, which do not comply with the territorial reordering intended by the companies' logic and expose the territorial inequalities [12]. The result is an already common scenario to cities that host very large industries, of which socioeconomic crises arise as fast as the population grows.

5. CONCLUSIONS

This work evidence that NTL data can be useful for identifying patterns of socioeconomic dynamics. Although many studies have been already using that data in regional and global scales for similar purposes, hereby we show that the historical context of occupation and development can be of great handiness and, therefore, help to understand how NTL are related to different socioeconomic and infrastructure drivers. The GDP, the road network density and the total number of households, when compared with the NTL data, stand out groups of cities with similar socioeconomic conjunctures, mostly mining and populational nuclei.

We would like to highlight three main topics on which future researches should focus. Firstly, the influence of the physical aspects is yet to be understood and integrated into studies of this nature, mainly related to the albedo and atmospheric scattering. Even though problems such as overglow and backscattering have been addressed by others, in quantitatively approaches those issues are particularly important. Secondly, other finer scales would help to understand inner cities dynamics, but the lack of socioeconomic data at this level is the main issue. Hence, methods of reallocation and specification may help to expand the capabilities of the usage of NTL data in socioeconomics studies. Finally, systemically approaches to pattern detection should be tested in order to broaden and strengthen scientific programs of monitoring natural resources and socioeconomic dynamics, which are essential tools on the Amazonian and Brazilian contexts.

6. ACKNOWLEDGEMENTS

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